INTERIM REPORT NO. 1

SHRP C103 Task 4
State-of-the-Art Report on

RAPID REPAIR TECHNIQUES FOR BRIDGE DECKS

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PREFACE

This report was prepared and distributed under the authority of Virginia Polytechnic Institute and State University (VPI & SU), the prime contractor for Strategic Highway Research Project C103 entitled Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques. The report was prepared at the Virginia Transportation Research Council (VTRC) to partially satisfy the requirements of a subcontract between the VPI & SU and the VTRC. A VTRC title page was prepared to properly include the report in the Council's bound volumes.

In addition to the authors, the report was prepared with help from Carolyn France, graduate student, who assisted with the collecting and storing of data obtained from the questionnaires and Max Natzet and Christine Wood, undergraduate students, who helped with the literature survey. Michael Burton, technician supervisor, was responsible for the preparation and testing of concrete in the laboratory. The report was typed by Arlene Fewell.

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ABSTRACT

Bridges that are candidates for rapid repair techniques have peak-hour traffic volumes that are so high that it is not practical to close a lane to repair the deck or to install a deck protection system except during off-peak traffic periods. This report summarizes the results of the first 25 months of a 55-month project (Task 4 of SHRP Project C103) to investigate rapid techniques for the protection, rehabilitation, and replacement of bridge decks. The report is based on a review of the literature and the responses to questionnaires sent to state DOTs, Canadian provinces, selected turnpike and thruway authorities, technology transfer centers, and material suppliers. The report identifies the techniques being used by the DOTs and compares the techniques from the standpoint of frequency of use, performance characteristics, time demands, service life, maintenance, initial cost, and life cycle cost.

EXECUTIVE SUMMARY

This report summarizes the results of the first 25 months of a 55-month project covering Task 4 of SHRP Contract C103 which has the objective to investigate rapid techniques for the protection, rehabilitation, and replacement of bridge decks. The report is based on a review of the literature and the responses to questionnaires sent to state DOTs, Canadian provinces, selected turnpike and thruway authorities, technology transfer centers, and material suppliers. The report identifies the techniques being used by the DOTs and compares the techniques from the standpoint of frequency of use, performance characteristics, time demands, service life, maintenance, initial cost, and life cycle cost.

For this study, rapid repair is not defined in terms of repair rate, such as surface area per unit of time, because repair rate is a function of manpower and equipment. Rather, rapid repair is defined in terms of suitability for stage construction. To be considered as a rapid repair technique the repair system must be suitable for installation during off-peak traffic periods and suitable for traffic during peak traffic periods. Bridges that are candidates for rapid repair techniques have peak-hour traffic volumes that are so high that it is not practical to close a lane to repair the deck or to install a deck protection system except during off-peak traffic periods. These bridges usually have one of four maximum lane closure time conditions as follows: $\leq$ 56 hours, $\leq$ 21 hours , $\leq$ 12 hours, or $\leq$ 8 hours.

Rapid protection systems that are frequently used include bituminous concrete overlays on prefabricated or liquid membranes, polymer overlays, high early strength portland cement concrete overlays, and penetrating sealers. Patching systems that are frequently used include high early strength portland cement concrete patches, bituminous concrete patches, and other hydraulic cement concrete patches. The rapid rehabilitation of a deck usually includes use of a rapid patching system followed by a rapid protection system. Rapid replacement systems that are frequently used include site cast high early strength portland cement concrete and precast concrete deck panels.

Based on the life cycle cost analysis, the most cost-effective protection system is the application of a penetrating sealer. The most cost-effective patching system based on the questionnaire responses, is patching with polymer concrete, and patching with high early strength portland cement concrete based on the literature survey. The most cost-effective replacement system is site cast high early strength portland cement concrete. The high early strength portland cement concrete overlay is the most expensive protection system and patching with bituminous concrete is the most expensive patching system. The analysis of some of the systems was based on a very limited data base and results may change if more data becomes available. Also, the average maintenance intervals and service life values used to compute life cycle costs are likely applicable for repairs done on typical decks. The service life values would likely decrease and the life cycle costs increase when the repairs are done on decks with a high rate of corrosion. The service life values should increase and the life cycle costs decrease when the repairs are applied to relatively new decks in good condition. Therefore, to make an accurate analysis of life cycle costs, information is needed on the effect of the rate of corrosion of the rebar on the life of the repair and the effect of the repair on the service life of the deck. As the project continues, an effort will be made to obtain this information and to expand, revise, and update the more promising techniques.

This report was prepared to partially satisfy the requirements of the C103 contract and to give readers the opportunity to provide comments.

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INTRODUCTION

SHRP Contract C103

The Strategic Highway Research Program (SHRP) awarded a contract (SHRP C103) to the VPI & SU on September 22, 1988, to conduct a 55-month study entitled "Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques" (1). The study is being conducted by 10 professional staff members under the direction of Dr. Richard Weyers of VPI & SU. The study requires the completion of 7 tasks as follows.

1. Cost and service life of existing methods.
2. Feasibility of new methods for protection and rehabilitation.
3. Concrete removal and bar and concrete surface preparation.
4. Rapid repair techniques.
5. Corrosion prevention treatments.
6. Field validation.
7. Field guide.

This report presents the information collected for Task 4 during the first 25 months of the 55-month study. The report was prepared to provide readers the opportunity to become aware of the rapid repair techniques being used, to reflect on the data provided by a review of the literature and the response to the questionnaires, and to contact the principal investigator with comments and suggestions that can be incorporated in subsequent reports.

A more complete discussion of the more promising techniques, including the effect of the repair on the service life of the deck and the effect of the rate of corrosion of the rebar on the life of the repair, will be included in subsequent reports.

Research Approach

The objective of Task 4 of C103 is to develop technically and economically feasible methods of deck protection, rehabilitation, and replacement that can be used where construction must be rapid (2). The objective will be accomplished by a progression through 6 steps that will include:

1. State-of-the-Art review and tabulation of information (September 1, 1988 - July 31, 1990).
2. Data reduction and analysis, comparison of alternatives, and preparation of Interim Report No. 1 (April 1, 1989 - September 30, 1990).
3. Refinement of details based on evaluations of representative decks and preparation of Interim Report No. 2. Refinements will include performance characteristics of the repairs, the service life of the repairs as influenced by the rate of corrosion of the rebar, and the effect of the repairs on the service life of the decks (October 1, 1990 - December 31, 1991).
4. Selection of sites and development of special provisions for field installations (January 1, 1992 - March 31, 1992).
5. Providing technical expertise for field installations and conducting tests necessary to evaluate the initial condition of the installations (April 1, 1992 - June 30, 1992).

6. Preparation of a field manual containing specifications, special provisions, a description of the recommended rapid repair techniques, and cost and service-life estimates for the recommended methods for inclusion in the decision model (Contract C-104) (July 1, 1992 - March 31, 1993).

The state-of-the-art review, the data reduction and analysis, and the comparison of alternatives (activities 1 and 2) are summarized in this report. This report is based on a review of the literature and the responses to three questionnaires. This report compares rapid repair techniques from the perspective of frequency of use, performance characteristics, time demands, service life, and cost.

This report is organized around the outline on rapid repair systems shown in Appendix A. The outline has three first order headings: Protection, Rehabilitation and Replacement. The rehabilitation of a deck usually requires crack repair, joint repair, patching, and the application of a protection system. To simplify the reporting of data, protective systems are not reported as part of rehabilitation systems. A detailed description of the systems is given in Appendix B. The outline and descriptions were prepared based on the response to the questionnaires sent to the DOTs, Canadian provinces, selected turnpike and thruway authorities, directors of technology transfer centers, and selected material suppliers (see Appendix C and D) and based on a review of the literature.

The three questionnaires on Rapid Repair Techniques for Bridge Decks were prepared and distributed in 1989 to obtain state-of-the-art information (see Appendix C). The respondents were requested to list the three most frequently used techniques for the rapid protection, rehabilitation, and replacement of bridge decks and to provide other information about these techniques. A summary of the responses to the questionnaires is shown in Appendix D.

Criteria for Rapid Repair Techniques

For this study, rapid repair is not defined in terms of repair rate, such as surface area per unit of time, because repair rate is a function of manpower and equipment. Rates at which repairs are done can best be controlled by contract requirements with incentives and penalties to promote rapid rates of repair so that contractors can invest in additional manpower and equipment to accelerate the rate of repair.

For this study, rapid repair is defined in terms of suitability for stage construction. To be considered as a rapid repair technique the repair system must be suitable for installation during off-peak traffic periods and suitable for traffic during peak traffic periods.

A flow diagram for rapid repair techniques for bridge decks is shown in Figure 1. Lane closure and surface preparation are necessary first steps for any rapid technique. Lane closure can be accomplished using cones or other temporary barriers. All unsound concrete must be removed in preparation for new repair materials. When performing a rapid replacement technique, existing rebar is usually replaced with new epoxy coated rebar. Necessary forms must be placed and surfaces to which concrete should bond must be blasted clean.

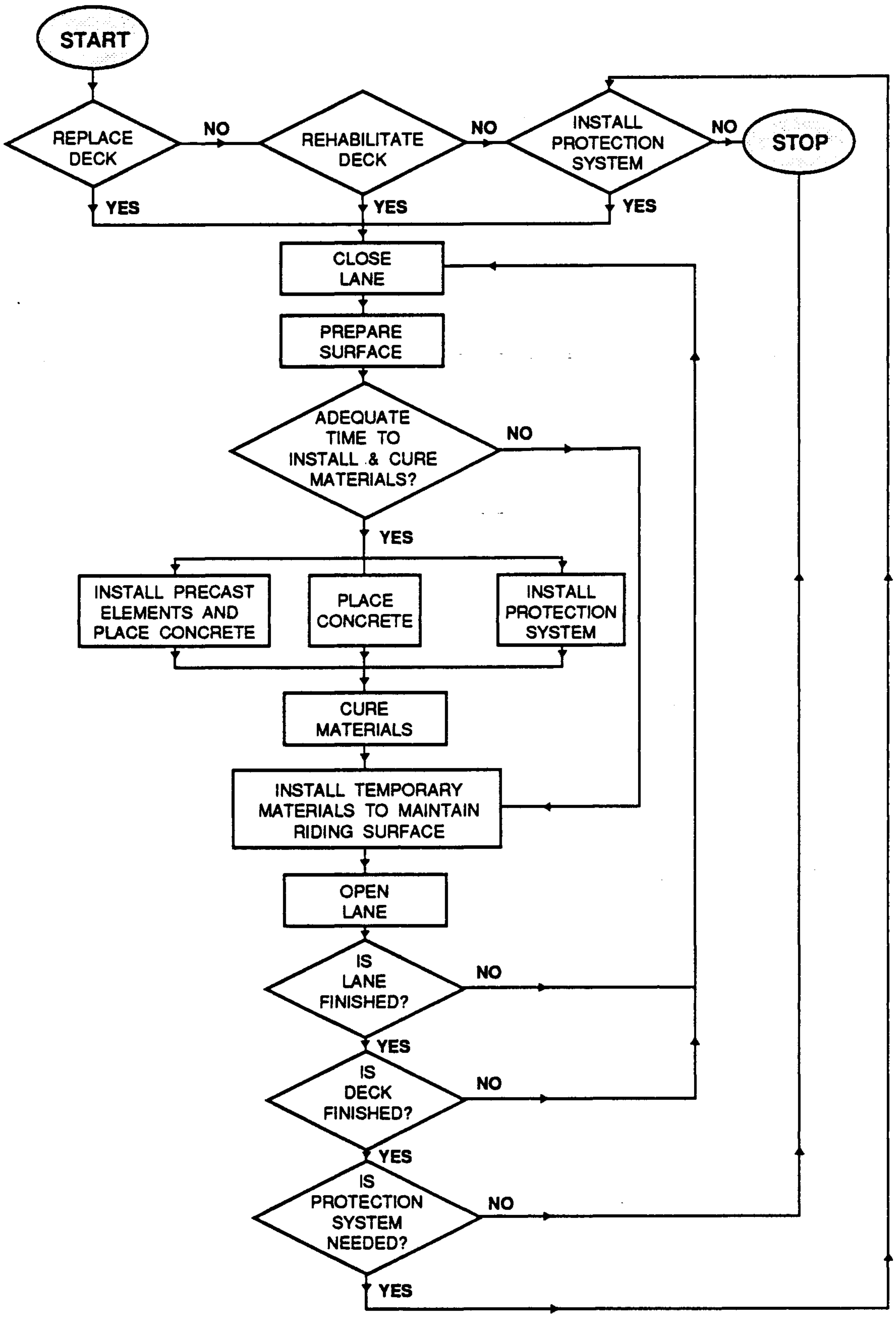


Figure 1. Flow diagram for rapid repair techniques for bridge decks.

If there is insufficient time to install and cure a protection system or repair material, temporary materials should be placed to maintain a traffic-bearing surface. Otherwise, the repair should continue with the installation of a protection system, a rapid-curing concrete repair material or a precast replacement section. The materials are allowed to cure to the required strength to receive traffic. Necessary temporary materials are installed and the lane is opened to traffic. If needed, a rapid deck protection system is installed following deck replacement or rehabilitation.

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

$\leq$ 56 hours - semirapid,
$\leq$ 21 hours - rapid,
$\leq$ 12 hours - very rapid, and
$\leq$ 8 hours - most rapid.

For example, a lane closure condition exists that requires the use of a semirapid technique when the lane must be open 5 days a week but can be closed on weekends from Friday at 9:00 p.m. until Monday at 5:00 a.m. A lane closure condition exists that requires the use of a rapid repair technique when the lane must be opened for about 3 hours each day such as from 3:30 p.m. to 6:30 p.m. or 6:30 a.m. to 9:30 a.m. A condition exists that requires the use of a very rapid repair technique when the lane must be opened during the day, e.g., as from 6:00 a.m. to 6:00 p.m. or the lane must be opened at night from 6:00 p.m. to 6:00 a.m. A condition exists that requires the use of a most rapid repair technique when the lane must be opened for all but 8 hours or less each day, i.e. the work must be done between 8:30 a.m. and 4:30 p.m. or typically from 9:00 p.m. to 5:00 a.m. A repair system must follow the flow diagram (see Figure 1) within the lane closure constraints of $\leq$ 56, $\leq$ 21, $\leq$ 12 or $\leq$ 8 hours to qualify as part of a rapid repair technique. An example of the sequence of repair activities for each of the lane closure constraints is given in Appendix E.

FREQUENCY OF USE

Table 1 shows the frequency of use of rapid repair systems based on the responses to questionnaires No. 1 and No. 2. Use of the systems and subsystems is reported in detail in Appendix D.

Based on the responses the rapid protection system most often used is the bituminous concrete overlay (35 responses), the second largest response came from those responding that they do not use rapid protection systems (33 respondents) and the third largest response was for the polymer overlay (13 responses). Nine agencies use high-early strength portland cement concrete overlays, and nine agencies use rapid curing penetrating sealers.

The use of a liquid or prefabricated membrane (Systems IA1 and IA2) under a bituminous concrete overlay was cited 22 times, the use of a tack coat (System IA4) was reported once and 9 respondents did not specify what was used under the bituminous concrete overlay (System IA). No one reported use of a penetrating sealer or coating (System IA3) under a bituminous concrete overlay. The use of a bituminous chip seal (System IA5) was cited three times. The prefabricated or liquid membrane is the most used protective layer under bituminous concrete overlays. Therefore, performance, service life and cost data are reported for this system.

The use of coatings on bridge decks was only cited three times. Two agencies reported use of high molecular weight methyacrylate (System IB1c) and one agency reported use of a polymer modified cementitious coating (System IB2b).

Table 1

Frequency of Use of Rapid Repair Systems

Protection System	No. Users	Rehabilitation System	No. Users	Replacement System	No. Users
Bituminous Concrete Overlay	35	Crack Repair and Sealing	3	Precast Concrete Slab Span	0
Coating	3	Joint Repair	0	Precast Concrete Box Beam	0
Portland Cement Concrete Overlay	9	Bituminous Concrete Patch	11	Precast Concrete Channel and Tee Beam	0
Penetrating Sealer	9	Portland Cement Concrete Patch	30	Precast Concrete Deck Panel	5
Polymer Overlay	13	Polymer Concrete Patch	3	Permanent Forms with Site Cast Concrete	0
Other Hydraulic Concrete Overlay	1	Other Hydraulic Concrete Patch	11	Site Cast Portland Cement Concrete	9
None	33	Steel Plate over Concrete	3	Site Cast Polymer Concrete	0
No Reply	13	None	31	Other Site Cast Hydraulic Concrete	3
		No Reply	10	None	43
				No Reply	20

The use of high early strength portland cement concrete overlays (System IC) was cited 9 times. More specifically, use of latex modified concrete overlays (System IC2e) was cited 4 times, use of low slump concrete (System IC3) was cited 2 times and use of each of the following was cited 1 time, blended portland cement (System IC1), concrete containing silica fume (System IC2d) and high early strength portland cement concrete (System IC).

The use of penetrating sealers (System ID) was cited 9 times. Use of silane (System ID5a) was cited 7 times and use of linseed oil (System ID3a) and asphalt emulsion (System ID7) were each cited 1 time.

The use of polymer overlays (System IE) was cited 13 times. Multiple layer overlays (System IE1) were cited 7 times, and premixed overlays (System 1E2) were cited 4 times. Two respondents did not report the particular type of polymer overlay placed. The most popular multiple layer overlay is constructed with an epoxy binder, and the most popular premixed overlay is constructed with a polyester styrene binder.

The use of an alumina cement concrete overlay was cited 1 time.

As can be seen from Table 1 most agencies do not use rapid rehabilitation systems (31 respondents). The rehabilitation system most often used is the high early strength portland cement concrete patch (System IID) (30 responses), and the second and third most often used are the bituminous concrete patch (System IIC) (11 responses) and other hydraulic cement concrete patch (System IIF) (11 responses), e.g., made with magnesium phosphate and alumina cement binders.

Forty-three respondents reported that they use no rapid replacement techniques. Another 20 respondents made no reply on the questionnaire. The replacement systems cited on the questionnaires are site cast portland cement concrete (System IIIF) (9 responses), precast concrete deck panels (System

(IIID) (5 responses), and other site cast hydraulic cement concrete (System IIIH) (3 responses). Evidently most agencies use a lane closure of > 56 hours for replacement.

PERFORMANCE CHARACTERISTICS

The most important performance characteristics of rapid protection and rehabilitation systems for bridge decks are the condition of the temporary surfaces, minimum curing time, the bond strength, the permeability to chloride ion, the skid resistance, and the wear. With two exceptions, the same performance characteristics apply to rapid replacement systems. Bond strength is not important unless a protective overlay will be applied, and permeability to chloride ion is less important because the rebar in new decks is usually coated with epoxy.

Temporary Surfaces

A major requirement for a rapid repair system is the suitability of the temporary surface for traffic during peak-hour traffic periods. The temporary surface is the disturbed surface between the original surface of the deck and the completed surface. For bridges whose entire deck surface can be repaired during one off-peak traffic period, there is no temporary surface. The surface must provide a safe ride when the lane is opened to traffic. Typical surface elevations for the rapid protection systems are summarized in Table 2, illustrated in Figure 2, and described below.

It can be seen from Table 2 and Figure 2 that the application of a penetrating sealer or coating has a negligible effect on the elevation of the riding surface; therefore, temporary materials are not needed, and speed reductions are not warranted unless there is concern about changing the

Table 2

Typical Surface Elevations for Rapid Protection Systems

Protection System	System Thickness, in	Surface Preparation Depth, in	Change in Elevation, in	Speed Reduction Warrants
Bituminous Concrete Overlay on Membrane	≥ 1.6	≤ 0.1	≥ 1.6	Major
Coating	≤ 0.1	≤ 0.1	≤ 0.1	Negligible
Portland Cement Concrete Overlay	≥ 1.3	≥ 0.5	≥ 0.8	Medium
" "	≥ 2.0	≥ 0.5	≥ 1.5	Major
Penetrating Sealer	≤ 0.1	≤ 0.1	≤ 0.1	Negligible
Polymer Overlay	≥ 0.3	≤ 0.2	≥ 0.1	Negligible
" "	≥ 0.5	≤ 0.2	≥ 0.3	Minor
Other Hydraulic Concrete Overlay	≥ 1.3	≥ 0.5	≥ 0.8	Medium
" "	≥ 2.0	≥ 0.5	≥ 1.5	Major

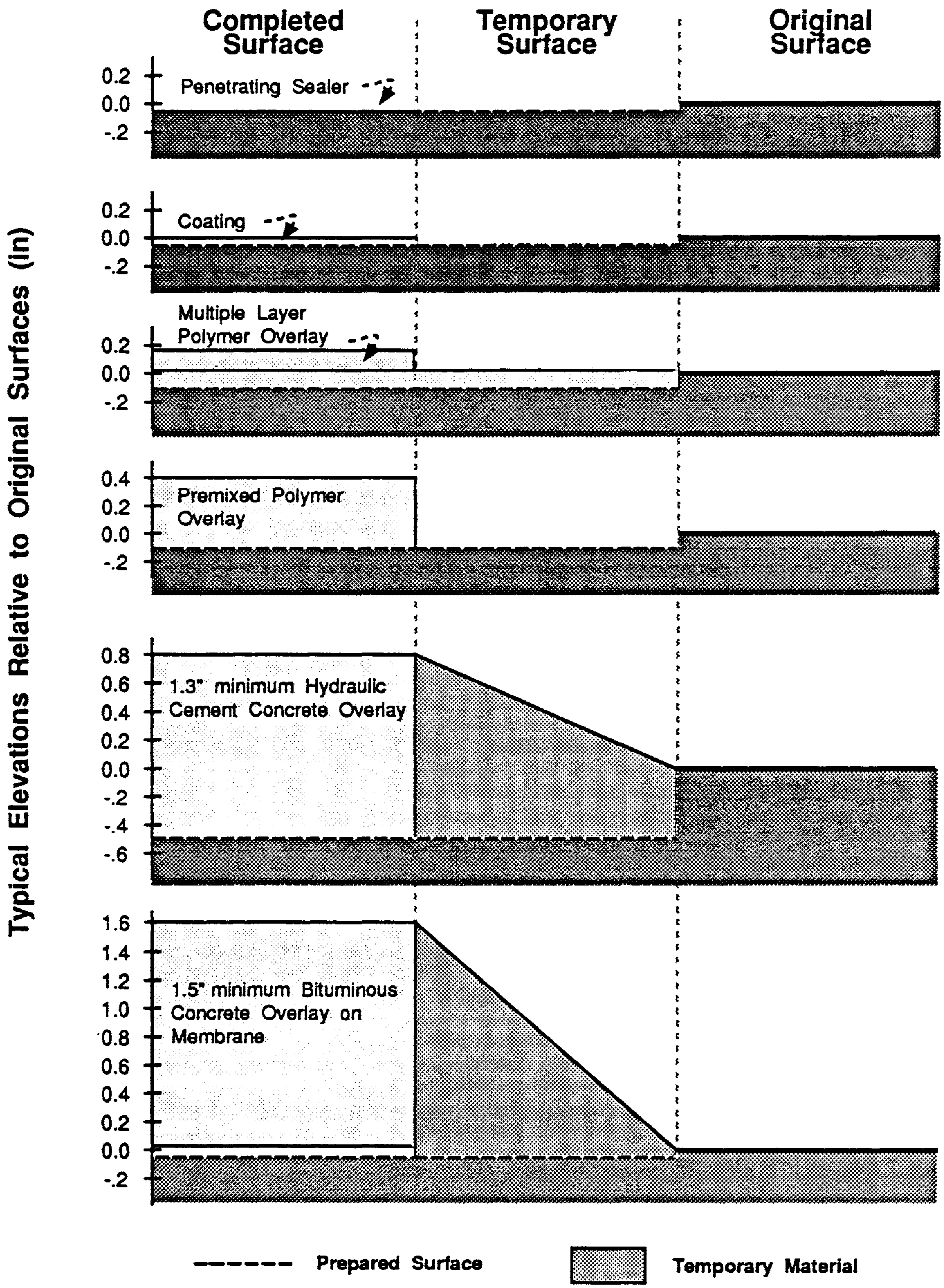


Figure 2. Typical surface elevations for rapid protection systems.

surface texture or color. A multiple layer polymer overlay also has a negligible effect on the elevation of the surface particularly if the first layer of a two-layer system serves as a temporary surface (see Figure 2). Premixed polymer overlays are usually $\geq$ 0.5 in thick and can warrant a minor speed reduction over the temporary surface. High early strength portland cement concete overlays and other hydraulic cement concrete overlays that are only 1.3 in thick may warrant a medium speed reduction because of the 0.8-in change in elevation between the new overlay and the original deck surface. Temporary materials may have to be applied to the prepared temporary surfaces because of the 1.3-in difference in elevation. Bituminous concrete overlays and hydraulic cement concrete overlays that are $\geq$ 1.5 in thick warrant major speed reductions, and temporary materials may have to be applied to the temporary surface to provide a safe ride (see Figure 2). Protection systems such as sealers, coatings, and multiple layer polymer overlays require negligible speed reductions during lane openings. Bituminous concrete overlays and thick hydraulic cement concrete overlays require major speed reductions and the application of temporary materials to the temporary surface.

Temporary surfaces are not required for crack repair and sealing. A temporary surface is also unnecessary if a repaired joint is not wide enough to cause a problem for the motorist. However, for joints with sufficient width, wide cavities can be covered with steel plates or filled with bituminous concrete. Timber planks have also been placed in joint areas. When patching, bituminous concrete or steel plates can be used to provide a temporary riding surface if the patching materials cannot be placed and cured properly prior to opening the surface to traffic.

Minimum Curing Time

One of the most important properties of a rapid protection, rehabilitation or replacement system 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. Obviously, a material must be relatively free of cracks and must be adequately bonded to the substrate to protect the deck and provide skid resistance. With the exception of bituminous concrete, sealers, and coatings, the most convenient indicators of strength are the compressive strengths of 4-by-8-in cylinders of concrete and 2-in cubes of mortar. Hydraulic cement concretes and polymer concretes are usually required to have a compressive strength of 2,500 to 4,000 psi prior to being subjected to traffic (3). Guillotine shear bond strengths of at least 200 to 400 psi are usually obtained at these compressive strengths when concrete substrates are properly prepared (4, 5). Tensile adhesion strengths greater than 100 psi are also indicative of satisfactory performance (6, 7). Coatings and sealers must be tack free at the time they are subjected to traffic. Membranes must be tack free prior to being overlaid with bituminous concrete, which is then allowed to cool to 150^{o}F before it is opened to traffic (3). Patches that can be protected with a steel plate can be opened to traffic once the plate is in place. Minimum curing times do not apply to precast members because they have adequate strength when installed. However, site cast materials used to connect the members must have adequate strength. Site cast concrete used for deck replacement should have a minimum compressive strength of 4,000 psi when subjected to traffic (3).

Table 3 shows estimates of the minimum curing times needed to subject protection systems to traffic without causing major damage to them. The estimates are based on compressive and bond strength data, tack free times, and bituminous concrete cooling rate data obtained from the literature and the responses to the questionnaire sent to the materials suppliers (3, 7, 8, 9, 10, 11, 12, 13). 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 3 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 3.

The minimum curing times in Table 3 for a bituminous concrete overlay are for an overlay placed on a prefabricated, rubberized asphalt membrane and prime coat. Approximately one hour is required for the prime coat to cure at 75°F. At 90°F the prime coat usually cures faster; however, a minimum of approximately one hour cure time is still required for the bituminous concrete to cool to 150°F (3, 8). At temperatures of 55°F and below, the curing time is controlled by the curing rate of the prime coat.

A high molecular weight methacrylate coating can be tack free in one hour at 90°F, but a longer time is required at lower temperatures (7, 9).

Laboratory data for a special blended repair mortar are shown in Table 3 as representative of the minimum obtainable cure times for portland cement concrete overlays (10, 11). Although it is likely that longer times would be required for most mixtures to reach 3,000 psi compressive strength, the responses to questionnaires No. 1 and No. 2 indicate that only 5.6 hours was required to place and cure this type of overlay.

Table 3

Minimum Curing Times of Rapid Protection Systems, hours

System	Installation Temperature, °F 40	55	75	90	References
Bituminous Concrete Overlay on Membrane	NA	2	2	2	3, 8
Coating	NA	9	3	1	7, 9
Portland Cement Concrete Overlay	8	6	4	4	10, 11
Penetrating Sealer	4	3	2	1	7
Polymer Overlay	2*	6	3	2	7, 12
Other Hydraulic Cement Concrete Overlay	1*	1*	1	1	10, 13

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

* Special cold weather formulation used.

Data for a silane penetrating sealer at tack free time, and data for an epoxy mortar, a methacrylate concrete (cured at $40^{o}F$) and a magnesium phosphate cement mortar at 3,000 psi compressive strength are also shown in Table 3 (7, 10, 12, 13).

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. Bituminous concrete cools more rapidly when placed in thin lifts, 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 3 with the exception of bituminous concrete patches. These patches are suitable for traffic in one hour or less.

Permeability to Chloride Ion

A rapid permeability test (AASHTO T277) can be used to measure the permeability to chloride ion of 4-in diameter by 2-in thick specimens prepared in the laboratory or 4-in diameter by 2-in thick slices of cores obtained from bridge decks. The results are usually reported in coulombs, which have the relationship to permeability as shown below Table 4.

Table 4 shows the permeability to chloride ion of cores taken from decks to which rapid protection systems had been applied and of specimens prepared in the laboratory (5, 7, 9, 14, 15, 16, 17). Results for specimens tested at early and later ages are reported where data is available to provide an indication of how the permeability changes with age.

Data for the same systems cited in Table 3 are cited in Table 4 with the exception that the portland cement concrete overlay is for a concrete

Table 4

Permeability to Chloride Ion of Rapid Proection Systems[a]

System	Laboratory Specimens	Cores at Indicated Age			References
		≤ 1 yr	5 yr	10 yr	
Bituminous Concrete Overlay on Membrane	—	N	—	—	14
Coating	—	L	—	—	7, 9
Portland Cement Concrete Overlay	L	L	VL	VL	5, 15, 16, 17
Penetrating Sealer	—	L, M	L, M	—	7
Polymer Overlay	N	N	VL, L	VL, L	7, 14
Other Hydraulic Cement Concrete Overlay	VL	—	—	—	15

[a]

Permeability		Coulombs
H = High	=	> 4,000
M = Moderate	=	2,000 - 4,000
L = Low	=	1,000 - 2,000
VL = Very Low	=	100 - 1,000
N = Negligible	=	< 100

rather than a mortar and includes latex-modified concrete and concrete containing silica fume (5, 15, 16, 17). The data for sealers also includes a water-dispersed and a solvent-dispersed epoxy (7). The data for polymer overlays also includes overlays constructed with polyester styrene and methacrylate binders (7, 14).

The protection systems differ as to permeability to chloride ion. Negligible values are reported for membranes and polymer overlays at one year of age; very low values are reported for latex-modified concrete and concrete containing silica fume at a later age; low values are reported for laboratory specimens made with special blended cements such as Pyrament; and low to moderate values are reported for concretes to which a coating or penetrating sealer had been applied. Typically, unprotected bridge deck concretes have a moderate to high permeability. The materials used to rehabilitate a deck should have a low permeability to chloride ion unless a protective system will be placed following the crack repair or patching. To properly rank the protection systems, the permeability over the life of the systems needs to be considered.

Skid Resistance and Wear

A protection system must have an adequate skid resistance to be used on traffic-bearing surfaces. Corrective action is required when smooth tire numbers (ASTM E524) are $\leq$ 20 and treaded tire numbers (ASTM E501) are $\leq$ 37. Table 5 shows skid numbers for the protection systems at $\leq$ 1 year of age and at 5 years of age to provide an indication of how the skid resistance changes with age (5, 7, 14, 18). As can be seen from Table 5, unacceptable skid numbers can be obtained when coatings and some penetrating sealers are applied to screeded concrete surfaces. Coatings and sealers can usually be

Table 5

Skid Numbers at 40 mph for Rapid Protection Systems

System	Texture	Smooth Tire ≤ 1 yr	Smooth Tire 5 yr	Treaded Tire ≤ 1 yr	Treaded Tire 5 yr	References
Bituminous Concrete Overlay on Membrane	Compacted	26	28	46	41	14
Coating	Screeded	7	—	7	—	7, 9
	Tined	36	—	47	—	
Portland Cement Concrete Overlay	Screeded	—	28	61	51	5, 18
	Tined	41	—	44	—	
Penetrating Sealer	Screeded	23	34	36	51	7
	Tined	45	45	46	45	
Polymer Overlay	Tined	38	45	45	48	7, 14
	Sand broadcast	63	36	64	45	

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 assure proper skid resistance. Silica aggregate can be broadcast onto polymer materials to provide a good skid number.

A protective system must have adequate abrasion resistance to prevent wear that results in a decrease in the level of protection. Most high early strength materials have good abrasion resistance as long as abrasion resistant aggregates are used in the mixtures. The life of a protection system can be determined by skid resistance and wear.

Materials used for crack repair, crack sealing, joint repair, and patching must also provide for good skid resistance and wear unless the materials are covered with a protective system. Skid numbers for these rehabilitation systems are not available; however, the results should be similar to those obtained for protection systems constructed with similar materials and surface textures.

Subjective Rating

A subjective rating of the most rapid protection systems based on performance characteristics, as shown in Table 6, can be used to select the optimum system. As can be seen from Table 6, typically, the best most rapid protection system (lowest total) is the polymer overlay (System IE) and the least desirable system (highest total) is the high early strength portland cement concrete overlay (System IC). Although the results shown in Table 6 would not necessarily be applicable to every situation, the application of a polymer overlay or penetrating sealer is typically desirable because acceptable skid resistance and permeability to chloride ion can be obtained with negligible speed reductions and with very short curing times. Also in situations where traffic begins to back up, these protective systems can be open to traffic in very short times to relieve conjestion. On the other hand, bituminous overlays and high early strength portland cement concrete overlays do not lend themselves to use where most rapid repairs are desired because of the speed reductions required and the effort required to remove installation equipment and apply temporary materials to prepare the surface for traffic. Bituminous overlays and portland cement concrete overlays become more desirable as longer times are allowed for lane closure. These systems are much better suited for rapid and particularly well suited for semirapid installations.

Table 6

Subjective Rating of Most Rapid Protection Systems

System	Temporary Surfaces	Minimum Curing Time	Permeability	Skid No.	Total	Rank
Bituminous Concrete Overlay on Membrane	4	2	1	3	10	#5
Coating	1	2	3	3	9	#4
High Early Strength Portland Cement Concrete Overlay	3	3	2.5	2	10.5	#6
Penetrating Sealer	1	1	3.5	2	7.5	#2
Polymer Overlay	1	2	2	1	6	#1
Other Hydraulic Cement Concrete Overlay	3	1	2	2	8	#3

1 - excellent
2 - very good
3 - good
4 - fair

TECHNIQUE TIME DEMANDS

Based on the responses to questionnaires No. 1 and No. 2, the time required to set up and remove traffic control, prepare the surface, and place and cure materials is summarized in Table 7. Table 7 shows that with the exception of a coating and the replacement of a deck with site cast portland cement concrete, each of the repair systems was cited at least one time as a most rapid system. However, deck replacement with site cast high early strength portland cement concrete made with a special blended cement should be possible as a most rapid system. With the exception of the other hydraulic cement concrete overlay and the bituminous concrete patch, each of the repair systems was cited at least one time as a very rapid system. The bituminous concrete overlay on membrane system, the polymer overlay, and the precast concrete deck panel system were each cited at least one time as a rapid system. Table 7 also shows the average deck area in square yards for which the time estimates were made.

The technique time demands for four of the most used rapid protection systems, three of the most used rapid patching systems, and two of the most used rapid replacement systems are illustrated in Figures 3, 4, 5, and 6, respectively. Figures 3, 4, 5 and 6 and the data in Table 7 should be useful to bridge engineers when planning rapid repairs for bridge decks.

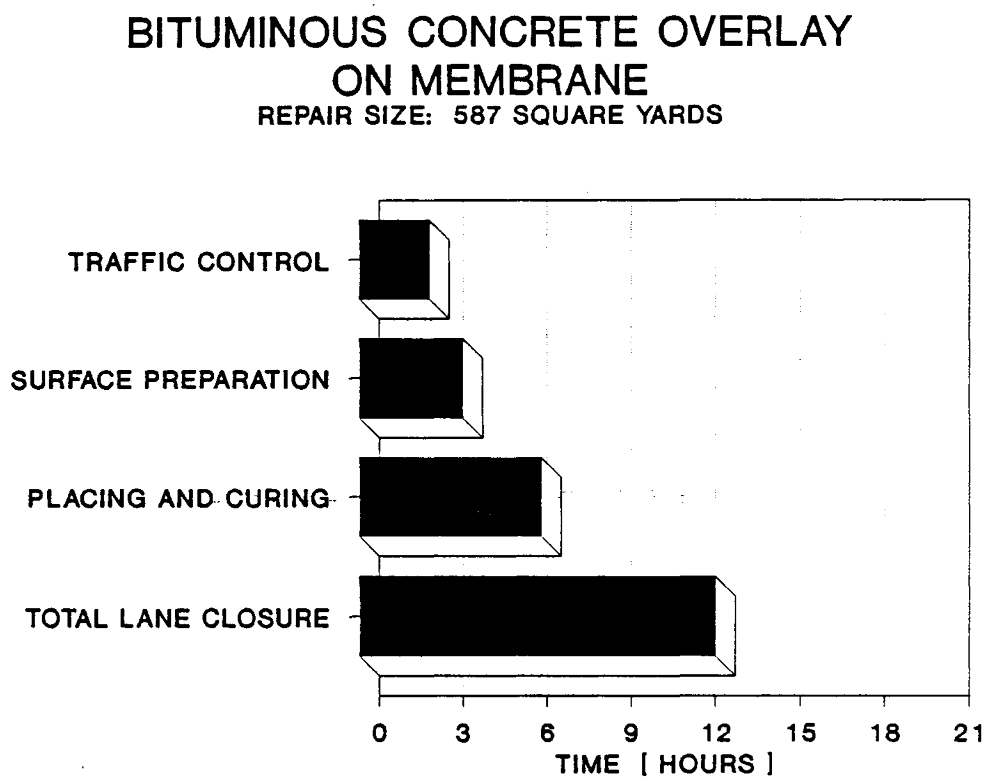
No time requirement data for joint repairs were obtained from the questionnaire responses. However, most joints that are prefabricated and secured with an adhesive and bolts can satisfy the criteria for a rapid repair. Also, concrete headers can be site cast with high-early-strength portland cement concrete, polymer concrete, or other hydraulic cement concrete.

Table 7

Technique Time Requirements

		Average Time Requirements, hr				Number of Responses Indicating Total Time		
System	Avg. Area, yd^2	Traffic Control	Surface Preparation	Placing and Curing	Total	≤ 8 hr	> 8 ≤ 12 hr	> 12 hr ≤ 21 hr
Bituminous Concrete Overlay on Membrane	587	2.5	3.7	6.5	12.7	5	8	12
Coating	519	2.0	1.8	5.7	9.5	0	3	0
Portland Cement Concrete Overlay	1181	0.9	2.3	5.6	8.8	2	3	0
Penetrating Sealer	673	1.5	2.2	3.4	7.1	6	1	0
Polymer Overlay	481	1.2	4.0	4.7	9.9	3	8	1
Other Hydraulic Concrete Overlay	452	0.9	4.0	3.1	8.0	1	0	0
Crack Repair and Sealing	700[a]	2.0	1.3	4.0	7.3	1	1	0
Bituminous Concrete Patch	5	0.9	0.4	0.7	2.0	6	0	0
Portland Cement Concrete Patch	9	1.7	3.3	2.6	7.6	14	9	0
Polymer Concrete Patch	202	2.1	1.9	5.2	9.2	1	2	0
Other Hydraulic Concrete Patch	43	1.5	2.2	3.1	6.8	6	4	0
Steel Plate over Concrete	2	0.8	1.7	2.2	4.7	1	1	0
Precast Concrete Deck Panel	1291	1.4	4.6	5.1	11.1	1	2	1
Site Cast Portland Cement Concrete	4	3.2	2.6	5.6	11.4	0	3	0
Other Site Cast Hydraulic Concrete	3	1.9	2.5	3.9	8.3	2	1	0

[a]Linear feet.



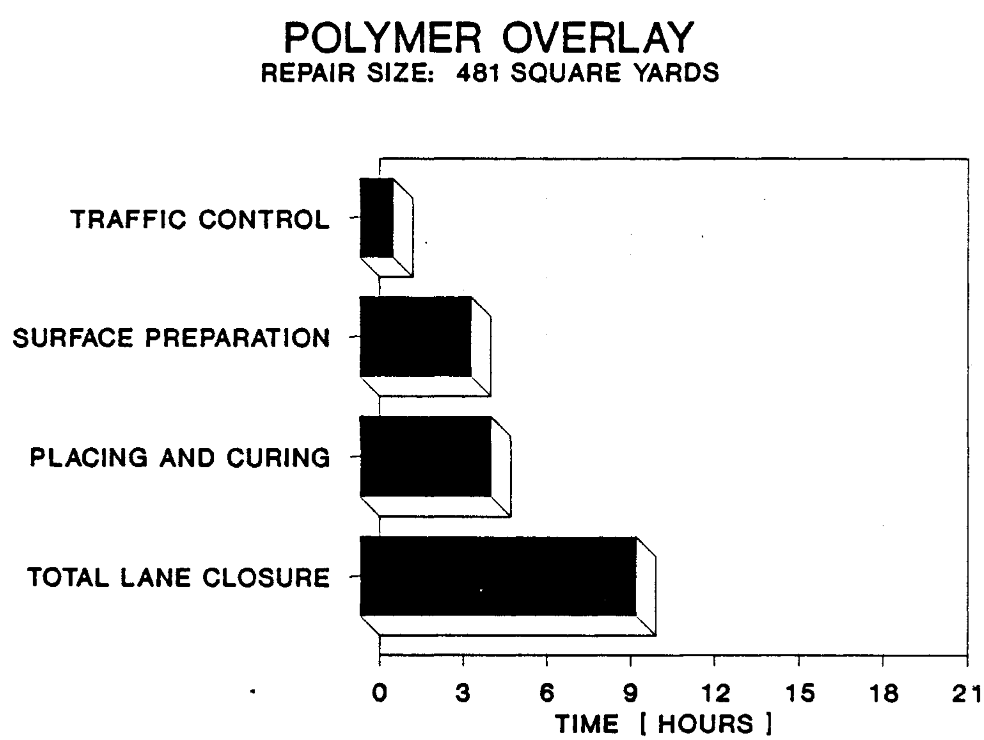
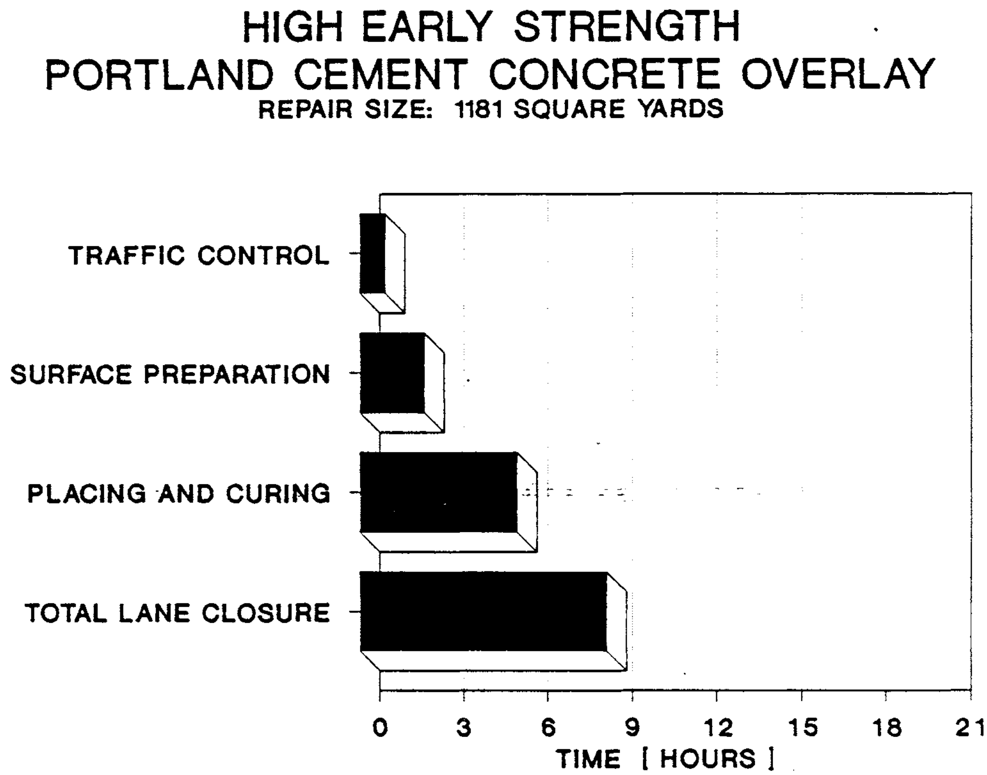


Figure 3. Technique time requirements for the two most frequently used rapid protection systems.



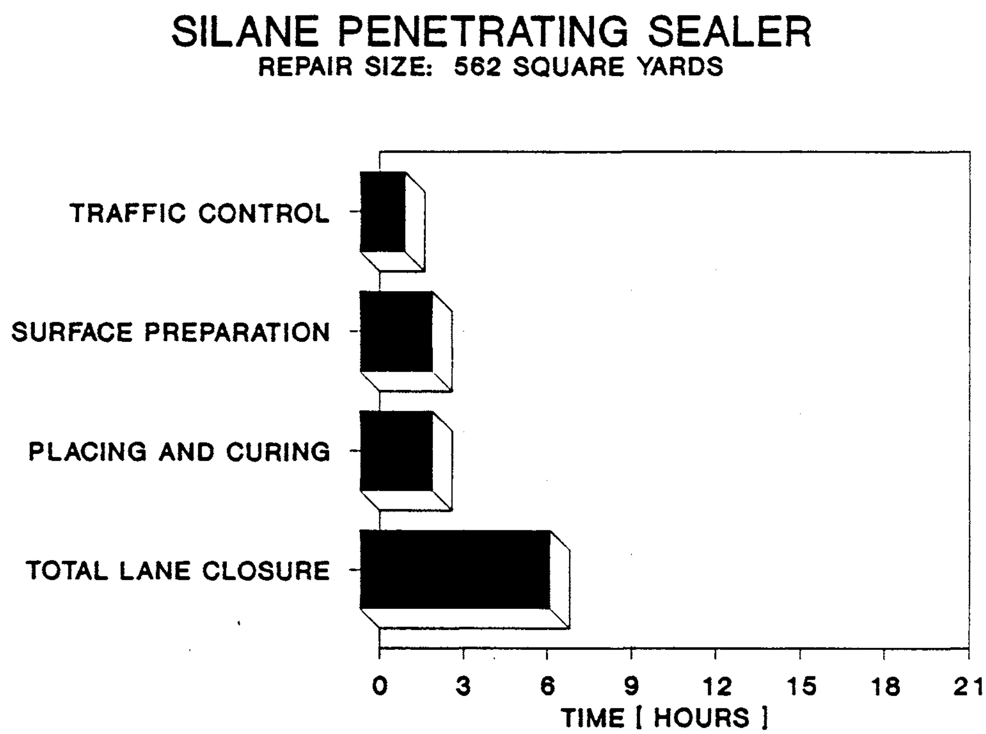


Figure 4. Technique time requirements for two other frequently used rapid protection systems.

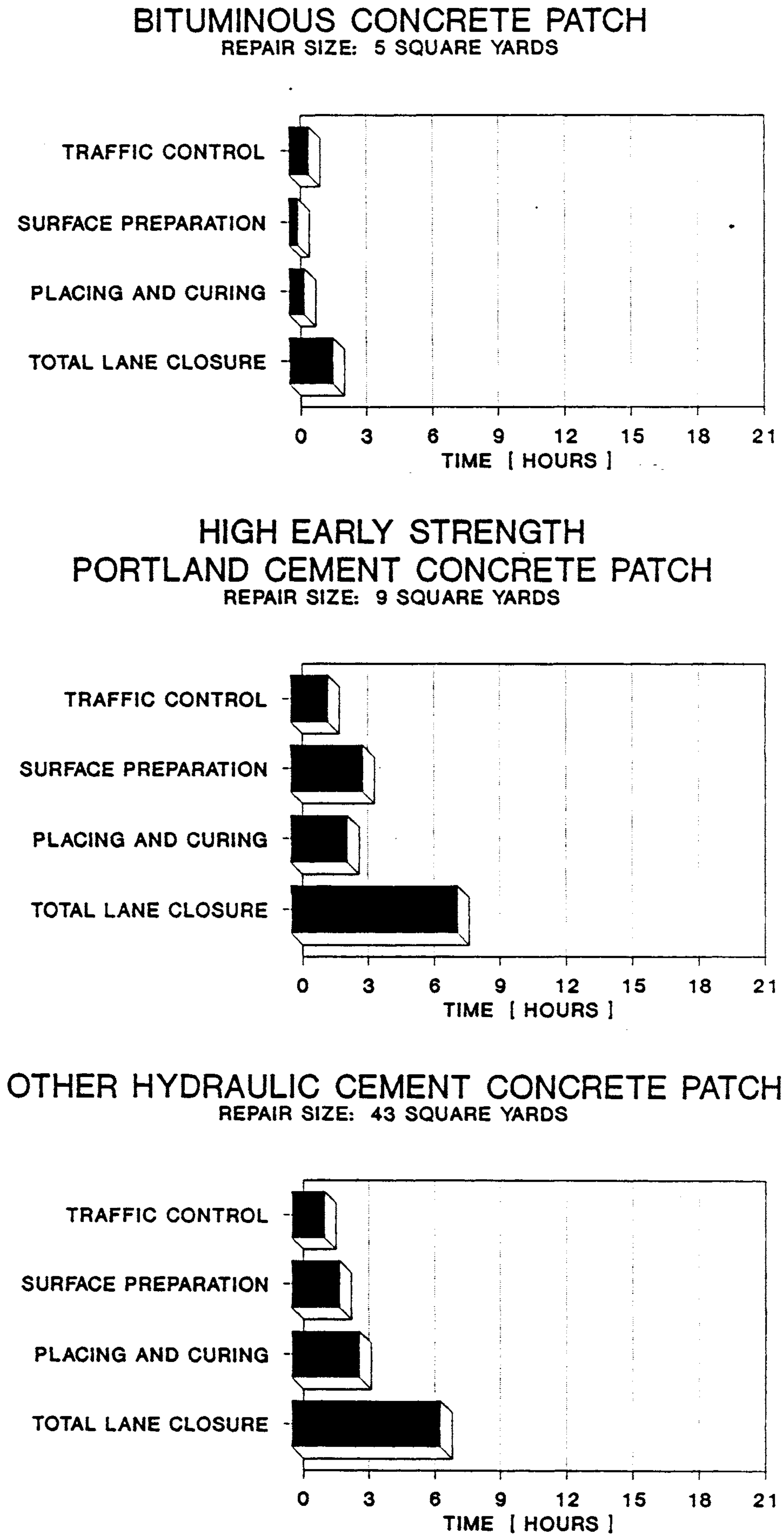
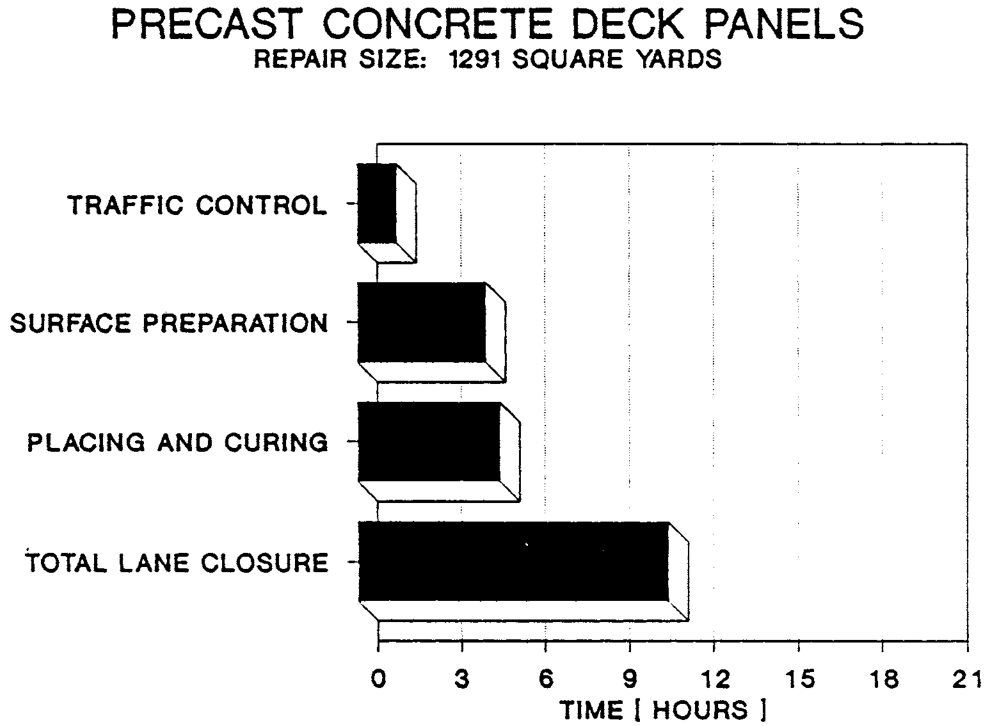


Figure 5. Technique time requirements for the three most frequently used rapid patching systems.



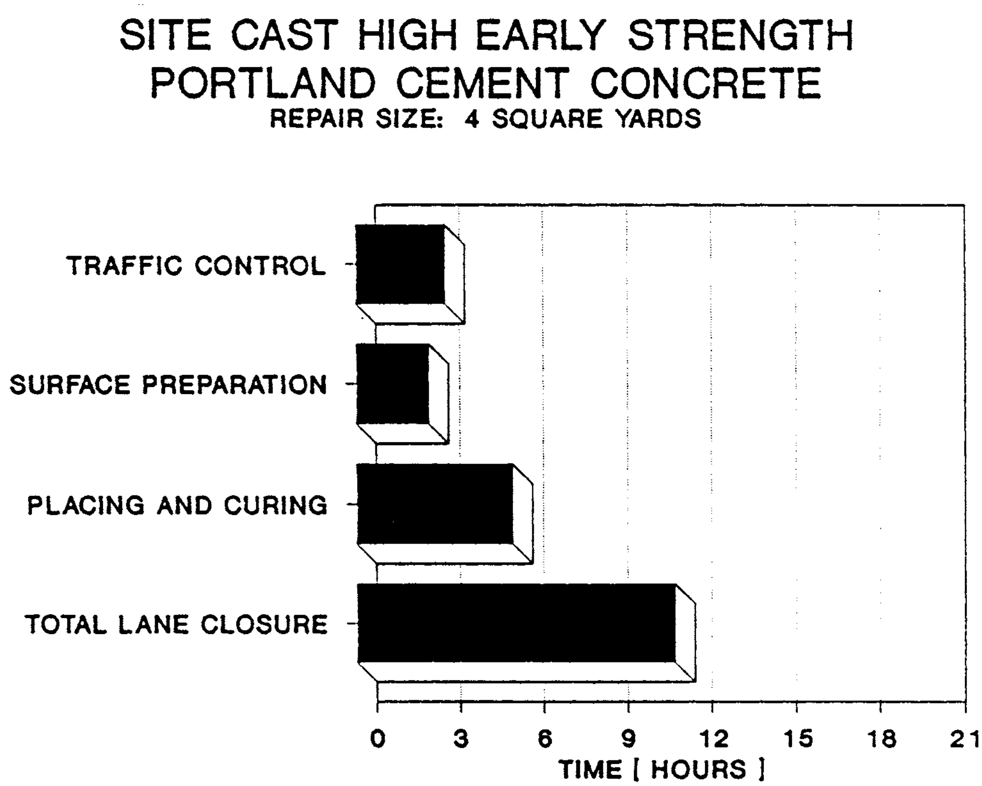


Figure 6. Technique time requirements for the two most frequently used rapid replacement systems.

No time requirement data for precast concrete slab spans, box beams, channel and tee beams were obtained from the responses to the questionnaires. However, these members can be used for rapid deck replacement when the spans are shorter than 100 ft (19). Also, no data were obtained for use of permanent forms with site cast concrete; however, the time requirements should be the same as those for deck replacement with site cast concrete. Finally, no time requirement data were obtained for deck replacement with polymer concrete. The technology has not been developed to the point that time data would be available.

SERVICE LIFE AND MAINTENANCE

The responses to questionnaires No. 1 and No. 2 provided sufficient information to estimate the service life of most of the rapid repair systems (see Table 8). The average service life ranged from a low of 1.7 years for patching with bituminous concrete patches to a high of 38.8 years for replacing a deck with precast concrete deck panels. The time until minor repairs (maintenance) are required is also shown in Table 8. The average time ranged from a low of 0.3 years for a bituminous concrete patch to a high of 20 years for the precast concrete deck panels. Service life data obtained from a review of the literature is shown in Table 9 (7, 14, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34). Site cast portland cement concrete decks can be constructed to last 50 years with maintenance in the form of an overlay applied at 25 years of age (35). The maintenance and service life estimates were used to determine the life cycle cost for each repair system. It is not known at this time at what age a deck may have to be replaced because of corrosion-induced failures. In other words, the maintenance interval and service life values reported in Table 8 are for

Table 8

Service Life and Maintenance Based on Questionnaire Response, years

System	Time until Maintenance Avg.	Low	High	Service Life Avg.	Low	High
Bituminous Concrete Overlay on Membrane	5.1	1.0	10.0	11.8	4.5	20.0
Coating	5.2	2.8	10.0	10.3	5.5	20.0
Portland Cement Concrete Overlay	8.3	5.3	11.9	15.5	10.0	22.5
Penetrating Sealer	6.8	4.0	10.1	16.5	10.0	25.0
Polymer Overlay	6.4	3.0	10.0	12.7	6.0	25.0
Crack Repair and Sealing[a]	7.5	5.0	10.0	15.0	10.0	20.0
Bituminous Concrete Patch	0.3.	0.1	0.8	1.7	1.0	3.0
Portland Cement Concrete Patch	2.8	0.3	7.0	5.9	1.8	10.0
Polymer Concrete Patch	10.0	—	—	20.0	15.0	25.0
Other Hydraulic Concrete Patch	6.3	1.0	10.0	11.9	2.0	20.0
Steel Plate over Concrete	10.0	—	—	15.0	—	—
Precast Concrete Deck Panel	20.0	12.5	30.0	38.8	30.0	50.0
Site Cast Portland Cement Concrete	6.2	4.0	8.0	11.7	7.5	15.0
Other Site Cast Hydraulic Concrete	2.0	—	—	5.5	5.0	6.0

[a]($/linear foot).

Table 9

Service Life and Initial Cost of Rapid Repair Systems Based on Literature Review

System	Service Life, yrs. Avg.	Service Life, yrs. Low	Service Life, yrs. High	Initial Cost, $/yd² Avg.	Initial Cost, $/yd² Low	Initial Cost, $/yd² High	References
Bituminous Concrete Overlay on Membrane	9.7	3.7	15.0	50.84	15.53	135.44	7, 20, 21, 22, 23
Coating	—	—	—	—	—	—	—
Portland Cement Concrete Overlay	17.9	13.6	25.0	83.21	11.19	287.75	20, 21, 22, 23, 24, 25, 26
Penetrating Sealer	5.0	—	—	5.45	2.58	9.84	7, 23, 27, 28, 29
Polymer Overlay	10.0	—	—	43.55	7.03	100.08	7, 14, 23, 24, 25, 30, 31,
Other Hydraulic Concrete Overlay	—	—	—	6.08	—	—	24
Crack Repair and Sealing[a]	10.0	—	—	—	—	—	23
Joint Repair[a]	3.7	3.5	3.9	78.23	77.73	78.72	21
Bituminous Concrete Patch	0.6	0.1	1.0	40.57	20.01	72.24	21, 23, 33, 34
Portland Cement Concrete Patch	14.8	4.3	35.0	202.17	164.71	239.63	20, 21, 23
Polymer Concrete Patch	5.5	—	—	247.07	—	—	21
Other Hydraulic Concrete Patch	3.8	—	—	235.16	—	—	21
Steel Plate over Concrete	—	—	—	—	—	—	—
Precast Concrete Box Beam	44.1	—	—	967.44	—	—	21
Precast Concrete Channel and Tee Beam	—	—	—	—	—	—	—
Precast Concrete Deck Panel	25.3	24.5	26.1	852.35	822.58	882.11	21
Site Cast Portland Cement Concrete	34.8	29.6	40.0	482.39	468.84	495.93	20, 21
Other Site Cast Hydraulic Concrete	12.5	—	—	686.64	—	—	21

[a]($/linear foot).

repairs done on typical decks. The life would likely be less if the repair is done to a deck with a high rate of corrosion of rebar and greater if done to a deck with a low or negligible rate of corrosion. It is anticipated that in SHRP contract year 3, the influence of rate of corrosion on repair life and the influence of a repair on the service life of a deck will be determined so that more accurate life cycle costs can be computed in contract year 4.

INITIAL COST AND LIFE CYCLE COST

The responses to questionnaires No. 1 and No. 2 provided initial costs for traffic control, surface preparation, placing and curing materials, and other items as shown in Table 10. The average total initial cost per square yard for the techniques ranged from a low of $2.77 for the application of a penetrating sealer to a high of $776.65 for the replacement of a deck with precast concrete deck panels. It was assumed the cost data was accurate for 1988. Costs obtained from a review of the literature were inflated at the rate of 5 percent per year to provide reasonable values for 1988 as shown in Table 9.

The information in Tables 8 and 10 was used to estimate the initial cost and life cycle costs for the rapid repair systems as shown in Table 11. To compute the life cycle costs shown in Table 11, it was assumed maintenance and system replacement occured at the time intervals shown in Table 8. The data from Table 9 was used to estimate the life cycle costs shown in Table 12. Since maintenance intervals were not obtained from the literature review, maintenance costs were not included in the life cycle costs shown in Table 12. Present values were calculated for a period of 50 years because present value data based on a 50-year period is available for new decks, and present values calculated for longer than 50 years are not much higher (35).

Table 10

Initial Cost of Rapid Repair Systems Based on Questionnaire Response, $\$/yd^2$

System	Traffic Control	Surface Preparation	Placing and Curing Materials	Other	Avg. Total	Low Total	High Total
Bituminous Concrete Overlay on Membrane	3.73	3.09	15.28	2.52	24.62	1.95	44.00
Coating	0.11	4.39	11.95	0.00	16.45	6.95	24.41
Portland Cement Concrete Overlay	19.31	21.39	38.02	8.73	87.45	77.28	95.60
Penetrating Sealer	0.67	0.46	1.57	0.07	2.77	1.36	4.55
Polymer Overlay	0.73	5.68	31.35	0.64	38.40	4.00	92.99
Other Hydraulic Concrete Overlay	0.36	46.80	53.30	0.00	100.46	—	—
Crack Repair and Sealing[a]	0.15	5.28	4.05	0.00	9.48	6.95	12.00
Bituminous Concrete Patch	63.42	7.54	39.57	0.63	111.16	7.00	250.00
Portland Cement Concrete Patch	30.93	108.34	119.74	7.12	266.13	15.00	611.43
Polymer Concrete Patch	0.11	18.00	48.75	0.00	66.86	—	—
Other Hydraulic Concrete Patch	32.84	31.26	102.92	14.30	181.32	3.96	527.47
Steel Plate over Concrete	9.00	6.00	9.00	60.00	84.00	—	—
Precast Concrete Deck Panel	149.37	176.29	288.55	162.44	776.65	741.94	800.00
Site Cast Portland Cement Concrete	33.14	33.77	74.65	0.00	141.56	34.32	249.00
Other Site Cast Hydraulic Concrete	271.67	94.33	297.33	0.00	663.33	249.00	980.00

[a] ($/linear foot).

Table 11

Initial Cost and Life Cycle Cost Based on Questionnaire Response, $/yd^2

Code Number	System	Initial Cost	Present Value Total Cost* 25-Yr Evaluation Period	50-Yr Evaluation Period
IA	Bituminous Concrete Overlay on Membrane	24.62	42.84	55.40
IB	Coating	16.45	31.69	41.03
IC	High Early Strength Portland Cement Concrete Overlay	87.45	127.08	160.77
ID	Penetrating Sealer	2.77	3.90	4.90
IE	Polymer Overlay	38.40	63.03	81.53
IF	Other Hydraulic Cement Concrete Overlay	100.46	—	—
IIA	Crack Repair and Sealing**	9.48	14.08	17.86
IIC	Patching with Bituminous Concrete	111.16	1,453.69	1,884.92
IID	Patching with High Early Strength Portland Cement Concrete	266.13	815.22	1,057.85
IIE	Patching with Polymer Concrete	66.86	81.36	104.88
IIF	Patching with Other Hydraulic Concrete	181.32	312.20	403.78
IIG	Temporary Steel Plate over Conventional Concrete Patch	84.00	123.77	157.14
IIID	Replacement with Precast Concrete Deck Panel	776.65	724.35	874.72
IIIF	Replacement with Site Cast High Early Strength Portland Cement Concrete	141.56	247.03	319.35
IIIH	Replacement with Other Site Cast Hydraulic Concrete	663.33	2,334.08	3,017.19

* Parameters: 10% interest rate; 5% inflation rate; maintenance cost 10% of initial cost.

** ($/linear foot).

Table 12

Initial Cost and Life Cycle Cost Based on Literature Review, $/yd^2

Code Number	System	Initial Cost	Present Value Total Cost*: 25-Yr Evaluation Period	Present Value Total Cost*: 50-Yr Evaluation Period
IA	Bituminous Concrete Overlay on Membrane	50.84	95.90	123.21
IB	Coating	—	—	—
IC	High Early Strength Portland Cement Concrete Overlay	83.21	103.13	130.96
ID	Penetrating Sealer	5.45	17.74	22.98
IE	Polymer Overlay	43.55	80.27	102.96
IF	Other Hydraulic Cement Concrete Overlay	—	—	—
IIA	Crack Repair and Sealing**	—	—	—
IIB	Joint Repair**	78.23	334.16	432.49
IIC	Patching with Bituminous Concrete	40.57	991.02	1,283.63
IID	Patching with High Early Strength Portland Cement Concrete	202.17	281.82	360.28
IIE	Patching with Polymer Concrete	247.07	742.20	958.46
IIF	Patching with Other Hydraulic Concrete	235.16	980.81	1,268.66
IIG	Temporary Steel Plate over Conventional Concrete Patch	—	—	—
IIIB	Replacement with Precast Concrete Box Beam	967.44	843.71	1,006.87
IIID	Replacement with Precast Concrete Deck Panel	852.35	849.37	1,098.63
IIIF	Replacement with Site Cast High Early Strength Portland Cement Concrete	482.39	442.27	547.01
IIIH	Replacement with Other Site Cast Hydraulic Concrete	686.64	1,059.77	1,372.73

* Parameters: 10% interest rate; 5% inflation rate; maintenance cost 10% of initial cost.

** ($/linear foot).

Present values were also calculated for a 25-year period because a deck with a high rate of corrosion would not likely be repairable for more than 25 years.

Table 11 shows that the lowest life cycle cost protection technique is the application of a penetrating sealer (System ID), the lowest cost rehabilitation technique is patching with polymer concrete (System IIE), and the lowest cost replacement technique is site cast high early strength portland cement concrete (System IIIF).

Figures 7 through 12 compare present value life cycle costs of repair systems based on the surveyed literature and the averaged questionnaire responses. The present value life cycle costs based on these two sources are fairly consistent for the high early strength portland cement concrete overlay (System IC), the polymer overlay (System IE), and the precast concrete deck panel (System IIID). The present value life cycle costs for the other systems lack this consistency.

For example, the initial cost of a bituminous concrete overlay according to the surveyed literature is more than twice the initial cost computed from the questionnaire responses. On the other hand, the service life of this system according to the literature was found to be only slightly over half of the average value cited by questionnaire respondents. The combination of higher initial cost and shorter service life cited in the literature relative to the average questionnaire response causes the literature based life cycle cost to be more than twice the questionnaire based cost (see Figures 7 and 8).

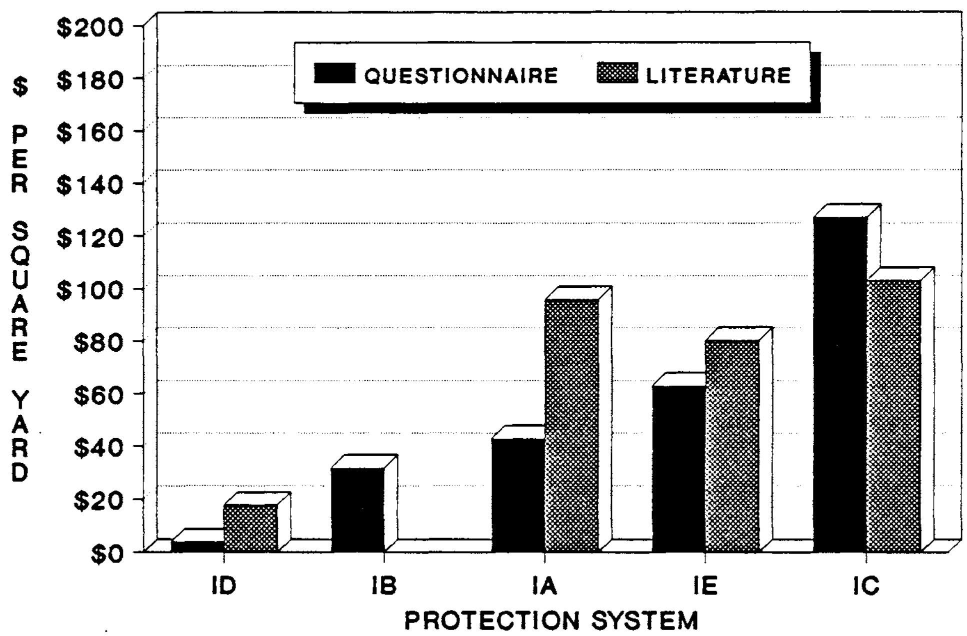


Figure 7. Present value life cycle cost of rapid protection systems based on questionnaire response and literature review (25-year evaluation period).

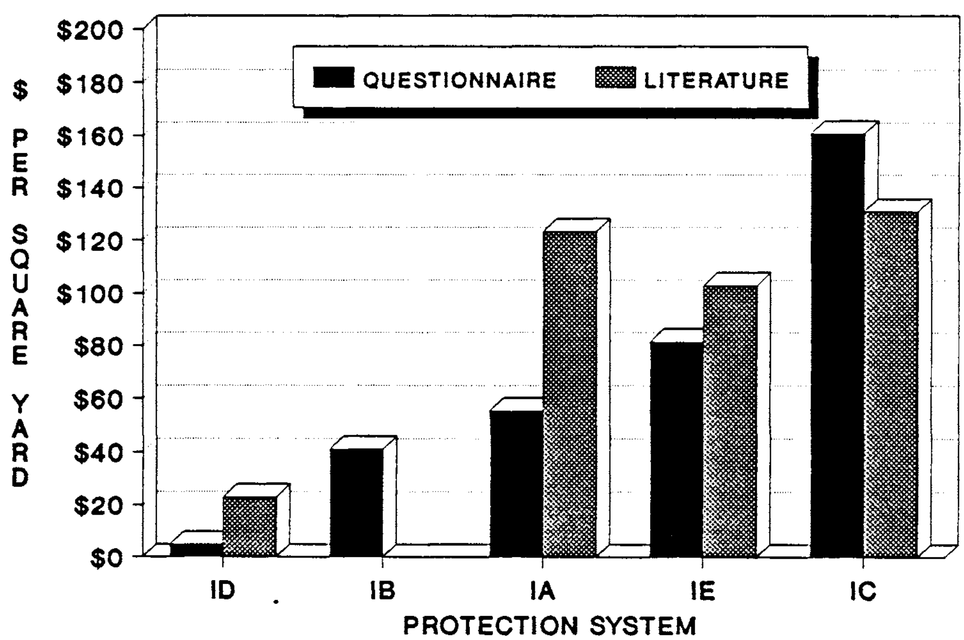


Figure 8. Present value life cycle cost of rapid protection systems based on questionnaire response and literature review (50-year evaluation period).

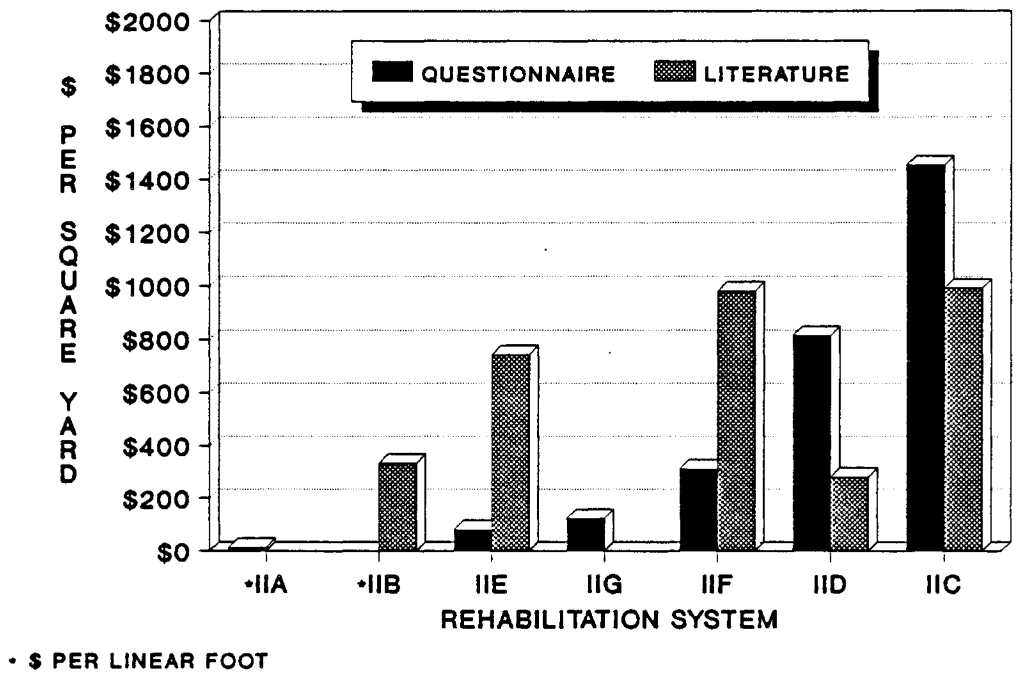


Figure 9. Present value life cycle cost of rapid rehabilitation systems based on questionnaire response and literature review (25-year evaluation period).

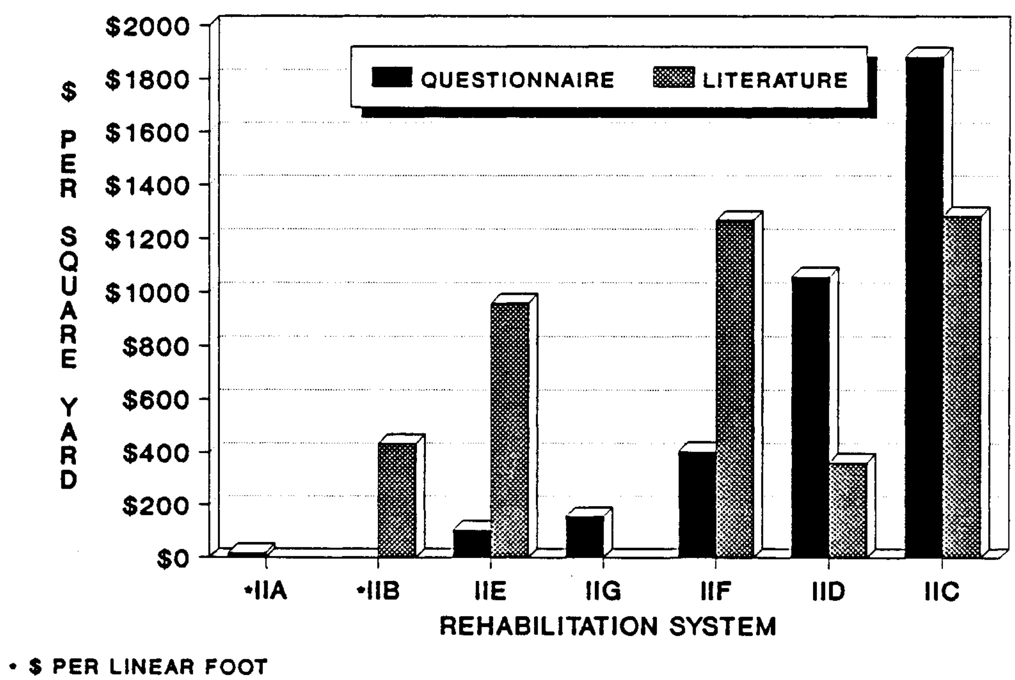


Figure 10. Present value life cycle cost of rapid rehabilitation systems based on questionnaire response and literature review (50-year evaluation period).

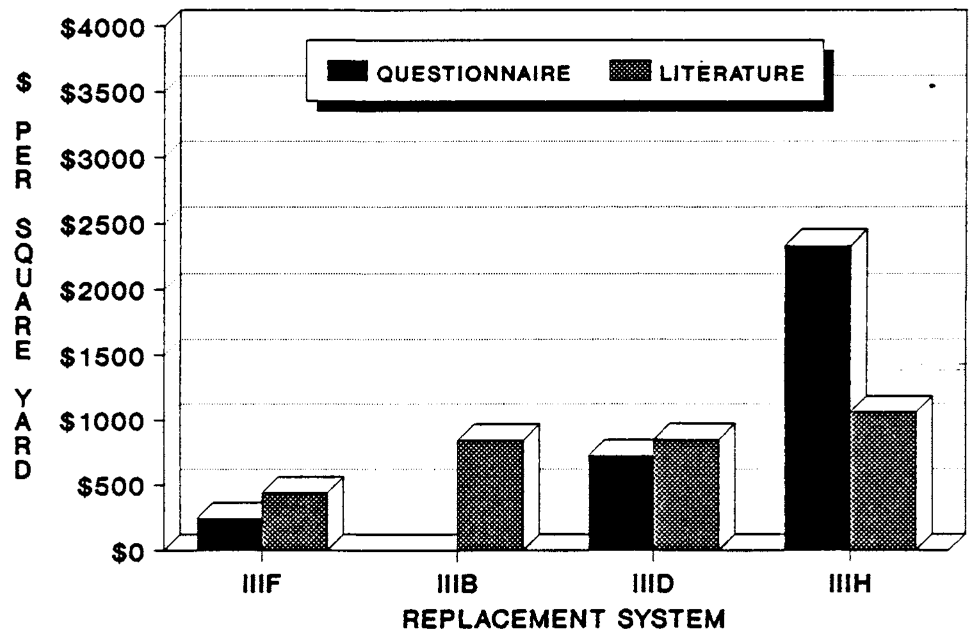


Figure 11. Present value life cycle cost of rapid replacement systems based on questionnaire response and literature review (25-year evaluation period).

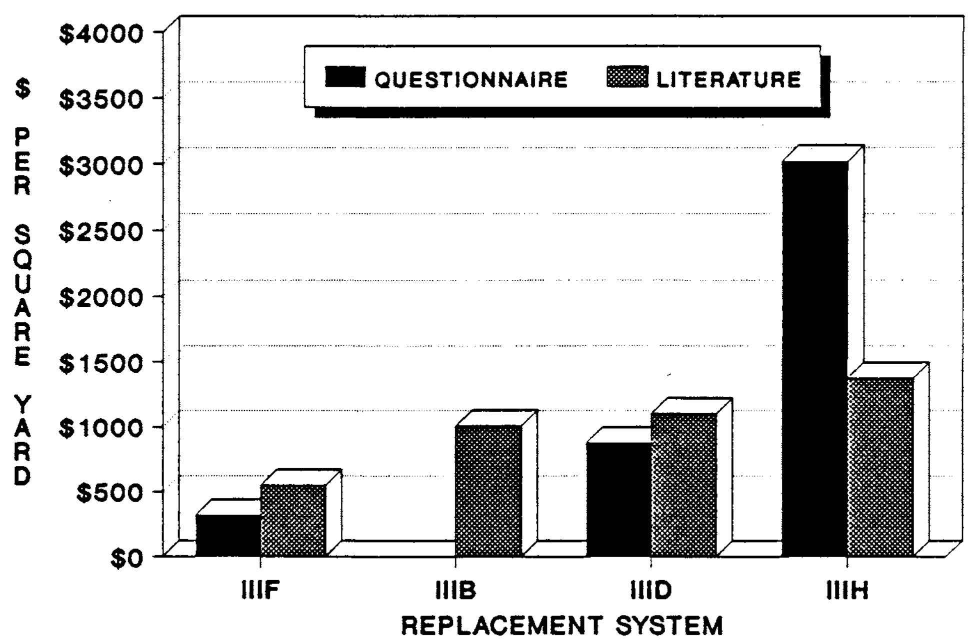


Figure 12. Present value life cycle cost of rapid replacement systems based on questionnaire response and literature review (50-year evaluation period).

The same reasons suggested for differences in life cycle costs of the bituminous concrete overlay are applicable to the penetrating sealer (see Figures 7 and 8), the polymer concrete patch, and the other hydraulic cement concrete patch (see Figures 9 and 10). The initial cost based on the literature is greater than that based on the questionnaire. The service life based on the literature is significantly less than the average questionnaire value. Again, this combination of higher initial cost and shorter service life from the literature causes the life cycle cost based on the literature to be greater than the value based on the responses to the questionaires.

The differences in the present value life cycle costs of the high early strength portland cement concrete patch (System IID) (see Figures 9 and 10) and the other site cast hydraulic concrete deck replacement (System IIIH) (see Figures 11 and 12) based on the two data sources stem mainly from inconsistent service life data. For both systems the service life cited in the literature is much greater than the service life computed from the questionnaire data. In comparison with the present value life cycle cost based on the questionnaire responses, a longer service life and approximately the same initial cost will cause a lower present value life cycle cost based on the literature.

For the bituminous concrete patch (System IIC) and the site cast high early strength portland cement concrete deck replacement (System IIIF), the initial cost and service life cited in the literature are significantly different than the values computed from the questionnaire data. In the case of the bituminous concrete patch, the initial cost and the service life cited in the literature are lower than the average questionnaire response for cost and life. Because of these differences the life cycle cost based on the literature was lower than the cost based on the response to the questionnaire. The opposite is true for the site cast high early strength portland cement concrete deck replacement. The initial cost and the service life cited in the literature are greater than the questionnaire cost and life causing a higher life cycle cost based on the literature review.

Several systems shown in Figures 7 through 12 have a present value life cycle cost based only on one source. A two-source comparison for these systems is not possible at this time because of a lack of questionnaire responses or because the cost and service life of these systems were not discussed in the surveyed literature.

Life cycle costs were also calculated using the shortest and longest service life values obtained from the literature and the questionnaire responses. The relative trends between the systems were similar to those observed when the average service life values were used.

The initial and life cycle costs and the time requirements are only as accurate as the data base. Therefore, results based on one or two responses to the questionnaires or only on one literature source can be misleading. It is anticipated that in SHRP contract year 4 more accurate values and precise conclusions will be available as the results of more studies of repair materials and techniques are added to the data base.

INTERIM CONCLUSIONS

1. Most transportation agencies do not use rapid repair techniques.
2. The most used rapid protection systems are bituminous concrete overlays on membranes, polymer overlays, high early strength portland cement concrete overlays, and penetrating sealers.
3. The most used rapid patching systems are high early strength portland cement concrete patches, bituminous concrete patches, and other hydraulic cement concrete patches.
4. The most used rapid deck replacement systems are site cast high early strength portland cement concrete and precast concrete deck panels.
5. Most of the rapid repair techniques can be done with lane closures less than or equal to 8 hours.
6. Based on the life cycle cost analysis, the most cost-effective protection system is the application of a penetrating sealer. The most cost-effective patching system is patching with polymer concrete based on the questionnaire response and patching with high early strength portland cement concrete based on the literature review. The most cost-effective replacement system is site cast high early strength portland cement concrete. High early strength portland cement concrete overlays are the most expensive protection systems, and patching with bituminous concrete is the most expensive patching system. Other site cast hydraulic concrete is the most expensive replacement system. The analysis of some systems was based on a limited data base and results can change as more data becomes available.

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7. Information on the effect of the repairs on the service life of a deck and the effect of the rate of corrosion of the rebar in a deck on repair life is needed to make an accurate assessment of life cycle costs.

APPENDIX A

Outline of Rapid Systems for Deck Protection, Rehabilitation and Replacement

I. RAPID PROTECTION SYSTEMS

A. BITUMINOUS CONCRETE OVERLAYS

1. ON LIQUID MEMBRANE (SEE IE1)
    a. EPOXY
    b. POLYURETHANE
    c. TAR EMULSION
    d. THERMOPLASTIC
2. ON PREFORMED MEMBRANE
    a. REINFORCED BITUMINOUS
    b. REINFORCED TAR RESIN
    c. RUBBER
    d. RUBBERIZED ASPHALT
    e. OTHER
3. ON PENETRATING SEALER OR COATING (SEE IB AND ID)
4. ON TACK COAT
5. MODIFIED BITUMINOUS CONCRETE OVERLAYS
    a. EPOXY MODIFIED ASPHALT
    b. PRIMERS AND SEALERS
    c. SURFACE TREATMENT CHIP SEAL

B. COATINGS

1. ACRYLIC
    a. ACRYLIC
    b. ACRYLIC COPOLYMER
    c. HIGH MOLECULAR WEIGHT METHACRYLATE
    d. METHACRYLATE
    e. METHYL METHACRYLATE
2. CEMENTITIOUS
    a. NONPOLYMERIC
    b. POLYMERIC
3. EPOXY

C. HIGH EARLY STRENGTH PORTLAND CEMENT CONCRETE OVERLAYS

1. BLENDED CEMENT
2. CONCRETE CONTAINING TYPE I, II, OR III CEMENT AND ADMIXTURES
    a. CORROSION INHIBITING
    b. EPOXY
    c. HIGH-RANGE WATER REDUCING
    d. SILICA FUME
    e. STYRENE BUTADIENE LATEX
    f. OTHER LATEXES
3. LOW SLUMP CONCRETE
4. RAPID HARDENING CEMENTITIOUS MATERIAL
    a. RAPID HARDENING (ASTM C928)
    b. VERY RAPID HARDENING (ASTM C928)

D. PENETRATING SEALERS (RAPID CURING)

1. ACRYLIC
   a. ACRYLIC
   b. ACRYLIC COPOLYMER
   c. METHACRYLATE
   d. METHYL METHACRYLATE
2. EPOXY
3. GUM RESIN
   a. LINSEED OIL
   b. MINERAL GUM
   c. OTHER
4. RUBBER
   a. CHLORINATED RUBBER
   b. EPOXIDE CHLORINATED RUBBER
   c. TRIPLEXY ELASTOMER
5. SILICONE BASED
   a. SILANE
   b. SILANE-SILICONE
   c. SILANE-SILOXANE
   d. SILICATE
   e. SILICONE
   f. SILOXANE
   g. SODIUM-SILICATE
6. URETHANE
   a. ALIPHATIC
   b. ISOCYANATE POLYETHER
7. ASPHALT EMULSION

E. 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. FURFURYL ALCOHOL
   e. POLYESTER STYRENE
   f. POLYURETHANE
   g. SULPHUR
3. SLURRY POLYMER OVERLAY
   a. ACRYLIC/METHACRYLATE
   b. EPOXY
   c. EPOXY-URETHANE
   d. POLYESTER STYRENE
   e. POLYURETHANE

F. OTHER HYDRAULIC CONCRETE OVERLAYS

1. ALUMINA CEMENT
   a. RAPID HARDENING CEMENTITIOUS MATERIAL (ASTM C928)
   b. VERY RAPID HARDENING CEMENTITIOUS MATERIAL (ASTM C928)
   c. OTHER
2. MAGNESIUM PHOSPHATE CEMENT
   a. RAPID HARDENING CEMENTITIOUS MATERIAL (ASTM C928)
   b. VERY RAPID HARDENING CEMENTITIOUS MATERIAL (ASTM C928)
   c. OTHER
3. OTHER HYDRAULIC CONCRETE

Y. NO REPLY TO QUESTIONNAIRE

Z. NO RAPID PROTECTION SYSTEM

II. RAPID REHABILITATION SYSTEMS

A. 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

B. JOINT REPAIR

C. PATCHING WITH BITUMINOUS CONCRETE

1. COLD MIX BITUMINOUS PATCH
2. HOT MIX BITUMINOUS PATCH

D. PATCHING WITH HIGH EARLY STRENGTH PORTLAND CEMENT CONCRETE

1. BLENDED CEMENT
2. CONCRETE CONTAINING TYPE I, II, OR III CEMENT AND ADMIXTURES
   a. ACCELERATING
   b. CORROSION INHIBITING
   c. EPOXY
   d. HIGH-RANGE WATER REDUCING
   e. SILICA FUME
   f. STYRENE BUTADIENE LATEX
   g. OTHER LATEXES
3. LOW SLUMP CONCRETE
4. RAPID HARDENING CEMENTITIOUS MATERIAL
   a. RAPID HARDENING (ASTM C928)
   b. VERY RAPID HARDENING (ASTM C928)

E. PATCHING WITH POLYMER CONCRETE

1. ACRYLIC
2. EPOXY
3. EPOXY-URETHANE
4. FURFURYL ALCOHOL
5. POLYESTER STYRENE
6. POLYURETHANE
7. SULPHUR

F. PATCHING WITH OTHER HYDRAULIC CONCRETE

1. ALUMINA CEMENT
   a. RAPID HARDENING CEMENTITIOUS MATERIAL (ASTM C928)
   b. VERY RAPID HARDENING CEMENTITIOUS MATERIAL (ASTM C928)
   c. OTHER
2. MAGNESIUM PHOSPHATE CEMENT
   a. RAPID HARDENING CEMENTITOUS MATERIAL (ASTM C928)
   b. VERY RAPID HARDENING CEMENTITIOUS MATERIAL (ASTM C928)
   c. OTHER
3. OTHER HYDRAULIC CONCRETE

G. STEEL PLATE OVER CONVENTIONAL CONCRETE

Y. NO REPLY TO QUESTIONNAIRE

Z. NO RAPID REHABILITATION SYSTEM

III. RAPID REPLACEMENT SYSTEMS

A. PRECAST CONCRETE SLAB SPANS

1. POST-TENSIONED
2. PRESTRESSED
3. POST-TENSIONED AND PRESTRESSED

B. PRECAST CONCRETE BOX BEAMS

1. POST-TENSIONED
2. PRESTRESSED
3. POST-TENSIONED AND PRESTRESSED

C. PRECAST CONCRETE CHANNEL AND TEE BEAMS

1. POST-TENSIONED
2. PRESTRESSED
3. POST-TENSIONED AND PRESTRESSED

D. PRECAST CONCRETE DECK PANELS

1. POST-TENSIONED
2. PRESTRESSED
3. POST-TENSIONED AND PRESTRESSED

E. PERMANENT FORMS WITH SITE CAST CONCRETE

1. STEEL STAY-IN-PLACE FORMS
2. SUBDECK PANELS

F. SITE CAST HIGH EARLY STRENGTH PORTLAND CEMENT CONCRETE

1. BLENDED CEMENT
2. CONCRETE CONTAINING TYPE I, II, OR III CEMENT AND ADMIXTURES
    a. ACCELERATING
    b. CORROSION INHIBITING
    c. EPOXY
    d. HIGH-RANGE WATER REDUCING
    e. SILICA FUME
    f. STYRENE BUTADIENE LATEX
    g. OTHER LATEXES
3. RAPID HARDENING CEMENTITIOUS MATERIAL
    a. RAPID HARDENING (ASTM C928)
    b. VERY RAPID HARDENING (ASTM C928)

G. SITE CAST POLYMER CONCRETE

1. ACRYLIC
2. EPOXY
3. EPOXY-URETHANE
4. FURFURYL ALCOHOL
5. POLYESTER STYRENE
6. POLYURETHANE
7. SULPHUR

H. OTHER SITE CAST HYDRAULIC CONCRETE

1. ALUMINA CEMENT
    a. RAPID HARDENING CEMENTITIOUS MATERIAL (ASTM C928)
    b. VERY RAPID HARDENING CEMENTITIOUS MATERIAL (ASTM C928)
    c. OTHER
2. MAGNESIUM PHOSPHATE CEMENT
    a. RAPID HARDENING CEMENTITIOUS MATERIAL (ASTM C928)
    b. VERY RAPID HARDENING CEMENTITIOUS MATERIAL (ASTM C928)
    c. OTHER
3. OTHER HYDRAULIC CONCRETE

Y. NO REPLY TO QUESTIONNAIRE

Z. NO RAPID REPLACEMENT SYSTEM

APPENDIX B

Description of Rapid Systems for Deck Protection, Rehabilitation and Replacement

RAPID DECK PROTECTION SYSTEMS

Introduction

Salt 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 1.3 lb/yd^3 at the reinforcement and there is sufficient oxygen and moisture present for the corrosion process to proceed (36). The purpose of a deck protection system is to reduce or prevent the infiltration of chloride ion to the level of the reinforcement and thereby maintain a chloride ion content at the reinforcement that is less than 1.3 lb/yd^3 and to reduce or prevent the infiltration of moisture to the reinforcement so that the rate of corrosion is reduced (37).

Appendix B describes the rapid deck protection systems that have been identified by the responses to the questionnaires and the review of the literature. The systems are discussed in the order presented in the outline in Appendix A. The discussion of each system includes a description of the construction technique, the performance characteristics of the materials, the frequency of use by DOTs, the technique time requirements, the service life and maintenance, and the cost.

Description of Systems

Bituminous Concrete Overlay

Bituminous 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. Prior to placing the bituminous overlay, all patching must be complete and a membrane, coating or penetrating sealer is usually placed on the portland cement concrete deck to protect the concrete from chloride ion infiltration (35). 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, coating or penetrating sealer. A tack coat can be applied to these surfaces prior to placing the overlay. To improve skid resistance an ultra thin bituminous overlay usually referred to as a chip seal or surface treatment can be applied to concretes with a low permeability.

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 Figure 13). The membranes usually extend 1 inch up faces of curbs, across backwalls, onto approach slabs, and across all joints except expansion joints (3). Within 24 hours prior to placing the membrane, the deck should be sandblasted or shotblasted to remove asphaltic 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 (3, 7). 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.

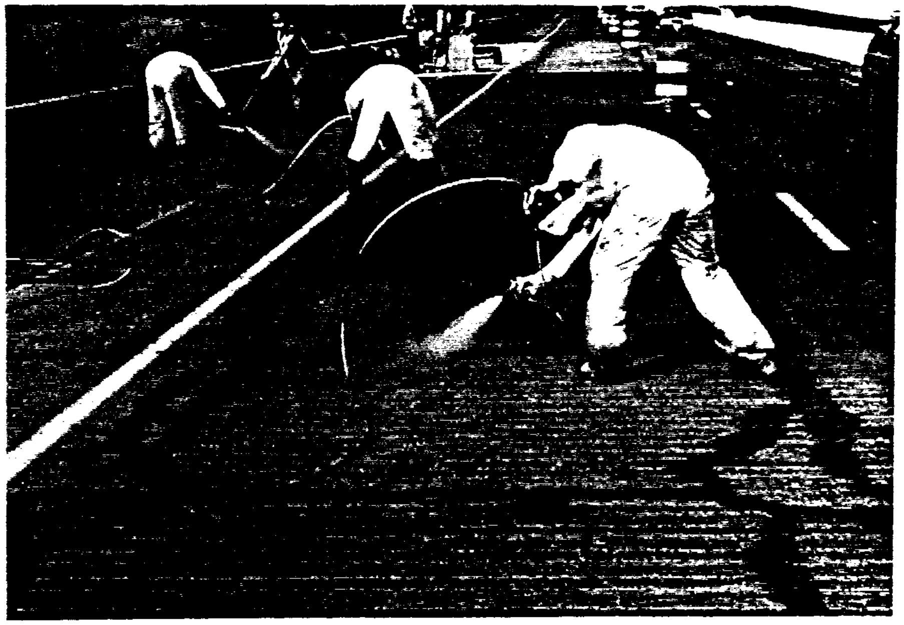

Figure 14. High molecular weight methacrylate coating is applied with an airless sprayer to a tined deck surface.

Coatings that have been used on bridge decks include acrylic, high molecular weight methacrylate, hydraulic cement, epoxy and rubber. To provide adequate skid resistance, coatings must be placed on heavily textured surfaces, filled with aggregate or overlaid with bituminous concrete. Satisfactory textures can be obtained by tining the fresh concrete, by shotblasting the hardened surface, or by sawcutting grooves 1/8 in wide by 1/8 in deep by approximately 3/4 in on centers in the hardened concrete. The deck must be patched prior to placing the coating. Within 24 hours prior to applying the coating the deck should be shotblasted or sandblasted as required for waterproofing membranes. The deck should be dry for placement (3, 7).

High Early Strength Portland Cement Concrete Overlays

Portland 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 (17, 35, 41, 42). 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. The overlays usually have a minimum thickness of 1.25 in for latex modified concrete and 2.0 in for most other concretes (see Figure 15). Some concretes such as those containing approximately 10 percent silica fume or special blended cements like Pyrament have permeabilities similar to latex modified concrete and should perform adequately at a thickness of 1.25 in. High early strength portland cement concrete mortars having a thickness of about 1 in have been used as overlays, but these overlays tend to crack and do not provide much protection unless latex is added to the mixture. Overlays can be constructed and cured to a strength suitable for traffic in less than 21 hours using special blended cements such as Pyrament, Type I, II, or III portland cement and admixtures such as corrosion inhibitors, high-range water reducers, latex, and silica fume, and rapid hardening cementitious materials that satisfy the requirements of ASTM C928 (5, 10, 11, 43, 44). The deck may be patched prior to placing the overlay or as the overlay is placed. The deck should be scarified, sandblasted (48 hours prior to application of overlay), 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 placing the overlay (3, 5).

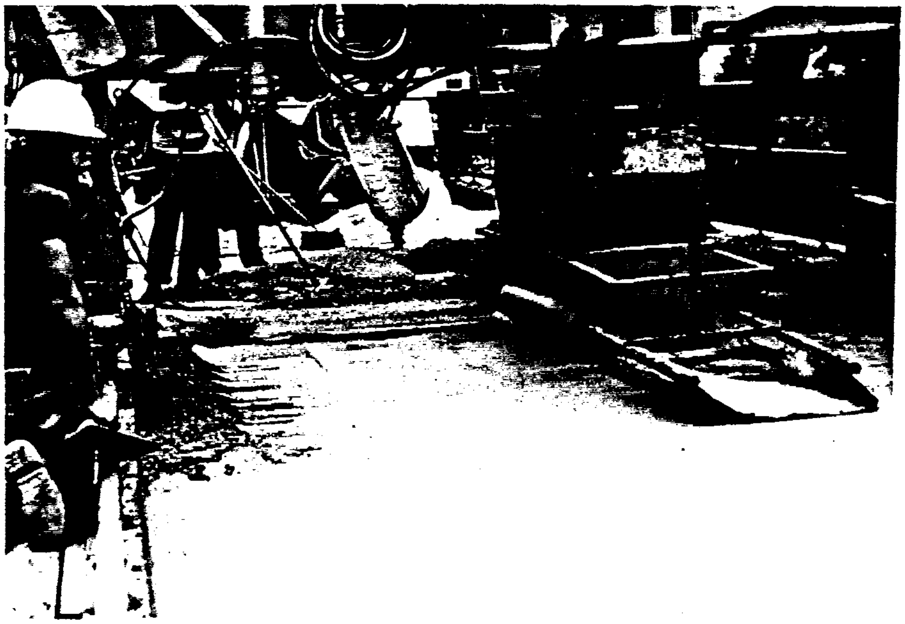

Figure 15. A high early strength latex modified portland cement concrete overlay is placed on a scarified and shotblasted deck surface.

Penetrating Sealers

Many different organic and inorganic sealers have been applied to concrete surfaces to reduce the infiltration of chloride ion and water. Like coatings the materials can be applied by spray, roller, brush or squeegee. Sealers have a low solids content, < 40%, and on evaporation of the carrier, they leave a thin hydrophobic film 0 to 10 mils thick on the surface of the pores and capillaries near the surface to which they are applied (39).

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 (7, 27, 38, 39, 40). 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 (38, 40). The deck must be patched prior to placing the sealers. The deck must be sandblasted or shotblasted to open the pores and capillaries so the sealer can penetrate (3, 7). The deck should be dry prior to placing the sealers; however, water-dispersed epoxies and silicates can be placed on damp decks.

Polymer Overlays

Polymer concrete overlays are placed on decks to reduce the infiltration of chloride ion and water and to increase the skid resistance (7, 14, 45, 46, 47, 48). Because they are thin and tend to follow the contours of the deck, they cannot be used to improve ride quality or drainage or to substantially increase the section modulus of the deck. However, because they are thin compared to bituminous and portland cement concrete overlays, the increase in dead load is less, and therefore, some additional live load capacity may be available. Polymer overlays are placed on decks using three techniques.

Multiple layer overlays are constructed by applying one or more layers of resin and aggregate to the deck surface (see Figure 16) (14, 45, 46, 47, 48). Like a coating, 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 application of resin and aggregate is made. Most overlays are constructed with two or three layers and have a thickness of 1/4 to 3/8 in. A prime coat without aggregate is specified for the first layer of some systems.

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Polymer Overlays

Polymer concrete overlays are placed on decks to reduce the infiltration of chloride ion and water and to increase the skid resistance (7, 12, 14, 45, 46, 47, 48). Because they are thin and tend to follow the contours of the deck, they cannot be used to improve ride quality or drainage or to substantially increase the section modulus of the deck. However, because they are thin compared to bituminous and portland cement concrete overlays, the increase in dead load is less, and therefore, some additional live load capacity may be available. Polymer overlays are placed on decks using three techniques.

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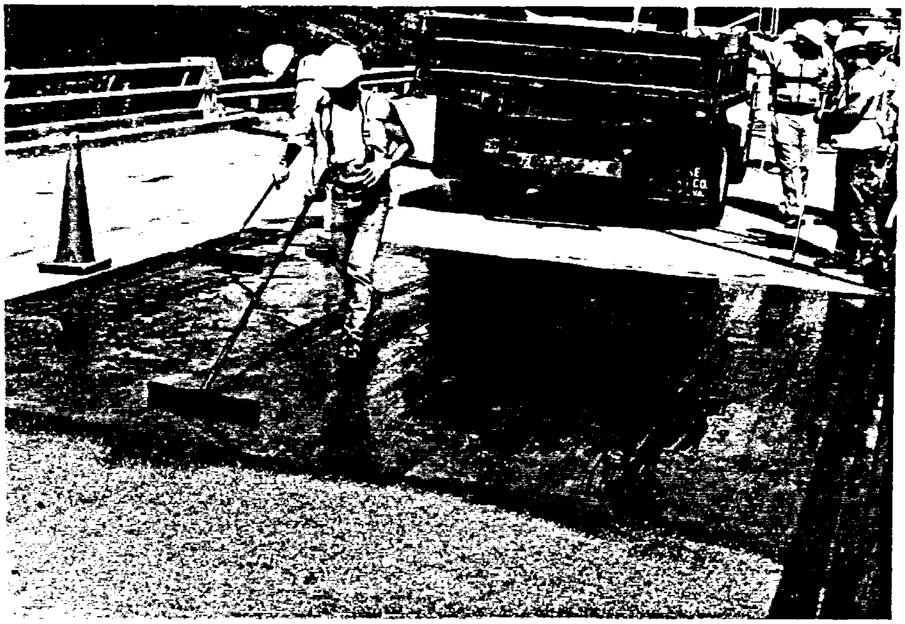

Figure 16. An epoxy-urethane binder is spread over a shotblasted surface with notched squeeges. Basalt aggregate is broadcast to excess to provide one layer of a multiple layer polymer overlay.

Premixed overlays are constructed like high early strength portland cement concrete overlays (45, 49, 50, 51). The polymer binder, properly graded aggregate, 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 thick.

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 1/4 in 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 applied. The overlays are usually about 3/8 in thick (52).

Polymer binders that have been used include acrylic, methacrylate, high molecular weight methacrylate, epoxy, epoxy-urethane, furfuryl alcohol, polyester styrene, polyurethane and sulphur. Aggregates are usually silica sand or basalt. Prior to placing the overlay the deck must be patched and shotblasted or sandblasted as required for membranes, coating and sealers. The deck should be dry for placement (3, 7, 14). Finally, prior to placing the overlay, test patches of the overlay are usually placed and tested in accordance with ACI 503R to insure that the surface preparation procedure is adequate and the materials will cure properly to provide a high bond strength (7, 14).

Other Hydraulic Cement Concrete Overlays

Hydraulic cement concrete overlays can be constructed with alumina cement and magnesium phosphate cement. 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 bags as a rapid hardening cementitious material (ASTM C928) (13, 15, 53, 54). A slower setting version of magnesium phosphate cement concrete can be mixed in a ready-mix truck and placed as an overlay (53). The deck may be patched prior to placing 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 (53). These materials have the added advantage in that they can be air cured rather than moist cured. Since these materials are typically used for patching, they will be discussed in more detail in that section of the report.

RAPID DECK REHABILITATION SYSTEMS

Introduction

The most frequently used method of rapidly rehabilitating a bridge deck involves removal of delaminated concrete, sandblasting the concrete surface and filling the cavity with a rapid curing concrete (42, 45, 55). To complete the rehabilitation cracks are usually repaired and a rapid curing protective system is installed. There are several advantages to this method. The patching, crack repair and the application of the protective system can be done in stages. Traffic can usually be applied to the materials in 2 to 4 hours. Concrete removal costs are low because very little concrete is removed, and the high cost of the patching materials is 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 salt 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 consolidated or placed, 5) the repairs must be opened to traffic before sufficient strengths are developed, and 6) the repair materials are not similar to or compatible with the materials repaired (7, 14, 36, 42, 48, 55).

This section of the report covers the rapid patching and crack repair systems that are used to rehabilitate a deck. The application of the protective system was covered in the previous section.

Description of Systems

Crack Repair and Sealing

Cracks in concrete can provide water and salt easy access to reinforcement, and 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 (42). Most deck repair contracts include crack sealing or crack repair. Cracks can be sealed or repaired by gravity fill, pressure injection, rout and seal, vee-groove and seal and vacuum injection (see Appendix A) (9, 56, 57, 58, 59). Cracks ranging in width from 0.08 mm to 6 mm have been successfully filled (42).

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 0.2 to 2.0 mm (see Figure 17) (58). A minimum crack width of 0.5 mm is recommended for gravity fill epoxy resins that usually have a viscosity of about 100 cp or more (42). A two component urethane, Percol, is also being marketed for crack repair. The urethane cures more rapidly than methacrylate and epoxy.

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 in which the binder is methacrylate or epoxy (58). Saws cannot be used to widen most cracks because they are usually too irregular in shape. 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 (9).

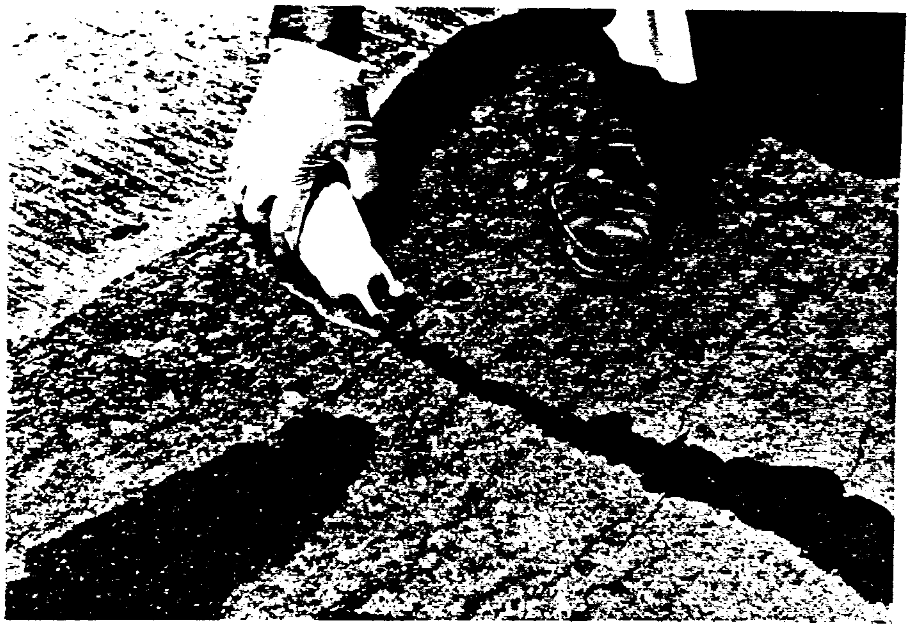

Figure 17. High molecular weight methacrylate is applied to fill and seal a crack.

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 crack with polymer, and thereby seal the crack. It is even more difficult to get proper bond between the polymer and the wall of the crack to repair it (9). The crack should be dry for the polymer to bond and cure properly unless a moisture cured urethane is used to fill the crack.

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 (9). To fill plastic shrinkage cracks the deck is usually flooded with monomer and the monomer is brushed into the cracks until they are filled. Aggregate is broadcast onto the monomer to provide adequate skid resistance (7).

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 bituminous concrete overlay material. Typically the joints and concrete headers have to be replaced when a deck is rehabilitated or replaced. Joint and header systems that can be installed during off-peak traffic periods are required for the deck rehabilitation to be done during off-peak periods.

Patching with Bituminous 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 bituminous concrete until a more permanent repair can be made. In warm weather a bituminous concrete mixture (hot mix) that hardens as it cools is used to fill potholes. 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 (34).

Patching with High Early Strength Portland Cement

The most common method of permanent spall repair is patching with portland cement concrete (see Figure 18). Patches may be shallow (above level of reinforcment but at least 1.3 in thick) half depth (at least 1 in below top mat of reinforcement but not deeper than one half the deck thickness) and full depth (3). A typical repair includes squaring up the area to be patched, saw cutting the perimeter to a depth of 1 in, removing concrete to the required depth with pneumatic hammers weighing $\leq$ 30 pounds, blasting the concrete surface and reinforcement with sand or slag, filling the cavity with the patching material, consolidating and striking off the material, and application of liquid or other curing material (3). When full depth patches are constructed, it is necessary to suspend forms from the reinforcing steel or to support forms from beam flanges (areas > 3 ft^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 (60, 61, 62). The most frequently used material is the rapid hardening cementitious material meeting the requirements of ASTM C928. The cavity can also be filled when a high early strength portland cement concrete overlay is placed. However, this option does not lend itself to a rapid repair because of the time required to prepare the deck surface and the areas to be patched.

Figure 18. A prepackaged rapid hardening portland cement concrete material is used for partial depth patching on a bridge deck.

Patching with Polymer Concrete

Patching with polymer concrete has been found to be effective when the thickness of the patches is $\leq$ 0.8 in (3). 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 (12, 62, 63).

Patching with Other Hydraulic Cement Concrete

The requirements and procedures for patching with other hydraulic cement concrete are generally the same as for patching with high early strength portland cement concrete. The binders are usually magnesium phosphate or alumina cement (63, 64).

Steel Plate over 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 Eric Public Bridge Authority (see Appendix D).

RAPID DECK REPLACEMENT SYSTEMS

Introduction

As the deck area in need of rehabilitation approaches 40 to 50 percent, deck replacement may be more economical than rehabilitation. Significant factors to consider include the quality of the concrete in the bottom half of the deck and the condition of the rebars. If less than 20 percent full depth replacement of the concrete is needed and the rebars are in acceptable condition, it may be more economical to rehabilitate the entire deck rather than replace the deck because of the high cost of containing the concrete that is removed to protect the environment and the public, and because of the cost of formwork for deck replacement.

The rapid replacement of a deck is usually done by removing a section of the deck and replacing it with site cast concrete or with a precast concrete component or a combination of the two (19, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74). Decks have also been replaced with prefabricated steel and aluminum orthotropic plate deck units to achieve a reduction in dead load, and with laminated timber members when decks are located on rural low volume roads (19, 75, 76, 77, 78, 79, 80, 81). Prefabricated steel, aluminum and timber components are not within the scope of this report, except when used as temporary components to maintain the riding surface as the deck is replaced with precast concrete or site cast concrete.

Description of Systems

Precast concrete components that have been used to replace bridge decks include the concrete slab span, the box beam, the tee beam, the channel beam and the deck panel. Temporary and permanent bridge deck forms such as prestressed concrete subdeck panels and steel stay-in-place forms, have been used with site cast concrete to replace bridge decks. Deck panels and permanent deck forms are usually placed in a direction transverse to traffic and are supported by prestressed I-beams or steel beams. Other precast concrete members are usually placed parallel to traffic and are supported by piers or abutments.

Precast Concrete Slab Spans

Precast solid slabs have been used for spans up to 30 ft but more structurally efficient prestressed or post-tensioned or voided slabs are commonly used for longer spans (19, 82, 83). Slabs are easy to precast, transport and erect. Shear transfer between slabs is usually provided by a grouted keyway or by weld plates (83, 84, 85). Most precast concrete producers and some state and local bridge crews can fabricate the slabs because of the ease with which the slabs can be precast (84, 86). The slabs are particularly suited for the rapid replacement of short span superstructures because they are easily installed while traffic is maintained in an adjacent lane (87). Because the individual slabs are usually not designed to support an HS20-44 loading without being connected, one lane of traffic can usually be maintained as the slabs are placed by limiting the loads that cross the bridge or by connecting the slabs as they are placed (19).

Precast Concrete Box Beams

Precast box beams are usually pretensioned but may be post-tensioned and may be precast in various lengths and widths to accommodate a range of spans and roadway widths. Box beams are generally used for spans of approximately 50 to 100 ft (65, 82). Except for the longer spans, the boxes are very easy to transport and erect. Box beams that are placed adjacent to each other are usually connected in the same way slabs are connected (83). A wearing surface is usually used with box beams. Box beams that are spaced apart (spread boxes) are tied together with diaphragms and a site cast concrete slab is added (88).

Like the slab spans, the box is particularly suited for the replacement of short-span superstructures. More expertise is required to fabricate a box than a slab because the box is usually prestressed, and because the proper location of the void material must be maintained during the casting operation. Most prestressed concrete producers can manufacture the boxes, usually pretensioned, and occasionally state and local bridge crews have fabricated the boxes, usually conventionally reinforced (86).

Precast Concrete Channel and Tee Beams

Most prestressed concrete producers have forms in several standard sizes to allow the production of pretensioned or post-tensioned single-tee, double-tee, and channel beams for a range of span lengths (82, 88). However, available forms may not be suitable for the the fabrication of members that are heavy enough for bridge loadings (89). Single-tee, double-tee and channel beams have been fabricated at the bridge site and at precasting plants (90, 91). Channels are usually fabricated in double-tee forms by blocking off a portion of the exterior flanges. Both the channel and double-tee may be fabricated for use with or without a topping. Both members are among the easiest to transport and erect. Single-tee beams are less stable and therefore more difficult to handle. Also, a site cast concrete deck must be placed on the tee beams. The members are typically used for spans of 20 to 60 ft (82). Shear transfer between the beams may be achieved through the use of grouted keyways or weld plates (90, 91, 92).

Precast Concrete Deck Panels

One of the more recent innovations in the use of fabricated elements is the use of precast concrete deck panels that are placed on steel stringers (19, 55, 68, 69, 70, 71, 72, 93, 94). Shear transfer between transverse panels is usually achieved with grouted keyways or a CIP concrete joint (70, 71, 93, 94, 95). Transverse panels may be post-tensioned parallel to the direction of traffic to improve shear transfer between panels (68, 70). Proper vertical alignment and uniform bearing on the top flanges of the supporting stringers can be obtained by placement of a bed of grout or epoxy mortar before setting the slabs, by use of shim pads with grout placed after the panels are placed on the shims, or by use of a detail that includes adjustable slab support on angles or bolts while grout or epoxy mortar is placed (72).

To develop composite action between the deck panel and the stringers, the connection must be adequate to transfer horizontal shear. Composite action was not achieved in the earlier bridges in which the panels were typically attached to the stringers with clips and bolts (70, 93, 94). Composite action is being achieved in the more recently constructed bridges through the use of studs or bolts as shear connectors (55, 71). The studs may be welded to the top flange of the stringers, or holes for high-strength bolts may be drilled in the top flanges. The shear connectors may be placed before or after the slabs are positioned, but if they are installed before, it is necessary to fabricate and erect the slabs with more precision. The voids around the studs or bolts are typically filled with nonshrink grout or epoxy mortar.

The deck panels eliminate most of the on-site formwork and concreting typically required for a steel stringer-concrete deck bridge (55, 72). Most precast concrete producers can fabricate the slabs, but state or local crews have not fabricated them to date. The use of the slabs to replace the deck of a bridge near Mount Vernon, Virginia is shown in Figure 19 (19, 71).

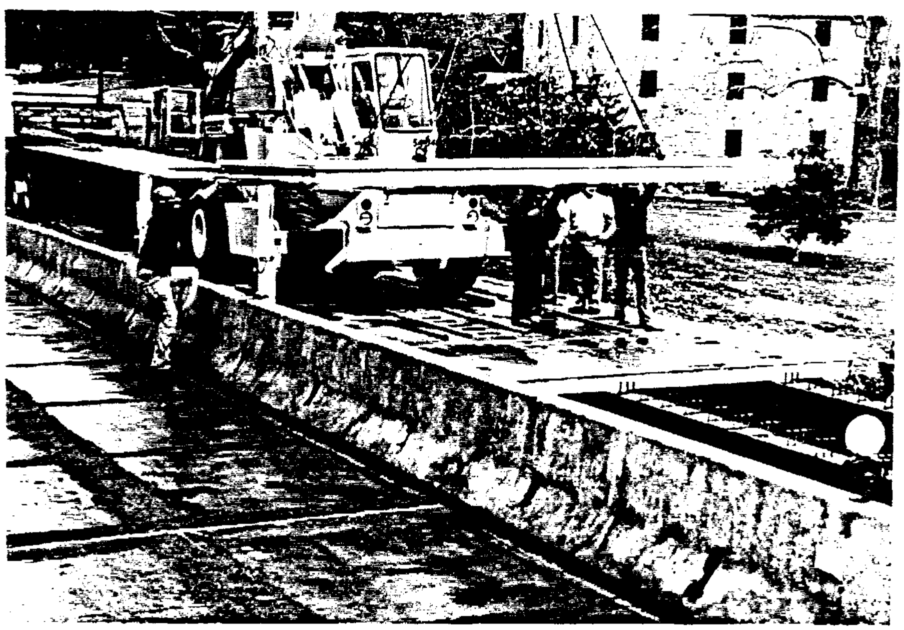

Figure 19. Precast concrete deck panel is lowered onto steel stringers, which are covered with epoxy mortar (19, 71).

Berger (72) discusses the use of precast, prestressed bridge deck panels on steel and prestressed concrete beams. He gives several details that can be used for connecting precast panels to beams, both on new construction and for replacement of existing bridge decks. Berger concludes that the precast slabs are more economical than CIP concrete decks because they may be pretensioned or post-tensioned and therefore, are more structurally efficient, requiring less material and fewer supporting elements, and because on-site construction costs are less as the precast slabs may be installed in less time.

The rehabilitation of the Fremont Street Bridge near Pittsburgh utlized precast deck panels set on the floor beams of a concrete arch bridge (96). These panels have the attributes of both deck panels and slab spans; they are longitudinally reinforced two-span continuous slabs. Leveling bolts were used to adjust the elevation of the slabs and dowels were placed and grouted into holes in the slabs and in the floor beams to anchor the slabs. Polymer mortar was pumped under the neoprene bearing pads to rigidly connect the slabs to the floor beams after the panels were post-tensioned transversely.

A recent example of the use of precast deck panels on steel beams was the replacement of the deck on the Woodrow Wilson Memorial Bridge on I-495 around Washington, D.C. (68, 69, 95). The deck of the 5,900-ft long, six-lane bridge was replaced during a period of twelve months without halting the flow of traffic, which averaged 125,000 vehicles per day.

The major work on the bridge was done each night for 10 hours, leaving open two of the six lanes to traffic as illustrated in Figure 20 (19, 68). A concrete-cutting circular saw cut the existing deck away in 40-ton segments. These segments were replaced by precast, lightweight concrete panels that were post-tensioned transversely at the plant. A typical panel was 46 ft 8 in wide, 10 to 12 ft long, and 8 in thick. The new panels widened the bridge by 4 ft. After placement, the panels were post-tensioned longitudinally in groups of 17 to reduce cracking, to seal the transverse joints between adjacent panels, and to eliminate water intrusion.

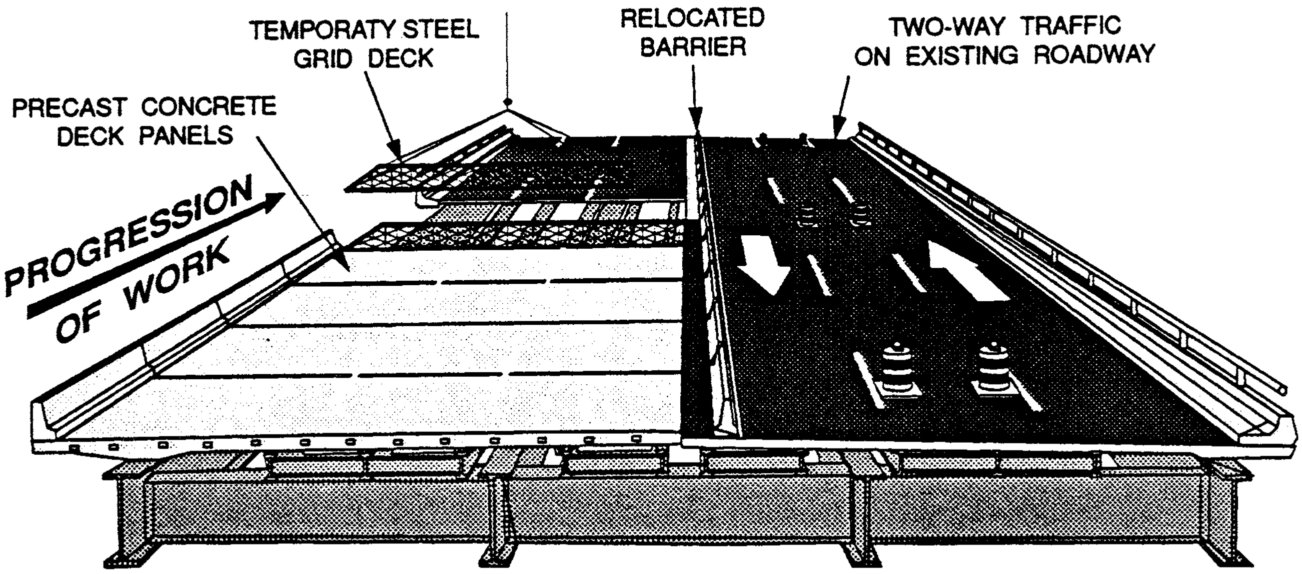

Figure 20. Precast, post-tensioned lightweight concrete deck panels were installed at night to replace the deck of the Woodrow Wilson Bridge (19, 68).

The concrete deck panels are supported by site cast polymer concrete bearing pads on the exterior girder and interior stringers. The polymer concrete is a methyl methacrylate product that reached 4,000 psi compressive strength after one hour and 8,000 psi after 24 hours. Each pad includes a sliding steel bearing plate on the stringer's flange that is tied into the polymer concrete by welded studs. The sliding plates prevent the introduction of stresses in the structural steel caused by shrinkage, creep, and foreshortening during post-tensioning of the deck.

Each night the contractor covered the gap between the old and the new deck with a steel grating deck that carried traffic during the day. The following night, crews lifted away the grating to install new deck while other workers removed concrete.

The redecking of the Woodrow Wilson Bridge exemplifies how, with proper planning and design that takes advantage of recent developments in high early strength materials and technology, prefabricated deck panels can be erected and connected with a minimum of disruption to the environment and at a savings to the public.

Precast concrete deck panels have been used in a limited number of states but an increase in use is anticipated as highway agencies are confronted with replacing the decks of bridges during off-peak traffic periods and with minimal lane closure time. Although the New York Thruway Authority has not experienced the cost savings and reduced construction time anticipated, their nine years of experience indicates that precast panels are an acceptable approach to deck replacement (67). Other examples of the use of the panels in highway bridges can be found in Alabama, California, Indiana, Maryland, Massachusetts, New York, Pennsylvania, Virginia, and West

Virginia. Examples of use on railroad bridges can be found in Delaware, New Mexico, and British Columbia (71). Plans have been prepared for the use of precast, prestressed, post-tensioned deck panels to replace the bridge deck on the George Washington Memorial Parkway over Pimmit Run in Fairfax County, Virginia. The deck will be replaced on weekends and on week days during periods other than rush hour. A high early strength latex modified concrete overlay will be placed after the panels are installed (97).

Permanent Bridge Deck Forms

The concrete required for site cast concrete must be formed with permament or temporary bridge deck forms. In recent years, steel stay-in-place forms and prestressed concrete subdeck panels have become popular because the high cost of the form removal is eliminated (85, 98, 99). Prestressed concrete subdeck panels provide an added advantage in that less concrete and reinforcing steel must be placed at the bridge site because the panels become an integral part of the deck. Most prestressed concrete producers can fabricate the subdeck panels, and the steel forms are available from most steel fabricators.

The prestressed panels are usually pretensioned and precast in widths of approximately 4 ft, but have been precast in widths of up to 8 ft, and in lengths that are controlled by the spacing of the beams in the bridge (100). On earlier installations the panels were set on a grout bed, approximately 1/2 in (13 mm) thick, which was placed along the supporting edge of the beams in the bridge. The grout provided for the uniform bearing of the panel by compensating for camber and surface irregularities. Because the panels are a constant thickness, they followed the camber in the supporting beams, and the thickness of the site cast concrete typically varied from a maximum at the bearings to a minimum at midspan. On more recent installations the thickness of the grout bed was varied to account for the camber in the supporting beams and to provide a deck of constant thickness.

The rectangular panels can be used on skewed bridges by cutting the end panels to the desired skew with a portable power saw and a concrete cutting blade (100). The installation of the panels can proceed rapidly with a minimum of labor and without the need for temporary platforms. Once the panels are in place, the finished grade of the deck surface can be set and the required concrete for the overlay placed.

Although cracks will usually occur in the deck surface directly above the butt joints between the panels, on short span bridges, the cracks typically extend only halfway through the site cast concrete and are not believed to have a significant effect on the performance of the deck (100). However, on long, continuous span plate girder bridges the cracks extend full depth and some DOT's restrict the use of panels to short concrete beam bridges (9). Epoxy-coated rebar can be used for the top mat of the steel in the deck or calcium nitrite can be used in the concrete to curtail the corrosion that might be accelerated by the presence of moisture and salt in the cracks.

Considerable laboratory and field work to evaluate prestressed concrete subdeck panels has been conducted (85, 99, 100, 101, 102, 103, 104, 105). Composite action between the panel and the site cast concrete and across adjacent panels has not been a problem (85, 98, 100, 101, 103).

Like the prestressed concrete subdeck panels, the steel stay-in-place forms can be placed with a minimum of labor. Metal screws are usually used to fasten the forms to metal angles that have been field welded to supporting devices at the proper elevation. The supporting devices are precast into the top flange of a concrete beam and hang from the top flange of a steel beam.

Opinions vary as to the advantages and disadvantages of using steel stay-in-place forms. Corrosion of the forms can be a problem if moisture has ready access to the form by drainage; penetration through poor quality, permeable concrete; or via other means. The forms are generally accepted in many states that believe the advantages outweigh the potential disadvantages (98, 106, 107).

Once subdeck panels or stay-in-place forms are in position, site cast concrete must be placed and cured before the replaced area can be opened to traffic. A discussion of the high early strength concrete materials that can be used follows.

Site Cast High Early Strength Portland Cement Concrete

Decks can be constructed and cured to a strength suitable for traffic in less than 21 hours using special blended cements such as Pyrament, Type I, II, or III portland cement and admixtures such as corrosion inhibitors, high-range water reducers, latex, and silica fume, and rapid hardening cementitious materials that satisfy the requirements of ASTM C928 (5, 10, 11, 43, 44). The completed deck is similar to a conventionally constructed concrete deck with the following exceptions: a) special high early strength and typically high later age strength mixtures are required, b) many construction joints are required as the deck is placed in stages, and c) damage due to a rapid rate of construction and premature loading of the concrete may cause a reduction in quality and therefore service life. High strength mixtures are usually high quality, low water to cement ratio mixtures, and therefore, site cast concrete decks should not need a protective system.

Site Cast Polymer Concrete

Decks can probably be constructed with site cast polymer concrete. Mixtures would be similar to those used for premixed polymer concrete overlays with the exception that the mixtures would be extended with coarse aggregate. The ACI has a committee studing the feasibility of structural applications of polymer concrete. Full depth concrete pavement slabs have been constructed with sulphur concrete (51). Because of the high cost of most polymer binders the use of site cast polymer concrete will likely be limited.

Other Site Cast Hydraulic Cement Concrete

Bridge decks can be constructed and cured to a strength suitable for traffic in less than 21 hours using other hydraulic cement concrete binders such as alumina cement and magnesium phosphate cement. Procedures would be similar to those required for site cast high early strength portland cement concrete.

APPENDIX C

Questionnaires

Questionnaire No. 1 was sent to state DOT coordinators, CSHRP provinical coordinators, and selected turnpike and thruway authorities. Questionnaire No. 2, a condensed 1-page version of questionnaire No. 1, was sent to the directors of the technology transfer centers for publication in their newsletter. Questionnaire No. 3 is an expanded 14-page version of questionnaire No. 1 and was designed to obtain detailed data on the properties of materials from selected material suppliers. The mailing list for questionnaire No. 2 was obtained from the director of the technology transfer center at the Virginai Transportation Research Council. The mailing list for questionnaire No. 3 was obtained from a May 1989 printing of the Federal Highway Administration SPEL Book. Companies with an accepted or pending product in the categories of adhesives, patching materials, skid control systems, and waterproofing membranes and materials, were sent a copy of the questionnaire. The questionnaires were distributed and returned as follows:

No.	Sent To	Date Mailed	No. Mailed	No. Returned
1	SHRP state DOT coordinators	March 8	55	49
1	CSHRP provincal coordinators	March 8	12	10
1	Selected turnpike and thruway authorities	May 30	44	9
2	Directors of technology transfer centers	April 26	58	8
3	Selected material suppliers	June 7	276	31

456

11.8.5

MEMORANDUM

DATE: March 30, 1989

TO: SHRP State DOT Coordinators, CSHRP Provincial Coordinators, Selected Thruway Authorities, Cities, Consultants, Material Suppliers, and Contractors.

FROM: Michael M. Sprinkel
Principal Investigator

PROJECT: SHRP Project C-103 - Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques

ACTIVITY: Task 4 Questionnaire

Dear Mr.

The objectives of Task 4 (Rapid Repair Techniques) are to identify and to develop technically and economically feasible methods of deck protection, rehabilitation, and replacement that can be used where construction must be rapid. The information obtained for Task 4 will be tabulated, reduced, analyzed, and eventually used to prepare a guide manual containing specifications, special provisions, descriptions, costs, and service life estimates for rapid repair techniques.

For this study, a rapid technique is tentatively defined as one that can be done with one or more lane closures of $\leq$24 hours. Also, techniques cited should be those that are used for the protection, rehabilitation, or replacement of a deck. An epoxy mortar overlay and an asphalt overlay placed on a membrane are examples of rapid protective systems. The removal of chloride contaminated and unsound concrete and the placement of a high early strength cement concrete patch is a rehabilitative system. Deck removal and the subsequent installation of a prestressed, precast concrete deck replacement panel is an example of a replacement system.

The purpose of the questionnaire is to solicit your help in obtaining information on rapid techniques for the protection, rehabilitation, and replacement of bridge decks. Please provide readily available information as requested on the attached four-page form for several of the techniques that are cost-effective or frequently used by your agency.

In addition, I would like to receive copies of specifications, special provisions, reports, literature, and other information that could be used to properly identify and describe a technique. Also, I would appreciate receiving any comments you may have that are not addressed by the questionnaire.

Several of the most cost-effective protective and rehabilitative techniques will be installed in trials for SHRP in the spring of 1992. You should answer "yes" to question 9 on the attached form if you would be interested in providing a site for an installation.

Please return all responses by July 15, 1989, to:

Michael M. Sprinkel
Virginia Transportation Research Council
P. O. Box 3817, University Station
Charlottesville, Virginia 22903
Telephone: (804) 293-1941

SHRP has approved the collection of this information

Thank you.

MMS:amf

cc: SHRP Regional Engineers
G. Williams, C-SHRP
R. Dindio, SHRP
J. Broomfield, SHRP
A. Horosko, SHRP
R. Weyers
H. Newlon, Jr.
H. Brown

QUESTIONNAIRE ON RAPID REPAIR TECHNIQUES FOR BRIDGE DECKS

SHRP C-103, TASK 4

Michael M. Sprinkel

Name: ______________________________

Agency: ______________________________

Phone No.: ______________________________

Date: ______________________________

1. For this questionnaire a rapid technique is tentatively defined as one that can be done with one or more lane closures of $\leq$24 hours. Do you consider this definition to be acceptable?

   Yes __________ No __________

   If your answer is "No," please provide the definition that you are using when completing this questionnaire.

   ____

   ____

   ____

   ____

2. List the three techniques you most frequently use for the rapid protection, rehabilitation, and replacement of bridge decks.

   A. Protection 1. ______________________________

   2. ______________________________

   3. ______________________________

   B. Rehabilitation 1. ______________________________

   2. ______________________________

   3. ______________________________

   C. Replacement 1. ______________________________

   2. ______________________________

   3. ______________________________

3. Please estimate the time (hours) required for traffic control, surface preparation, and placing and curing materials using these techniques.

		Traffic Control	Surface Preparation	Placing and Curing Materials	Total Time	Yds^2*
A.	1.					
	2.					
	3.					
B.	1.					
	2.					
	3.					
C.	1.					
	2.					
	3.					

* Please indicate the yds^2 of deck surface for which the times are estimated.

4. Please estimate the approximate cost per yd^2 for traffic control, surface preparation, and placing and curing materials for these techniques.

		Traffic Control	Surface Preparation	Placing and Curing Materials	Other	Total*
A.	1.					
	2.					
	3.					
B.	1.					
	2.					
	3.					
C.	1.					
	2.					
	3.					

* Please attach copies of bid tabs or engineering estimates.

5. Please estimate the time (years) until some maintenance or major repair will be required using these techniques.

		Some Maintenance	Major Repair
A.	1.	______	______
	2.	______	______
	3.	______	______
B.	1.	______	______
	2.	______	______
	3.	______	______
C.	1.	______	______
	2.	______	______
	3.	______	______

6. Please cite the principal advantages of these techniques.

A. 1. ______________________________

2. ______________________________

3. ______________________________

B. 1. ______________________________

2. ______________________________

3. ______________________________

C. 1. ______________________________

2. ______________________________

3. ______________________________

7. Please cite the principal disadvantages of these techniques.

   A. 1. ______________________________

      2. ______________________________

      3. ______________________________

   B. 1. ______________________________

      2. ______________________________

      3. ______________________________

   C. 1. ______________________________

      2. ______________________________

      3. ______________________________

8. On a separate sheet of paper, please provide a brief description and additional information on the rapid techniques listed above. (Please attach specifications and reports).

9. Interested in experimental installation for SHRP?

   Yes __________ No __________

Please return all responses by July 15, 1989, to:

Michael M. Sprinkel
Virginia Transportation Research Council
P. O. Box 3817, University Station
Charlottesville, Virginia 22903
Telephone: (804) 293-1941

Thank you.

11.8.5

MEMORANDUM

TO: Directors of T2 Centers

FROM: Mehmet C. Anday ____________________

DATE: April 26, 1989

SUBJECT: Publication in Newsletter

Mr. Sprinkel, of our staff, would appreciate it if you could print as much of the attached as possible in your upcoming newsletter.

Should you have questions, please call Mr. Sprinkel at (804) 293-1941.

MCA/bat
Attachment

cc: Dr. Richard Weyers
Mr. Howard Newlon, Jr.
Mr. H. E. Brown
Mr. M. M. Sprinkel

Questionnaire No. 2

CAN YOU HELP?

The objectives of Task 4 (Rapid Repair Techniques) of SHRP Project C-103 -- Concrete Bridge Protection and Rehabilitation, are to identify and to develop technically and economically feasible methods of deck protection, rehabilitation, and replacement that can be used where construction must be rapid. The information obtained for Task 4 will be tabulated, reduced, analyzed, and eventually used to prepare a guide manual containing specifications, special provisions, descriptions, costs, and service life estimates for rapid repair techniques.

Your help is needed to obtain readily available information for several of the techniques that are cost-effective of frequently used by your agency.

Needed for copies of specifications, special provisions, reports, literature, and other information that could be used to properly identify and describe a technique. Also, it would be appreciated if you could provide answers to the nine questions on the reverse side.

Please return all responses by June 30, 1989, to Mike Sprinkel, whose address is shown on the back.

QUESTIONS ON RAPID REPAIR TECHNIQUES FOR BRIDGE DECKS

1. A rapid technique is tentatively defined as one that can be done with one or more lane closures of <24 hours. Do you consider this definition to be acceptable? Yes _____ No _____

   If your answer is "No," please provide the definition that you are using when answering the following questions.

   ____

   ____

2. What technique do you most frequently use for the rapid protection, rehabilitation, and replacement of bridge decks?

   ____

   ____

3. What is the time (hours) required for traffic control, surface preparation, and placing and curing materials using these techniques?

   ____

4. What is the approximate cost per yd^2 for traffic control, surface preparation, and placing and curing materials for these techniques?

   ____

5. What is the time (years until some maintenance or major repair will be required using these techniques?

   ____

6. What are the principal advantages of these techniques?

   ____

7. What are the principal disadvantages of these techniques?

   ____

   ____

8. Do you have additional information on the rapid techniques listed above? (Please attach specifications and reports).
9. Interested in experimental installation for SHRP? Yes _____ No _____

11.8.5

MEMORANDUM

DATE: June 7, 1989

TO: Material Suppliers

FROM: Michael M. Sprinkel
Principal Investigator

PROJECT: SHRP Project C-103 - Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques

ACTIVITY: Task 4 Questionnaire

Gentlemen:

The objectives of Task 4 (Rapid Repair Techniques) are to identify and to develop technically and economically feasible methods of deck protection, rehabilitation, and replacement that can be used where construction must be rapid. The information obtained for Task 4 will be tabulated, reduced, analyzed, and eventually used to prepare a guide manual containing specifications, special provisions, descriptions, costs, and service life estimates for rapid repair techniques.

For this study, a rapid technique is tentatively defined as one that can be done with one or more lane closures of $\leq$24 hours. Also, techniques cited should be those that are used for the protection, rehabilitation, or replacement of a deck. An epoxy mortar overlay and an asphalt overlay placed on a membrane are examples of rapid protective systems. The removal of chloride contaminated and unsound concrete and the placement of a high early strength cement concrete patch is a rehabilitative system. Deck removal and the subsequent installation of a prestressed, precast concrete deck replacement panel is an example of a replacement system.

The purpose of the questionnaire is to solicit your help in obtaining information on rapid materials for the protection, rehabilitation, and replacement of bridge decks. Please provide readily available information as requested on the attached fourteen-page form for several of the materials that are cost-effective or frequently distributed by your company.

In addition, I would like to receive copies of specifications, special provisions, reports, literature, and other information that could be used to properly identify and describe a material or technique. Also, I would appreciate receiving any comments you may have that are not addressed by the questionnaire.

Several of the most cost-effective protective and rehabilitative techniques will be installed in trials for SHRP in the spring of 1992. You should answer "yes" to question 29 on the attached form if you would be interested in donating material for an installation.

Please return all responses by July 15, 1989, to:

Michael M. Sprinkel
Virginia Transportation Research Council
P. O. Box 3817, University Station
Charlottesville, Virginia 22903
Telephone: (804) 293-1941

SHRP has approved the collection of this information

Thank you.

MMS:amf

cc: SHRP Regional Engineers
G. Williams, C-SHRP
R. Dindio, SHRP
J. Broomfield, SHRP
A. Horosko, SHRP
R. Weyers
H. Newlon, Jr.
H. Brown

QUESTIONNAIRE ON RAPID REPAIR TECHNIQUES FOR BRIDGE DECKS

SHRP C-103, TASK 4

Michael M. Sprinkel

Name: ________________________________

Company: ________________________________

Phone No.: ________________________________

Date: ________________________________

1. For this questionnaire a rapid technique is tentatively defined as one that can be done with one or more lane closures of ≤24 hours. Do you consider this definition to be acceptable?

   Yes __________ No __________

   If your answer is "No," please provide the definition that you are using when completing this questionnaire.

   ____

   ____

   ____

   ____

2. List the three materials you most frequently distribute for the rapid protection, rehabilitation, and replacement of bridge decks.

   A. Protection
      1. ________________________________
      2. ________________________________
      3. ________________________________

   B. Rehabilitation
      1. ________________________________
      2. ________________________________
      3. ________________________________

   C. Replacement
      1. ________________________________
      2. ________________________________
      3. ________________________________

3. Please estimate the time (hours) required for traffic control, surface preparation, and placing and curing these materials (Assume 75°F).

		Traffic Control	Surface Preparation	Placing and Curing Materials	Total Time	Yds^2*
A.	1.					
	2.					
	3.					
B.	1.					
	2.					
	3.					
C.	1.					
	2.					
	3.					

* Please indicate the yds^2 of deck surface for which the times are estimated.

4. Please estimate the approximate cost per yd^2 for traffic control, surface preparation, and placing and curing these materials.

		Traffic Control	Surface Preparation	Placing and Curing Materials	Other	Total*
A.	1.					
	2.					
	3.					
B.	1.					
	2.					
	3.					
C.	1.					
	2.					
	3.					

* Please attach copies of bid tabs or engineering estimates.

5. Please estimate the time (years) until some maintenance or major repair will be required using these materials.

		Some Maintenance	Major Repair
A.	1.	______	______
	2.	______	______
	3.	______	______
B.	1.	______	______
	2.	______	______
	3.	______	______
C.	1.	______	______
	2.	______	______
	3.	______	______

6. Please cite the principal advantages of these materials and techniques.

A. 1. ______________________

2. ______________________

3. ______________________

B. 1. ______________________

2. ______________________

3. ______________________

C. 1. ______________________

2. ______________________

3. ______________________

7. Please cite the principal disadvantages of these materials and techniques.

A. 1. ______________________________

2. ______________________________

3. ______________________________

B. 1. ______________________________

2. ______________________________

3. ______________________________

C. 1. ______________________________

2. ______________________________

3. ______________________________

8. Please describe the composition of these materials.

A. 1. ______________________________

2. ______________________________

3. ______________________________

B. 1. ______________________________

2. ______________________________

3. ______________________________

C. 1. ______________________________

2. ______________________________

3. ______________________________

470

9. Please describe the surface preparation required for these materials.

A. 1. ______________________

2. ______________________

3. ______________________

B. 1. ______________________

2. ______________________

3. ______________________

C. 1. ______________________

2. ______________________

3. ______________________

10. Please indicate the required minimum strength of these materials for opening to traffic, psi

		Compressive (ASTM C 39)	Tensile ( )*	Flexural (ASTM C 78)	Bond (ASTM C882)
A.	1.				
	2.				
	3.				
B.	1.				
	2.				
	3.				
C.	1.				
	2.				
	3.				

* Note test method.

11. Please estimate the time for placing and curing these materials prior to opening them to traffic at

		40°F	55°F	90°F	°F*
A.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
B.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
C.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____

* Other temperature for which you have information ____________.

12. Please indicate the compressive strength (ASTM C 39) of these materials at 24 hours, psi at

		40°F	55°F	75°F	90°F
A.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
B.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
C.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____

13. Please indicate the compressive strength (ASTM C 39) of these materials at 28 days, psi at

		40°F	55°F	75°F	90°F
A.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
B.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
C.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____

14. Please indicate the tensile strength of these materials at 24 hours, psi at

		40°F	55°F	75°F	90°F
A.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
B.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
C.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____

15. Please indicate the tensile strength of these materials at 28 days, psi at

		40°F	55°F	75°F	90°F
A.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
B.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
C.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____

16. Please indicate the flexural strength (ASTM C 78) of these materials at 24 hours, psi at

		40°F	55°F	75°F	90°F
A.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
B.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
C.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____

17. Please indicate the flexural strength (ASTM C 78) of these materials at 28 days, psi at

		40°F	55oF	75°F	90°F
A.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
B.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____
C.	1.	____	____	____	____
	2.	____	____	____	____
	3.	____	____	____	____

18. Please indicate the slant shear bond strength (ASTM C 882) of these materials at the following ages (75°F).

		24 Hours	28 Days	Other Age*
A.	1.	____________	____________	____________
	2.	____________	____________	____________
	3.	____________	____________	____________
B.	1.	____________	____________	____________
	2.	____________	____________	____________
	3.	____________	____________	____________
C.	1.	____________	____________	____________
	2.	____________	____________	____________
	3.	____________	____________	____________

* Note age ____.

19. Please indicate the quillotine shear bond strength of these materials at the following ages (75°F).

		Suitable for Traffic	24 Hours	28 Days
A.	1.	________	________	________
	2.	________	________	________
	3.	________	________	________
B.	1.	________	________	________
	2.	________	________	________
	3.	________	________	________
C.	1.	________	________	________
	2.	________	________	________
	3.	________	________	________

20. Please indicate the tensile adhesion bond strength (ACI 503R) of these materials at the following ages (75°F).

		Suitable for Traffic	24 Hours	28 Days
A.	1.	________	________	________
	2.	________	________	________
	3.	________	________	________
B.	1.	________	________	________
	2.	________	________	________
	3.	________	________	________
C.	1.	________	________	________
	2.	________	________	________
	3.	________	________	________

21. Please indicate the linear shrinkage (ASTM C 157) of these materials, %*

		24 Hours	28 Days	Other Age**
A.	1.	______	______	______
	2.	______	______	______
	3.	______	______	______
B.	1.	______	______	______
	2.	______	______	______
	3.	______	______	______
C.	1.	______	______	______
	2.	______	______	______
	3.	______	______	______

* Note if use other test method ______________________.
** Note age ______________________.

22. Please indicate the modulus of elasticity of these materials, psi*

		Compression	Tension
A.	1.	______	______
	2.	______	______
	3.	______	______
B.	1.	______	______
	2.	______	______
	3.	______	______
C.	1.	______	______
	2.	______	______
	3.	______	______

* Note test methods and age of specimens ______________________.

23. Please indicate the tensile elongation (ASTM D 638) of these materials, %*.

A. 1. ______________________

2. ______________________

3. ______________________

B. 1. ______________________

2. ______________________

3. ______________________

C. 1. ______________________

2. ______________________

3. ______________________

* Note age of specimens ______________________.

24. Please indicate the permeability to chloride ion (AASHTO T277) of these materials, coulombs*.

A. 1. ______________________

2. ______________________

3. ______________________

B. 1. ______________________

2. ______________________

3. ______________________

C. 1. ______________________

2. ______________________

3. ______________________

* Note age of specimens ______________________.

25. Please indicate the skid number at 40 mph of these materials (ASTM E 524).*

A. 1. ______

2. ______

3. ______

B. 1. ______

2. ______

3. ______

C. 1. ______

2. ______

3. ______

* Note if use other test method ______.

26. Please list the State DOT's, Thruway Authorities, Cities, Towns, etc. that have successfully used these materials.

A. 1. ______

2. ______

3. ______

B. 1. ______

2. ______

3. ______

C. 1. ______

2. ______

3. ______

27. Please provide names and addresses of contractors that have successfully used these materials.

A. 1. ____________________

2. ____________________

3. ____________________

B. 1. ____________________

2. ____________________

3. ____________________

C. 1. ____________________

2. ____________________

3. ____________________

28. On a separate sheet of paper, please provide a brief description and significant additional information on the rapid materials or techniques listed above. (Please attach specifications and reports).

29. Interested in donating material for an experimental installation for SHRP?

Yes __________ No __________

Please return all responses by July 15, 1989, to:

Michael M. Sprinkel
Virginia Transportation Research Council
P. O. Box 3817, University Station
Charlottesville, Virginia 22903
Telephone: (804) 293-1941

Thank you.

APPENDIX D

Questionnaire Response

Appendix D includes the following:

a) The number of users of each rapid repair technique and the names of the users based on responses to questionnaires no. 1 and no. 2.

b) A summary of the material supplier response to questionnaire no. 3.

c) The data submitted by each respondent to questionnaires no. 1 and no. 2.

The response sent to the state DOTs and Canadian Provinces was very good. The response by the other transportation agencies was not very good but provides additional data. It is obvious from the response to the questionnaires that many transportation agencies do not use rapid repair techniques. The principal problem with some of the responses by the DOTs and Canadian Provinces was unreasonable and incomplete data. To make use of the available data the following procedure was used.

1. Examine the data for blank entries and unreasonable totals which are defined as total lane closure times, total costs or service life data that are greater than 3 standard deviations from the average of the other data in the category or total lane closure times that are greater than 21 hours.

2. Make telephone contacts with those that completed the questionnaire and try to fill in the blanks and to revise the unreasonable data.

3. Re-examine the data and delete the entries that have unreasonable totals.

4. Examine traffic control time data for the time required to set up and remove traffic control. If there is no response to traffic control time and total time for an entry, the computed average traffic control time for all the complete, reasonable entries for the same system is inserted as the traffic control time. The sum of the traffic control time, the surface preparation time, and the placing and curing time becomes the total time for the entry. If there is a response for total time but there is no response to traffic control time or the traffic control time equals the total time, then the average traffic control time and the average total time for all the complete, reasonable entries for the same system are computed. The average traffic control time is then represented as a percentage of the average total time. This percentage of the total time in the incomplete entry is then substituted as the traffic control time for the incomplete entry. One half of the traffic control time is then subtracted from both the surface preparation time and the placing and curing time to maintain the accuracy of the total time for the entry.
5. Examine traffic control cost data. If there is no response to traffic control cost and total cost for an entry, the computed average traffic control cost for all the complete, reasonable entries for the same system is inserted as the traffic control cost. The sum of the traffic control cost, the surface preparation cost, the placing and curing cost, and the other costs becomes the total cost for the entry. It is assumed that there are no other costs involved in the repair if there is no response on the questionnaire in the specified blank, unless the only value cited

on the questionnaire is a total cost response. It can not be assumed that the total cost does not include some additional costs other than traffic control cost, surface preparation cost, and placing and curing cost. In the case of the response where only a total cost value is given, the average traffic control cost and the average total cost for all the complete, reasonable entries for the same system are computed. The average traffic control cost is then represented as a percentage of the average total cost. This percentage of the total cost is then substituted as the traffic control cost for the incomplete entry.

6. The procedure described in step 5 for calculating a traffic control cost based only on a total cost is also used to calculate a surface preparation cost, a placing and curing cost, and any other costs based on the same total cost response. In the case of an entry where only total time is supplied, the same procedure is used to calculate a traffic control time, a surface preparation time, and a placing and curing time.

SHRP PROJECT C-103 QUESTIONNAIRE--DEPARTMENT OF TRANSPORTATION, TURNPIKE AND THRUWAY AUTHORITY, AND TECHNOLOGY CENTER RESPONSE SUMMARY

CODE NUMBER	NUMBER OF UNITED STATES DEPARTMENT OF TRANSPORTATION RESPONSES	NUMBER OF CANADIAN DEPARTMENT OF TRANSPORTATION RESPONSES	NUMBER OF TURNPIKE AND THRUWAY AUTHORITY RESPONSES	NUMBER OF TECHNOLOGY CENTER RESPONSES	TOTAL NUMBER OF RESPONSES	AGENCIES RESPONDING
1A	7	0	1	1	9	LA, MD1, ME, PA TPK, PA, TN, UMPQUA T^2, WA DC, WI
1A1	2	1	0	0	3	MO, NY1, NS
1A1D	1	0	0	0	1	WA
1A2	5	0	0	0	5	ID, MO, NJ1, NJ2, SC
1A2A	3	0	0	0	3	CT, NH, NY1
1A2B	5	0	0	0	5	CT, NH, NY1, TN, WA
1A2D	5	0	0	0	5	CT, NH, NY1, TN, WA
1A4	1	0	0	0	1	NC
1A5C	3	0	0	0	3	ID, MO, SD
1B1C	1	0	0	1	2	CA, UMPQUA T^2
1B2B	0	0	0	1	1	UMPQUA T^2
1C	1	0	0	0	1	NY1
1C1	0	1	0	0	1	ALTA
1C2D	1	0	0	0	1	WA
1C2E	3	0	1	0	4	MD1, NJ1, PA TPK, WA
1C3	1	1	0	0	2	BC, ID
1D3A	1	0	0	0	1	WV
1D5A	5	2	0	0	7	ALTA, BC, CA, MD1, NE, OH, OK
1D7	0	1	0	0	1	ALTA
1E	1	1	0	0	2	BC, NY2
1E1	2	0	0	0	2	NS, WA
1E1B	3	0	0	0	3	OH, TN, VA
1E1C	1	0	0	0	1	VA
1E1D	1	0	0	0	1	VA
1E2A	0	1	0	0	1	ALTA
1E2B	1	0	0	0	1	SC
1E2E	2	0	0	0	2	CA, WA
1F1	0	1	0	0	1	BC
1Y	5	1	2	5	13	ARE T^2, F'BURG T^2, IA, KS, KY TPK, LUFKIN T^2, MD2, MA TPK, PULASKI T^2, SHAWNEE T^2, TX, WY, YT
1Z	19	6	6	2	33	AK, AZ, AR, BUFFALO TRW, CHESAPEAKE TRW, CLARK T^2, CO, DE TRW, FL, FORT SCOTT T^2, HI, IL, IN, KY, MACKINAC TRW, ME, MANT, MI, MN, MT, NV, NB, NJ TRW, NM, ND, NW TERR, ONT, OR, PEI, SASK, THI TRW, UT, VT

CODE NUMBER	NUMBER OF UNITED STATES DEPARTMENT OF TRANSPORTATION RESPONSES	NUMBER OF CANADIAN DEPARTMENT OF TRANSPORTATION RESPONSES	NUMBER OF TURNPIKE AND THRUWAY AUTHORITY RESPONSES	NUMBER OF TECHNOLOGY CENTER RESPONSES	TOTAL NUMBER OF RESPONSES	AGENCIES RESPONDING
2A1B	2	0	0	0	2	CA, OH
2A2A	1	0	0	0	1	SD
2C	2	1	0	0	3	NJ1(2), NS
2C1	2	1	0	1	4	IN, KS, NS, PULASKI T^2
2C2	2	1	0	1	4	IN, KS, NS, SHAWNEE T^2
2D	6	0	1	0	7	BUFFALO TRW, IN(2), MD1, NH, PA, TX
2D1	1	0	0	0	1	IN
2D4	11	2	0	1	14	ALTA, AR, CO(2), KS, MD1, NJ1, NJ2, NY1, NC, NS, SHAWNEE T^2, TN, WI
2D4A	1	0	0	0	1	VA
2D4B	6	0	0	1	7	F'BURG T^2, KY, MD2, MO, OK, VA(2)
2E	1	0	0	0	1	WY
2E2	1	0	0	0	1	NH
2E5	1	0	0	0	1	CA
2F1A	1	0	0	0	1	CA
2F2	1	0	1	0	2	OR, PA TPK
2F2B	6	2	0	0	8	ALTA, CA, HI, IN, MT, OK, SD, YT
2G	2	0	1	0	3	BUFFALO TRW, NH, WA DC
2Y	4	1	2	3	10	ARE T^2, BC, FL, IA, KY TPK, LUFKIN T^2, MA TPK, MS, NY2, UMPQUA T^2
2Z	18	6	5	2	31	AK, AZ, CHESAPEAKE TRW, CLARK T^2, CT, DE TRW, FORT SCOTT T^2, ID, IL, LA, MACKINAC TRW, ME, MANT, MI, MN, NE, NV, NB, NJ TRW, NM, ND, NW TERR, ONT, PEI, SASK, SC, THI TRW, UT, VT, WA, WV

CODE NUMBER	NUMBER OF UNITED STATES DEPARTMENT OF TRANSPORTATION RESPONSES	NUMBER OF CANADIAN DEPARTMENT OF TRANSPORTATION RESPONSES	NUMBER OF TURNPIKE AND THRUWAY AUTHORITY RESPONSES	NUMBER OF TECHNOLOGY CENTER RESPONSES	TOTAL NUMBER OF RESPONSES	AGENCIES RESPONDING
3D	2	0	2	0	4	BUFFALO TRW, CA, PA TPK, WA
3D1	1	0	0	0	1	IL
3F	3	1	1	1	6	ARE T^2, BUFFALO TRW, CA, NY1, NS, WA
3F2	1	0	0	0	1	NJ1
3F3A	1	0	0	0	1	CO
3F3B	1	0	0	0	1	OK
3H2B	3	0	0	0	3	IN, MT, OK
3Y	12	2	2	4	20	BC, CT, FL, F'BURG T^2, IA, KS, KY TPK, MD2, MA TPK, MS, NH, NJ2, NY2, PULASKI T^2, SHAWNEE T^2, TX, UMPQUA T^2, WA DC, WY, YT
3Z	28	7	5	3	43	AK, ALTA, AZ, AR, CHESAPEAKE TRW, CLARK T^2, DE TRW, FORT SCOTT T^2, HI, ID, KY, LA, LUFKIN T^2, MACKINAC TRW, MB, MANT, MD1, MI, MN, MO, NE, NV, NB, NJ TRW, NM, NC, ND, NW TERR, OH, ONT, OR, PA, PEI, SASK, SC, SD, TN, THI TRW, UT, VT, VA, WV, WI

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CODE NUMBER	NUMBER OF RESPONSES	NUMBER OF MATERIAL SUPPLIER RESPONDENTS	MATERIAL SUPPLIER RESPONDENTS	PRODUCT USERS
1A1A	1	1	Dural International Corporation	NJ; NEW YORK CITY, NY; NY
1A1B	3	1	Gates Engineering Company, Inc.	
1A2C	1	1	Carlisle Syntec Systems	
1A2D	1	1	Royston Laboratories Division	CALGARY, ALTA; IL; MA; MI; SOMERSET COUNTY, NJ; NJ; DEPOSIT, NY; LEWISTON, NY; WAYNE COUNTY, NY; NY TRW; NY; OH; GUELPH, ONT; ALLEGHENY COUNTY, PA; PITTSBURGH, PA; PA; UT
1C2D	4	2	Elkem Materials, Inc. Fox Industries, Inc.	AL; IL; BARTHOLOMEW COUNTY, IN; ME; MI; NY; OH TPK; OH; PA TPK; VA; VT; WA; WA DC METRO AREA TRANSIT AUTHORITY; WA DC
1C2E	1	1	Fox Industries, Inc.	
1D1C	1	1	Fosroc, Inc.	NJ TRANSIT AUTHORITY, NY, ONT, OR
1D1D	1	1	Fox Industries, Inc.	WA DC METRO AREA TRANSIT AUTHORITY, WA DC
1D2	3	3	Adhesives Technology Corporation Fox Industries, Inc. Robson-Downes Associates, Inc.	MD TOLL FACILITIES AUTHORITY, MD, NJ TPK, PA, VA
1D5A	5	3	Advanced Chemical Technologies Fox Industries, Inc. Hydrozo, Inc.	CA; CT; DE; FL; ID; IL; KY; BALTIMORE CITY, MD; MD TOLL FACILITIES AUTHORITY; MD SAA; MD; MI; MN; MT; NV; NM; NY; NC; ND; OK; OR; SD; WY
1D5C	1	1	Hydrozo, Inc.	OH, OK, PA, SC, TN, WA, WV
1D5F	6	2	Conseal International, Inc. Prosoco, Inc.	CA; CT; FL; KANSAS CITY, KS; KS TPK; MI; MS; MO; NY; OK; PA; VA
1E1B	3	3	Fosroc, Inc. Dural International Corporation Thermoflex, Inc.	CANADA; AIR AND NAVAL ENGINEERING CENTER, NJ; NY; PA; VA; WA
1E1C	1	1	Adhesives Technology Corporation	F.H.W.A., WA
1E1D	1	1	Dural International Corporation	CA, VA
1E3A	1	1	Belzona Molecular, Inc.	CT
1E3B	2	1	Fosroc, Inc.	AIR AND NAVAL ENGINEERING CENTER, NJ
1Y		6	Euclid Chemical Five Star Products, Inc. Hilti, Inc. Hodson Chemical Construction Corporation Pyrament/Lone Star Industries, Inc. The Quikrete Companies	
1Z		10	Anti Hydro Company Buehler Limited De Neef America, Inc. Dow Chemical, USA Emeri-Crete, Inc. Garland Floor Company Respecta America Solite Corporation Surface Preparation Technologies, Inc. The Norton Company	

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CODE NUMBER	NUMBER OF RESPONSES	NUMBER OF MATERIAL SUPPLIER RESPONDENTS	MATERIAL SUPPLIER RESPONDENTS	PRODUCT USERS
2A1A	1	1	Adhesives Technology Corporation	
2A2A	3	3	Adhesives Technology Corporation	AL, AK, AZ, AR, CA, CO, DE, FL, GA, HI, ID, IL, IN, IA, KS, KY, ME, MD, MA, MI, MN, MS, MO, MT, NH, NJ, NM, NV, NC, ND, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VT, WA, WV, WI, WY
			De Neef America, Inc.	
			Hilti, Inc.	
2B	1	1	Adhesives Technology Corporation	
2D1	1	1	Pyrament/Lone Star Industries, Inc.	CANADA, TX
2D2A	1	1	Fox Industries, Inc.	BALTIMORE CITY, MD; MD
2D2C	1	1	Hodson Chemical Construction Corporation	CA, UT
2D2F	1	1	Dural International Corporation	NY TRW, NY
2D2G	1	1	Fosroc, Inc.	CT, NEW YORK CITY TRW
2D4A	1	1	The Quikrete Companies	OH, TN
2D4B	6	5	Euclid Chemical	AL, CA, CANADA, CO, CT, FL, GA, IL, KY, MD TOLL FACILITIES AUTHORITY, MD, NJ, NY, OH, PA, RI, SC, TN, TX, VA, WV
			Fosroc, Inc.	
			Fox Industries, Inc.	
			Pyrament/Lone Star Industries, Inc.	
			The Quikrete Companies	
2E1	3	2	Belzona Molecular, Inc.	CT, MD TOLL FACILITIES AUTHORITY, WA DC METRO AREA TRANSIT AUTHORITY
			Fox Industries, Inc.	
2E2	4	3	Adhesives Technology Corporation	CANADA; NJ; NEW YORK CITY, NY; NY; OH; PA; NJ; VA; WA
			Dural International Corporation	
			Garland Floor Company	
2E4	1	1	The Horton Company	
2F2B	1	1	Euclid Chemical	
2F3	3	1	Five Star Products, Inc.	
2Y		5	Carlisle Syntec Systems	
			Conseal International, Inc.	
			Gates Engineering Company, Inc.	
			Hydrozo, Inc.	
			Royston Laboratories Division	
2Z		12	Advanced Chemical Technologies	
			Anti Hydro Company	
			Buehler Limited	
			Dow Chemical, USA	
			Elkem Materials, Inc.	
			Emeri-Crete, Inc.	
			Prosoco, Inc.	
			Respecta America	
			Robson-Downes Associates, Inc.	
			Solite Corporation	
			Surface Preparation Technologies, Inc.	
			Thermoflex, Inc.	

CODE NUMBER	NUMBER OF RESPONSES	NUMBER OF MATERIAL SUPPLIER RESPONDENTS	MATERIAL SUPPLIER RESPONDENTS	PRODUCT USERS
3F1	1	1	Pyrament/Lone Star Industries, Inc.	ALTA, CANADA, TX
3F2G	1	1	Fosroc, Inc.	CT, NEW YORK CITY TRW
3Y		13	Belzona Molecular, Inc.	
			Carlisle Syntec Systems	
			Conseal International, Inc.	
			Euclid Chemical	
			Five Star Products, Inc.	
			Garland Floor Company	
			Gates Engineering Company, Inc.	
			Hilti, Inc.	
			Hodson Chemical Construction Corporation	
			Hydrozo, Inc.	
			Royston Laboratories Division	
			Solite Corporation	
			The Quikrete Companies	
3Z		16	Adhesives Technology Corporation	
			Advanced Chemical Technologies	
			Anti Hydro Company	
			Buehler Limited	
			De Neef America, Inc.	
			Dow Chemical, USA	
			Dural International Corporation	
			Elkem Materials, Inc.	
			Emeri-Crete, Inc.	
			Fox Industries, Inc.	
			Prosoco, Inc.	
			Respecta America	
			Robson-Downes Associates, Inc.	
			Surface Preparation Technologies, Inc.	
			The Horton Company	
			Thermoflex, Inc.	

COST, SERVICE LIFE, AND TIME DEMAND DATA SPREADSHEET NO.1--
DATA TAKEN FROM DOT, CSHRP, TPK, TRW, AND T^2 QUESTIONNAIRE RESPONSES
SHRP PROJECT C-103 TASK 4
MICHAEL SPRINKEL

CODE NUMBER	AGENCY	AGENCY TYPE	SQUARE YARDS	TRAFFIC COST ($/YD²)	SURFACE PREPARATION COST ($/YD²)	PLACING AND CURING COST ($/YD²)	OTHER COST ($/YD²)	TOTAL COST ($/YD²)	TRAFFIC TIME (HOURS)	SURFACE PREPARATION TIME (HOURS)	PLACING AND CURING TIME (HOURS)	TOTAL TIME (HOURS)	MAINTENANCE (YEARS)	SERVICE LIFE (YEARS)
1A	MD1	STA	333.0	$1.88	$1.30	$1.90	$0.00	$5.08	1.0	3.0	1.0	5.0	8.0	13.5
1A	NE	STA	533.0					$23.50		2.0	6.0	8.0		
1A	PA TPK	TPK	116.6	$70.47	$7.00	$71.01	$0.00	$148.48	2.0	4.0	4.0	10.0	10.0	15.0
1A	PA	STA	300.0						1.5	3.5	7.0	12.0	2.5	4.5
1A	TN	STA	800.0	$1.50	$1.00	$10.50	$0.00	$13.00	2.0	4.0	8.0	14.0	3.5	8.0
1A	UMPQUA	T^2	333.3					$4.57		0.5	3.0			5.5
1A	WI	STA											2.0	7.5
1A1	NY1	STA	450.0		$11.25	$22.62			5.0	2.0	11.0	18.0	1.0	5.5
1A1	NS	CAN	800.0					$10.94		6.0	14.0	20.0	8.0	15.0
1A1D	WA	STA	913.7	$0.70	$1.49	$7.70	$8.80	$18.69		3.6	6.4	10.0	5.5	9.5
1A2	ID	STA	700.0	$0.07	$0.28	$1.60	$0.00	$1.95	0.5	2.0	4.0	6.5		20.0
1A2	NJ2	STA	600.0	$0.75	$125.00	$30.00	$0.00	$155.75		8.0	2.0	10.0		8.0
1A2	SC	STA	710.0						1.0	1.0	3.0	5.0		
1A2A	CT	STA	500.0	$3.00	$0.00	$25.00	$0.00	$28.00	3.0	4.0	9.0	16.0	10.0	20.0
1A2A	NH	STA	600.0	$12.50	$2.00	$22.00	$7.50	$44.00	1.5	10.0	4.0	15.5		15.0
1A2A	NY1	STA	450.0		$11.25	$22.62			5.0	2.0	11.0	18.0	1.0	5.5
1A2B	CT	STA	500.0	$3.00	$0.00	$25.00	$0.00	$28.00	3.0	4.0	9.0	16.0	10.0	20.0
1A2B	NH	STA	600.0	$12.50	$2.00	$22.00	$7.50	$44.00	1.5	10.0	4.0	15.5		15.0
1A2B	NY1	STA	450.0		$11.25	$22.62			5.0	2.0	11.0	18.0	1.0	5.5
1A2B	TN	STA	800.0	$1.50	$1.00	$14.00	$0.00	$16.50	2.0	2.0	8.0	12.0	3.5	15.0
1A2B	WA	STA	913.7	$0.70	$1.49	$7.70	$8.80	$18.69		3.6	6.4	10.0	5.5	9.5
1A2D	CT	STA	500.0	$3.00	$0.00	$25.00	$0.00	$28.00	3.0	4.0	9.0	16.0	10.0	20.0
1A2D	NH	STA	600.0	$12.50	$2.00	$22.00	$7.50	$44.00	1.5	10.0	4.0	15.5		15.0
1A2D	NY1	STA	450.0		$11.25	$22.62			5.0	2.0	11.0	18.0	1.0	5.5
1A2D	TN	STA	800.0	$1.50	$1.00	$14.00	$0.00	$16.50	2.0	2.0	8.0	12.0	3.5	15.0
1A2D	WA	STA	913.7	$0.70	$1.49	$7.70	$8.80	$18.69		3.6	6.4	10.0	5.5	9.5
1A4	NC	STA											5.0	10.0
1A5C	ID	STA	700.0	$0.07	$0.07	$0.20	$0.00	$0.34	0.5	0.5	0.5	1.5		
1A5C	SD	STA						$2.50						
1B1C	CA	STA	1000.0	$0.11	$3.87	$2.97	$0.00	$6.95	2.0	0.5	6.0	8.5	10.0	20.0
1B1C	UMPQUA	T^2	222.2					$18.00		2.0	5.0			5.5
1B2B	UMPQUA	T^2	333.3		$4.50	$19.80				3.0	6.0			5.5

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1C1	ALTA	CAN	200.0	$1.28	$39.95	$43.78	$0.00	$85.01		11.1	6.7	17.8	7.5	20.0
1C2D	WA	STA	43.0	$40.40	$5.00	$32.00	$18.20	$95.60		5.0	5.0	10.0	8.5	12.5
1C2E	PA TPK	TPK	4666.0			$2.51			1.0	0.5	4.0	5.5	3.0	10.0
1C2E	WA	STA	42.8	$35.30	$4.60	$35.30	$16.70	$91.90		0.9	9.1	10.0	8.5	12.5
1C3	BC	CAN	452.2	$0.28	$36.00	$41.00	$0.00	$77.28		4.5	3.5	8.0		22.5
1C3	ID	STA	700.0	$0.07	$0.28	$3.20	$0.00	$3.55	0.5	2.0	8.0	10.5		
1D3A	WV	STA	700.0	$0.70	$0.00	$0.60	$0.30	$1.60		0.0	8.0	8.0	1.0	
1D5A	ALTA	CAN	1000.0	$0.09	$0.38	$2.34	$0.00	$2.81		4.0	4.0	8.0	8.5	20.0
1D5A	CA	STA	1000.0	$0.11	$0.04	$1.60	$0.00	$1.75	2.0	2.0	5.0	9.0		25.0
1D5A	MO1	STA	9.0	$1.88	$1.30				1.0	3.0	1.0	5.0		
1D5A	NE	STA						$4.50						
1D5A	OH	STA	400.0	$0.50				$10.00	2.0	2.0	2.0	6.0	5.0	10.0
1D5A	OK	STA	400.0					$2.80	1.0	3.0	2.0	6.0		10.0
1D7	ALTA	CAN	1200.0	$0.17	$0.27	$0.92	$0.00	$1.36		2.9	5.1	8.0	6.5	17.5
1E	BC	CAN	452.2	$0.36	$46.80	$53.30	$0.00	$100.46		4.5	3.5	8.0	3.0	
1E	NY2	STA	90.0		$11.25	$81.00						8.0	2.5	6.0
1E1	MS	STA	1500.0	$0.20	$0.30	$3.50	$0.00	$4.00	2.0	5.0	5.0	12.0	10.0	15.0
1E1	WA	STA	272.1	$0.78	$9.62	$33.40	$5.86	$49.66		6.6	3.4	10.0	6.5	10.5
1E1B	OH	STA	400.0	$6.00				$14.00	2.0	3.0	5.0	10.0	5.0	10.0
1E1B	TN	STA	800.0	$1.50	$2.50	$7.50	$0.00	$11.50	2.0	3.0	8.0	13.0	5.0	10.0
1E1B	VA	STA	500.0	$1.00	$3.00	$27.00	$0.00	$31.00	0.5	4.0	5.0	9.5	7.0	10.0
1E1C	VA	STA	500.0	$1.00	$3.00	$31.00	$0.00	$35.00	0.5	4.0	6.0	10.5	7.0	10.0
1E1D	VA	STA	500.0	$1.00	$3.00	$24.00	$0.00	$28.00	0.5	4.0	6.0	10.5	7.0	10.0
1E2A	ALTA	CAN	300.0	$0.56	$4.25	$46.19	$0.00	$51.00		1.6	14.4	16.0	6.5	25.0
1E2B	SC	STA	10.0	$800.00		$11.11		$811.11	1.0	3.0	4.0	8.0		
1E2E	CA	STA	600.0	$0.11	$18.00	$48.75	$0.00	$66.86	2.0	2.0	5.0	9.0	10.0	25.0
1E2E	WA	STA	149.9	$14.18	$37.83	$52.00	$20.28	$124.29		7.1	2.9	10.0	6.5	10.5
1F1	BC	CAN	452.2	$0.36	$46.80	$53.30	$0.00	$100.46		4.5	3.5	8.0		

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** 2A1B	CA	STA	1000.0	$0.11	$3.87	$2.97	$0.00	$6.95	2.0	0.5	6.0	8.5	10.0	20.0
** 2A1B	OH	STA	400.0	$3.00				$12.00	2.0	2.0	2.0	6.0	5.0	10.0
2C	NS	CAN	50.0					$164.13		8.0	10.0	18.0		10.0
2C1	IN	STA	1.0	$100.00	$10.00	$60.00	$0.00	$170.00	1.0	0.1	0.5	1.6	0.1	2.0
2C1	KS	STA	10.0	$1.00	$2.00	$3.00	$1.00	$7.00	1.0	1.0	1.0	3.0	0.1	1.3
2C1	NS	CAN	3.0							0.5	1.0	1.5	1.0	1.0
2C1	PULASKI	T^2						$10.00				6.0		5.0
2C2	IN	STA	1.0	$100.00	$10.00	$60.00	$0.00	$170.00	1.0	0.1	0.5	1.6	0.3	2.0
2C2	KS	STA	10.0	$1.00	$2.00	$3.00	$1.00	$7.00	1.0	1.0	1.0	3.0	0.1	1.3
2C2	NS	CAN	3.0							0.5	1.0	1.5	1.0	1.0
2C2	SHAWNEE	T^2						$250.00				8.0		3.0
2D	BUFFALO	TRW	0.8	$30.00	$24.00	$24.00	$20.00	$98.00				1.0		1.0
2D	IN	STA	1.0	$500.00	$120.00	$360.00	$0.00	$980.00	1.0	1.0	3.0	5.0	2.0	5.0
2D	IN	STA	7.0	$285.71	$274.29	$51.43	$0.00	$611.43	1.0	16.0	3.0	20.0	10.0	20.0
2D	MD1	STA	11.0	$1.88	$236.00	$57.00	$0.00	$294.88		8.0	1.0		1.5	4.0
2D	NH	STA	3.0						1.5	3.0	3.0	7.5	10.0	15.0
2D	PA	STA											2.5	9.0
2D	TX	STA	6.0					$260.00	1.0	4.5	13.0	18.5		
2D1	IN	STA	1.0	$500.00	$120.00	$360.00	$0.00	$980.00	1.0	1.0	3.0	5.0	2.0	5.0
2D4	ALTA	CAN	18.0	$5.95	$34.00	$130.05	$0.00	$170.00		5.0	3.0	8.0	3.0	4.0
2D4	AR	STA	21.0	$11.50	$19.00	$7.50	$0.00	$38.00	3.0	5.0	2.0	10.0	4.0	7.0
2D4	CO	STA	1.0	$12.50	$40.00	$75.00	$0.00	$127.50	5.0	1.0	2.0	8.0		
2D4	CO	STA	1.0	$12.50	$57.00	$75.00	$0.00	$144.50	5.0	2.0	2.0	9.0		
2D4	KS	STA	5.0	$1.00	$4.00	$8.00	$2.00	$15.00	1.0	3.0	3.0	7.0	0.3	3.0
2D4	MD1	STA	4.0	$1.88	$81.25	$147.00	$0.00	$230.13		3.0	2.0		0.8	2.5
2D4	NJ2	STA	18.0	$16.00	$375.00	$110.00	$0.00	$501.00		6.0	6.0	12.0	3.0	5.0
2D4	NY1	STA	1.0		$247.50	$282.50			0.5	1.0	1.3	2.8	7.0	10.0
2D4	NC	STA											5.0	10.0
2D4	NS	CAN	1.0					$420.84		2.0	2.0	4.0		5.0
2D4	SHAWNEE	T^2						$250.00				8.0		3.0
2D4	TN	STA	25.0	$1.50	$5.00	$120.00	$0.00	$126.50	3.0	6.0	3.0	12.0	2.0	4.0
2D4A	VA	STA	15.0	$1.00	$120.00	$180.00	$0.00	$301.00	0.5	6.0	5.0	11.5	5.0	10.0
2D4B	P-BURG	T^2						$87.50				9.0		20.0
2D4B	KY	STA	2.0	$57.00	$171.00	$210.00	$0.00	$438.00	1.0	3.0	3.0	7.0	1.0	4.0
2D4B	MD2	STA	2.0	$103.13	$103.13	$271.88	$103.13	$581.27	2.0	2.0	2.0	6.0		1.8
2D4B	GK	STA	10.0	$30.00	$16.00	$43.50	$0.00	$89.50	2.0	1.0	3.0	6.0		
2D4B	VA	STA	15.0	$1.00	$120.00	$200.00	$0.00	$321.00	0.5	6.0	3.0	9.5	5.0	10.0
2D4B	VA	STA	25.0	$1.00	$70.00	$130.00	$0.00	$201.00	0.5	6.0	3.0	9.5	5.0	10.0

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2E	WY	STA	3.0							2.0	10.0	12.0		
2E2	NH	STA	3.0						1.5	3.0	2.0	6.5	10.0	15.0
2E5	CA	STA	600.0	$0.11	$18.00	$48.75	$0.00	$66.86	2.0	2.0	5.0	9.0	10.0	25.0
2P1A	CA	STA	1.0	$0.11	$18.00	$67.50	$0.00	$85.61	2.0	3.0	4.0	9.0	10.0	20.0
2P2	OR	STA	0.5	$15.00	$150.00	$150.00	$100.00	$415.00	1.0	1.0	1.0	3.0	2.0	4.0
2P2	PA TPK	TPK	116.6	$70.47	$7.00	$450.00	$0.00	$527.47	2.0	4.0	4.0	10.0	10.0	15.0
2P2B	ALTA	CAN	18.0	$5.95	$34.00	$130.05	$0.00	$170.00		5.0	3.0	8.0	3.0	4.0
2P2B	CA	STA	1.0	$0.11	$18.00	$67.50	$0.00	$85.61	2.0	3.0	4.0	9.0	10.0	20.0
2P2B	HI	STA	10.0	$5.00	$9.00	$9.00	$3.00	$26.00	1.0	2.0	2.0	5.0	10.0	20.0
2P2B	IN	STA	1.0	$100.00	$10.00	$60.00	$0.00	$170.00	1.0	0.1	3.0	4.1	1.0	2.0
2P2B	MT	STA	270.0	$1.74	$0.56	$1.66	$0.00	$3.96		4.0	8.0	12.0	4.0	10.0
2P2B	OK	STA	10.0	$30.00	$16.00	$43.50	$0.00	$89.50	2.0	1.0	3.0	6.0		
2P2B	YT	CAN	1.0	$100.00	$50.00	$50.00	$40.00	$240.00		1.0	1.0	2.0		
2G	BUFFALO	TRW	0.8	$9.00	$6.00	$9.00	$60.00	$84.00				0.8		
2G	NH	STA	3.0						1.5	3.0	4.0	8.5	10.0	15.0

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3D	BUFFALO	TRW		$30.00	$144.00	$294.00	$320.00	$788.00						5.0
3D	CA	STA	5000.0	$0.22				$800.00	2.0	8.0	8.0	18.0	30.0	50.0
3D	PA TPK	TPK	8.1	$264.25	$203.27	$274.42	$0.00	$741.94	2.1	2.2	2.2	6.5	20.0	40.0
3D	WA	STA	22.3	$14.70		$160.00	$66.70	$241.40	2.9		7.1	10.0	17.5	35.0
3D1	IL	STA	135.0						1.0	4.0	5.0	10.0	12.5	30.0
3F	ARE	T^2	9.3	$8.01				$83.42	1.3	2.0	8.0	11.3		12.5
3F	BUFFALO	TRW	2.3	$30.00	$144.00	$294.00	$320.00	$788.00				12.0		7.5
3F	CA	STA											30.0	50.0
3F	NS	CAN						$34.32					8.0	15.0
3F3A	CO	STA	1.0	$25.00	$75.00	$99.50	$0.00	$199.50	5.0	3.0	3.0	11.0		
3F3B	OK	STA	5.0	$80.00	$32.00	$137.00	$0.00	$249.00	2.0	1.0	5.0	8.0		
3H2B	IN	STA	1.0	$500.00	$120.00	$360.00	$0.00	$980.00	1.0	1.0	3.0	5.0	2.0	5.0
3H2B	MT	STA	2.0	$235.00	$131.00	$395.00	$0.00	$761.00		7.0	5.0	12.0	2.0	6.0
3H2B	OK	STA	5.0	$80.00	$32.00	$137.00	$0.00	$249.00	2.0	1.0	5.0	8.0		

APPENDIX E

Sequence of Rapid Repair Activities for Four Lane Closure Constraints

The number of lane closures required to make a rapid repair is a function of the length of the bridge, the number of lanes and the efficiency of the crew. An efficient operation would typically have several activities occurring under one lane closure but at different locations along the lane. To expedite a repair, contracts need to be properly worded to require the contractor to minimize the number of lane closures. Otherwise, contractors will likely use many lane closures since they are usually reimbursed for the cost of traffic control based on the number of hours or days it is in place or the number of times it has to be set up and removed.

Cones and barrels work well for rapid repair techniques because typically less than 30 minutes is required to close and open the lane. In situations where concrete barricades must be used, it may be necessary to use a rapid or semirapid repair because several hours are usually required to install and remove the barricades. The use of special equipment designed to install and remove the barricades in less than an hour is necessary to make most rapid and very rapid repairs feasible when concrete barricades must be used.

An example of the sequence of repair activities for each of four lane closure constraints follows. Once the repair is under way several repair teams can work at several locations under one lane closure and thereby conduct the activities described under several of the lane closures.

Lane Closure Time $\leq$ 8 hrs

Most Rapid Repair -- Patch Deck and Install Polymer Overlay

Lane Closure 1

A. Close lane with cones
B. Mark areas to be patched
C. Saw cut areas to be patched
D. Open lane

Lane Closure 2

A. Close lane with cones
B. Remove concrete
C. Fill cavities with high early strength portland cement concrete
D. Cure concrete patches
E. Open lane

Lane Closure 3

A. Close lane with cones
B. Shotblast deck
C. Install overlay test patches (ACI 503R)
D. Cure test patches
E. Open lane

Lane Closure 4

A. Close lane with cones
B. Test overlay test patches
C. Shotblast deck
D. Install polymer overlay
E. Cure polymer overlay
F. Open lane

Lane Closure Time $\leq$ 12 hrs

Very Rapid Repair -- Patch Deck and Apply Penetrating Sealer

Lane Closures 1 and 2 (same activities cited for most rapid repair)

Lane Closure 3

A. Close lane with cones
B. Shotblast deck
C. Apply penetrating sealer
D. Cure penetrating sealer
E. Open lane

Lane Closure Time ≤ 21 hrs

Rapid Repair -- Patch Deck and Install Bituminous Overlay on Prefabricated Membrane

Lane Closures 1 and 2 (same activities cited for most rapid repair)

Lane Closure 3

A. Close lane with cones
B. Shotblast deck
C. Apply tack coat
D. Cure tack coat
E. Apply prefabricated membrane
F. Place and compact bituminous overlay
G. Open lane

Lane Closure Time ≤ 56 hrs

Semirapid Repair -- Patch Deck and Place High Early Strength Portland Cement Concrete Overlay

Lane Closure 1

A. Close lane with cones or concrete barricades
B. Scarify deck
C. Mark areas to be patched
D. Remove concrete
E. Fill cavities with high early strength portland cement concrete
F. Cure concrete patches
G. Open lane

Lane Closure 2

A. Close lane with cones or concrete barricades
B. Patch with high early strength portland cement concrete
C. Cure concrete patches
D. Open lane

Lane Closure 3

A. Close lane with cones or concrete barricades
B. Shotblast deck
C. Place overlay
D. Cure overlay
E. Open lane

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