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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 333

Concrete Bridge Deck Performance

A Synthesis of Highway Practice

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Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2004
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP SYNTHESIS 333

Project 20-5 FY 2002 (Topic 34-09)
ISSN 0547-5570
ISBN 0-309-07011-2
Library of Congress Control No. 2004108041

Price $18.00

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The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street
Washington, D.C. 20001

and can be ordered through the Internet at:

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Printed in the United States of America

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FOREWORD

By Staff
Transportation Research Board

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

Information exists on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

The synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This synthesis report provides information on previous and current design and construction practices used to improve the performance of bridge decks. The primary focus is on North American practice for cast-in-place (full depth and partial depth), reinforced concrete bridge decks on steel beams, concrete I- and T-beams, or concrete box beams. Information was obtained on the following topics: factors that contribute to the durability of concrete bridge decks; performance of various types of deck protection strategies; lessons learned and the current state of the practice in design, construction, and maintenance of concrete bridge decks; available comparative analysis of the effects of using different methods and materials; specific reports of successes and failures; sample design and construction specifications; available life-cycle cost information; research in progress; and suggestions for future study.

This synthesis report of the Transportation Research Board combines information obtained from survey responses from bridge owners and from a literature review.

A panel of experts in the subject area guided the work of organizing and evaluating the collected data and reviewed the final synthesis report. A consultant was engaged to collect and synthesize the information and to write this report. Both the consultant and the members of the oversight panel are acknowledged on the title page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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ACKNOWLEDGMENTS

Henry G. Russell, Henry G. Russell, Inc., Glenview, Illinois, was responsible for collection of the data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Harry Capers, New Jersey Department of Transportation; David Darwin, Civil, Environmental, and Architectural Engineering, University of Kansas; Amir N. Hanna, Senior Program Officer, Transportation Research Board; Joseph L. Hartmann, Structural Research Engineer, Federal Highway Administration, HRD1-06; Erol Kaslan, California Department of Transportation; Joe Lenzini, Illinois Department of Transportation; Myint Lwin, Structural Research Design Engineer, Federal Highway Administration Western Resource Center; Stephen F. Maher, Engineer of Design, Transportation Research Board; Dr. Barney T. Martin, Jr., Vice President, Modjeski & Masters, Inc.; Brian Merrill, Texas Department of Transportation—Bridge Division; and Mark L. Whittemore, New Hampshire Department of Transportation.

This study was managed by Jon Williams, Manager, Synthesis Studies, who worked with the consultant, the Topic Panel, and the Project 20-5 Committee in the development and review of the report. Assistance in project scope development was provided by Donna Vlasak, Senior Program Officer. Don Tippman was responsible for editing and production. Cheryl Keith assisted in meeting logistics and distribution of the questionnaire and draft reports.

Crawford F. Jencks, Manager, National Cooperative Highway Research Program, assisted the NCHRP 20-5 Committee and the Synthesis staff.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

CONCRETE BRIDGE DECK PERFORMANCE

SUMMARY

Concrete bridge decks can deteriorate as a result of concrete distress from freeze-thaw damage, abrasion damage, alkali-aggregate reactivity, excessive cracking, or spalling caused by corrosion of the reinforcement. As concern about deterioration of concrete bridge decks from corrosion of reinforcement increased in the 1960s and 1970s, attention focused on several strategies to prevent or slow down the penetration of chlorides to the reinforcement. These strategies included the use of increased concrete cover, low-slump dense concrete overlays, latex-modified concrete overlays, interlayer membranes, asphaltic concrete systems, and epoxy-coated reinforcement. In the survey for this synthesis, the three strategies currently being used by most respondents to prevent corrosion of reinforcement in bridge decks were increased clear cover to the reinforcement, epoxy-coated reinforcement, and low-permeability concrete.

This synthesis report provides information on previous and current design and construction practices that have been used to improve the performance of concrete bridge decks. North American practices for cast-in-place (full and partial depth), reinforced concrete bridge decks on steel beams, concrete I- and T-beams, and concrete box beams are the primary focus. To accomplish this study, information was obtained from a survey distributed to highway agencies in the United States and Canada and a review of the literature. The report includes information on the effects of concrete constituent materials and concrete mix proportions on the durability of concrete and its effectiveness in protecting steel reinforcement from corrosion, summarizes systems that have been used as alternatives to noncoated steel reinforcement, discusses barrier systems designed to protect primary concrete and reinforcement from deterioration, provides information about design and construction practices related to bridge deck performance, and discusses cracking of concrete bridge decks.

The use of fly ash, silica fume, and ground-granulated blast furnace slag as supplementary cementitious materials facilitates the achievement of low-permeability concretes that slow down the ingress of chlorides. The use of high-range, water-reducing admixtures means that these concretes can be produced at a low water-cementitious materials ratio and still be placed and finished without too much difficulty. These concretes, however, require greater attention to environmental conditions during placement and greater attention to concrete curing.

The use of concretes with low water-cementitious materials ratios and supplementary cementitious materials has resulted in concretes having higher concrete compressive strengths, higher moduli of elasticity, and lower creep. Although the tensile strength is higher, the other properties have led to an increase in the amount of cracking, which provides the chlorides with an easier path to the reinforcement. As a result, the increase in the number of cracks offsets the benefits of the low-permeability concrete between the cracks. Concrete mix proportions should, therefore, be selected to produce a reasonably low permeability, while not increasing the propensity for cracking.

Epoxy-coated reinforcement continues to be the most common reinforcement used to reduce the potential for deterioration of concrete bridge decks from reinforcement corrosion. However, epoxy-coated reinforcement cannot be relied on to never corrode in a wet or chloride environment. Other materials offer the potential for use as reinforcement; however, their long-term performance in bridge decks is not proven at this time.

Bridge deck protective systems that are designed to protect the primary concrete and reinforcement from conditions that will cause their deterioration include overlays, membranes, sealers, and cathodic protection. Latex-modified concrete overlays and low-slump dense concrete overlays have, in general, performed satisfactorily. Results with membranes appear to be mixed. The life of the membrane system is limited more by the life of the protective cover over the membrane than by the life of the membrane itself. However, states with more experience in using membranes have achieved longer lives for their systems.

Sealing of concrete surfaces can be used to delay the effects of deterioration if deterioration is not already underway. However, the performance of sealers is difficult to assess because of inconsistencies between laboratory tests and field tests and a lack of national standard testing specifications. Nevertheless, sealers do offer a low initial cost approach. Cathodic protection systems have been used, but have not been proven to be maintenance-free or cost-effective.

Several design practices can be beneficial to improve concrete bridge deck performance, including increasing deck thickness, minimizing restraints to shrinkage of the deck, using smaller size reinforcing bars at closer spacing, and providing adequate cover. In construction, the need to provide adequate curing is an essential component to obtaining a durable concrete bridge deck.

Present practice and research results indicate that use of the following materials and practices enhances the performance of concrete bridge decks:

- Concrete Constituent Materials
  - Types I, II, and IP cements;
  - Fly ash up to 35% of the total cementitious materials content;
  - Silica fume up to 8% of the total cementitious materials content;
  - Ground-granulated blast furnace slag up to 50% of the total cementitious materials content;
  - Aggregates with low modulus of elasticity, low coefficient of thermal expansion, and high thermal conductivity;
  - Largest size aggregate that can be properly placed;
  - Water-reducing and high-range water-reducing admixtures;
  - Air-void system with a spacing factor no greater than 0.20 mm (0.008 in.), specific surface area greater than 23.6 mm^2/mm^3 (600 $in.^2/in.^3$) of air-void volume, and number of air voids per inch of traverse significantly greater than the numerical value of the percentage of air;
  - Water-cementitious materials ratio in the range of 0.40 to 0.45;
  - Concrete compressive strength in the range of 28 to 41 MPa (4,000 to 6,000 psi); and
  - Concrete permeability per AASHTO Specification T277 in the range of 1,500 to 2,500 coulombs.
- Reinforcement Materials
  - Epoxy-coated reinforcement in both layers of deck reinforcement and
  - Minimum practical transverse bar size and spacing.

- Design and Construction Practices
  - Maintain a minimum concrete cover of 64 mm (2.5 in.);
  - Use moderate concrete temperatures at time of placement;
  - Use windbreaks and fogging equipment, when necessary, to minimize surface evaporation from fresh concrete;
  - Provide minimum finishing operations;
  - Apply wet curing immediately after finishing any portion of the concrete surface and wet cure for at least 7 days;
  - Apply a curing compound after the wet curing period to slow down the shrinkage and enhance the concrete properties;
  - Use a latex-modified or dense concrete overlay;
  - Implement a warranty requirement on bridge deck performance; and
  - Gradually develop performance-based specifications.

CHAPTER ONE

INTRODUCTION

BACKGROUND

Concrete bridge deck deterioration, in the form of concrete distress and reinforcement corrosion, is one of the leading causes of structural deficiency listed in the National Bridge Inventory. Transportation agencies are investing significant resources to solve the problem. These agencies often specify material properties, mix designs, and construction methods in their efforts to address concrete bridge deck distress. To reduce corrosion, alternative reinforcement, appropriate slab design practices, protective barrier methods, electrochemical methods, and corrosion inhibitors may be used. The success and performance of these efforts has not yet been compiled in a document widely available to transportation agencies.

In a 1955 survey to ascertain the principal problems faced by bridge maintenance engineers, concrete deterioration was rated fourth, although the specific deteriorating components were not described (McGovern 1955). In a 1967 survey, however, concrete bridge decks were rated first in the type of structure requiring the greatest structural maintenance (*NCHRP Synthesis of Highway Practice 4* 1970).

Deicing salts were not commonly used until the 1950s. Their use increased as more and more states instituted a “bare pavements“ policy in response to public demand. Salt can have a pronounced deleterious effect on concrete. First, the potential for freeze-thawing damage leading to surface scaling is greater when deicing salts are used. Second, the presence of chlorides at the level of the reinforcement intensifies corrosion of the reinforcement leading to spalling. Although scaling and spalling can occur without the presence of deicing salts, their presence accelerates the process (*Guide to Durable Concrete* 1992).

The first NCHRP synthesis report on bridge deck durability, *NCHRP Synthesis of Highway Practice 4*: *Concrete Bridge Deck Durability*, was published in 1970. It reported that bridge deck deterioration was a major maintenance item, with the most commonly reported conditions being cracking, scaling, and spalling. Cracking was not considered to be serious and scaling could be virtually eliminated by the use of high-quality, air-entrained concrete assisted, when necessary, by periodic applications of linseed oil. Spalling was considered to be the most serious defect with its cause attributed to corrosion of the reinforcing steel. Cracks provided ready access for salt and moisture to reach the steel, although porous concrete without cracks was also considered as a means for chlorides and moisture to reach the reinforcement.

In 1972, the FHWA introduced a policy that required application of a deck protective system to all structures on the federal-aid system likely to be subjected to potentially damaging applications of deicing salts (Manning 1995). The market for waterproofing systems expanded as new products were introduced and put to use. In addition, increased cover over reinforcing steel, increased efforts at crack control, and the use of less porous concrete were implemented.

A second NCHRP synthesis dealing with durability of concrete bridge decks, *NCHRP Synthesis of Highway Practice 57*: *Durability of Concrete Bridge Decks,* was published in 1979. This synthesis reported that concrete bridge deck durability continued to be a problem because of corrosion of the steel reinforcement. It reported that design practices that improve durability included lesser skews, better drainage, thicker slabs, and greater cover to the reinforcement. Beneficial construction practices included achievement of the specified cover, use of concrete with the lowest possible water–cement ratio, and good consolidation. The most effective coating to reduce the susceptibility of steel reinforcement to corrosion was identified as fusion-bonded epoxy powder.

The 1979 synthesis also reported that sealants, impregnants, overlays, membranes, or cathodic protection had been used to improve durability. Sealants were reported to not be effective in preventing corrosion; polymer impregnators showed promise; overlays were low-slump concrete, latex-modified concrete, or internally sealed concrete; membranes were available in a variety of systems, however, field experience had been highly variable leading to doubt about their long-term performance; and cathodic protection was described as the only practical method to stop active corrosion.

This synthesis also reported that for many years the prevailing attitude was that if the requirements for specified concrete strength were satisfied, the deck would perform adequately. The most important factors for the durability of concrete were identified as selection of good quality materials and provision of a low water–cement ratio and air-entrained concrete.

NCHRP Report 297: *Evaluation of Bridge Deck Protective Strategies* (Babaie and Hawkins 1987) reported the results of an investigation of the following five strategies for preventing corrosion in new bridge decks:

1. Concrete cover, 75 mm (3 in.) or more;
2. Low-slump concrete overlay;
3. Latex-modified concrete overlay;
4. Waterproof membrane and asphalt overlay; and
5. Epoxy-coated reinforcing steel.

The performance of these strategies was examined through a literature review, survey of transportation departments, and visual inspection of selected bridge decks. Concrete protective systems using increased concrete cover, low-slump concrete overlays, and latex-modified concrete overlays were found to be resistant, but not impermeable, to salt penetration.

Waterproof membranes with asphalt overlays were found to be effective in preventing salt intrusion into the underlying deck. Nevertheless, after 15 years of service, membranes had deteriorated as the result of aging and traffic. Epoxy coating of reinforcing steel prevented corrosion; however, breaks in the coating provided potential sites of accelerated corrosion. The long-term durability of epoxy coating in chloride-contaminated concrete was stated to be unknown, but concern was expressed about the presence of pinholes and the coating's adhesion to the reinforcement.

A November 2002 multistate survey for the Michigan Department of Transportation (DOT) showed that 21 or 68% of the 31 responding states believed that the concrete deck service life would meet their expectations (Aktan and Fu 2003). When asked how long they believed their reinforced concrete deck would last under average traffic, the overwhelming response was 30 to 40 years. Thirty states responded that they have taken action to improve the durability of reinforced concrete bridge decks. At least 23 or 74% of the responding states indicated that they have increased concrete cover, changed the mix design, or changed curing procedures.

SCOPE

This synthesis provides information on previous and current design and construction practices that have been used with the goal of improving the performance of concrete bridge decks. The primary focus is North American practices for cast-in-place (CIP), reinforced concrete bridge decks on steel beams, concrete I- and T-beams, or concrete box beams. Full-depth CIP slabs and partial-depth CIP slabs on precast panels are included. Post-tensioned concrete bridge decks are not included in this report. The information was obtained from a literature review and from the 45 responses to a survey questionnaire sent to 64 highway agencies in the United States and Canada.

The objective of the questionnaire was to obtain information on the following topics:

- Factors that contribute to the durability of concrete bridge decks;
- Performance of various types of deck protection strategies;
- Lessons learned and the current state of the practice in design, construction, and maintenance of concrete bridge decks;
- Available comparative analyses of the effects of using different methods and materials;
- Specific reports of successes and failures;
- Sample design and construction specifications;
- Available life-cycle cost information;
- Research in progress; and
- Suggestions for future study.

The remaining text of this synthesis is organized as follows:

- Chapter two reports on the effects of concrete constituent materials and concrete mix proportions on the durability of concrete and its effectiveness in protecting steel reinforcement from corrosion.
- Chapter three summarizes different reinforcement systems that have been used as alternatives to noncoated steel reinforcement. These systems either provide a barrier for the corrosive agent or use a noncorrosive material.
- Chapter four deals with barrier systems that are designed to protect the primary concrete and reinforcement from conditions that will cause their deterioration. The barrier systems include overlays, membranes, sealers, and cathodic protection systems.
- Chapter five provides information about design and construction practices that are related to bridge deck performance, as well as limited information about costs.
- Chapter six presents a discussion about cracking in concrete bridge decks.
- Chapter seven contains the conclusions from this synthesis and suggestions for future study.

Appendices provide the questionnaire survey (Appendix A), a list of responding agencies (Appendix B), a summary of the results (Appendix C), and a summary of research in progress (Appendix D). Full details of the responses of each agency are available on-line at http://www4.trb.org/trb/onlinepubs.nsf, under National Cooperative Highway Research Program (NCHRP), NCHRP Synthesis Reports, Synthesis 333.

TYPES OF DETERIORATION

The types of deterioration that generally appear in concrete bridge decks are scaling, mortar flaking, spalling, abrasion damage, alkali-aggregate reactivity, and cracking

Scaling is a general loss of surface mortar usually associated with freeze-thaw damage and aggravated by the presence of deicer chemicals. Scaling is primarily a physical action caused by pressure from water freezing within the concrete (*Concrete Slab Surface Defects* . . . 2001). It may occur in small areas or be widespread, as shown in Figure 1.

FIGURE 1 Surface scaling caused by freeze-thaw cycles.

Mortar flaking is similar to scaling, but occurs over coarse aggregate particles. Early drying out of the surface mortar over the aggregate results in insufficient moisture for cement hydration, leading to a mortar layer of lower strength. Upon freezing in a saturated condition, the thin layer of mortar breaks away. Whereas scaling occurs over a general area, mortar flaking only occurs above coarse aggregate particles.

Spalling is a larger surface defect than scaling or mortar flaking and is generally caused by internal pressure or expansion within the concrete. The two common causes of spalling are corrosion of the reinforcement and improperly constructed or maintained joints (*Guide for Concrete Highway* . . . 1997; *Concrete Slab Surface Defects* . . . 2001). When spalling is caused by corrosion of the reinforcement, the depth of the spall extends to the level of the reinforcement, as shown in Figure 2. If not treated when it first appears, spalling can lead to large-scale delaminations.

Abrasion damage in wheel tracks can be caused by studded tires and chain wear as shown in Figure 3. Such damage can also be caused by the blades of snow ploughs, particularly on the corners of grooved surfaces. In addition, abrasion damage manifests itself as polishing of the aggregates, which can lead to a slippery surface.

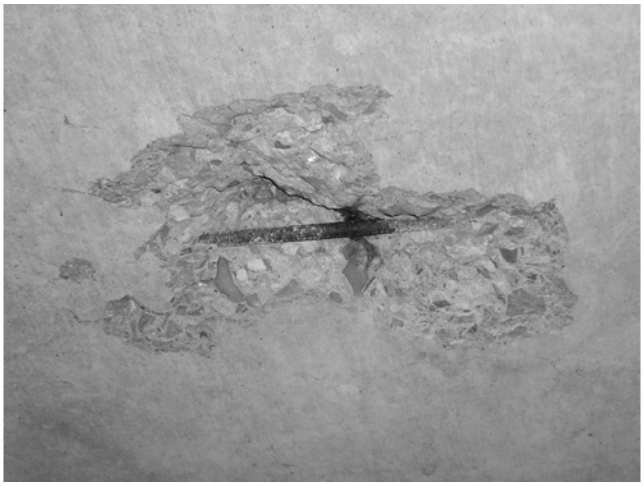


FIGURE 2 Spalling caused by corroded reinforcement.

FIGURE 3 Abrasion damage caused by chain wear.

Alkali-aggregate reactivity is a chemical reaction in concrete between alkalies from portland cement or other sources and certain constituents of some aggregates. Under certain conditions, the reaction may cause abnormal expansion and cracking of concrete in service (*Cement and Concrete Terminology* 2000). The causes and remedies have been extensively researched and are not included in this synthesis (Stark et al. 1993; *State-of-the-Art* . . . 1998).

Cracking is a characteristic of concrete because of its low tensile strength. The significance of cracks and their effect on the durability of a concrete deck are dependent on their cause, width, depth of penetration, and the concrete age when they occur. The effects of cracks on bridge deck performance are discussed in more detail in chapter six.

DESIRED DECK PERFORMANCE

A high-quality concrete bridge deck has at a minimum the following characteristics:

- Low chloride permeability,

- A top surface that does not deteriorate from freeze-thaw or abrasion damage,
- Cracking that is limited to fine flexural cracks associated with the structural behavior, and
- Smooth rideability with adequate skid resistance.

All of these characteristics in a bridge deck should lead to a long service life with minimum maintenance.

CHAPTER TWO

CAST-IN-PLACE CONCRETE

Concrete in a bridge deck functions as a structural member to support live loads, provides a riding surface for traffic, and protects the steel reinforcement from corrosive attack. At the same time, concrete should not deteriorate as a result of deicer scaling, freeze-thaw damage, internal chemical attack, or abrasion damage. This chapter reports on the effects of concrete constituent materials and mix proportions on the durability of concrete and its effectiveness in protecting steel reinforcement.

CONSTITUENT MATERIALS

Early concrete production relied on the four constituent materials of cement, sand, coarse aggregate, and water. As technology improved, various types of cements, air-entraining admixtures, chemical admixtures, and mineral admixtures became available. These all helped to improve the properties of the fresh and hardened concrete but, at the same time, have made concrete production more complex. This section of the synthesis discusses the various constituent materials of today's concretes.

Cement

Cement for use in bridge decks generally conforms to one of the following specifications:

- AASHTO M85 (ASTM C150) portland cement,
- AASHTO M240 (ASTM C595) blended hydraulic cement, or
- ASTM C1157 blended hydraulic cement.

Table 1 provides a list of most cement types described in the AASHTO and ASTM international specifications. These cements are classified according to their intended application (Tennis 2001). Although there is a large variety of cement types covered by the AASHTO and ASTM specifications, all types are not readily available in all geographic areas and not all types are used or need to be used in concrete bridge decks. For example, the use of a sulfate-resistant cement is not necessary where exposure to sulfates is not a concern. According to responses to the questionnaire for this synthesis, cement Types I, II, and IP were allowed by more than 50% of the 45 respondents, with Types III, IS, and I(SM) allowed by more than 20% of the respondents. Other cement types were allowed by less than 20% of the respondents.

Responses to a Michigan DOT survey indicated that 52% of the 31 responding states use a cement content of 390 kg/m^3 (658 lb/yd^3) and 32% use 335 kg/m^3 (564 lb/yd^3) (Aktan and Fu 2003). Responses to the survey questionnaire for this synthesis showed that 28 or 62% of the 45 respondents use a minimum cementitious materials content to provide a low-permeability concrete. Values ranged from 307 to 421 kg/m^3 (517 to 710 lb/yd^3) for conventional CIP decks. Twenty-nine or 64% of the respondents indicated that they use a minimum cement content. In most cases, cement content is specified in terms of quantity per unit volume, although some respondents specify a minimum percentage of the total cementitious materials.

TABLE 1
APPLICATIONS FOR CEMENT TYPES (Tennis 2001)

Cement Specification	General Purpose	Moderate Heat of Hydration	High Early Strength	Low Heat of Hydration	Moderate Sulfate Resistance	High Sulfate Resistance	Resistance to Alkali-Silica Reactivity[a]
AASHTO M85 (ASTM C150)	I	II (moderate heat option)	III	IV	II	V	Low alkali option
AASHTO M240 (ASTM C595)	IS IP I(PM) I(SM) P	IS(MH) IP(MH) I(PM)(MH) I(SM)(MH)	—	P(LH)	IS(MS) IP(MS) P(MS) I(PM)(MS) I(SM)(MS)	—	Low reactivity option
ASTM C1157[b]	GU	MH	HE	LH	MS	HS	Option R

Notes: For purposes of this table, the AASHTO and ASTM specifications are considered equivalent. — = not applicable.

[a] The option for low reactivity with aggregates can be applied to any cement type in the columns to the left.

[b] ASTM C1157 is a specification giving performance requirements.

Fly Ash and Raw or Calcined Natural Pozzolans

AASHTO specification M295 lists three classes of mineral admixtures:

- Class N raw or calcined natural pozzolans,
- Class F fly ash, and
- Class C fly ash.

Class F fly ash has pozzolanic properties. Class C fly ash has some cementitious properties in addition to pozzolanic properties. Selection of a particular fly ash depends on its local availability and its effect on concrete properties. Questionnaire responses for this synthesis indicated that 32 or 71% of the 45 respondents allowed Class F fly ash and 24 or 53% allowed Class C fly ash.

The benefits of using fly ash on the properties of the fresh concrete are reduced water demand, increased cohesiveness, improved pumpability, reduced segregation, reduced heat of hydration, and improved finishability (“Benefits of Fly Ash in HPC” 2002). The benefits to the hardened concrete properties occur as a result of the pozzolanic reaction and include reduced permeability, reduced chloride diffusivity, and increased resistivity. Fly ash also helps increase resistance to alkali-silica reactivity and sulfate attack while contributing to long-term strength gain (“Benefits of Fly Ash in HPC” 2002). The 2002 survey for the Michigan DOT indicated that 26 or 84% of the 31 responding states were using fly ash in deck concrete, with amounts ranging from 15% to 35% of the total cementitious materials (Aktan and Fu 2003). Responses to the questionnaire for this synthesis indicated that 20 or 44% of the 45 respondents use fly ash, with specified amounts ranging from minimums of 0% to 25% and maximums of 10% to 35% by weight of the total cementitious materials.

Silica Fume

Silica fume is specified according to AASHTO specification M307. In the lime-rich environment of a portland cement system, silica fume quickly forms calcium silicate hydrate (Whiting and Detwiler 1998). The hydrate fills the interstitial spaces between the cement paste matrix and aggregate particles, resulting in a dense, strong, and relatively impermeable material.

Silica fume is used in relatively small amounts (5% to 10% of the total cementitious materials) to enhance the properties of fresh and hardened concrete. The primary use of silica fume in concrete bridge decks has been to reduce the permeability to chloride penetration. According to Whiting and Detwiler (1998), chloride diffusivity may be reduced by a factor of three or more over conventional concrete not containing silica fume. Most of the reduction occurs as silica fume content is increased from zero to the 6% to 8% range of the total cementitious materials. Further additions of silica fume provide little additional benefit.

Silica fume was first used in concrete bridge decks in Scandinavia beginning in the 1970s, with the first reported use in the United States as an overlay in Ohio in 1984 (Luther 1988). By 1991, its use was reported by 30 state highway agencies (Luther 1993). Responses to the Michigan DOT survey indicated that in 2000 15 or 48% of the 31 responding states used silica fume, with amounts ranging from 5% to 10% of the total cementitious materials (Aktan and Fu 2003). Responses to the questionnaire for this synthesis indicated that 19 or 42% of the respondents use silica fume, with specified amounts ranging from minimums of 3% to 7.5% and maximums of 5% to 12% of the total cementitious materials. Some states specify a minimum quantity of silica fume, with values ranging from 15 to 31 kg/m^3 (25 to 52 lb/yd^3).

A study undertaken in Kansas by Miller and Darwin (2000) compared the performance of 16 concrete bridge decks with conventional high-density concrete overlays to that of 20 concrete bridge decks with silica fume overlays. The study found that decks with silica fume overlays had lower chloride ion penetrability than conventional concrete decks when measured using the rapid chloride permeability test (AASHTO T277). However, the diffusion coefficients for the two different types of decks were similar at ages of between 500 and 1,500 days. This apparent contradiction is explained by Pfeifer et al. (1994), who showed that mineral admixtures have a much greater effect on reducing the coulomb reading than in reducing the permeability of concrete to chloride penetration. Chloride content taken at crack locations at depths just above and below the transverse reinforcement exceeded the corrosion threshold level in as little as 1,000 days, regardless of bridge deck type. Increased paste contents in bridge subdecks resulted in cracking in decks with overlays, regardless of the quality of the overlay. Increasing cement content or compressive strength was not beneficial in improving cracking performance.

Although the use of silica fume can reduce the permeability by a significant amount, the compressive strength of the concrete will also be increased, particularly at early ages. This results in a higher value for the modulus of elasticity and reduced creep. These latter two properties may contribute to the cracking that has been observed on bridge decks made with concrete containing silica fume (Krauss and Rogalla 1996).

The water demand of concrete containing silica fume increases with increasing amounts of silica fume because of the high surface area of the silica fume. Consequently, silica fume is generally used in combination with a high-range, water-reducing admixture. Because silica fume concrete does not bleed, there are no capillary channels left after the bleed water evaporates. This allows for earlier finishing and curing, but requires that the concrete be protected to prevent plastic shrinkage cracking during placing and finishing (Holland 2001).

Ground-Granulated Blast Furnace Slag

Ground-granulated blast furnace slag (GGBFS) is a hydraulic cement that works synergistically with portland cement to increase concrete strength and improve durability. GGBFS should conform to AASHTO specification M302. Blended cements containing GGBFS should conform to AASHTO M240 or ASTM C1157. GGBFS is used in bridge deck concrete to reduce permeability. The chloride permeability decreases as the percentage of GGBFS increases. GGBFS improves the workability, placeability, and consolidation of concrete, resulting in easier and better finishing of the deck surface. On the other hand, strength gain of the concrete is slower during the first 7 days, but the strength is greater than that of comparable portland cement concrete by 28 days (Prusinski 2002). Because the strength gain is slower at early ages, drying shrinkage stresses can cause cracking if the concrete is not properly cured.

Responses to the Michigan DOT survey indicated that 17 or 55% of the 31 responding states use GGBFS, with amounts ranging from 20% to 50% of the total cementitious materials (Aktan and Fu 2003). Responses to the questionnaire for this synthesis indicated that 10 or 22% of the 45 respondents use GGBFS, with specified amounts ranging from 25% to 50% of the total cementitious materials.

Aggregates and Aggregate Gradations

Aggregates for concrete bridge decks may be normal weight aggregates conforming to AASHTO specifications M6 and M80, lightweight aggregates conforming to AASHTO M195, or a combination of the two. The coarse aggregate size is generally selected to be the largest size practical under job conditions (Kosmatka et al. 2002). The maximum aggregate size depends on factors such as size and shape of the concrete member to be cast, amount and distribution of the reinforcing steel, and thickness of the deck. The use of a large aggregate size minimizes the water requirement and, at a constant water-cementitious materials ratio (w/cm), allows a lower cement content. This can be beneficial in reducing the amount of drying shrinkage and heat of hydration. Rounded aggregates require less mixing water than crushed aggregates for the same slump. In the responses to the questionnaire for this synthesis, the specified maximum size of coarse aggregate ranged from 10 to 50 mm (3/8 to 2 in.).

Krauss and Rogalla (1996) suggested that aggregates with a low modulus of elasticity, low coefficient of thermal expansion, and high thermal conductivity result in reduced shrinkage and thermal stresses. Aggregates with a higher modulus of elasticity increase the modulus of elasticity of the concrete resulting in greater restraint to drying shrinkage and thermal shortening.

The most desirable fine-aggregate grading depends on the application, paste content of the mixture, and maximum size of coarse aggregate. The amounts of fine aggregate that pass smaller size sieves (Nos. 50 and 100) affect workability, surface texture, air content, and bleeding (Kosmatka et al. 2002). It is important to have uniformity of grading from batch to batch so that bleeding and finishability are not subject to large variability (*Guide for Concrete Highway* . . . 1997).

In addition to separate gradations for coarse and fine aggregates, a combined grading may be specified. A combined grading can be used to improve the workability of concrete at given water and paste contents, minimize water and paste contents for a given workability, or improve workability and hardened properties of the concrete (Russell et al. 2003). Although combined gradings for aggregates are not generally specified, the AASHTO Subcommittee on Bridges and Structures has approved an appendix to the *AASHTO LRFD Bridge Construction Specifications* (AASHTO 1998) for combined gradings.

Chemical Admixtures

Chemical admixtures, except air-entraining admixtures, should conform to the requirements of AASHTO specification M194, which lists the following types of admixtures:

Type A—water-reducing;
Type B—retarding;
Type C—accelerating;
Type D—water-reducing and retarding;
Type E—water-reducing and accelerating;
Type F—water-reducing, high-range; and
Type G—water-reducing, high-range, and retarding.

Water-reducing admixtures have been particularly beneficial in increasing workability while maintaining a constant w/cm or maintaining workability while lowering the w/cm. This facilitates the development of a workable concrete mix for which a maximum w/cm is specified. In projects with closely spaced or congested reinforcement, the use of high-range, water-reducing admixtures help concrete flow around these obstructions without segregation.

Responses to the Michigan DOT survey indicated that most states use chemical admixtures in their bridge deck concrete (Aktan and Fu 2003). This was confirmed by responses to the questionnaire for this synthesis.

Air-Entraining Admixtures

Air entrainment is used in concrete primarily to increase the resistance of concrete to freeze-thaw damage in the presence of water and deicing chemicals. A supplemental benefit of air entrainment is that workability is improved and bleeding is reduced (Kerkhoff 2002).

Air entrainment is produced through the use of either air-entraining portland cement or air-entraining admixtures. The advantage of using an admixture is that the dosage rate can be adjusted independently of the cement content. This is particularly important in complex mixes, where interaction between different constituent materials varies from day to day. On Chicago's Wacker Drive project, it was reported that large fluctuations in air content occurred after the addition of high-range, water-reducing admixtures (Schmidt 2003). For some batches, the air content increased and in other batches it decreased.

Responses to the Michigan DOT survey indicated that nearly all states use air entrainment in their bridge deck concrete (Aktan and Fu 2003). Responses to the questionnaire for this synthesis indicated that 39 or 87% of the 45 respondents specified total air content, which includes entrained and entrapped air. All other respondents, except Hawaii, specified air-void parameters, freeze-thaw testing, or deicing scaling tests. Six of the eight respondents that specified air-void parameters were Canadian provinces.

Hardened concrete is considered to have an adequate air-void system if, when tested in accordance with ASTM C457, the spacing factor is no greater than 0.20 mm (0.008 in.), the specific surface is greater than approximately 23.6 mm^2/mm^3 (600 $in.^2/in.^3$) of air-void volume, and the number of air voids per inch of traverse is significantly greater than the numerical value of the percentage of air in concrete (*Chemical Admixtures for Concrete* 1991). Despite these known parameters, most specifications for bridge decks in the United States only specify total air content. The total air content can be misleading in that it does not guarantee an adequate air-void system. Properly air-entrained concrete needs to have closely spaced air voids that are extremely small in size (Kerkhoff 2002). The use of the air-void analyzer offers the potential for a rapid on-site determination of the air-void parameters of fresh concrete (Crawford et al. 2003).

Corrosion Inhibitors

Corrosion inhibitors are various liquid admixtures that are designed to interfere with the corrosion process. In general, corrosion inhibitors raise the chloride threshold at which corrosion starts and slow the rate of corrosion after it begins (Gaidis and Rosenberg 2002). Although some corrosion inhibitors have been available for more than 20 years, their use in bridge decks is relatively recent. The addition of a corrosion inhibitor to a concrete mix can affect the properties of the fresh and hardened concrete. Responses to the questionnaire for this synthesis indicated that only a few respondents specified a corrosion inhibitor. Sufficient time has not elapsed to enable an assessment of the effect of corrosion inhibitors on long-term concrete bridge deck performance.

WATER-CEMENTITIOUS MATERIALS RATIO

The water-cementitious materials ratio (w/cm) is the mass of water, not including that absorbed by the aggregate, divided by the mass of total cementitious materials. With the increased use of supplementary cementitious materials, the terminology of w/cm is replacing the traditional terminology of water–cement ratio. However, some specifications use the terms synonymously. The w/cm is generally selected for concrete mix design as the lowest value to satisfy the exposure condition or specified compressive strength. As the w/cm decreases for a given combination of materials, the permeability of the concrete decreases and the compressive strength increases. This has led to the misleading concept that a high-strength concrete is always a durable concrete. A high-strength concrete will generally have a low permeability. However, the use of a high-strength concrete for durability in bridge decks is not beneficial, because it is not economical and leads to increased cracking. Hence, specifying a low w/cm as the only means to obtain a low-permeability concrete is not appropriate.

In *NCHRP Synthesis of Highway Practice 57* (1979), it was reported that many states had modified their specifications in the previous 2 years to reduce the maximum permissible water–cement ratio of concrete. A 1977 survey of current practices of state highway departments indicated that the maximum water–cement ratios ranged from a high of 0.53 to a low of 0.40, with a value of 0.44 being used by 21 of 48 states reporting values.

In *NCHRP Report 297* (Babaie and Hawkins 1987), it was concluded that for salt exposures greater than 6 Mg per lane-kilometer per year (10 tons per lane-mile per year) the specified maximum water–cement ratio must be 0.42 or less if the effective service life is to be 50 years. With salt applications of 17 to 25 Mg per lane-kilometer per year (30 to 45 tons per lane-mile per year), the effective service period even for a specified water–cement ratio of 0.42 may be 10 to 15 years. The same report indicated that in 1987 80% of the transportation departments were specifying a maximum water–cement ratio of 0.45. Responses to the questionnaire for this synthesis indicated that 42 or 93% of the respondents specify a maximum w/cm ranging from 0.32 to 0.53, with approximately half of the respondents using values of 0.40 to 0.45.

A 1995 scanning tour reported that concrete mixes in Europe were designed with prime considerations given to durability and not strength. In France, water–cement ratios of 0.40 to 0.45 were commonly used and ratios as low as 0.35 were being contemplated with the use of plasticizers (*NCHRP Report 381* 1996).

CONCRETE COMPRESSIVE STRENGTH

In *NCHRP Synthesis of Highway Practice 57* (1999), it was reported that, for many years, an attitude had prevailed that if the requirements for the specified concrete compressive strengths were satisfied, the deck would perform adequately. This was evident in specifications that were written for strength and did not address durability performance. This same attitude was again evident in the 1990s with the introduction of high-performance concrete (HPC). Russell et al. (2003) reported values of specified compressive strengths for bridge decks that ranged from 28 to 55 MPa (4,000 to 8,000 psi). Most strengths were specified at 28 days, although some states used 56 days. One deck had a measured compressive strength greater than 70 MPa (10,000 psi) at 56 days.

A misconception that has developed is that all HPC is a high-strength concrete. Most definitions of HPC include multiple performance criteria of which high compressive strength is only one (Russell 1999). For example, the American Concrete Institute lists 10 possible characteristics for HPC and the FHWA quantifies 8 (Goodspeed et al. 1996). Consequently, by definition, all HPC is not high-strength concrete and experience has shown that the use of high-strength concrete does not necessarily lead to a highly durable concrete. Conversely, a highly durable concrete is not necessarily a high-strength concrete.

Research and practice have shown that design for durability involves more than specifying a compressive strength. With the intent of obtaining durable bridge decks, many states introduced prescriptive requirements for a minimum cement content and a maximum water–cement ratio. With the availability of supplementary cementitious materials, these terms changed to minimum cementitious materials content and a maximum w/cm. The outcome was that the mix proportions were controlled by these requirements and achievement of the compressive strength became a by-product when the specified strength was not too high. Because higher strengths were being achieved, it became acceptable to specify higher values. In the specifications for the replacement post-tensioned deck of the Wacker Drive bridge in Chicago, the specified minimum compressive strength was 41 MPa (6,000 psi) (Kaderbek et al. 2002). However, the specifications also included a maximum strength of 66 MPa (9,500 psi). For the Route 11 bridge over the Susquehanna River in Pennsylvania, minimum and maximum strengths of 27 and 43 MPa (4,000 and 6,200 psi), respectively, were specified. In the responses to the questionnaire for this synthesis, the minimum specified concrete compressive strength for bridge decks ranged from 24 to 50 MPa (3,500 to 7,250 psi).

CONCRETE PERMEABILITY

Although permeability, in general, refers to the ability of concrete to resist penetration by water or other substances, the main concern for bridge decks is the penetration of chlorides to the level of the reinforcement. The discussion in this section, therefore, focuses on chloride permeability. Various methods to measure chloride penetration have been described by Hooton et al. (2001). The traditional method in the United States is AASHTO T259—Standard Method of Test for Resistance of Concrete to Chloride Ion Penetration. This test is more commonly referred to as the salt ponding test. The disadvantage of this test is that it requires approximately 4 months to complete from the time the concrete is cast. To overcome this disadvantage, the so-called rapid chloride permeability test was developed by Whiting (1981) and adopted as AASHTO T277. This test indirectly provides a measure of chloride permeability by measuring current flow through a piece of concrete.

According to Hooton et al. (2000), the relationship between results from the rapid chloride permeability test and diffusion coefficients calculated from ponding tests is quite good for a wide variety of concretes including those containing fly ash, GGBFS, and silica fume. In contrast, Pfeifer et al. (1994) concluded that reliable and proper correlations do not exist between the rapid chloride permeability test results and the 90-day ponding test results when different studies are compared. Miller and Darwin (2000) concluded that the lower rapid chloride permeability values measured in silica fume overlays may be the result of the effect of silica fume on the pore solution of the concrete and do not, necessarily, reflect lower chloride permeability. Whiting and Mitchell (1992) cautioned that the rapid chloride permeability test should only be used for quality control for a particular set of materials. It should not be used to compare concretes made with different mineral admixtures.

Concretes containing latex, Class F fly ash, GGBFS, silica fume, or combinations of these materials generally have lower permeabilities than concretes containing only portland cement (Ozyildirim 1994). With only portland cement, it is difficult to achieve test values using AASHTO

T277 of less than 2,000 coulombs. With fly ash or GGBFS, values below 2,000 coulombs can be obtained, and with silica fume, values below 500 coulombs are possible. The rapid chloride permeability decreases with a decrease in the w/cm and with concrete age (Ozyildirim 1994; Kosmatka et al. 2002). This had led many states to test for rapid chloride permeability at a concrete age of 56 days as being more representative of the permeability of a concrete in service.

The effect of silica fume on chloride penetration was measured by Whiting and Detwiler (1998) for a range of silica fume contents and w/cms. They observed that increasing the silica fume content up to approximately 6% of the total cementitious materials reduced the chloride diffusivity. However, above approximately 6%, a much greater addition of silica fume was needed to effect the same change.

In the HPC showcase bridges, most states specified a rapid chloride permeability for the bridge deck concrete with values ranging from 1,000 to 2,500 coulombs. Measured values ranged from 200 to 5,600 coulombs (*High-Performance Concrete* 2003; Russell et al. 2003). Ozyildirim (2003) has suggested that a value of 2,000 to 2,500 coulombs at 56 days represents a good starting point for bridge deck concrete, whereas lower values may be appropriate and should be considered for harsher climates.

In the questionnaire for this synthesis, agencies were asked to identify which strategies were the most effective in providing a low-permeability concrete. The use of fly ash, silica fume, and GGBFS or combinations of these materials was listed by several agencies. A maximum w/cm and a minimum cementitious materials content were listed by some agencies as the least effective.

CONCLUSIONS ABOUT EFFECTIVENESS OF CONCRETE MATERIALS IN ENHANCING BRIDGE DECK PERFORMANCE

Concrete cover provides a barrier to protect reinforcement from corrosion. Ideally, the concrete should be uncracked and have a high resistance to chloride penetration. Resistance to chloride penetration can be achieved through the use of supplementary cementitious materials such as fly ash, silica fume, or GGBFS. It can also be achieved through the use of a lower w/cm. The latter approach may not be desirable because it may increase the likelihood of cracking in the concrete owing to the higher modulus of elasticity and lower creep. Careful selection of the concrete constituent materials can result in a concrete with a low permeability and, thereby, extend the length of time before the corrosion threshold at the level of the reinforcement is reached. On the other hand, selection of the materials should not result in concrete that has an increased tendency for plastic shrinkage cracks, settlement cracks, or drying shrinkage cracks. The presence of these cracks offsets the benefits of the lower-permeability concrete.

Further research on the use of supplementary cementitious materials to enhance the durability of concrete bridge decks is underway as NCHRP Project No. 18-08A. The objective of the research is to develop a methodology for designing hydraulic cement concrete mixtures incorporating supplementary cementitious materials that will enhance durability of CIP concrete decks.

The following materials and criteria have been identified as beneficial in enhancing the performance of concrete bridge decks:

- Types I, II, and IP cements;
- Fly ash up to 35% of the total cementitious materials content;
- Silica fume up to 8% of the total cementitious materials content;
- GGBFS up to 50% of the total cementitious materials content;
- Aggregates with low modulus of elasticity, low coefficient of thermal expansion, and high thermal conductivity;
- Largest size aggregate that can be properly placed;
- Water-reducing and high-range, water-reducing admixtures;
- Air-void system with a spacing factor no greater than 0.20 mm (0.008 in.), specific surface area greater than 23.6 mm^2/mm^3 (600 $in.^2/in.^3$) of air-void volume, and number of air voids per inch of traverse significantly greater than the numerical value of the percentage of air;
- Water-cementitious materials ratio in the range of 0.40 to 0.45;
- Concrete compressive strength in the range of 28 to 41 MPa (4,000 to 6,000 psi); and
- Concrete permeability per AASHTO T277 in the range of 1,500 to 2,500 coulombs.

CHAPTER THREE

REINFORCEMENT MATERIALS

Until the 1960s, reinforced concrete bridges performed reasonably well, with delaminations and spalling caused by corrosion limited to structures exposed to salt in coastal areas. With the increased use of deicing salts in the 1960s, the amount of corrosion began to increase. By the 1970s, it was recognized that spalling was caused by corrosion of the reinforcing steel from the ingress of chloride ions from deicing salts. It is now generally accepted that corrosion of reinforcement begins when the chloride content at the level of the reinforcing steel reaches 0.6 to 0.9 kg/m^3 (1.0 to 1.5 lb/yd^3). As a means of reducing or preventing corrosion of reinforcement, the reinforcement may be coated or a noncorrosive material may be used. This chapter summarizes the different reinforcement systems that have been used as alternatives to noncoated reinforcement.

EPOXY-COATED REINFORCEMENT

The first installation of epoxy-coated bars in a bridge deck was in 1973 on a bridge near Philadelphia, Pennsylvania (Kilareski 1997). By the fall of 1977, 17 states had adopted the use of epoxy-coated bars as a standard construction procedure in some structures and nine others had installed coated bars on an experimental basis. The main difficulties at that time were damage to the coating during transportation and handling and cracking of the coating as a result of inadequate preparation of the bar or bending of the bar after coating (*NCHRP Synthesis of Highway Practice 57* 1979). New methods such as bending the bars before coating, increasing the number of supports during shipping, padding the bundles, and using nylon slings for loading and unloading were developed in an attempt to overcome these problems (Virmani and Clemena 1998). Most specifications for the use of epoxy-coated bars required that all damage or exposed areas be patched with an approved liquid epoxy repair material before concreting (*NCHRP Synthesis of Highway Practice 57* 1979).

According to a 1977 survey, 20 of 37 responding states reported that the preferred protective system for new deck construction was epoxy-coated bars (*NCHRP Synthesis of Highway Practice 57* 1979). The simplicity of concept, ease of implementation, and existence of specifications and approved products were listed as reasons for the popularity and widespread use. In 1987, Babaie and Hawkins reported that 41 state DOTs were using epoxy-coated reinforcement for reinforced concrete decks built without overlays. They also reported that using epoxy-coated bars for the top layer of reinforcement, combined with a limit of 0.45 for the water–cement ratio and 64 mm (2.5 in.) of cover over the reinforcement promised to provide 50 years of corrosion-free life even in severe chloride environments. Responses to the Michigan DOT survey in 2002 indicated that 26 or 84% of the 31 responding states used epoxy-coated reinforcement as their most common type of reinforcement in bridge decks (Aktan and Fu 2003). Responses to the questionnaire conducted for this synthesis identified that 38 or 84% of the 45 respondents use epoxy-coated reinforcement as a strategy to prevent corrosion of reinforcement. Thirty-two or 71% of respondents specified epoxy-coated reinforcement for the top and bottom layers of reinforcement and 5 or 11% of respondents specified it for the top layer only. Nineteen or 42% of respondents specified epoxy-coated reinforcement for the reinforcement that projects from the girder into the deck. All respondents except one stated that Grade 60 reinforcement is used.

In the 1970s, epoxy-coated bars were only used in the top layer of reinforcement (Virmani and Clemena 1998; Kepler et al. 2000). Based on test data, Virmani and Clemena (1998) estimated that, if it required 1 year to consume a given amount of uncoated reinforcement, then 12 years would be required to consume the same amount of coated reinforcement when the epoxy-coated reinforcement was used only in the top layer of reinforcement. Forty-six years would be required if the coated reinforcement was used in both top and bottom layers. Data from field investigations have indicated that better corrosion performance is obtained when epoxy-coated reinforcement is used in both layers of reinforcement than when it is used in the top layer only (Smith and Virmani 1998). Most states now recognize the importance of using epoxy-coated reinforcement in both layers of deck reinforcement, but not for the girder reinforcement that protrudes into the deck.

In 1976, three bridge decks were constructed in Michigan using epoxy-coated, galvanized, and noncoated steel reinforcement in adjacent spans. In 1991, these decks were evaluated along with nine newer decks built between 1977 and 1982 with epoxy-coated reinforcement. Cores indicated that the epoxy-coated reinforcement was in the best condition of the three bar types, especially in cores taken near cracks in the concrete (McCrum and Arnold 1993).

In 1979, the Florida DOT began construction of a series of bridges in the Florida Keys using epoxy-coated reinforcement. For the next 6 to 13 years, each of the five major bridges began to show signs of corrosion in the splash zone of piers. Upon examination, the coatings were observed to have disbonded from the reinforcement (Manning 1996).

In 1996, the condition of epoxy-coated reinforcement taken from 18 bridge decks constructed between 1977 and 1995 in Virginia was evaluated by Pyc et al. (2000). The study concluded that, although the reinforcement appeared to be in good condition, the loss of adhesion was a matter of concern for the long-term performance of epoxy-coated reinforcement in concrete. Ninety-four percent of the sample size showed evidence of adhesion reduction, including some complete coating disbondment. The reduction of adhesion was attributed to water penetrating the coating and accumulating at the metal-to-coating interface, water peeling stress exceeding the coating adhesive bond strength, and oxidation at the steel interface. Kepler et al. (2000) reported that other studies have found that reinforcement in concrete with high moisture contents suffers reduced adhesion of the coating (Schiessl 1992; Smith and Virmani 1996; Weyers et al. 1997).

Thirteen bridge decks with epoxy-coated reinforcement and ages ranging from 9 to 13 years were evaluated by Kenneth C. Clear Inc. (Kepler et al. 2000). The bridges were located in New York, Ohio, Pennsylvania, Virginia, and Wisconsin, and had been exposed to freeze-thaw cycles and deicing salts. The average cover over the top mat of reinforcement was 64 mm (2.5 in.) and the chloride ion concentration at the level of the reinforcement had reached the accepted threshold level for corrosion in about one-half of the bridges. Kenneth C. Clear Inc., reported that 87% of the top layer of epoxy-coated reinforcement was free of corrosion and that all the bars exhibiting significant corrosion came from cores with cracks that extended to the level of the reinforcement.

Smith and Virmani (1996) reported on the performance of epoxy-coated reinforcement used on 92 bridge decks and 3 barrier walls in 11 states and 3 Canadian provinces. The epoxy-coated reinforcement had been in service for up to 20 years. Eighty-one percent of the 202 epoxy-coated reinforcement samples that were extracted from the bridge decks exhibited no signs of corrosion, although the chloride concentration in the concrete at the level of the bars was above the threshold level for corrosion in most of the decks. Corrosion was worse in locations with cracking, less cover, high-permeability concrete, and/or high chloride concentrations.

Detailed inspections of three bridge decks in Indiana were reported by Samples and Ramirez (2000b). The bridges were constructed in 1976 and 1980 and contained epoxy-coated reinforcement with a design clear cover of 64 mm (2.5 in.). For all three bridges, the reported level of chlorides at the depth of the top reinforcement mat exceeded the estimated level for initiation of corrosion. None of the bridge decks showed visible signs of distress. Two of nine cores removed from the decks showed evidence of corrosion of the epoxy-coated reinforcement. The coating was easy to remove and underfilm corrosion was observed. The coating was debonded in a third core, but no corrosion of the reinforcement was observed. The authors concluded that, over the past 23 years, the use of epoxy-coated reinforcement with 64 mm (2.5 in.) of good quality concrete has clearly outperformed all other methods of corrosion protection used in Indiana.

Samples and Ramirez (2000a) also reported on field investigations of new bridge deck construction using epoxy-coated reinforcement. They found that epoxy-coated bars had an average of 40 defects per meter (12 defects per foot) after casting and most of the defects were created when concrete was placed with a pump. They also found that increasing the thickness of the epoxy coating reduced the number of defects.

Based on their literature review, Kepler et al. (2000) concluded the following:

- Epoxy coatings lose their adhesion to steel reinforcement when exposed to moisture.
- Most reported problems with epoxy-coated reinforcement occur in environments where the concrete is continuously wet and oxygen is available.
- Time to corrosion-induced cracking is increased in many concrete structures when epoxy-coated reinforcement is used.

METALLIC COATINGS

Various types of metallic coatings have been considered for the protection of reinforcement in concrete, including zinc (galvanized), stainless steel, nickel, and copper.

In 1983–1984, the New Jersey DOT constructed a bridge deck with stainless clad reinforcement. The bridge deck also used a 25 to 37-mm (1 to 1.5-in.)-thick latex-modified concrete overlay. McDonald et al. (1995) reported that nine stainless clad samples of reinforcement from four concrete cores had no corrosion except where a plastic cap covered one end of a bar. However, the chloride content at the level of the reinforcement did not exceed the threshold level for corrosion.

In 2000, the Ontario Ministry of Transportation used Grade 316L stainless steel clad reinforcement in a bridge deck as an innovative technology demonstration project (Pianca 2000). The purpose was to examine the viability of the stainless steel clad reinforcement on a large scale under normal construction practices. Inspection of the bars on delivery resulted in approximately 20% being rejected. An initial condition survey per ASTM C876, approximately 5 months after concrete placement in April 2000, indicated that the reinforcement had an average potential of –0.09V and a standard deviation of –0.03V. This means that there was a 90% probability that no reinforcing steel corrosion was occurring at the time and location of the measurements. No work has proceeded beyond one trial structure.

Kahrs et al. (2001) reported on corrosion potential tests and macrocell corrosion tests of a prototype 304 stainless steel clad reinforcing bar. Laboratory test results were compared with results from conventional reinforcing bars. The results indicated that the prototype reinforcement exhibited superior corrosion resistance compared with the conventional reinforcement, but required adequate protection at cut ends where the steel core was not covered by the cladding. Long-term tests of the reinforcement and its use in a demonstration bridge deck were recommended.

Ten respondents to the questionnaire for this synthesis indicated that they had used zinc-coated reinforcement. Iowa reported that two bridges were constructed in 1967 with galvanized reinforcement. Some corrosion occurred below cracks; otherwise, the performance was acceptable. New York reported that zinc-coated reinforcement had caused some scaling of the concrete surface owing to the formation of hydrogen gas bubbles, which were trapped under the concrete surface. South Carolina, Quebec, and Saskatchewan reported good performance. Nine respondents indicated that they had used stainless steel clad reinforcement. In most cases, the application was too new to provide any data about long-term performance.

Based on limited available information about the use of reinforcement with metallic coatings, no general conclusions or recommendations about its effect on long-term bridge deck performance can be made.

STAINLESS STEEL REINFORCEMENT

The advantage of solid stainless steel bars is that they can be shipped, handled, and bent without fear of damage to the coating. In addition, the ends do not have to be coated after cutting. In 1984, stainless steel reinforcing bars were installed in part of a bridge deck north of Detroit, Michigan. In 1993, the deck was inspected and cores taken. Two cores had cracks that intercepted the reinforcing bars; however, no evidence of corrosion was found. The chloride ion concentration had approached the corrosion threshold for uncoated steel (McDonald et al. 1995).

McDonald et al. (1995) reported the results of a study comparing the costs of three bridge projects in Illinois using different types of reinforcement. The on-site cost of the stainless steel reinforcement was approximately six times that of the conventional reinforcement. The increase to the overall project cost ranged from 6% to 16%. Darwin et al. (2002) also compared the costs of different types of reinforcement in a 45.7-m (150-ft) long, 11.0-m (36-ft) wide, 215-mm (8.5-in.) thick deck. They reported an initial cost of \$185/m^2 (\$154/yd^2) of deck area for stainless steel versus \$134/m^2 (\$112/yd^2) for conventional reinforcement. However, based on total costs over 75 years, the stainless steel reinforcement was more economical.

Responses to the questionnaire for this synthesis showed that nine respondents had used stainless steel reinforcement. In most cases, the application was too new to have any data about long-term performance. Ontario indicated that there was no corrosion activity to date. Two respondents expressed concern about the high cost of installed reinforcement, but no data were provided.

FIBER-REINFORCED POLYMER REINFORCEMENT

Fiber-reinforced polymer (FRP) reinforcement consists of a continuous fiber, such as glass, aramid, or carbon, embedded in a resin material. The advantage of this reinforcement is that it does not corrode like steel reinforcement. However, it may be susceptible to other forms of deterioration (*State-of-the-Art Report on Fiber . . .* 1996).

The early use of FRPs in reinforcement in highway and pedestrian bridges built in Europe, Japan, and Canada was reported by Khalifa et al. (1993) and Erki and Rizkalla (1993). The first bridge built in the United States using FRP reinforcement in the concrete deck was in Virginia in 1996. The bridge used glass FRP bars as deck reinforcement (Thippeswamy et al. 1998).

NCHRP Project 10-55 concluded that the use of FRP composites as internal reinforcement for concrete bridge decks provides a potential for increased service life and economic and environmental benefits. However, current standards and test methods do not account for the properties of FRP composite reinforcement and their relationship to performance. As part of the research, limited data were obtained from bridge decks in Quebec and West Virginia (*NCHRP Research Results Digest 282* 2003).

Several other states and provinces have begun using FRP in bridge decks on an experimental basis. These include New Hampshire (Goodspeed et al. 2002), Ohio (Eitel and Huckelbridge 2000), Manitoba (Rizkalla et al. 1998), Quebec (Tadros 2000), and Calgary (Tadros 2000). Because these applications are relatively new, the long-term performance of the bridge decks is unknown.

Responses to the questionnaire for this synthesis indicated that 10 respondents had used FRP reinforcement. Idaho used it in a latex-modified concrete overlay and performance to date has been satisfactory. New Hampshire reported that their deck has performed well for 3 years. Quebec reported applications on five decks with no problems observed to date. All other applications were too new to have data about long-term performance.

OTHER SYSTEMS

Balma et al. (2002) evaluated the corrosion resistance of three microalloyed steels and two conventional steels. The microalloyed steels contained concentrations of chromium, copper, and phosphorus higher than that used in conventional reinforcing steel. One of the conventional steels and the three microalloyed steels were quenched and tempered immediately after rolling, whereas the other conventional steel was hot rolled. The steels were tested in the laboratory using the corrosion potential test, corrosion macrocell test, southern exposure test, cracked beam test, and the ASTM C109 test. Although the steels showed improved corrosion-resistant performance compared with conventional steel, the improvement was judged to be insufficient to warrant further research.

In recent years, there has been interest in a microcomposite steel known as MMFX. This steel has a high-chromium and low-carbon content and may have enhanced corrosion resistance in comparison with conventional reinforcement. Bridge decks with MMFX reinforcement have been constructed in at least eight states and one Canadian province.

When tested using the pending Accelerated Chloride Threshold test procedure, the reinforcement had a critical chloride threshold level of approximately 5.3 kg/m^3 (9 lb/yd^3) compared with approximately 0.9 kg/m^3 (1.5 lb/yd^3) for conventional reinforcement (Trejo 2002). Darwin et al. (2001) and Gong et al. (2002) compared the performance of MMFX and conventional reinforcement based on the macrocell test, Southern Exposure test, and cracked beam test. The results indicated that the corrosion threshold of MMFX reinforcement was approximately four times higher than that of conventional reinforcement and that it has a corrosion rate of between one-third and two-thirds that of conventional reinforcement. However, the corrosion resistance was less than that of epoxy-coated reinforcement.

CONCLUSIONS ABOUT EFFECTIVENESS OF REINFORCEMENT MATERIALS IN ENHANCING BRIDGE DECK PERFORMANCE

Epoxy-coated reinforcement continues to be the most effective reinforcement used to reduce the potential for deterioration of concrete bridge decks from reinforcement corrosion. The use of epoxy-coated reinforcement in both layers of deck reinforcement provides better corrosion performance than when it is used in the top layer only. However, epoxy-coated reinforcement cannot be relied on to never corrode in a wet or chloride environment. Other reinforcement materials offer the potential as alternative reinforcement materials; however, none of these have been extensively used in practice to develop any general conclusions about their performance in actual bridges.

CHAPTER FOUR

BRIDGE DECK PROTECTIVE SYSTEMS

This chapter deals with systems that are designed to protect the primary concrete and reinforcement from conditions that will cause their deterioration. The primary systems are overlays, membranes, sealers, and cathodic protection. In responses to the synthesis questionnaire, 24 or 53% of the 45 respondents had used overlays, 17 or 38% had used membranes, 19 or 42% had used sealers, and 24 or 53% had used cathodic protection. A brief description of each system, how it has been used, and lessons learned is included in this chapter.

OVERLAYS

The purpose of an overlay is to create a protective barrier over a concrete deck. Overlays may consist of asphalt, latex-modified concrete, low-slump dense concrete, silica fume concrete, or polymer concrete. The overwhelming number of concrete overlays in 1979 consisted of low-slump, dense concrete; polymer-modified concrete; or internally sealed concrete (*NCHRP Synthesis of Highway Practice 57* 1979). Initially, overlays were no more than 32 mm (1.25 in.) thick (Bergren and Brown 1975); however, later a nominal thickness of 50 mm (2 in.) was specified. By 1977, approximately 600 concrete overlays had been constructed on primary and Interstate bridges in Iowa. Nineteen other states had installed low-slump concrete overlays, and many had adopted their use as a routine procedure. Generally, good performance was reported (Bergren and Brown 1975; Tracy 1976; Manning and Owens 1977).

In the questionnaire for this synthesis, each agency was asked to identify which overlay systems they have used in the past and which they currently use. They were also asked to rate the system's performance on a scale of 1 to 5, where 1 = excellent and 5 = poor. A summary of the results is given in Table 2.

Based on the data, it may be concluded that the use of asphalt, latex-modified concrete, and low-slump dense concrete overlays has decreased and the use of fly ash and silica fume concrete overlays has increased. With the exception of fly ash and silica fume overlays, all overlays had ratings of 1 or excellent to 5 or poor. The average rating of all overlays was between 2.0 and 2.8 except for asphalt, which was slightly worse in its performance rating.

Latex-Modified Overlays

Latex-modified concrete consists of a conventional portland cement concrete supplemented by a polymeric latex emulsion. The use of latex-modified concrete overlays was reported previously to be more widespread than low-slump concrete overlays; a number of states preferring the system because of its ease of application. Nightime placement of a latex-modified overlay is illustrated in Figure 4.

By the end of 1977, 24 states had installed latex-modified concrete overlays, although most were less than 5 years old. Numerous cracks, which developed shortly after placing, were reported to have been observed (Westall 1960, Steele and Judy 1977). In Iowa, three latex-modified concrete overlays that were 5 years old were inspected in 1978 and no evidence of surface distress in the overlays was reported (Brown 1979). In Minnesota, the condition of eight latex-modified concrete overlays with ages ranging

TABLE 2
USE OF OVERLAY SYSTEMS

Overlay	No. of Respondents[a] Past	Current	Performance Rating[b] Range	Average
None	6	5	—	—
Asphalt[c]	28	16	1 to 5	3.6
Latex-Modified Concrete	26	20	1 to 5	2.4
Low-Slump Dense Concrete	26	12	1 to 5	2.4
Fly Ash Concrete	4	11	2 to 4	2.4
Silica Fume Concrete	10	21	1 to 3	2.0
Epoxy	11	11	1 to 5	2.6
Polyester	4	2	1 to 5	2.5
Other	5	4	1 to 5	2.8

[a] Total number of survey respondents = 45.
[b] 1 = excellent, 5 = poor, — = not applicable.
[c] Asphalt without a membrane.

FIGURE 4 Placement of a latex-modified overlay.

from 6 to 9 years was reported by Hagen (1982). Three overlays showed signs of scaling over approximately 1% of the surface area. Bishara (1979), in an investigation of 47 bridges in Ohio, 57 in Michigan, 17 in Kentucky, and 11 in West Virginia, reported that the overlays with ages of between 1 and 13 years provided adequate freeze-thaw resistance and virtually no scaling. In Virginia, Sprinkel (1992) reported that the use of latex-modified concrete overlays placed on decks with less than 1.2 kg/m^3 (2 lb/yd^3) of chloride ion at the reinforcement level can be expected to have a service life of more than 20 years.

Low-Slump Dense Concrete Overlays

Low-slump dense concrete overlays are produced using a concrete with a cement content as high as 470 kg/m^3 (800 lb/yd^3) and a w/cm as low as 0.30. These overlays were first placed in the 1960s in Iowa and Kansas. An evaluation of 15 low-slump dense concrete overlays in Iowa in 1978 revealed no evidence of surface distress. The overlays were 5 to 13 years old (Brown 1979). In Minnesota, an evaluation of 31 overlays, with ages ranging from 4 to 6 years, indicated that 39% did not show any signs of scaling, 45% showed scaling over less than 1% of the deck area, and 16% showed scaling over 1% to 4% of the deck area (Hagen 1982). The first low-slump concrete overlay in Iowa lasted 23 years (Kepler et al. 2000). Later overlays are still in place after more than 25 years. During 1999, more than 38,000 m^3 (45,000 yd^3) of dense concrete overlay were placed in Iowa.

In 1985, surface defects, delaminations, half-cell potentials, and chloride concentrations were examined on 50 randomly selected bridges in New York State on which low-slump concrete overlays had been placed from 1979 to 1981 (Chamberlin 1988). Physical damage that could potentially have been caused by corrosion, delaminations, spalls, or patches was found on 60% of the bridges and affected 0.84% of the total deck area of the study. All of the spalling and almost one-half of the damage was around joints, which did not reflect the integrity of the overlays. The service life of these overlays was estimated to be 25 years.

In 1991, 152 bridge decks with latex-modified concrete overlays and 153 bridge decks with low-slump dense concrete overlays were evaluated as part of a Strategic Highway Research Program project (Weyers et al. 1991). The study reported that the performance of the overlays was less dependent on the type of overlay than on the methods used to prepare the deck. Both overlay types performed best when concrete was removed from areas that had half-cell potentials more negative than –350 mV, when concrete was removed to below the reinforcement, and when the exposed surface was sandblasted. In these procedures, both latex-modified overlays and low-slump dense concrete overlays were estimated to have a potential service life of 30 to 50 years (Chamberlin and Weyers 1994).

Silica Fume Concrete Overlays

Three silica fume concrete overlays were placed on bridge decks in Virginia between 1987 and 1991 to evaluate the properties of silica fume concrete overlays and to determine the minimum amount of silica fume needed to reduce the permeability of the decks to chloride ion penetration (Ozyildirim 1992). The study concluded that the addition of 7% silica fume with a maximum w/cm of 0.40 is expected to achieve permeabilities comparable to latex-modified concrete. In addition, silica fume could be used effectively in thin overlays for bridge desks; however, plastic shrinkage cracking was a concern and proper placing and curing procedures needed to be followed.

A study of silica fume overlays and conventional concrete overlays on bridges in Kansas concluded that decks of the same age range of 1.5 to 4 years had similar crack densities. Similar chloride contents at the depth of the reinforcement were measured both at and away from crack locations (Miller and Darwin 2000). Chloride contents were above the threshold level for corrosion in as little as 1,000 days for both overlay types.

Polymer Concrete Overlays

Polymer concrete is concrete in which the portland cement is replaced by a polymer. Overlays made with polymer concrete are generally less than 13 mm (0.5 in.) thick. In 1990, the Missouri DOT began using epoxy–polymer overlays to rehabilitate bridge decks. The overlays consisted of a thin two-part epoxy with aggregate filler and a minimum thickness of 6 mm (0.25 in.) (Kepler et al. 2000). A number of different materials for polymer concrete overlays were investigated in the late 1970s and early 1980s, but most have since been discontinued (Kepler et al. 2000). However, new materials are available that are being tried by several states, including California and Nevada, which use only polyester concrete in overlays.

Internally Sealed Concrete Overlay

Internally sealed concrete involves adding fusible polymeric particles to a concrete mix and then applying heat that causes the additive to flow into the micropore structure to seal the concrete against the ingress of moisture and chemicals. The polymeric particles generally consisted of wax beads. The first internally sealed concrete overlay was placed in Oklahoma in 1976. By the end of 1978, a total of 14 internally sealed concrete overlays had been constructed on new decks and were considered experimental (*NCHRP Synthesis of Highway Practice 57* 1979). Although some laboratory testing and field demonstrations showed that internally sealed concrete overlays were technically feasible, the economic feasibility and practicability remained doubtful (*NCHRP Synthesis of Highway Practice 57* 1979). Other laboratory tests showed that the wax deformed under load causing the permeability to increase. The use of internally sealed concrete appears to have been discontinued.

MEMBRANES

A membrane is a barrier placed on top of the concrete and then protected by another material that functions as the riding surface. *NCHRP Synthesis of Highway Practice 4* (1970) reported that the use of an impermeable interlayer membrane had won favor throughout the country. Maine, Massachusetts, New Hampshire, and Rhode Island were specifying an interlayer on all important bridges. California, Illinois, Michigan, Ohio, and Tennessee were specifying membranes on selected bridges.

In 1977, only 19% of the respondents to a survey indicated that membranes were the preferred protective system on new decks and only 11% selected membranes as one of the first three options for deck repair (Manning 1995). By 1986, the popularity of membranes for use on new decks had dropped slightly. In the questionnaire for this synthesis, each agency was asked to identify which waterproofing membrane system they had used in the past and which they currently use. They were also asked to rate the system's performance on a scale of 1 to 5, where 1 = excellent and 5 = poor. A summary of the results is given in Table 3. Based on these data, it may be concluded that the only major changes in the use of membranes have been a reduction in the use of asphalt-impregnated fabric and polymer sys-

TABLE 3
USE OF WATERPROOFING MEMBRANE SYSTEMS

	No. of Respondents[a]		Performance Rating[b]	
Material	Past	Current	Range	Average
Preformed Systems				
None	10	10	—	—
Asphalt-impregnated fabric	15	9	2 to 5	3.0
Polymer	4	0	2 to 5	2.8
Elastomer	3	4	1 to 5	3.2
Asphalt-laminated board	7	3	2 to 4	3.0
Other	2	2	2 to 4	2.7
Liquid Systems				
Bituminous	11	10	1 to 5	2.8
Resinous	3	3	1 to 5	3.3
Other	4	3	1 to 4	2.6

[a] Total number of survey respondents = 45.
[b] 1 = excellent, 5 = poor, — = not applicable.

tems. All membrane materials had average ratings of between 2.6 and 3.3.

In *NCHRP Report 297*, it was reported that debonding and stripping of asphaltic concrete overlays had been a major problem for some DOTs, with some systems requiring removal and replacement in 10 years or less (Babaie and Hawkins 1987). The report explained that accumulation of water above the membrane in the bottom portion of the asphaltic concrete was the primary cause. This phenomenon, combined with freezing and thawing and repeated hydraulic pressure from traffic, weakens both the bottom layer of the asphalt and the bond between the asphaltic concrete and the membrane. Although the chloride-proofing abilities of some membrane systems seemed to satisfy 50-year service life criteria, the actual life was governed by deterioration of the asphalt wearing surface, which was generally 10 to 15 years, depending on weathering and exposure to traffic.

NCHRP Synthesis of Highway Practice 220 (Manning 1995) summarized the use of waterproofing membranes for concrete bridge decks. That synthesis reported that the use of membranes resulted largely from a 1972 FHWA requirement that bridge decks be protected against corrosion. Surveys over the 20 years before 1995 had shown a sharp decline in the number of agencies using waterproofing membranes in new construction. In 1994, 25% of state highway agencies reported using membranes on new decks.

The synthesis went on to report that agencies are sharply divided on the merits of waterproofing decks. Reasons given for not using membranes included the inability to inspect the top surface of the deck slab, poor performance of experimental installations, and short service life of asphalt overlays. Other jurisdictions reported that membranes are cost-effective in new construction, especially in rehabilitation.

The survey for the *NCHRP Synthesis of Highway Practice 220* identified 22 different proprietary waterproofing products used in the United States in 1992. Most of the membranes were preformed products, with three products dominating the usage. In Canada, hot-rubberized asphalt membranes were widely used. In Europe, many resin-based and bitumen-based liquid membranes were being used. A 1995 scanning tour reported that bridge decks in Europe are generally covered with a waterproofing layer or system (*NCHRP Report 381* 1996). In Denmark and Germany a multilayer system is used, with an expected service life of 30 years in Denmark and 20 to 25 years in Germany. In France, all bridge decks receive a waterproofing membrane consisting of mastic asphalt, synthetic chemical resins, prefabricated sheets, or a proprietary system. In the United Kingdom, bridge decks are waterproofed using certified systems. Life expectancy is at least 20 years.

Field studies have shown that the performance of waterproofing systems has been extremely variable. Many of the systems installed in the 1970s failed after only a few years of service and some had to be removed before the bridge was open to traffic. More recent studies showed generally satisfactory performance especially by agencies with a long experience in installing membranes. Several studies have shown that the thickness of the asphalt surfacing is important in reducing damage to the membrane from both traffic loading and thermal effects. Hot rubberized liquid asphalt membranes used in Ontario have worked extremely well and most of the membranes are still in place (Manning 1995). There are several bridges in Kansas that have membranes with asphalt overlays. Some have performed well whereas others have not (Kepler et al. 2000).

Waterproof membranes cannot be used by themselves, because they are only one component in a waterproofing system. Other components are used to improve adhesion of the membrane to the deck and the protective riding surface and to protect the membrane. Consequently, inadequate performance by any component of the system can result in inadequate performance of the system. This also adds to the complexity of the system and complexity of the specifications for the systems.

Nearly all agencies in North America that use waterproofing membranes have prescriptive material specifications, many of which originate from the 1970s, and are based on manufacturers' recommendations. In some cases, the requirements for the waterproofing materials are part of the construction specifications. In most agencies, membranes are specified by a clause that requires the contractor to use only approved products (Manning 1995). In the absence of performance specifications, there is little reason for manufacturers to improve their products because improvement tends to increase costs without increasing sales as a result of the low bid process (Manning 1995).

SEALERS

The use of sealers for portland cement concrete highway facilities was documented in *NCHRP Synthesis of Highway Practice 209* (Cady 1994). According to this synthesis, surface sealers and coatings are used to protect concrete from aggressive environments. Initially, these materials were used to counteract freezing and thawing damage and deicer scaling. With the proper use of air-entraining admixtures, the primary purpose for sealers changed to preventing or retarding the ingress of chlorides.

One of the early sealers used was linseed oil. In 1970, it was widely accepted that two coats of boiled linseed oil in solution were beneficial in reducing scaling, particularly in improperly air-entrained concrete (*NCHRP Synthesis of*

Highway Practice 4 1970). Studies by the FHWA (Clear 1974, 1976) and a study on a bridge deck in Vermont (Frascoia 1973) showed that linseed oil retarded chloride penetration, but did not stop it. It was also shown that linseed oil was ineffective in resisting moisture penetration of concrete.

Many sealer products exist today covering a broad range of generic types. In 1994, these types in order of decreasing popularity were silanes, siloxanes, and silicates; epoxies; gum resins and mineral gums; linseed oil; stearates; acrylics, silicates, and fluosilicates; urethanes and polyurethanes; polyesters; chlorinated rubber; silicones; and vinyls. Each of the types is discussed in detail by Cady (1994).

In general, no sealer can fully prevent any of the various potential forms of concrete deterioration (Cady 1994). However, good quality products can retard the attack of all types of concrete deterioration (except alkali-aggregate reactivity) and can mitigate the effects of attack in progress by some of the deteriorative mechanisms. Sealer performance is difficult to assess. Relative ratings from laboratory testing ranked dual systems as the top performing type. Dual systems usually consist of a water-repellant primer and a pore-blocking top coat, typically alkylalkoxysilane and polymethylmethacrylate, respectively. Gum resins, urethanes, silanes, chlorinated rubbers, epoxies, siloxanes, silicones, and stearates displayed average performance. Acrylics, linseed oil, and silicates performed poorly in laboratory testing. Limited field results supported most of these ratings. The most notable exception was acrylics, which performed considerably better in the field than in laboratory tests. In addition, silanes and siloxanes displayed ranges of performance from best to worst. A paradox existed with linseed oil, which performed poorly in laboratory tests, yet was reported to retard chloride penetration in the FHWA studies (Clear 1974, 1976) and the bridge deck in Vermont (Frascoia 1973).

In the questionnaire for this synthesis, each agency was asked to identify which sealers they had used in the past and which they use currently. They were also asked to rate the system's performance on a scale of 1 to 5, where 1 = excellent and 5 = poor. A summary of the results is given in Table 4. Based on these data, it may be concluded that the use of linseed oil as a sealer has declined, the use of other sealers has remained about the same, and the number of states using a sealer has decreased. The reported performance of all sealers was wide ranging. The average performance ratings of sealers was slightly worse than the average performance ratings for overlays and membrane systems.

TABLE 4
USE OF SEALERS

Sealer	No. of Respondents[a]		Performance Rating[b]	
	Past	Current	Range	Average
None	4	7	—	—
Silanes, Siloxanes	17	19	1 to 5	2.8
Epoxies	10	9	1 to 4	3.0
Linseed Oil	24	7	1 to 5	3.6
Other	11	8	1 to 5	4.2

[a] Total number of survey respondents = 45.
[b] 1= excellent, 5 = poor, — = not applicable.

CATHODIC PROTECTION SYSTEMS

A cathodic protection system for reinforced concrete consists of the reinforcement to be protected; concrete surrounding the reinforcement; an anode, power source, cables for power, and monitoring; and a monitoring system. Cathodic protection works by using current to shift the potential of the reinforcing steel in the negative direction. If the potential is shifted so that all the steel reinforcement becomes cathodic, corrosion will stop. Both impressed current and sacrificial anode systems have been used on bridges in the United States. In the impressed current system, external power is supplied and the driving voltage and current can be varied. In the sacrificial anode system, the driving voltage is supplied by galvanic anodes and is limited by the potential of the metal. Impressed current systems are more suitable for bridge decks. Various types of anodes have been used with impressed current systems and various materials have been used for sacrificial anodes as described by Virmani and Clemena (1998). From 1973 to 1996, cathodic protection systems had been installed in more than 550 bridge decks in North America (Bettigole and Robison 1996).

According to Kepler et al. (2000), Missouri has installed 145 cathodic protection systems on approximately 110 bridge decks since 1977 and expects that one-half of these systems will still be protecting the decks 20 years after their initial installation. The first deck to have cathodic protection in 1977 was still being supplied with current in 1999. Whether or not the cathodic protection system was actually working was not reported.

In 1988, three different anode systems were installed on a bridge deck at Big Spring, Texas. The first system used a titanium mesh as the anode and was still in place and reported to be working 5 years later. The second system used flexible conductive polymer strands as the anode. All of the circuits failed within 4 years of installation. The third system used platinized wire with a carbon filament as the anode. Only one strand was in operation after 5 years. Based on assumptions about the maintenance costs and service lives of the systems, it was determined that cathodic protection systems would not generally be a cost-effective method for maintaining or protecting bridge decks in Big Spring (Nash et al. 1994).

Based on their literature search, Kepler et al. (2000) concluded that the most common impressed current system in use for cathodic protection of reinforced concrete bridge decks is the titanium mesh anode used in conjunction with a concrete overlay. In response to the questionnaire for this synthesis, 24 of the 45 respondents reported that they had tried cathodic protection systems. Several respondents reported on the successful use; however, many respondents cited difficulties with reliability and maintenance of the systems.

OTHER SYSTEMS

Electrochemical chloride extraction is a process of removing chloride ions from contaminated concrete by electrochemical means (Virmani and Clemena 1998). The process is similar to that of cathodic protection. An electrical current is passed through the reinforcement to the anode. The chloride ions are pulled away from the reinforcement towards the electrolyte where they are absorbed for removal. Based on their literature review, Kepler et al. (2000) concluded that electrochemical chloride extraction can remove substantial amounts of chloride from contaminated concrete and lead to an increase in the pH of the concrete and repassivation of corroding reinforcing steel. The length of time that the benefits of electrochemical chloride extraction on a structure will last is unknown; therefore, estimating the life-cycle cost of the treatment is difficult (Virmani and Clemena 1998).

CONCLUSIONS ABOUT THE USE OF PROTECTIVE SYSTEMS

Bridge deck protective systems that are designed to prevent the primary concrete and reinforcement from conditions that will cause their deterioration include overlays, membranes, sealers, and cathodic protection. Latex-modified concrete overlays and low-slump dense concrete overlays have, in general, performed satisfactorily. Results with membranes appear to be mixed. In states with more experience, the results have been better. However, the life of the membrane system is limited more by the life of the protective cover over the membrane than the membrane itself.

Sealing of concrete surfaces can be used to delay the effects of deterioration if deterioration is not already underway. However, the performance of sealers is difficult to assess because of inconsistencies between laboratory tests and field tests and a lack of national standard testing specifications. Nevertheless, sealers do offer a low initial cost approach. Cathodic protection systems have been used; however, they have not proven to be maintenance-free or cost-effective.

CHAPTER FIVE

STRUCTURAL DESIGN PRACTICES, CONSTRUCTION PRACTICES, SPECIFICATIONS, AND COSTS

This chapter is concerned with aspects of structural design practices, construction practices, specifications, and costs that are related to concrete bridge deck performance.

STRUCTURAL DESIGN PRACTICES

General

Responses to the questionnaire for this synthesis indicated that most agencies use a minimum deck thickness in the range of 190 to 230 mm (7.5 to 9 in.) Reinforcement bar sizes are typically 16 and 19 mm in diameter (No. 5 and No. 6), with a bar spacing not exceeding 305 mm (12 in.). Seventeen of the 38 U.S. respondents reported HS 20 as the design live load, 17 reported HS 25, and 14 reported HL 93. Twelve respondents reported using more than one design load.

Cover to Reinforcement

In 1970, the general recommendation for concrete cover was a minimum clear cover of 50 mm (2 in.) over the top-most steel (*NCHRP Synthesis of Highway Practice 4* 1970). *NCHRP Synthesis of Highway Practice 57*, published in 1979, reported that the specified concrete cover, until recently, was typically 38 mm (1.5 in.). Currently, the *AASHTO Standard Specifications for Highway Bridges* (2002) requires a minimum cover of 65 mm (2.5 in.) for top reinforcement in concrete deck slabs that have no positive corrosion protection and are frequently exposed to deicing salts. Positive corrosion protection methods may include epoxy-coated reinforcement, special concrete overlays, and impervious membranes, or a combination of these methods. Reference is made to *NCHRP Report 297* for additional information (Babaie and Hawkins 1987). The *AASHTO LRFD Bridge Design Specifications* (2004) require a minimum cover of 65 mm (2.5 in.) for concrete that is exposed to deicing salts or on deck surfaces that are subject to stud or chain wear. The cover may be decreased to 40 mm (1.5 in.) when epoxy-coated reinforcement is used.

In the survey for the Michigan DOT, the typical concrete cover to the top layer of reinforcement was reported to range from 51 to 76 mm (2 to 3 in.), with 64 mm (2.5 in.) being the most common value (Aktan and Fu 2003). Most states also reported that the present requirement for cover was larger than it had been in the past, with 38 mm (1.5 in.) being the most common previous value. Responses to the questionnaire for this synthesis indicated that 39 or 87% of the 45 responding agencies specified a minimum clear cover of 50 to 64 mm (2.0 to 2.5 in.) for the top layer of reinforcement and 42 or 93% specified 25 to 38 mm (1.0 to 1.5 in.) for the bottom layer.

Several studies have identified that the depth of cover over the top reinforcing steel is the most significant factor contributing to the durability of the deck (Stark 1970; Crumpton and Bukovatz 1974; Clear 1976). In a Kansas DOT study, it was estimated that increasing the cover from 50 to 75 mm (2 to 3 in.) and decreasing the water–cement ratio of the concrete from 0.44 to 0.35 would triple the life of a deck (McCollum 1976).

In *NCHRP Report 57* (1979), it was pointed out that, if the cover distance had a standard deviation of 10 mm (0.375 in.), the specified cover must be approximately 67 mm (2.625 in.) for a minimum cover of 50 mm (2 in.) with a 95% compliance (Weed 1974; Van Daveer 1975).

The authors of *NCHRP Report 297* concluded that the effective service period for a bridge deck with 90-mm (3.5-in.) cover to the reinforcement may be 50 years or more when salt exposure is less than 3 Mg per lane-kilometer per year (5 tons per lane-mile per year) (Babaie and Hawkins 1987). For higher salt applications, the water–cement ratio of the concrete determines the service life.

CONSTRUCTION PRACTICES

Stay-in-Place Concrete Panels

Precast concrete, stay-in-place deck panels are used extensively in several parts of North America to support the CIP concrete deck. After the concrete is placed, the panel becomes an integral part of the composite deck to resist both transverse and longitudinal bending. Because the panels are not continuous for the complete length of the bridge or across the supporting beams, there is a tendency for cracks to occur in the CIP concrete above the discontinuities in the panels. This is often called reflective cracking.

Concrete Temperature

NCHRP Synthesis of Highway Practice 4 reported that concrete mix temperatures of 27°C to 32°C (80°F to 90°F) were believed to play a major role in crack development, high water requirement, and strength loss (1970). Krauss and Rogalla (1996) reported that reducing placement and peak concrete temperatures relative to ambient temperatures can reduce deck cracking. They recommended that concrete temperature at time of casting be 5°C (10°F) cooler than ambient, except when temperatures are below 16°C (60°F), when the concrete temperature should be the same as ambient.

Responses to the questionnaire for this synthesis indicated that the majority of the agencies specified a maximum concrete temperature at time of placement of 32°C (90°F). However, very few respondents specified a maximum temperature for the deck concrete during the curing period.

Placement Procedures

NCHRP Synthesis of Highway Practice 4 reported that excessive surface manipulation lowers the surface scaling resistance especially if the manipulation occurs during the bleeding period (1970). The addition of water to the surface to facilitate finishing led to decreased scaling resistance (Malisch et al. 1966). Other experiments showed that concrete surfaces struck off immediately after casting with no further finishing operations showed greater resistance to surface scaling compared with surfaces given a second and final finish (Klieger 1955).

Schmitt and Darwin (1995) in an investigation of 40 bridge decks in northeast Kansas could not identify any relationship between cracking and placement length for monolithic bridge decks. However, cracking clearly increased as placement length increased for bridge deck overlays. Krause and Rogalla (1996) reported that placement sequence is important, but that sequence is not a primary cause of transverse deck cracking.

In *NCHRP Synthesis of Highway Practice 57* (1979), it was reported that insufficient bridge deck slope makes construction without localized depressions difficult. This accelerates the ingress of chlorides and promotes scaling as water containing deicing salts collects in these areas. Deterioration in gutter areas is common on flat bridges.

Curing Practices

The *AASHTO Standard Specifications for Highway Bridges* (2002) and the *AASHTO LRFD Construction Specifications* (1998) require that all newly placed concrete be cured for 7 days, except that the curing period shall be 10 days when pozzolans in excess of 10% by mass of the portland cement are used. The alternative curing methods that may be used are the water method, the liquid membrane curing compound method, and the waterproof cover method. For bridge decks, the specifications require that a combination of the liquid membrane curing compound method and the water method be used. The curing compound shall be applied immediately after the finishing operations on each portion of the deck are complete. The water cure shall be applied not later than 4 h after completion of deck finishing. For portions of the deck on which finishing is completed after normal working hours the water cure shall be applied not later than the following morning.

Responses to the Michigan DOT survey indicated that 90% of the 31 responding states have a continuous wet cure with a duration of 5 to 14 days (Aktan and Fu 2003). Nineteen of the states allow a burlap cover and 16 allow the use of a curing compound. No states reported using air curing. When asked about the probable causes of early age deck cracking, most states responded “substandard curing.”

In the questionnaire for this synthesis, each agency was asked to identify the type of curing that they specify. The responses are summarized in Figure 5. Forty of the 45 responding agencies specify a water-saturated cover, although 27 or 60% of the respondents specify more than one method. Thirty-seven or 82% of the respondents reported that they specify that curing must begin immediately after finishing any portion of the deck. Thirty-two or 71% of the respondents specify a 7-day curing period.

The advantages of using a longer curing period include a lower permeability, increased hydration of the cement so that less free water is available to produce shrinkage, and higher tensile strength when the concrete begins to shrink. All of these factors contribute to a more durable bridge deck. The disadvantage of a longer curing period is that it extends the construction time. However, extending the curing period on most projects represents only a minor extension of the total schedule.

Improper curing is thought to significantly contribute to cracking (*Durability of Concrete Bridge Decks* 1970; Poppe 1981; Kochanski et al. 1990). According to Krauss and Rogalla (1996), the most significant construction-related factors affecting transverse deck cracking involved weather and curing. They reported that transportation agencies observed more cracking when concrete was placed during lower humidities and higher evaporation rates. They recommended immediate water fogging or application of evaporation-retarding films regardless of evaporation rates or temperature. Early wet curing was recommended to reduce evaporation of mix water and to cool the concrete.

With HPCs, application of water curing immediately after concrete finishing, as illustrated in Figure 6, is ex-

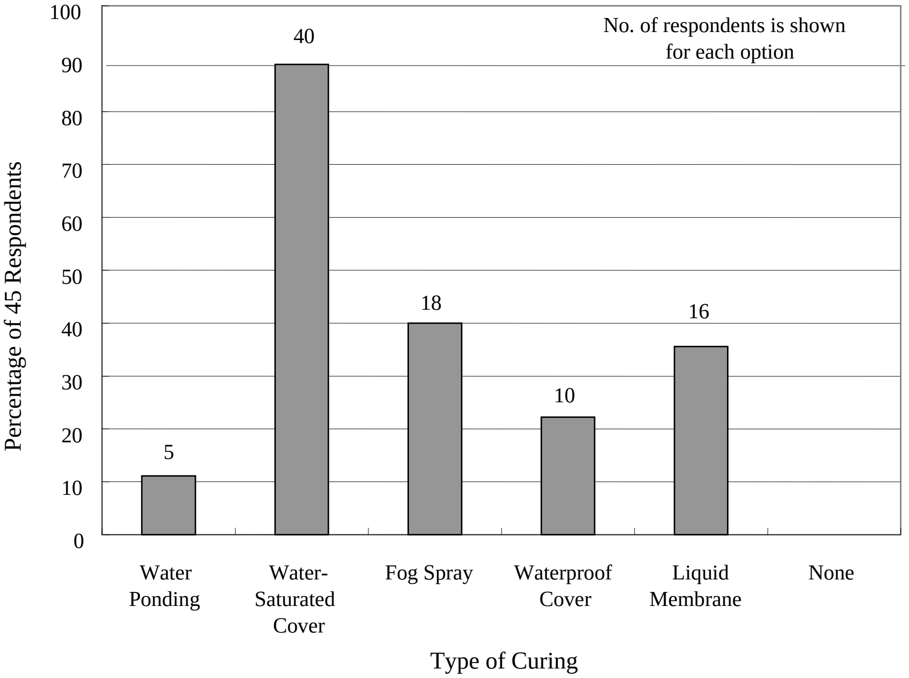


FIGURE 5 Survey results of bridge deck curing methods.

FIGURE 6 Application of wet burlap immediately after concrete curing (Schell and Konecny 2001). (*Courtesy*: HPC Bridge Views published by FHWA and NCBC.)

tremely important because these concretes have less bleed water and the likelihood of plastic shrinkage cracking is greater (Khaleghi and Weigel 2001; Praul 2001; Schell and Konecny 2001). Whiting and Detwiler (1998) emphasized the importance of curing silica fume concrete. The lack of bleeding means that water lost from the surface as a result of evaporation cannot be readily replaced. Consequently, Whiting and Detwiler recommended the following precautions:

- Strict adherence to specifications regarding evaporation rates and cessation of concrete placement if relative humidities are low and temperatures and wind speeds are high;

FIGURE 7 Nozzles attached to the finishing equipment (Schell and Konecny 2001). (*Courtesy*: HPC Bridge Views published by FHWA and NCBC.)

- Expeditious finishing of concrete and use of fog sprays during finishing;
- Use of evaporation-retarding agents during and immediately after finishing; and
- Initiation of wet curing as soon as possible after finishing.

Use of these techniques has, in general, reduced the incidence of plastic shrinkage cracking and allowed for the successful placement of many hundreds of silica fume concrete overlays (Whiting and Detwiler 1998). In their study of silica fume bridge deck overlays, Miller and Darwin (2000) concluded that improved curing reduced cracking.

The use of fogging equipment to reduce evaporation rates is shown in Figure 7.

Traffic-Induced Vibrations

For replacement of existing bridge decks, it is frequently necessary to undertake the construction in several phases so that part of the bridge can remain open to traffic. As a result, the fresh concrete in the new bridge deck may be exposed to vibrations from traffic on an adjacent structure.

Based on laboratory tests using simulated traffic-induced vibrations, Harsh and Darwin (1986) concluded that traffic-induced vibrations have no detrimental effect on either bond strength or compressive strength of concrete in bridge deck repairs, if high-quality, low-slump concrete is used. As slump increased, the vibrations resulted in lower bond and compressive strengths. Slumps in the range of 100 to 130 mm (4 to 5 in.) could be detrimental and slumps of 175 to 200 mm (7 to 8 in.) were found to decrease the bond and compressive strengths by 5% to 10%.

In their study on transverse cracking in newly constructed bridge decks, Krauss and Rogalla (1996) reported that other research showed that traffic-induced vibrations before or after concrete hardening do not cause cracking. They reported that deflections associated with the vibrations are too small to damage the concrete. More information on traffic-induced vibrations is available in *NCHRP Synthesis of Highway Practice 86* (Manning 1981).

Maintenance

In the survey for this synthesis, 15 or 33% of the 45 respondents indicated that they repair cracks in bridge decks, 9 or 20% indicated that they did not repair cracks, and 17 or 38% indicated that they repair cracks sometimes. “Sometimes” depended on the severity of the cracking. The more frequently listed crack repair methods were epoxy injection and the use of methacrylates or other sealants. Of these, epoxy injection and methacrylates were identified as the most effective in prolonging bridge deck life.

The survey respondents were asked to identify what method they use to repair freeze-thaw damage. Most responded that they removed the damaged concrete and repaired with a deck patching material or overlay. Overlays were identified as the most effective surface repair method in prolonging bridge deck life.

SPECIFICATIONS

Prescriptive Versus Performance Specifications

The traditional approach to achieving a durable concrete bridge deck has been a prescriptive one, where certain parameters of the concrete mix proportions are specified. These typically include a maximum w/cm, a minimum cementitious materials content, and a percentage of supplementary cementitious materials. For bridge decks exposed to freezing and thawing cycles, a range of air contents is specified. The parameters are selected in anticipation that they will result in a concrete with a low permeability and high freeze-thaw resistance. In some instances, testing is performed to verify that the desired properties will be achieved.

With the FHWA initiative to implement the use of HPC in bridges, at least 16 states moved in the direction of performance-based specifications (*High-Performance Concrete* 2003). Subsequently, many other states have implemented HPC (Triandafilou 2004). In this approach, the end performance characteristic is specified. The range of characteristics includes freeze-thaw resistance, deicer scaling resistance, chloride permeability, abrasion resistance, alkali-aggregate reactivity, and sulfate resistance. It is then the contractor’s responsibility to conduct the necessary tests to prove that the proposed concrete mix proportions will satisfy the specified performance characteristics. This approach is similar to that used for concrete compressive strength. However, its application for durability characteristics presents new challenges that the industry may not be ready to handle at this time.

For early HPC bridge projects, the Texas DOT (TxDOT) did not specify how the contractor was to obtain durable concrete other than requiring adherence to the specifications for the project. Contractors were alerted that the bridges were part of a research program and that concrete mix designs would be developed by TxDOT and the research team to meet strength and durability guidelines. A by-product of the research was an HPC specification for use on future projects. The specifications required that mix designs be formulated and verified to meet strength and durability requirements. “After several projects, it became apparent that the contractors, the concrete suppliers, and TxDOT lacked the experience necessary to efficiently design concrete that would meet performance-based specification requirements for durability” (Cox and Pruski 2003).

To gain experience and a better understanding of the role that concrete constituent materials have on permeability, TxDOT began and continues to use prescriptive specifications that require the use of supplementary cementitious materials at a prescribed rate. The contracting community has expressed minimal opposition to this approach even though some projects require the use of supplementary cementitious materials where they have not been used before. TxDOT is aware of concerns about prescriptively specifying the use of supplementary cementitious materials when the materials supplier and contractor are not experienced with the materials. To address these concerns, TxDOT requires contractors to develop strength versus time curves for the concrete during the mix design process. For verification of durability parameters, additional concrete test specimens are supplied to the central laboratory for durability tests (Cox and Pruski 2003).

A further example of the reluctance is provided in the FHWA HPC demonstration bridges. Of the four characteristics for durability—freeze-thaw resistance, scaling resistance, abrasion resistance, and chloride penetration—only chloride penetration was consistently specified (Russell et al. 2003). This reluctance may be the result of a lack of familiarity with the test method, a lack of in-house capability to perform the tests, impact of costs when additional performance requirements are specified, or increased time to perform the tests. Whereas performance-based specifications for durability seem to be highly desirable, a lot more experience is needed before they can be fully implemented.

Warranties

In the survey conducted for this synthesis, the Ohio DOT was the only U.S. transportation agency that reported the use of warranties as part of their specifications. In 1999, Ohio introduced a specification requiring contractors to warrant new bridge decks constructed with HPC (Schultz 2002). The contractor is required to warrant against alligator and map cracking for 1 year and against scaling and spalling for 7 years. The deck is evaluated for alligator and map cracking at 1 year. Scaling and spalling are evaluated at 2 years and 1 month before the end of the warranty period. If any of the defects becomes evident during the warranty period, the contractor is required to make repairs at no cost to the state. Alligator and map cracks over 20% or less of the deck area are required to be sealed. If deck scaling occurs on 20% or less of the deck area and the depth is greater than 3 mm (1/8 in.), but not greater than 6 mm (1/4 in.), the defective areas are to be ground out. If the scaling is greater than 6 mm (1/4 in.) deep, the scaled area must be removed to a depth of 25 mm (1 in.) and replaced. If the area of map cracking or scaling is greater than 20%, the top 25 mm (1 in.) of the whole deck must be removed and replaced with an overlay. Schultz (2002) reported that 6 of the 16 decks that received the 1-year review required corrective work for alligator or map cracking.

The contractor is required to provide the Ohio DOT with a maintenance bond for the bridge deck for a period of 7 years. The amount of the bond is 50% of the total price bid for the HPC (Schultz 2002). Although unit prices for the HPC increased during the first year of the program, the prices in the second year were the same as those before the program was introduced.

COSTS

Methods for Predicting Life-Cycle Costs

A key element in the prediction of life-cycle costs is adequately estimating the service life of the bridge deck. The *AASHTO LRFD Bridge Design Specifications* (2004) defines service life as the period of time that the bridge is expected to be in operation. The end of the service life occurs when the bridge becomes functionally obsolete or accumulated damage in the bridge exceeds acceptable performance limits. However, service life is typically extended by performing periodic repairs to restore the serviceability of the structure. Responses to the Michigan DOT survey in 2002 indicated that most respondents believed that their reinforced concrete bridge decks will last 30 to 40 years (Aktan and Fu 2003).

Bhidé (2002) identified some of the service life prediction models available in 2002 as follows:

- Life-365—Computer software developed by M.D.A. Thomas and E.C. Bentz that addresses time-dependent diffusion of chlorides and predicts service life and life-cycle costs for various protection strategies.
- CIKS—Computer-Integrated Knowledge System developed by D. Bentz that predicts chloride ion diffusivity coefficients and time to initiation of corrosion.
- Duramodel—Model developed by W.R. Grace that uses effective diffusion coefficients to account for mechanisms other than pure diffusion.
- ConFlux—Personal computer-based Multimechanistic Chloride Transport Model developed by A. Boddy, E.C. Bentz, M.D.A. Thomas, and R.D. Hooton that accounts for diffusion, permeability, chloride binding, and wicking.
- ClinConc—Chloride penetration model developed by L. Tang, based on mass balance and genuine flux equations to predict chloride profiles in submerged parts of structures.
- HETEK Model—Ten-step spreadsheet calculation for service life developed by AEC Laboratory, Denmark, and applicable to marine structures and salt water splash zones.

It should be noted that all of these programs are based on uncracked concrete and do not include the effects of cracking on service life predictions. Additional information about prediction of service life is being developed in NCHRP Project 18-06A, Service Life of Corrosion-Damaged Reinforced Concrete Bridge Elements. The objective of the project is to develop a manual that provides step-by-step procedures for (1) assessing the condition of reinforced concrete bridge superstructure elements subjected to corrosion-induced deterioration, (2) predicting the remaining service life of such elements, and (3) quantifying the service-life extension expected from alternative maintenance and repair options.

Service-Life Costs

Babaie and Hawkins (1987) compared lifetime costs for several different bridge deck protection strategies, including increased concrete cover from 38 to 89 mm (1.5 to 3.5 in.), epoxy-coated top layer of reinforcement, special concrete overlays, and interlayer membranes. They also included three double protection strategies of epoxy-coated top and bottom layers of reinforcement, epoxy-coated top layer of reinforcement with special concrete overlay, and epoxy-coated top layer of reinforcement with interlayer membrane. An annual interest rate of 10% and an annual inflation rate of 5% were assumed in the calculation for 50-year lifetime costs.

For the singly protected decks, the least expensive strategy was the provision of a concrete cover of at least 89 mm (3.5 in.) over the uppermost bar. The other strategies in order of increasing costs were epoxy-coated top layer, interlayer membrane with asphaltic concrete, and a low-permeability concrete overlay of either low-slump dense concrete or latex-modified concrete. The least expensive of the double protection strategies was epoxy-coated top and bottom layers of reinforcement.

In 1999, the National Institute of Standards and Technology published software to help bridge designers determine the cost-effectiveness of new alternative construction materials based on a life-cycle costing methodology (Ehlen 1999). A sample analysis compares a bridge with conventional strength precast, prestressed concrete girders and a normal permeability concrete deck to one that has high-strength precast, prestressed concrete girders and a low-permeability concrete deck. The use of high-strength and HPCs was the more cost-effective solution.

Kepler et al. (2000) compared the present value of costs for 33 corrosion protection methods assuming discount rates of 2%, 4%, and 6%. The total present value was calculated by adding the initial cost to the present values of costs for repair and replacement, maintenance, and operation. A 75-year service life was selected as the basis of comparison. A 230-mm (9-in.)-thick reinforced concrete bridge deck with 50 mm (2 in.) cover over the top layer of reinforcement was generally used. However, a 205-mm (8-in.)-thick deck was used for bridges with epoxy-coated reinforcement as the only corrosion protection method. Based on their analysis, the system with the lowest present value consisted of stainless steel clad reinforcement. The cost did not change with discount rate because it was assumed that repairs or maintenance would not be necessary. At the 2% discount rate, solid stainless steel reinforcement was a cost-effective option. At the 4% rate, hot rubberized asphalt membranes and calcium nitrite as a corrosion inhibitor were cost-effective. At the 6% rate, calcium nitrite was cost-effective.

CONCLUSIONS ABOUT STRUCTURAL DESIGN PRACTICES, CONSTRUCTION PRACTICES, SPECIFICATIONS, AND COSTS

The most important structural design practice to reduce corrosion of reinforcement in uncracked concrete bridge decks is to provide a minimum cover to the top layer of reinforcement of 64 mm (2.5 in.). The most important construction practices to achieve a low-permeability, uncracked bridge deck with adequate freeze-thaw resistance is to initiate wet curing of the concrete immediately after finishing any portion of the concrete surface and maintaining wet curing for a minimum of 7 days. Other practices that are beneficial include moderate concrete temperatures at time of placement, minimum finishing operations consistent with achieving the desired concrete surface, gradual development of performance specifications, and warranties.

CHAPTER SIX

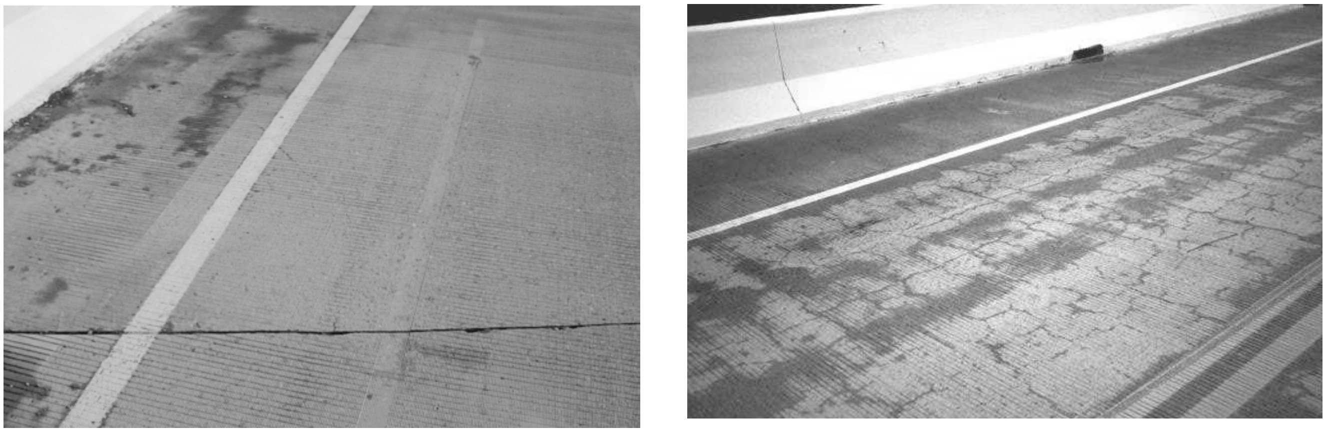
CRACKING IN CONCRETE BRIDGE DECKS

Cracks in bridge decks are generally characterized by their orientation with respect to the longitudinal axis of the bridge. The major types, as illustrated in Figure 8, are transverse, longitudinal, diagonal, map, and random (Schmitt and Darwin 1995). In fresh concrete, cracks may be caused by rapid loss of moisture or by settlement around reinforcing bars (Babaie and Fouladgar 1997; *Causes, Evaluation, and Repair* . . . 1998). In hardened concrete, cracks form whenever the tensile stress in the concrete exceeds the tensile strength of the concrete. Tensile stresses are caused by applied loads such as vehicles or restraint to the length changes caused by shrinkage or temperature changes. Tensile strength of concrete is dependent on the concrete constituent materials and curing environment, and generally increases with concrete age.

In a typical slab-on-beam bridge, the deck slab spans between the longitudinal girders and the primary deck reinforcement runs in the transverse direction. Small size bars as distribution reinforcement run in the longitudinal direction below the top transverse bars and above the bottom transverse bars (*Guide for Concrete Highway* . . . 1997). In continuous structures, larger bars run longitudinally over the piers. Reinforcement that runs parallel to the direction of concrete tensile stress functions as the tensile reinforcement and controls crack widths after the crack forms. Reinforcement that runs perpendicular to the direction of the concrete tensile stress acts as a stress raiser and crack former by reducing the concrete cross section. A larger diameter bar reduces the cross section more than a smaller bar.

Transverse

Longitudinal



Diagonal

Map

FIGURE 8 Examples of crack patterns.

CAUSES OF CRACKING IN CONCRETE BRIDGE DECKS

In 1961, the Portland Cement Association began a study of concrete bridge deck durability (*Durability of Concrete Bridge Decks* 1970). The study included a survey of 1,000 bridges selected at random in 8 states, plus a detailed survey of 70 bridges in 4 states. The study concluded that transverse cracking was the predominant type of cracking. The cracks were typically located above transverse reinforcement. Based on the study, the use of the largest practical maximum size of coarse aggregate was recommended to minimize the water content. In addition, it was recommended to use the lowest reasonable slump and to keep the maximum slump within a range of 50 to 75 mm (2 to 3 in.). Several other studies have identified that longitudinal and transverse cracks tend to form directly above reinforcement in the top layer of bars because the presence of the reinforcement acts as a stress raiser (Cheng and Johnston 1985; Perfetti et al. 1985; Kochanski et al. 1990). This effect can be reduced by using smaller diameter bars in combination with a thicker deck (Kochanski et al. 1990).

It has been reported that the incidence of cracking increases with span length (Larson et al. 1968; Axon et al. 1969; *Durability of Concrete Bridge Decks* 1970), angle of skew (Larson et al. 1968), and the use of continuous structures (Axon et al. 1969; *Durability of Concrete Bridge Decks* 1970).

A California study (Poppe 1981) showed that air content had no effect on cracking; however, a study by North Carolina State University found that low slump and air content increased cracking (Cheng and Johnson 1985). A study of premature cracking in concrete bridge decks for the Wisconsin DOT resulted in several recommendations to reduce cracking of bridge decks (Kochanski et al. 1990). These included limiting the water–cement ratio to 0.40 and using coarse aggregate with a maximum size greater than 19 mm (0.75 in.).

In Kansas, 40 bridge decks were investigated to identify factors that contribute to cracking (Schmitt and Darwin 1995, 1999; Miller and Darwin 2000). The investigations showed that cracking increased with increasing values of slump, percent volume of water and cement, water content, cement content, and compressive strength. Based on these trends, they concluded that concrete shrinkage or restraint of concrete shrinkage was a major contributor to bridge deck cracking. Decreases in cracking were noted with increases in air content. No conclusions were made about the effect of water–cement ratio because the values only varied from 0.42 to 0.44 with one exception.

Schmitt and Darwin (1995) reported that transverse crack density, in terms of crack length per unit area, for bridge decks using 19-mm diameter (No. 6) bars was higher than for bridge decks using 16-mm diameter (No. 5) bars or a combination of 13- and 16-mm diameter (No. 4 and No. 5) bars as transverse reinforcement. Miller and Darwin (2000) also reported that, in general, a larger transverse bar size and spacing tends to increase levels of cracking. Schmitt and Darwin (1995) also reported that transverse crack density in decks with bonded overlays was considerably less when transverse bar spacing was less than or equal to 150 mm (6 in.). However, the authors also pointed out that smaller spacing is associated with the use of smaller bar sizes. In addition, the authors found that steel girder bridges with integral abutments had more cracking near the abutments than bridges with girders on bearings. The magnitude of the cracking increased as the length of bridge deck along the abutment increased above 14 m (45 ft). Smaller size and closer spacing for the transverse bars resulted in less cracking in two-layer bridge decks.

Krauss and Rogalla (1996) examined the effects of concrete materials, design practices, and construction practices on transverse deck cracking. They concluded that concrete material factors important in reducing early cracking included low shrinkage, low modulus of elasticity, high creep, low heat of hydration, and selection of aggregates and concrete that provided a low cracking tendency. Other material factors helpful in reducing cracking included reducing the cement content, increasing the water–cement ratio, using shrinkage-compensating cement, and avoiding materials that produced very high early compressive strengths and modulus of elasticity values.

The type of cement also had a large effect on deck cracking. Decks constructed with Type II cement cracked less than those constructed with Type I cement. Type III cement gains strength more rapidly than other cement types and may increase the risk of cracking. Krauss and Rogalla also pointed out that the general chemistry and fineness of cements have changed over time. The end result is that today's cements and, therefore, the concretes made with the cements, gain strength more rapidly than previous cements. As a result, modern concretes with a high early compressive strength and modulus of elasticity have an increased risk of cracking because of the higher stresses that develop as a result of early shrinkage and thermal strains.

Krauss and Rogalla (1996) identified that the major design factors affecting transverse cracking in bridge decks were related to restraint, specifically bridge type, girder type, and girder size. Multispan continuous composite large steel girder bridges were most susceptible to bridge deck cracking. CIP, post-tensioned bridges were the least likely to have transverse deck cracking because the girders and the deck shrink together and post-tensioning introduces compressive stresses in the deck. Other design factors that moderately contributed to early cracking were continuous spans, alignment of top and bottom transverse bars, and the use of stay-in-place forms (Krauss and Rogalla 1996).

Silica fume concrete is very susceptible to plastic shrinkage cracking owing to its lack of bleeding. Therefore, immediate application of fog sprays or misting after placement is essential to avoid formation of plastic shrinkage cracks in silica fume concrete (Ozyildirim 1991). According to laboratory tests by Whiting and Detwiler (1998), the cracking tendency of concrete was influenced by the addition of silica fume only when the concrete was improperly cured. When concrete containing silica fume was cured for 7 days under continuously moist conditions, there was no statistically significant effect of silica fume on the tendency of the concrete to exhibit early age cracking. They recommended that specifications for silica fume concretes in bridge deck construction include a provision for 7-day continuous moist curing of exposed surfaces.

A survey of 72 bridges for transverse deck cracking in the Minneapolis/St. Paul metropolitan area was reported by French et al. (1999). The survey included 34 simply supported prestressed concrete girder bridges; 34 continuous steel girder bridges; and 4 continuous rolled steel, wide-flange girder bridges. The dominant material-related parameters associated with transverse deck cracking included cement content, aggregate type and quality, air content, rate of shrinkage, and deck concrete modulus of elasticity (French et al. 1999). Overall, the decks of bridges with simply-supported prestressed concrete girders were observed to be in better condition than decks on continuous steel girder bridges. This was attributed to reduced end restraint and the beneficial creep and shrinkage characteristics of the prestressed concrete girders. The few prestressed concrete girder bridge decks that consistently performed poorly were either bridges with reconstructed or reoverlayed decks or bridges that had decks placed during extreme temperature conditions. Cracking as a result of deck reconstruction was attributed to shrinkage of the deck being restrained by the aged prestressed concrete girders.

For steel girder bridges, end restraint and shrinkage were the most significant factors contributing to deck cracking. The steel girder bridges exhibited more cracking on interior spans than end spans, more cracking in curved bridges compared with straight bridges, more cracking with 19-mm diameter (No. 6) bars than 16-mm diameter (No. 5) bars as transverse reinforcement, and more cracking with increased restraint owing to steel configuration, girder depth, or close girder spacing.

Hadidi and Saadeghraziri (2003) summarized material and mix design factors that contribute to transverse deck cracking. Based on a comprehensive literature search, they made the following recommendations as positive steps to reduce the potential for deck cracking:

- Reduce cement content to 385 to 390 kg/m^3 (650 to 660 lb/yd^3),
- Consider using low early strength concrete when early opening of the deck is not required,
- Limit the water–cement ratio to 0.40 to 0.45 or lower with the use of water reducers,
- Use the largest maximum aggregate size with the maximum aggregate content, and
- Do not use concrete mixes that have a high tendency for cracking.

EFFECT OF CRACKS ON BRIDGE DECK PERFORMANCE

It is generally recognized that cracks perpendicular to reinforcing bars hasten corrosion of the intersected reinforcement by facilitating the ingress of moisture, oxygen, and chloride ions to the reinforcement at the crack location. Studies have shown that crack widths of less than 0.3 mm (0.01 in.) have little effect on the overall corrosion of the reinforcing steel (Houston et al. 1972; Ryell and Richardson 1972). Although wider cracks accelerate the onset of corrosion over several years, crack width has little effect on the rate of corrosion (Beeby 1978). Cracks that follow the line of a reinforcing bar are much more serious because the length of the bar equal to the length of the crack is exposed to the ingress of moisture, oxygen, and chlorides. In addition, the presence of the cracks reduces the resistance of the concrete to spalling as the reinforcement corrodes.

Miller and Darwin (2000) reported chloride levels in bridge decks at both cracked and uncracked locations. Their results showed significantly higher chloride contents at the locations of the cracks. At the level of the transverse reinforcement, the chloride contents exceeded the threshold level for corrosion in as little as 1,000 days.

CURRENT PRACTICES RELATED TO BRIDGE DECK CRACKING

Responses to the Michigan DOT survey showed that 30 or 97% of the 31 responding states had detected early age cracking in reinforced concrete bridge decks and 25 or 81% of the states reported that this cracking was observed in the first few months (Aktan and Fu 2003). Almost all states reported that transverse cracking was the most prevalent.

In the questionnaire for this synthesis, agencies were asked to identify which strategies they currently use to minimize cracking in bridge decks. Their responses, together with the number and percentage of responses from the 45 agencies, were as follows:

- Specify minimum curing time (42 or 93%),
- Specify maximum slump (40 or 89%),
- Specify maximum concrete temperature (36 or 80%),
- Require fogging during and immediately after placement (30 or 67%),
- Specify maximum cementitious materials content (15 or 33%),
- Require evaporation retardants (13 or 29%),
- Require wind breaks during concrete placement (10 or 22%), and
- Specify maximum concrete compressive strength (2 or 4%).

Other strategies that were listed included the use of wet mats, nighttime casting, and controlling the evaporation rate. The most effective strategies listed by the respondents were fogging and adequate curing.

Responses to the questionnaire for this synthesis indicated that the maximum size bar used for deck reinforcement was a 16-mm diameter (No. 5) bar for 13 or 29% of the respondents and a 19-mm diameter (No. 6) bar for 23 or 51% of the respondents. A maximum spacing of 305 mm (12 in.) or less was used by 29 or 64% of the respondents for longitudinal reinforcement and by 43 or 96% for transverse reinforcement. For 21 or 47% of the respondents, the minimum deck thickness was 200 mm (8 in.).

The cracking tendency of restrained concrete specimens can be determined using AASHTO Designation PP34—Standard Practice for Estimating the Cracking Tendency of Concrete. In this method, the strain in a steel ring is measured as a surrounding concrete ring shrinks. The time-to-cracking of the concrete ring is determined. The test can be used to determine the effect of variations in concrete constituent materials or curing regimes on cracking tendency. The procedure is comparative and is not intended to determine the time of initial cracking of concrete cast in a specific type of structure.

SUMMARY OF PRACTICES TO REDUCE CRACKING IN CONCRETE BRIDGE DECKS

Practices that can reduce cracking in bridge decks are as follows:

- Minimize potential shrinkage by decreasing the volume of water and cement paste in the concrete mix consistent with achieving other required properties;
- Use the largest practical maximum size aggregate to reduce water content;
- Use minimum transverse bar size and spacing that are practical;
- Avoid high concrete compressive strengths;
- Use windbreaks and fogging equipment, when necessary, to minimize surface evaporation from fresh concrete;
- Apply wet curing immediately after finishing the surface and cure for at least 7 days; and
- Apply a curing compound after the wet curing period to slow down the shrinkage and enhance the concrete properties.

CHAPTER SEVEN

CONCLUSIONS

As concern about deterioration of concrete bridge decks from corrosion of reinforcement increased in the 1960s and 1970s, attention focused on several strategies to prevent or slow down the penetration of chlorides to the reinforcement. These strategies included the use of increased concrete cover, low-slump dense concrete overlays, latex-modified concrete overlays, interlayer membranes, asphaltic concrete systems, and epoxy-coated reinforcement. With the advent of a rapid chloride permeability test and the availability of fly ash, silica fume, and ground-granulated blast furnace slag as supplementary cementitious materials, resources became available to achieve and easily quantify low-permeability concretes. Most transportation agencies now recognize that these materials can be used to produce a low-permeability concrete that will slow down the ingress of chlorides. The availability of high-range, water-reducing admixtures also meant that these concretes could be produced at a low water-cementitious materials ratio and still be placed and finished without too much difficulty. These concretes, however, required greater attention to environmental conditions during placement and greater attention to concrete curing.

The use of concretes with low water-cementitious materials ratios and supplementary cementitious materials has resulted in concretes having higher concrete compressive strengths, higher moduli of elasticity, and lower creep. Even though the tensile strength is higher, the other properties have led to an increase in the amount of cracking. The increased amount of cracking allows the chlorides to have an easier path to the reinforcement. As a result, the increase in the number of cracks offsets the benefits of the low-permeability concrete between the cracks. Concrete mix proportions should, therefore, be selected to produce a reasonably low permeability, while not increasing the propensity for cracking.

Epoxy-coated reinforcement continues to be the most common reinforcement used to reduce the potential for deterioration of concrete bridge decks from reinforcement corrosion; however, it cannot be relied on to never corrode in a wet or chloride environment. Other materials offer the potential as alternatives for steel reinforcement, but their long-term performance in bridge decks is not proven at this time.

Bridge deck protective systems that are designed to prevent the primary concrete and reinforcement from conditions that will cause their deterioration include overlays, membranes, sealers, and cathodic protection. Latex-modified concrete overlays and low-slump dense concrete overlays have, in general, performed satisfactorily. Results with membranes appear to be mixed. In states with more experience, the results have been better. However, the life of the membrane system is limited more by the life of the protective cover over the membrane than by the membrane itself.

Sealing of concrete surfaces can be used to delay the effects of deterioration if it is not already underway. However, the performance of sealers is difficult to assess because of inconsistencies between laboratory tests and field tests and a lack of national standard testing specifications. Nevertheless, sealers do offer a low initial cost approach. Cathodic protection systems have been used; however, they have not proven to be maintenance-free or cost-effective.

Several design practices can be beneficial to improve concrete bridge deck performance, including minimizing restraints to shrinkage of the deck, using smaller size reinforcing bars at closer spacing, and providing adequate cover. In construction, the need to provide adequate curing is an essential component to obtaining a durable concrete bridge deck.

Present practice and research results indicate that use of the following materials and practices enhances the performance of concrete bridge decks:

- Concrete Constituent Materials
  - Types I, II, and IP cements;
  - Fly ash up to 35% of the total cementitious materials content;
  - Silica fume up to 8% of the total cementitious materials content;
  - Ground-granulated blast furnace slag up to 50% of the total cementitious materials content;
  - Aggregates with low modulus of elasticity, low coefficient of thermal expansion, and high thermal conductivity;
  - Largest size aggregate that can be properly placed;
  - Water-reducing and high-range water-reducing admixtures;
  - Air-void system with a spacing factor no greater than 0.20 mm (0.008 in.), specific surface area greater than 23.6 mm^2/mm^3 (600 $in.^2/in.^3$) of air-void volume, and number of air voids per inch of traverse significantly greater than the numerical value of the percentage of air;

  - Water-cementitious materials ratio in the range of 0.40 to 0.45;
  - Concrete compressive strength in the range of 28 to 41 MPa (4,000 to 6,000 psi); and
  - Concrete permeability per AASHTO T277 in the range of 1,500 to 2,500 coulombs.
- Reinforcement Materials
  - Epoxy-coated reinforcement in both layers of deck reinforcement and
  - Minimum practical transverse bar size and spacing.
- Design and Construction Practices
  - Maintain a minimum concrete cover of 64 mm (2.5 in.);
  - Use moderate concrete temperatures at time of placement;
  - Use windbreaks and fogging equipment, when necessary, to minimize surface evaporation from fresh concrete;
  - Provide minimum finishing operations;
  - Apply wet curing immediately after finishing any portion of the concrete surface and wet cure for at least 7 days;
  - Apply a curing compound after the wet curing period to slow down the shrinkage and enhance the concrete properties;
  - Use a latex-modified or dense concrete overlay;
  - Implement a warranty requirement on bridge deck performance; and
  - Gradually develop performance-based specifications.

Responses to the synthesis questionnaire provided the following suggestions for future research and development programs:

- Monitor and evaluate performance of concrete bridge decks, including full-depth concrete slabs with supplementary cementitious materials, overlays, concrete sealers, different types of reinforcement, curing practices, compatibility of overlays and patching materials with substrate, factors contributing to shrinkage, and modulus of elasticity to determine which approaches are most effective in enhancing bridge deck performance.
- Prepare a synthesis report every 5 years to document recent developments.
- Investigate the effects of traffic vibrations on staged new construction and existing bridges to determine any beneficial or detrimental results.
- Develop an impermeable concrete and a quick permeability test to enhance bridge deck performance.
- Develop an economic noncorrosive reinforcement to prevent corrosion of reinforcement.
- Develop fast track repair and construction methods, including use of precast concrete for decks to accelerate construction, reduce traffic congestion, and enhance safety.
- Develop end-result specifications to encourage cost-effective innovations.
- Develop a central resource for information on completed research to enhance technology transfer.

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APPENDIX A

Survey Questionnaire

The following survey for this synthesis was mailed in March 2003 to 50 state highway agencies and the District of Columbia in the United States and 13 provincial highway agencies in Canada to collect information on the state of the practice for concrete bridge decks. A total of 45 responses were received for a response rate of 70%.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Synthesis of Highway Practice
Topic 34-09

CONCRETE BRIDGE DECK PERFORMANCE

QUESTIONNAIRE

PURPOSE OF THE SYNTHESIS

Concrete bridge deck deterioration, in the form of concrete distress and reinforcement corrosion, is one of the leading causes of structural deficiency in the National Bridge Inventory. Transportation agencies are investing significant resources to solve the problem. These agencies often specify material properties, mix designs, and construction methods to address concrete bridge deck distress. To address corrosion, alternative reinforcement, alternative slab design practices, protective barrier methods, electrochemical methods, and corrosion inhibitors have been used. The success and performance of these efforts has not yet been compiled in a document widely available to state transportation agencies.

This synthesis will collect and provide information on current design and construction practices that are being used to improve the performance of bridge decks. The primary focus of the synthesis is North American practices for cast-in-place, full-depth and partial-depth, reinforced concrete bridge decks on steel or concrete beams.

OBJECTIVE OF THIS QUESTIONNAIRE

The objective of the questionnaire is to obtain and share information on the following topics:

- Factors that contribute to the durability of concrete bridge decks
- Performance of various types of deck protection strategies
- Lessons learned and the current state of the practice in design, construction, and maintenance of concrete bridge decks
- Available comparative analyses of the effects of using different methods and materials
- Specific reports of successes and failures
- Sample design and construction specifications
- Available life-cycle cost information
- Research in progress
- Recommendations for future research.

RESPONDING AGENCY INFORMATION

Please complete the following request for information to aid in processing this questionnaire:

Agency: ____________________

Address: ____________________

City: ____________ State/Province: ____________ Zip: ____________

Primary Person Completing Questionnaire: ____________________

Current Position/Title: ____________________

Date: ____________________ E-mail: ____________________

Phone: ____________________ Fax: ____________________

Agency Contact (if different from above): ____________________

Phone: ____________________ E-mail: ____________________

INSTRUCTIONS

Because many questions are open-ended, follow-up telephone interviews may be necessary to confirm or enhance the understanding of the response. Please be sure to provide a contact person for each section of the questionnaire.

Where the answer to a question is "Other," please provide details.

Please provide a copy (Word or WordPerfect files preferred) or web address of your design and construction specifications for bridge decks. Please provide any other information that is relevant to the answers provided in the questionnaire, including applicable procedures, policies, or other information that might be of interest to other transportation agencies.

PLEASE RETURN THE COMPLETED QUESTIONNAIRE BY MARCH 21, 2003.

To: Henry G. Russell,
Henry G. Russell, Inc. Phone: 847-998-9137
720 Coronet Rd. Fax: 847-998-0292
Glenview, IL 60025-4457 E-mail: hgr-inc@att.net

Please contact Henry Russell with any questions.

THANK YOU FOR YOUR HELP AND COOPERATION WITH THIS PROJECT.

SECTION A—BRIDGE DECK PROTECTION STRATEGIES

A1. What strategies does your agency currently use to provide a low-permeability concrete?

Yes	No	
☐	☐	None
☐	☐	Specify minimum cementitious materials content
☐	☐	Specify minimum cement content
☐	☐	Specify maximum water-cementitious materials ratio
☐	☐	Require the use of fly ash
☐	☐	Require the use of silica fume
☐	☐	Require the use of ground-granulated blast furnace slag
☐	☐	Specify rapid chloride permeability testing
☐	☐	Specify ponding test
☐	☐	Other: ____________________

Which strategy has been most effective?____________________

Which strategy has been least effective? ____________________

A2. What strategies does your agency currently use to provide a concrete that is resistant to freeze-thaw damage and deicer scaling?

Yes	No	
☐	☐	None
☐	☐	Specify air content only
☐	☐	Specify air-void parameters
☐	☐	Specify freeze-thaw testing
☐	☐	Specify deicer scaling testing
☐	☐	Other: ____________________

Which strategy has been most effective? ____________________

Which strategy has been least effective? ____________________

A3. What strategies does your agency currently use to provide abrasion resistant concrete?

Yes	No	
☐	☐	None
☐	☐	Specify high-strength concrete
☐	☐	Specify abrasion testing
☐	☐	Other: ____________________

A4. What strategies does your agency currently use to minimize cracking in bridge decks?

Yes	No	
☐	☐	None
☐	☐	Specify maximum cementitious materials content
☐	☐	Specify maximum concrete compressive strength
☐	☐	Specify maximum concrete temperature
☐	☐	Specify maximum slump
☐	☐	Require wind breaks during concrete placement
☐	☐	Require evaporation retardants
☐	☐	Require fogging during and immediately after placement
☐	☐	Specify minimum curing times
☐	☐	Other: ____________________

Which strategy has been most effective? ____________________

Which strategy has been least effective? ____________________

A5. What strategies does your agency currently use to prevent corrosion of reinforcement in bridge decks?

Yes	No	
☐	☐	None
☐	☐	Low-permeability concrete
☐	☐	Corrosion inhibitor
☐	☐	Epoxy-coated reinforcement
☐	☐	Fiber-reinforced polymer reinforcement
☐	☐	Metallic-coated reinforcement
☐	☐	Stainless steel
☐	☐	Other corrosion-resistant reinforcement
☐	☐	Reinforcement free deck
☐	☐	High-strength concrete: $f_c' =$
☐	☐	Clear cover distance
☐	☐	Protective barriers
☐	☐	Other: ____________________

If your agency uses more than one of the above, list combinations usually used together:

____

Which strategy has been most effective? ____________________

Which strategy has been least effective? ____________________

A6. What strategies does your agency currently use to provide a protective barrier for the deck concrete?

Yes	No	
☐	☐	None
☐	☐	Overlays
☐	☐	Membranes
☐	☐	Sealers
☐	☐	Other:

Which strategy has been most effective?

Which strategy has been least effective?

A7. What strategies has your agency used in the past to enhance bridge deck performance but no longer uses? Explain why they are not used currently.

A8. Please supply any information about life-cycle costs for the different strategies that your agency has used:

☐ Attached
☐ Sent by fax
☐ Sent under separate mailing
☐ Sent by e-mail
☐ See reference:
☐ None available

A9. Does your agency require any warranties for bridge decks?

☐Yes ☐No

If yes, please provide details or source of information:

Section A completed by:
E-mail:
Phone:
Fax:

SECTION B—DESIGN

B1. What design live loads does your agency use for bridge decks?

☐HS 20 ☐HS 25 ☐MS 18 ☐HL 93 ☐Other: ______________________________

B2. What minimum deck thickness does your agency require?

☐None ☐6 in. ☐6.5 in. ☐7 in. ☐7.5 in.

☐8 in. ☐8.5 in. ☐9 in. ☐10 in. ☐Other: ______________________________

B3. What is the minimum clear cover that your agency specifies for the top layer of reinforcement?

☐1.5 in. ☐2 in. ☐2.5 in. ☐3 in. ☐Other: ______________________________

B4. What is the minimum clear cover that your agency specifies for the bottom layer of reinforcement?

☐1 in. ☐1.5 in. ☐2 in. ☐2.5 in. ☐Other: ______________________________

B5. What is the maximum bar size that your agency uses for deck reinforcement?

☐No. 3 ☐No. 4 ☐No. 5 ☐No. 6 ☐Other: ______________________________

B6. What is the maximum spacing for longitudinal bars?

☐3 to 6 in. ☐6 to 9 in. ☐9.1 to 12 in. ☐12.1 to 15 in. ☐15.1 to 20 in.

☐Other: ______________________________

B7. What is the maximum spacing for transverse bars?

☐3 to 6 in. ☐6.1 to 9 in. ☐9.1 to 12 in. ☐12.1 to 15 in. ☐15.1 to 20 in.

☐Other: ______________________________

Section B completed by: ______________________________
E-mail: ______________________________
Phone: ______________________________
Fax: ______________________________

SECTION C—DECK REINFORCEMENT MATERIALS

C1. What grade of reinforcement does your agency specify for deck reinforcement?

☐40 ☐60 ☐75

C2. Does your agency specify epoxy-coated reinforcement?

Yes	No	
☐	☐	Top layer of bars in the deck
☐	☐	Bottom layer of bars in the deck
☐	☐	Girder reinforcement projecting into the deck

C3. What types of reinforcement with metallic coating has your agency used?

☐None ☐Zinc coated ☐Stainless steel clad ☐Other: ______________________

Explain how its use affected deck performance: ______________________

C4. Has your agency used solid stainless steel reinforcement?

☐Yes ☐No

If yes, describe the type of stainless steel and explain how its use affected deck performance: ______________________

C5. Has your agency used fiber-reinforced polymer (FRP) reinforcement?

☐Yes ☐No

If yes, explain how its use affected deck performance: ______________________

C6. Has your agency used other corrosion-resistant reinforcement?

☐Yes ☐No

If yes, describe the type of corrosion-resistant reinforcement and explain how its use affected deck performance: ______________________

Section C completed by: ______________________
E-mail: ______________________
Phone: ______________________
Fax: ______________________

SECTION D—DECK CONCRETE MATERIALS

D1. For each of the following items, please list maximum and minimum values that your agency specifies and typical values used or achieved. Where units are not listed, please state your units in the Comments column (lb/yd^3, % of cementitious materials, etc.)

Material or Test	Specified		Typically Used	Comments (Units)
	Min.	Max.		
Cementitious materials content				
Water-cementitious materials ratio				
Cement content				
Fly ash content				
Silica fume content				
Ground-granulated blast furnace slag content				
Coarse aggregate maximum size, in.				
Water-reducer quantity				
High-range, water-reducer quantity				
Retarder quantity				
Corrosion inhibitor quantity				
Air content percentage				
Compressive strength, psi				
Tensile strength, psi				
Slump, in.				
Chloride permeability (AASHTO T277), coulombs				
Freeze-thaw resistance (AASHTO T161), %				
Deicer scaling resistance (ASTM C672)				
Abrasion resistance (ASTM C944), gm or mm				
Other				

D2. What types of cement does your agency allow?

AASHTO M85 (ASTM C150)
☐I ☐II ☐III ☐IV ☐V ☐IA ☐IIA ☐IIIA

AASHTO M240 (ASTM C595)
☐IS ☐IP ☐I(PM) ☐I(SM) ☐P ☐IS(MH) ☐IP(MH) ☐I(PM)(MH) ☐I(SM)(MH)

☐P(LH) ☐IS(MS) ☐IP(MS) ☐P(MS) ☐I(PM)(MS) ☐I(SM)(MS)

ASTM C1157
☐GU ☐MH ☐HE ☐LH ☐MS ☐HS

D3. What fly ash and pozzolan types does your agency allow?

☐C ☐F ☐N

D4 Does your agency have information of situations when the use of specific materials or test values were beneficial to enhancing bridge deck performance?

☐Yes. Please explain or supply separate information: ____________________

☐No

D5. Does your agency have information of situations when the use of specific materials or test values were <u>not</u> beneficial to enhancing bridge deck performance?

☐Yes. Please explain or supply separate information: ____________________

☐No

Section D completed by: ____________________
E-mail: ____________________
Phone: ____________________
Fax: ____________________

SECTION E—PROTECTIVE SYSTEMS

E1. Which of the following overlay systems has your agency used in the past and which does your agency currently use? For each overlay system that your agency has used, please rate its performance on a scale of 1 to 5, where 1 = excellent and 5 = poor.

Past	Current	Performance	
☐	☐	[ ]	None
☐	☐	[ ]	Asphalt
☐	☐	[ ]	Low-slump dense concrete
☐	☐	[ ]	Latex-modified concrete
☐	☐	[ ]	Fly ash concrete
☐	☐	[ ]	Silica fume concrete
☐	☐	[ ]	Epoxy
☐	☐	[ ]	Polyester
☐	☐	[ ]	Other: ______________________________

E2. Which of the following waterproofing membrane systems has your agency used in the past and which does your agency currently use?
For each waterproofing membrane system that your agency has used, please rate its performance on a scale of 1 to 5, where 1 = excellent and 5 = poor.

Past	Current	Performance	
PREFORMED SHEET SYSTEMS			
☐	☐	[ ]	None
☐	☐	[ ]	Asphalt-impregnated fabric
☐	☐	[ ]	Polymer
☐	☐	[ ]	Elastomer
☐	☐	[ ]	Asphalt-laminated board
☐	☐	[ ]	Other: ______________________________
LIQUID SYSTEMS			
☐	☐	[ ]	Bituminous
☐	☐	[ ]	Resinous
☐	☐	[ ]	Other: ______________________________

E3. Which of the following sealers has your agency used in the past and which does your agency currently use. For each sealer that your agency has used, please rate its performance on a scale of 1 to 5, where 1 = excellent and 5 = poor.

Past	Current	Performance	
☐	☐	[ ]	None
☐	☐	[ ]	Silanes, siloxanes, and siliconates
☐	☐	[ ]	Epoxies
☐	☐	[ ]	Gum resins and mineral spirits
☐	☐	[ ]	Linseed oil
☐	☐	[ ]	Stearates
☐	☐	[ ]	Acrylics
☐	☐	[ ]	Silicates and fluorosilicates
☐	☐	[ ]	Urethanes and polyurethanes
☐	☐	[ ]	Polyesters
☐	☐	[ ]	Chlorinated rubber
☐	☐	[ ]	Silicones
☐	☐	[ ]	Vinyls
☐	☐	[ ]	Other: ______________________________

E4. If your agency has used cathodic protection systems in the past, please provide the name of the system(s) and describe how successful it was:

____
____
____
____
____
____

E5. Describe your agency's experience with protective systems.

____
____
____
____
____
____

Section E completed by: ____
E-mail: ____
Phone: ____
Fax: ____

SECTION F—CONSTRUCTION PRACTICES FOR FULL-DEPTH DECKS

F1. What maximum delivery time after batching does your agency specify?

☐30 min ☐60 min ☐90 min ☐Other: ____________________

F2. Does your agency specify the concrete placement method?

☐Yes ☐No

F3. What methods of concrete placement are used?

☐Pumps ☐Conveyors ☐Buckets ☐Direct discharge

F4. Under what conditions does your agency require fogging systems? ____________________

F5. What surface finish does your agency specify for deck concrete? ____________________

F6. Under what conditions does your agency require the use of evaporation retardants prior to initiation of curing?

F7. What type of curing does your agency specify?

☐Water ponding ☐Water-saturated cover ☐Fog spray ☐Waterproof cover

☐Liquid membrane ☐None

F8 When does your agency specify that curing must begin?

☐ Immediately after finishing any portion of the deck
☐ Immediately after finishing the whole deck
☐ No later than 4 hours after finishing the deck
☐ Next morning
☐ Other: ____________________

F9. What length of curing period does your agency specify?

☐3 days ☐7 days ☐10 days ☐14 days ☐Other: ____________________

F10. What range of initial concrete temperature does your agency permit? ____________________

F11. What value, if any, does your agency specify for maximum temperature of deck concrete during the curing period?
____
____
____

F12. How frequently are the following tests made for quality control during deck placement?

Slump: ______________________________________
Air content: _________________________________
Unit weight: _________________________________
Initial concrete temperature: ___________________
Water content: _______________________________
Compressive strength: _________________________
Other: ______________________________________

F13. Does your agency conduct tests of the hardened in-place concrete to check end-product performance?

☐Yes ☐No ☐Sometimes

If sometimes, please explain: ____________________
____
____
____

If yes, what tests are made and what are the general results?______________
____
____
____

F14. Does your agency use any in-place sensors or instrumentation for quality control during construction?

☐Yes ☐No

If yes, please explain: __________________________
____
____
____

F15. When staged construction is used, does your agency require that the freshly placed concrete be isolated from traffic-induced vibrations in adjacent open traffic lanes?

☐Yes ☐No

If yes, explain what techniques are used:________________
____
____
____

F16. Does your agency require repair of cracks if they occur during construction?

☐Yes. Go to F17 and F18.
☐No. Go to end of section.

F17. What methods are used to repair cracks?____

F18. Explain which repair methods are most effective in prolonging deck service life:____________________

Section F completed by: ____
E-mail: ____
Phone: ____
Fax: ____

SECTION G—MAINTENANCE

G1. Does your agency repair cracks when they occur in bridge decks?

☐ Yes. Go to G2.
☐ No. Go to G4.
☐ Sometimes. Explain: ______________________________

G2. What methods does your agency use to repair cracks? ______________________________

G3. Which crack repair methods are most effective in prolonging bridge deck life? ______________________________

G4. What methods does your agency use to repair freeze-thaw surface damage? ______________________________

G5. Which surface repair methods are most effective in prolonging bridge deck life? ______________________________

G6. What deicing agents are used on bridge decks by your agency? ______________________________

Section G completed by: ______________________________
E-mail: ______________________________
Phone: ______________________________
Fax: ______________________________

SECTION H—LESSONS LEARNED

H1. Of all the strategies and methods that your agency has used to improve bridge deck performance, please list those that were effective, those that were not effective, and those for which the verdict is unknown. Explain the reasons, if known, or provide additional documentation about the outcomes. Specific case studies would be useful for the synthesis.

H2. Please list any research in progress by your agency related to concrete bridge deck performance:

H3. Please list any recommendations for future research: __________

Section H completed by: __________
E-mail: __________
Phone: __________
Fax: __________

APPENDIX B

Survey Respondents

Responses to the survey were received from the following U.S. highway agencies and Canadian provinces:

Alabama
Alaska
Arkansas
California
Colorado
Connecticut
Delaware
District of Columbia
Georgia
Hawaii
Idaho
Illinois
Indiana
Iowa
Kansas
Kentucky
Maryland
Massachusetts
Minnesota
Mississippi
Montana
Nebraska
Nevada
New Hampshire
New Jersey
New Mexico
New York
North Carolina
North Dakota
Ohio
Oklahoma
South Carolina
Tennessee
Texas
Utah
Virginia
Washington
Wisconsin

Alberta
New Brunswick
Newfoundland
Nova Scotia
Ontario
Quebec
Saskatchewan

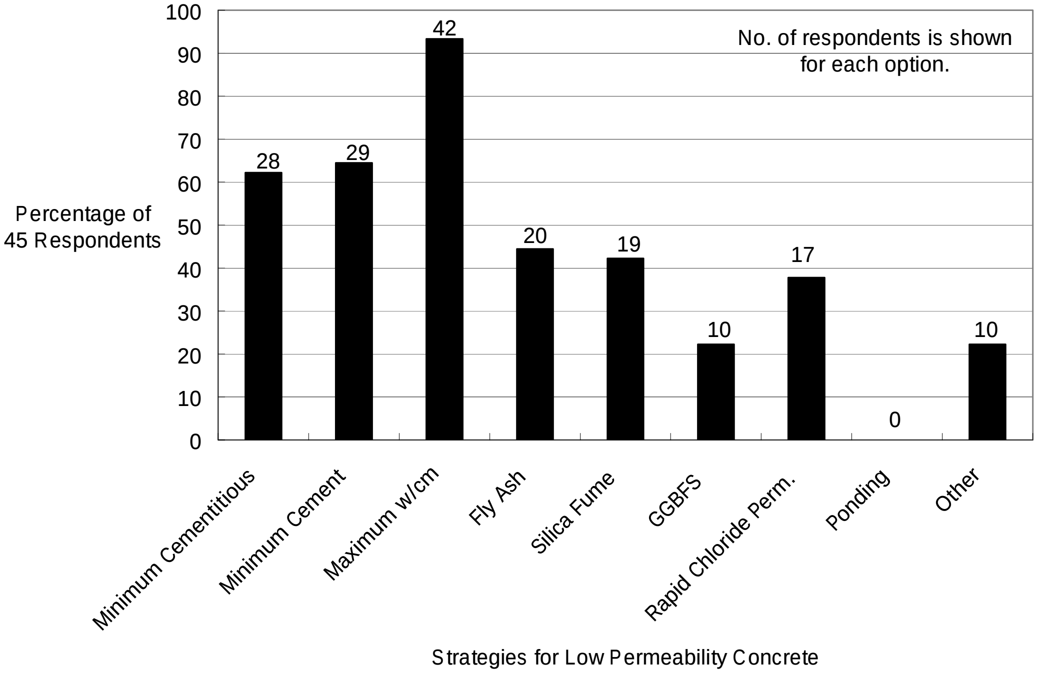
APPENDIX C

Summary of Responses to Survey Questionnaire

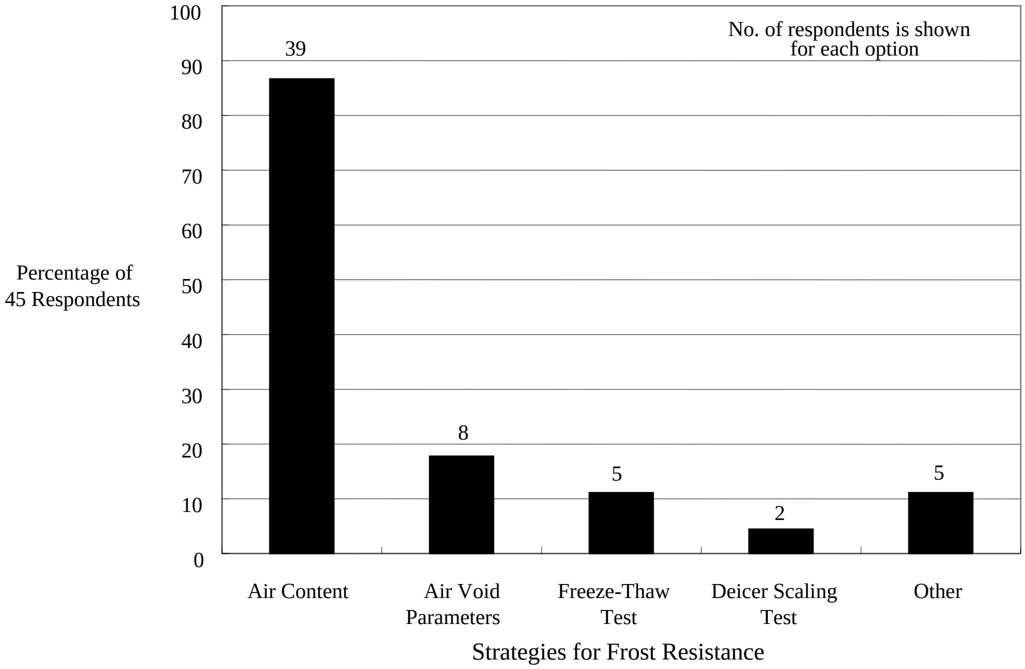
Responses to the survey questions are summarized in the graphs and tables on the following pages. In the graphs, the percentage of respondents on the vertical axes is expressed as a percentage of the 45 surveys that were returned. The number of respondents is shown at the top of each bar where space permits. Full details of the responses of each agency are available on-line at http://www4.trb.org/trb/onlinepubs.nsf, under National Cooperative Highway Research Program (NCHRP), NCHRP Synthesis Reports, Synthesis 333.

SECTION A—BRIDGE DECK PROTECTION STRATEGIES

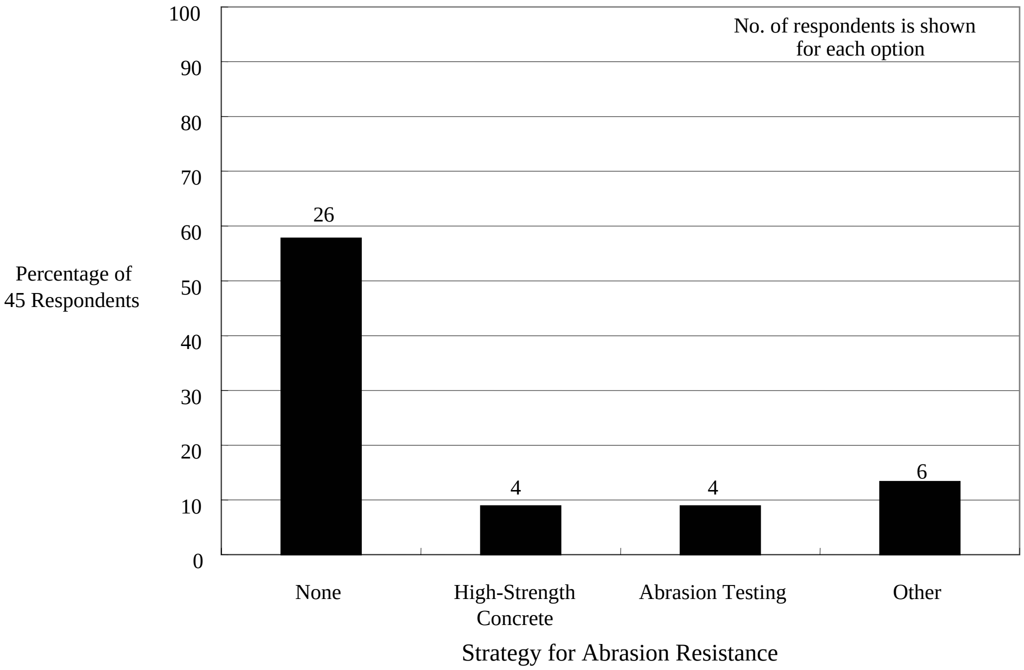
A1. What strategies does your agency currently use to provide a low-permeability concrete?



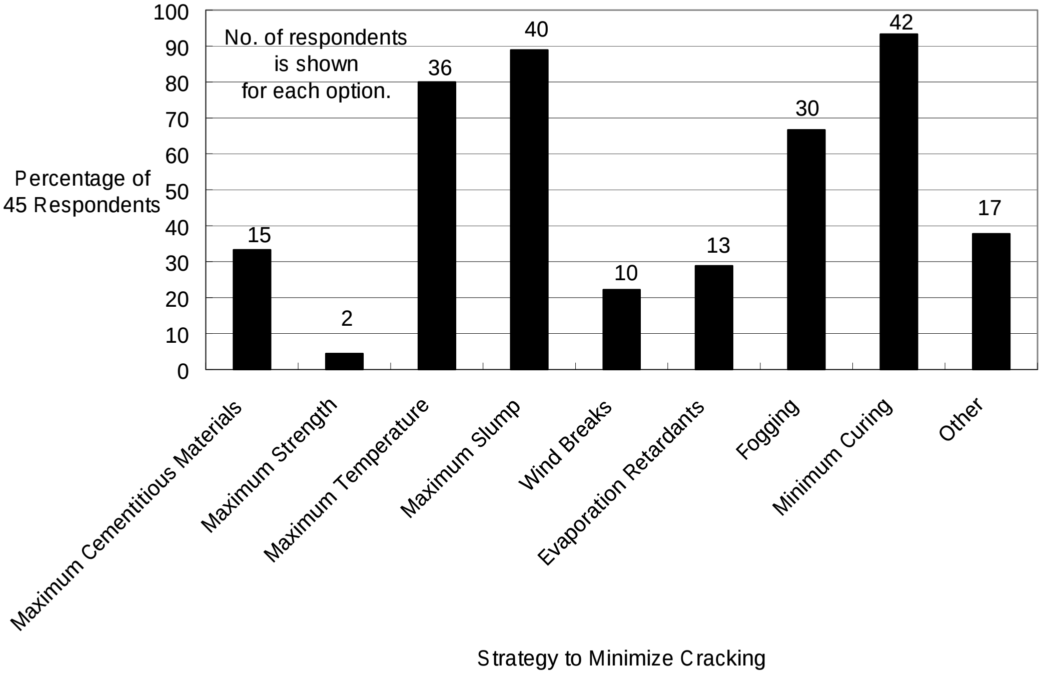
A2. What strategies does your agency currently use to provide a concrete that is resistant to freeze-thaw damage and deicer scaling?



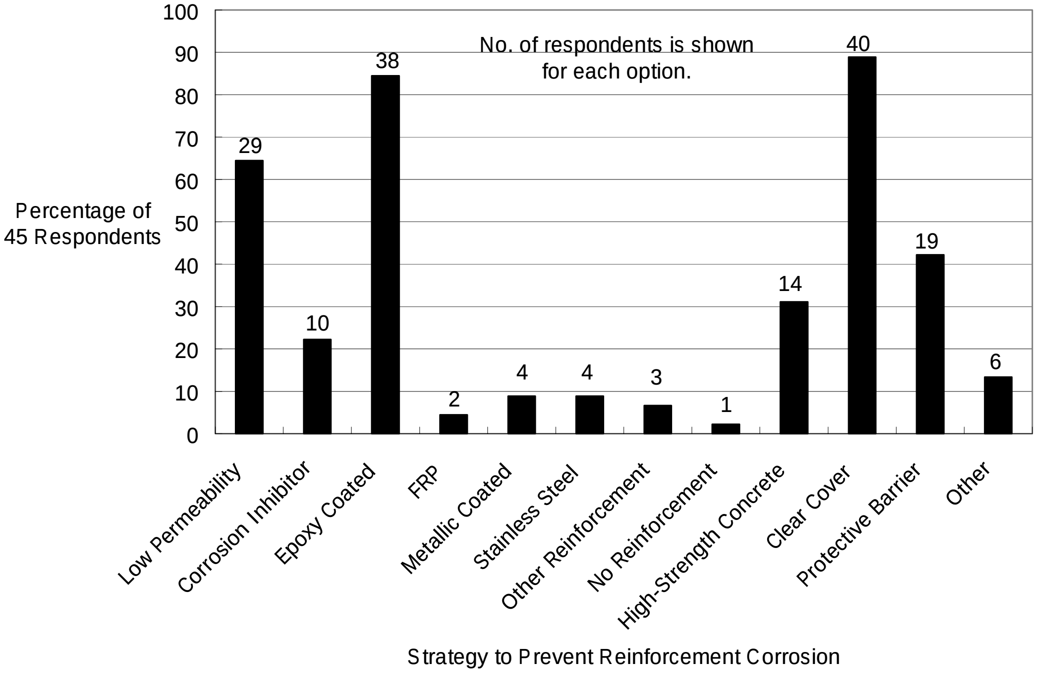
A3. What strategies does your agency currently use to provide abrasion resistant concrete?



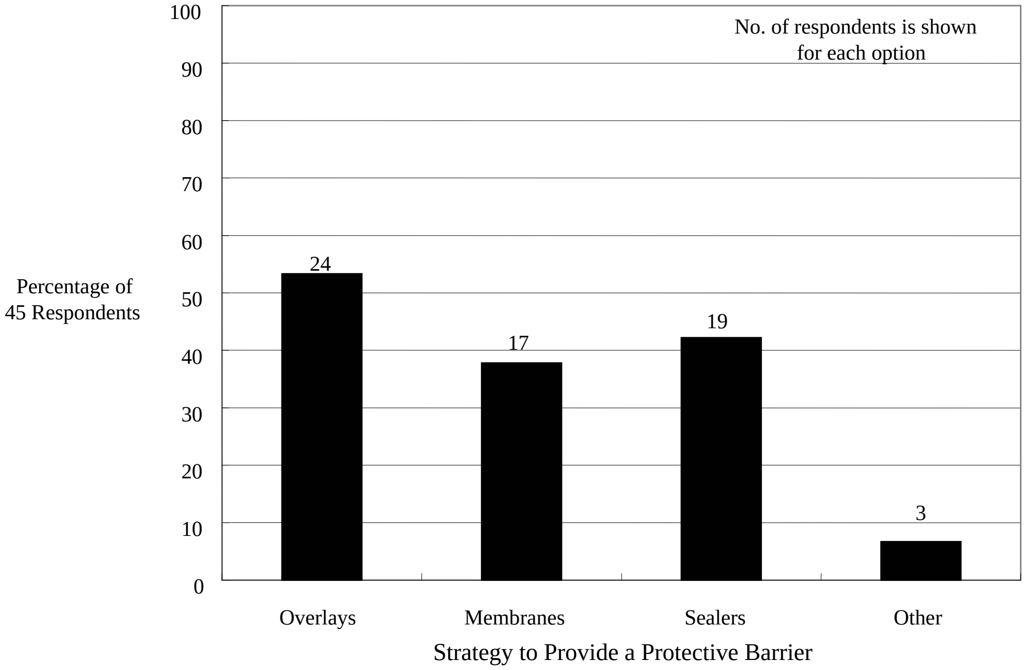
A4. What strategies does your agency currently use to minimize cracking in bridge decks?



A5. What strategies does your agency currently use to prevent corrosion of reinforcement in bridge decks?



A6. What strategies does your agency currently use to provide a protective barrier for the deck concrete?



A7. What strategies has your agency used in the past to enhance bridge deck performance but no longer uses?

State/Province	Used But No Longer Uses
Alabama	Linseed oil coating. Lasted only 6 months—not worth cost.
Alaska	Latex-modified concrete overlay—difficult to mix and place.
Arkansas	None.
Colorado	Minimum cement content without a maximum. Maximum w/c ratio without minimum (I think). Lower doses of silica fume. Restrictions on fly ash content.
Connecticut	Various sheet membranes were previously used, but often did not bond sufficiently to the deck. These were discontinued and the woven glass system substituted. There have been no debonding problems with the current system.
District of Columbia	Membranes were used in the distant past when asphalt cover was routinely used on bridge decks. We abandoned the use of asphalt on bridge decks 25 years ago, so the use of membranes was discontinued.
Georgia	None.
Hawaii	None.
Illinois	Not applicable.
Indiana	Asphalt deck membrane, bad performance in the past. Use of No. 3 longitudinal reinforcement above the top mat of steel; the steel was not epoxy coated and depth of cover was minimal so delaminations resulted.
Iowa	Iowa has tried an ACC overlay above a waterproofing membrane. The membrane bubbled owing to outgassing of the concrete deck, and the bubbling caused debonding problems. Overall the construction process was difficult.
Kansas	HSC (4A) f_c' = 5 ksi. Cracking, too much cement. Siloxes and silanes just do not work.
Kentucky	HSC Class AAA (5,500 psi) with silica fume. Transverse cracking in decks—suspended until further testing conducted.
Maryland	Cathodic protection—stopped because of maintenance and cost factor.
Massachusetts	LMC—FHWA no longer supports its use.
Minnesota	Have not changed strategy in 20+ years. Did not have much success using bituminous overlays with membranes.
Mississippi	None.
Nebraska	Sealers, membrane covering.
Nevada	1. Waterproof membranes—Required an overlay on bridge, minimum 3 in. to keep the membrane in place. Required repaving and new membranes every 8 to 15 years. Some studies indicated membranes were effective. We had fair to good performance for protecting decks. 2. Latex-modified concrete overlays—Late 1970s and early 1980s. Used on about five bridges. Overlays debonded, had to be removed from all bridges. Low humidity and high temperatures identified as problems. 3. Low-slump concrete (Iowa)—Late 1970s and 1980s. 50 bridges. Fair performance as far as debonding and surface cracking. 20%—significant debonding problems requiring repair. 90%—some level of surface cracking. 25% of these sealed (methacrylate). Surface cracking (10%) observed within 1 month of construction. Most (90%) surface cracking observed after overlay went into service. Low humidity and high temperatures identified as problems.
New Hampshire	1. Rewarded contractors for increasing permeabilities down to as low as they could achieve. Decks cracked with the high cementitious contents. Changed our permeability target values. 2. Sheet membranes performed poorly. Bubbled up with moisture trapped below them.
New Jersey	Two course deck. Second course used to be LMC or SF overlay. Now require all decks to be HPC with permeability prime performance measure.
New Mexico	Epoxy sand overlays used late 1970s, early 1980s—separated from concrete.
North Carolina	Coating with linseed oil—deemed ineffective.
North Dakota	Linseed oil discontinued—switched to silane.
Ohio	Moving away from asphalt overlays with membrane. Membrane integrity impossible to control.
Oklahoma	In the 1970s, we did a few new bridge decks with high-density concrete overlays and some decks with membranes. This practice was discontinued because of the expense and because of the development of sealers.

South Carolina	Bridge deck sealers and epoxy-coated rebar not effective.
Tennessee	Three-in. asphalt overlay with sandwich seal. Sealant membrane placed between two layers of sand–asphalt mix (E-mix). Top 1 in. used as top lift on approach roadway. System worked well, but only 10-year life—increased dead loads. Still use sandwich seal when repairs to bridge decks with black reinforcing bars and less cover. Protection very good.
Texas	Specified deck concrete with f'_c = 8,000 psi. No longer specifying high-strength decks owing to cracking. Post-tensioned decks. Construction problems outweighed benefits.
Virginia	Linseed oil. Slippery surface when placed on old concrete.
Wisconsin	We tried pilot decks with Type K cement for about 5 years in early 1990s for reduction of cracking, but quit because of problems with scaling, low strength, and high permeability on some decks. (Due to additional water needed to activate expansive component in Type K product.) Note though that it was very effective in stopping deck cracking.
Alberta	Deck concrete cast to grade. Often had full-depth transverse cracks at 1.2 to 2.0 m spacing.
New Brunswick	Epoxy rebar to limited extent. Not considered effective by other agencies.
Newfoundland	Not applicable.
Ontario	Epoxy-coated rebars under review.
Quebec	Bituminous mastic as waterproofing membrane. Too brittle in cold temperatures.
Saskatchewan	High-density concrete overlays no longer used. Only 20-year life before rehabilitation—ride not good.

A8. Please supply any information about life-cycle costs for the different strategies that your agency has used.

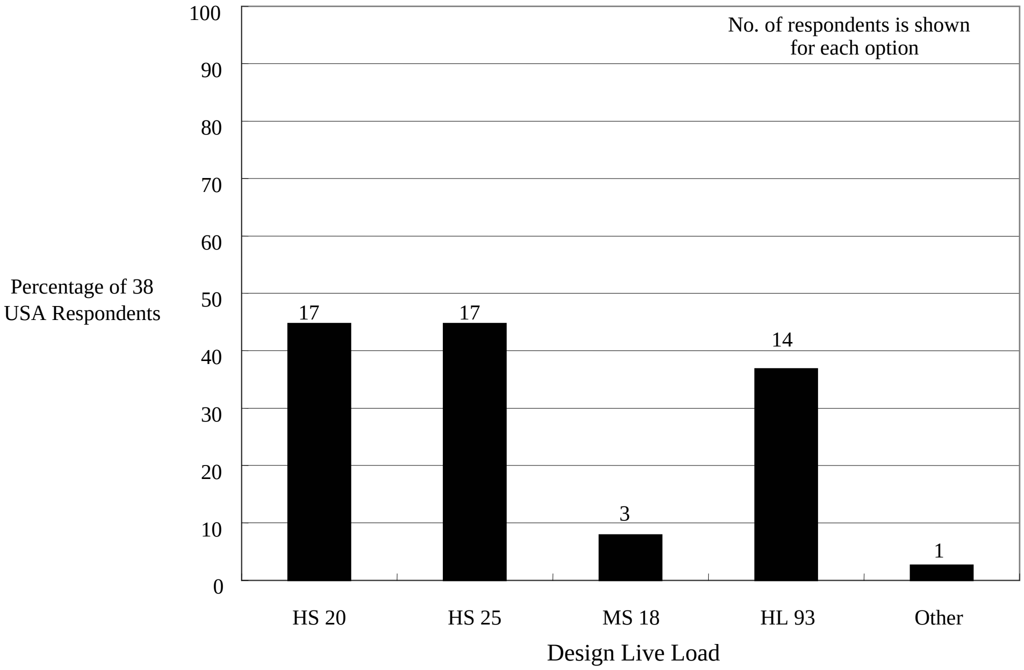
Kansas, Wisconsin, and Saskatchewan supplied information.

A9. Does your agency require any warranties for bridge decks?

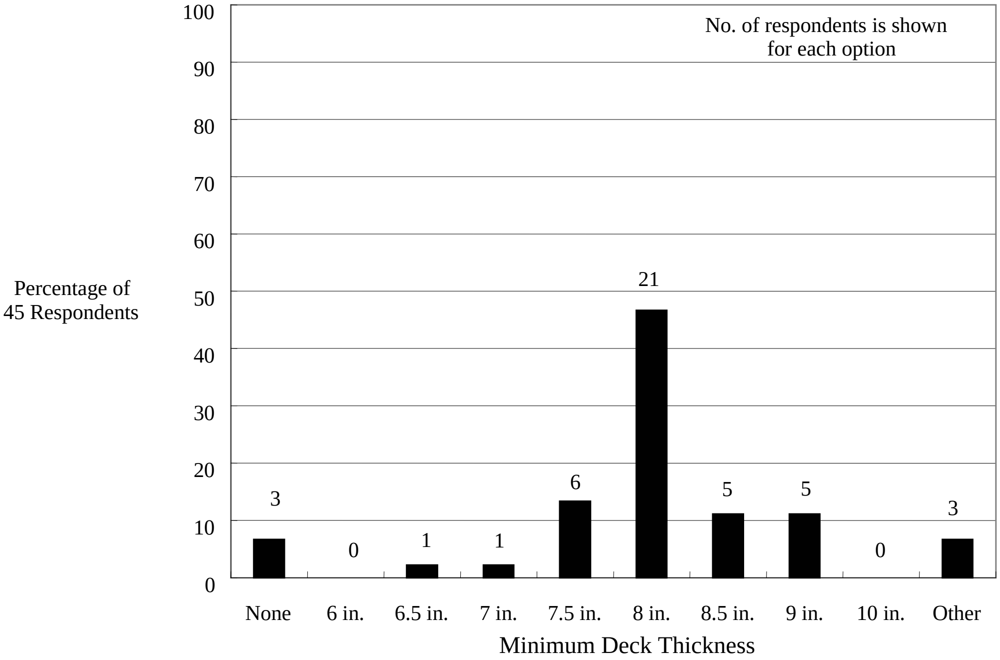
Ohio, Alberta, Newfoundland, and Ontario responded yes.

SECTION B—DESIGN

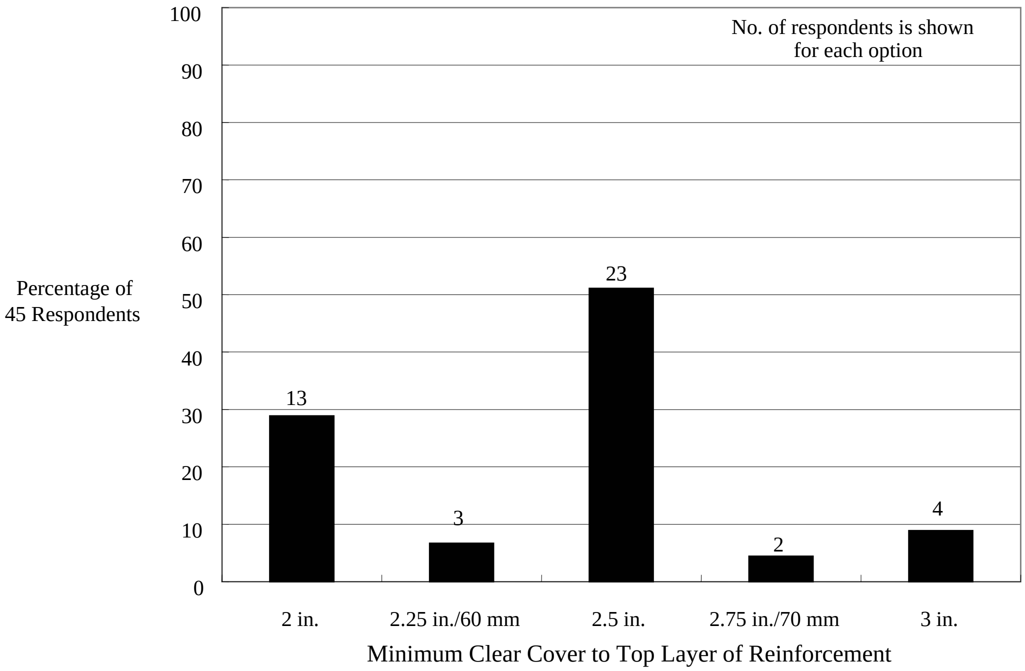
B1. What design live loads does your agency use for bridge decks?



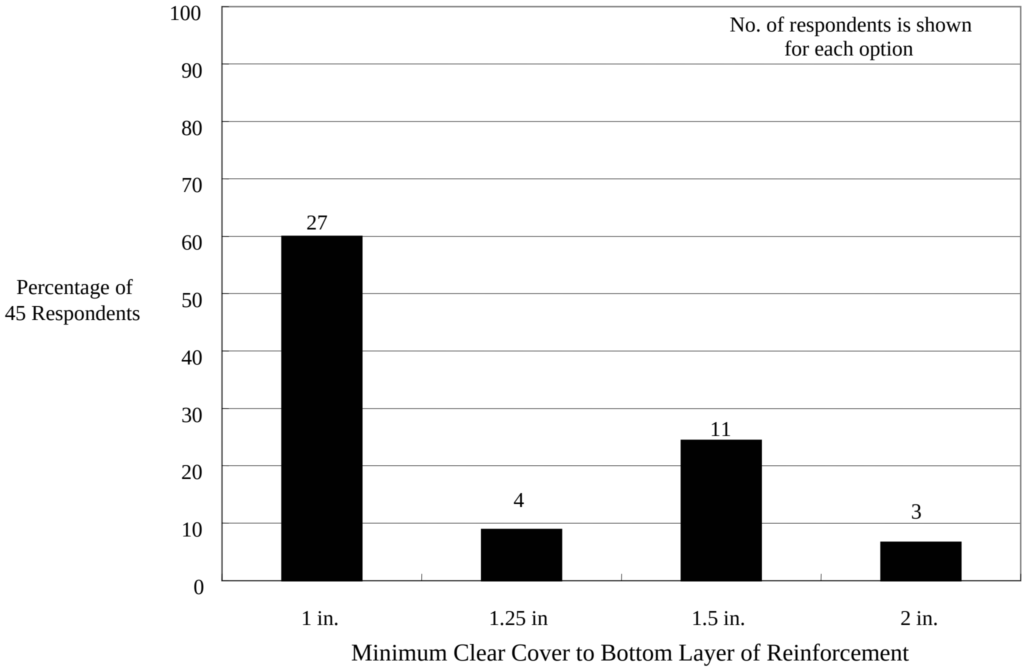
B2. What minimum deck thickness does your agency require?



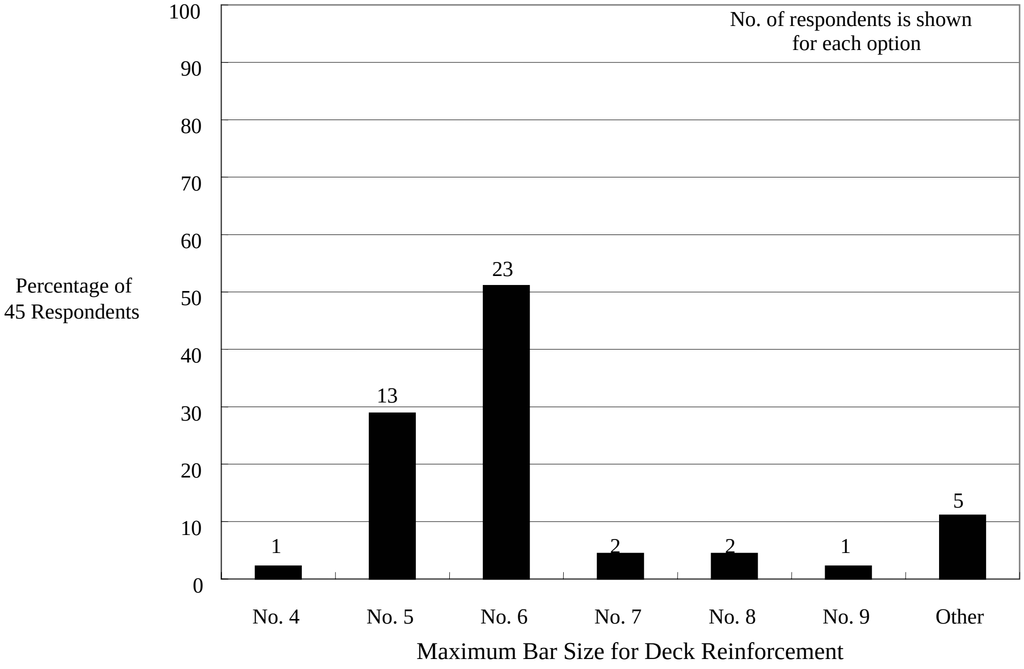
B3. What is the minimum clear cover that your agency specifies for the top layer of reinforcement?



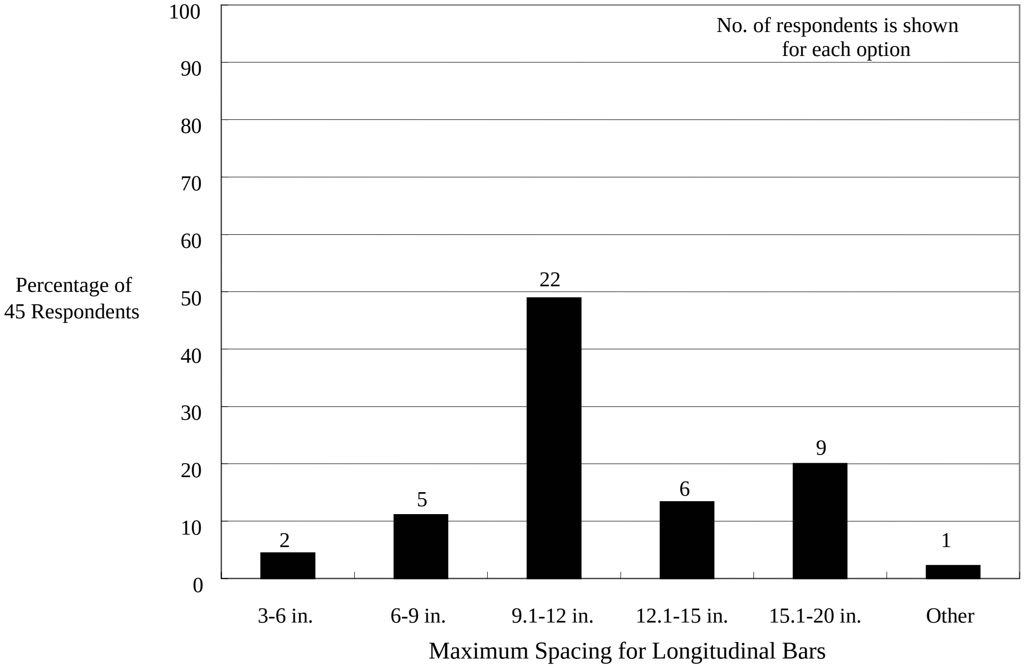
B4. What is the minimum clear cover that your agency specifies for the bottom layer of reinforcement?



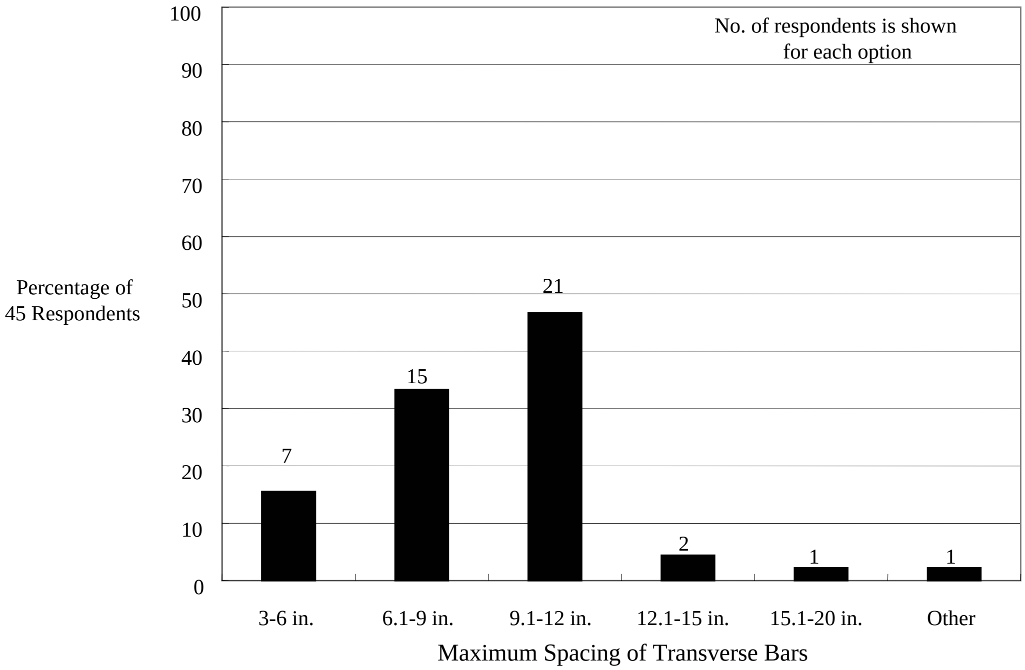
B5. What is the maximum bar size that your agency uses for deck reinforcement?



B6. What is the maximum spacing for longitudinal bars?

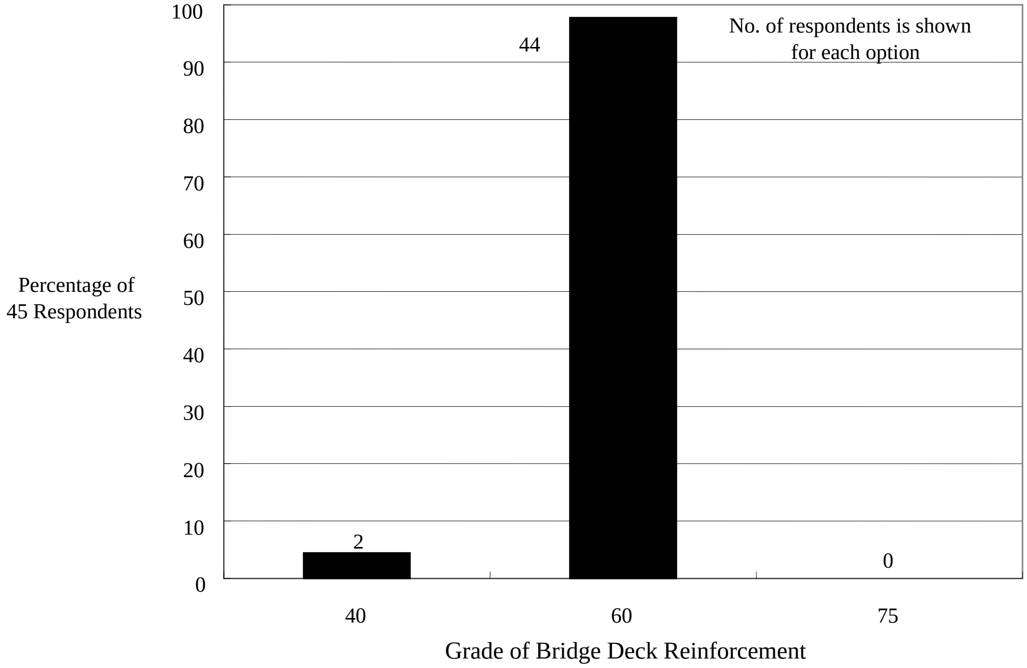


B7. What is the maximum spacing for transverse bars?

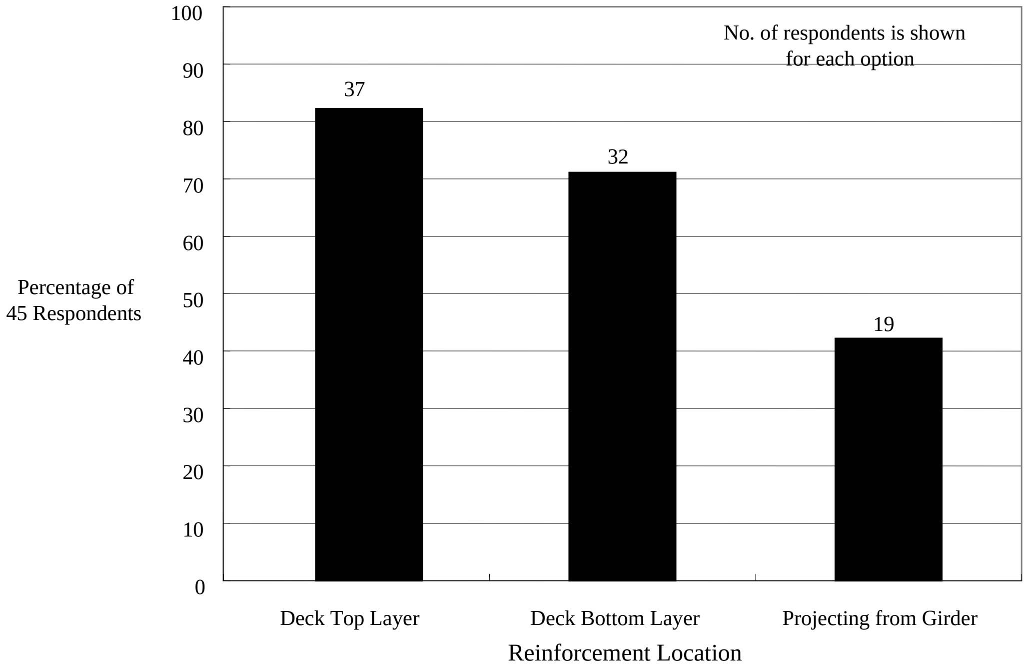


SECTION C—DECK REINFORCEMENT MATERIALS

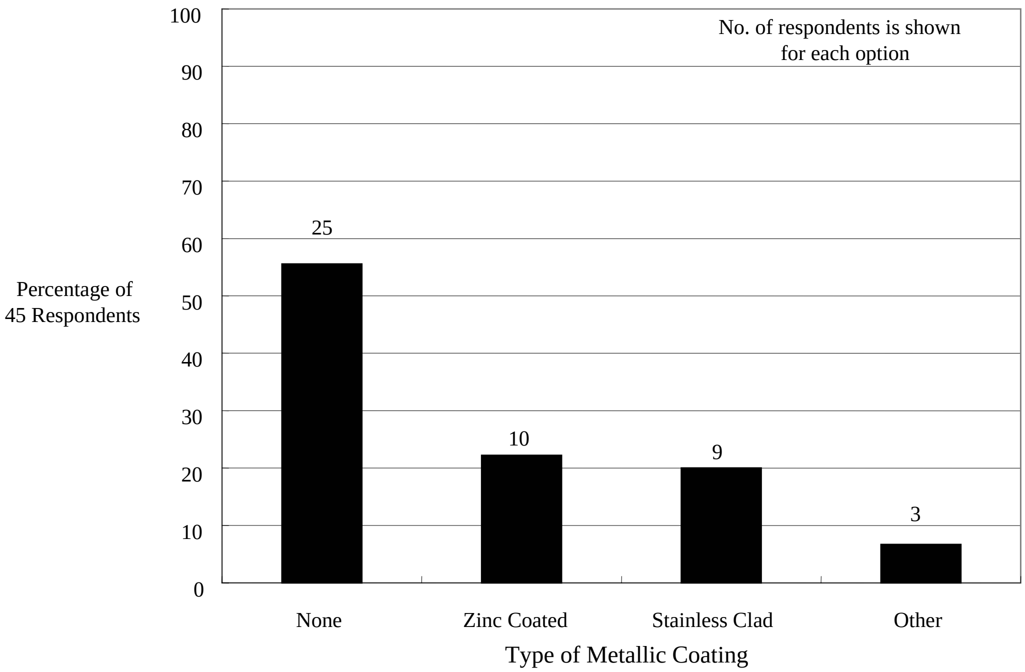
C1. What grade of reinforcement does your agency specify for deck reinforcement?



C2. Does your agency specify epoxy-coated reinforcement?



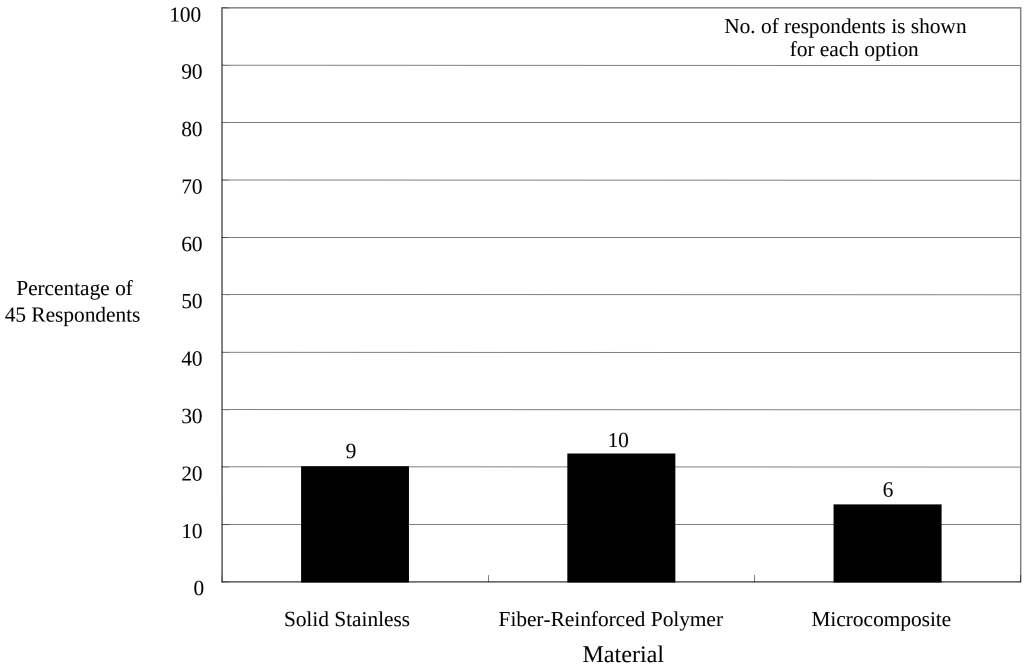
C3. What types of reinforcement with metallic coating has your agency used?



C4. Has your agency used solid stainless steel reinforcement?

C5. Has your agency used fiber-reinforced polymer (FRP) reinforcement?

C6. Has your agency used other corrosion-resistant reinforcement?



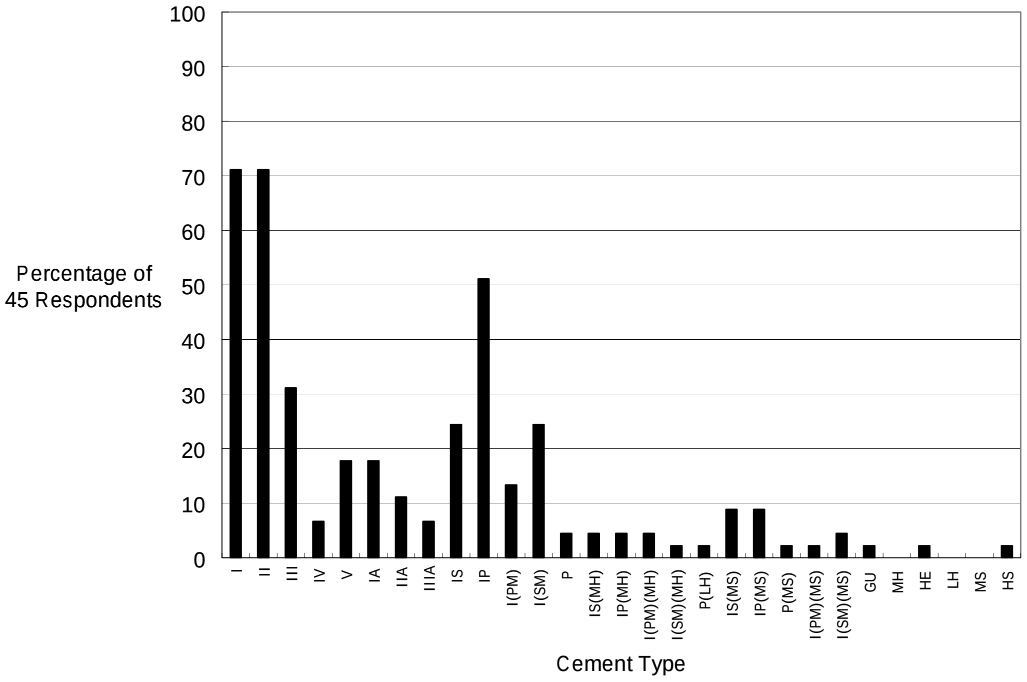
SECTION D—DECK CONCRETE MATERIALS

D1. For each of the following items, please list maximum and minimum values that your agency specifies and typical values used or achieved. Where units are not listed, please state your units in the Comments column (lb/yd^3, % of cementitious materials, etc.)

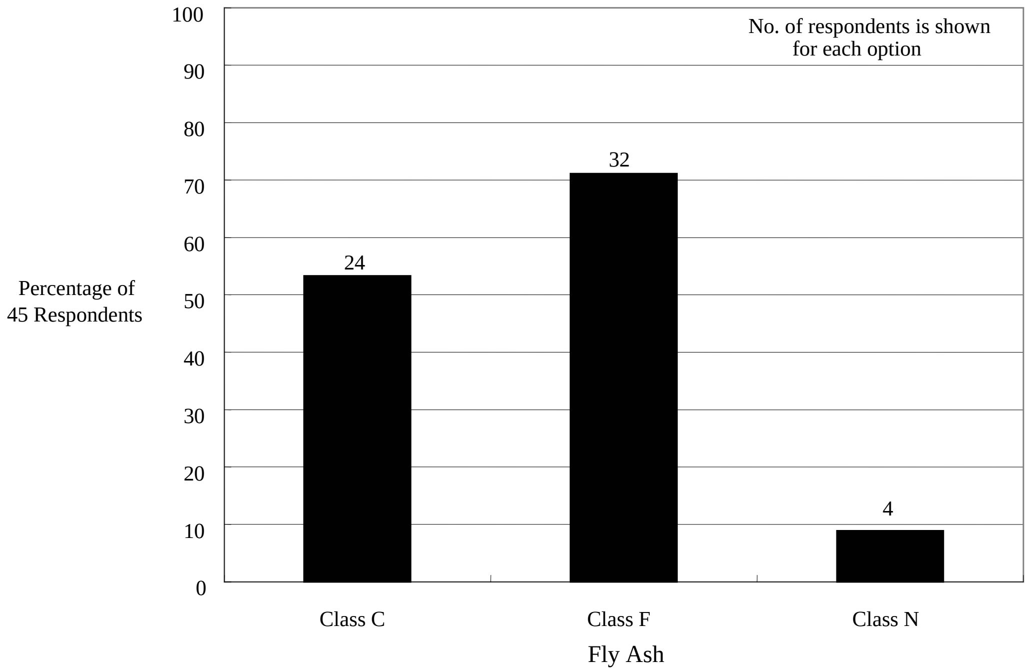
Material or Test	Specified[1]		Typically Used
	Minimum	Maximum	
Cementitious materials content, lb/yd^3	517 to 800	541 to 809	503 to 800
Water-cementitious materials ratio	0.30 to 0.45	0.32 to 0.53	0.32 to 0.47
Cement content,[2] lb/yd^3	467 to 800	590 to 800	500 to 800
Fly ash content,[3] %	0 to 25	10 to 35	15 to 25
Silica fume content,[3,4] %	3 to 7.5	5 to 12	6 to 8
Ground-granulated blast furnace slag content,[3] %	25 to 50	25 to 50	25 to 50
Coarse aggregate maximum size, in.	3/8 to 1-1/2	3/8 to 2	3/4 to 1-1/2
Water-reducer quantity	—[5]	—[5]	—[5]
High-range, water-reducer quantity	—[5]	—[5]	—[5]
Retarder quantity	—[5]	—[5]	—[5]
Corrosion inhibitor quantity	—[5]	—[5]	—[5]
Air content percentage[6]	3 to 6.5	6 to 10	4 to 7
Compressive strength, psi	3,500 to 7,250	4,000 to 7,250	3,500 to 9,000
Tensile strength, psi	—[7]	—[7]	—[7]
Slump, in.	1/2 to 5-1/2	1 to 9	1 to 6-3/4
Chloride permeability (AASHTO T277), coulombs	—[7]	600 to 3,000	1,000 to 2,000
Freeze-thaw resistance (AASHTO T161), %	—[7]	—[7]	—[7]
Deicer scaling resistance (ASTM C672)	—[7]	—[7]	—[7]
Abrasion resistance (ASTM C944), gm or mm	—[7]	—[7]	—[7]
Other	—[7]	—[7]	—[7]

[1] Includes data for HPC mixes and overlays.
[2] Some respondents use a percentage of total cementitious materials.
[3] Percent of total cementitious materials.
[4] Some respondents use an absolute quantity per unit volume.
[5] Quantities vary by product; limited data reported.
[6] Excludes Hawaii.
[7] Limited data reported.

D2. What types of cement does your agency allow?



D3. What fly ash and pozzolan types does your agency allow?



D4. Does your agency have information of situations when the use of specific materials or test values were beneficial to enhancing bridge deck performance?

Yes—11 respondents or 24%
No—25 respondents or 56%

Alaska: Silica fume overlay tested per AASHTO T277 (705 and 722 coulombs).

Indiana: INDOT has recently adopted the use of QC/QA superstructure concrete in bridges through special provisions that require a better quality concrete.

Kansas: Use of silica fume gave lower permeability values than a low water-cement ratio high-density overlay.

Maryland: HPC mix with water-cementitious materials ratio of 0.40, minimum compressive strength of 4,200 psi, polypropylene fibers, corrosion inhibitors, and was tested for chloride permeability.

Nebraska: All materials must be tested and approved before used.

North Carolina: On Manteo Bypass, mix design specifications were based on chloride permeability values obtained by laboratory testing.

North Dakota: The use of fly ash and ground-granulated blast furnace slag for permeability and durability of concrete.

Alberta: Performance monitoring has proven that the use of specific materials is beneficial.

Newfoundland: Core testing versus wet concrete air-void testing confirmed that pumping of concrete did not result in a loss of the air-void system.

Nova Scotia: Use of HPC reduced the number of girders required on one project. Use of waterproofing membranes and increasing the cover has increased the time between repairs.

Quebec: Use of ternary blend of cementitious materials plus fogging as a method of intermediate curing.
Placement of concrete by the finisher (Gomaco type).
Placing concrete at night with lower temperatures.

D5. Does your agency have information of situations when the use of specific materials or test values was <u>not</u> beneficial to enhancing bridge deck performance?

Yes—5 respondents or 11%
No—28 respondents or 62%

Indiana: Type K cement, DCI and Postrite corrosion inhibitors, slag cement, and Flexolith epoxy overlay do not meet design life.

Iowa: Silica fume and high-range, water-reducer in a deck caused inconsistent air contents.

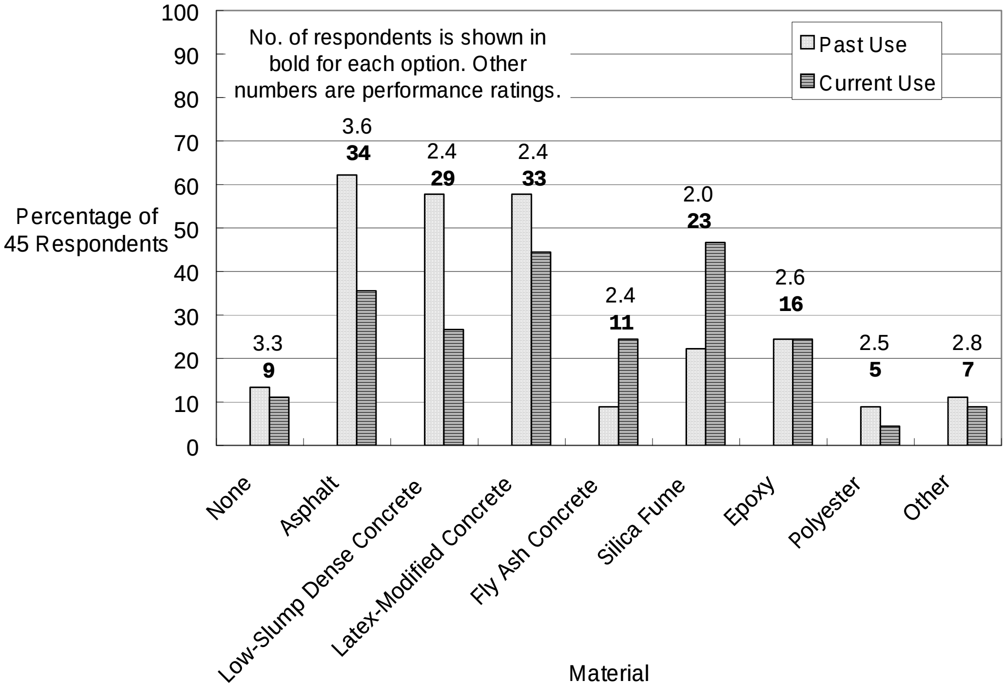
Texas: High-strength concrete due to cracking.

Wisconsin: Twenty bridge decks with a specification requiring a maximum water-cementitious materials ratio of 0.40 and mandatory use of high-range, water-reducing admixture. High level of early cracking occurred on several decks.

Quebec: Evaporation retardants not effective.
Daytime concreting produced temperature problems.

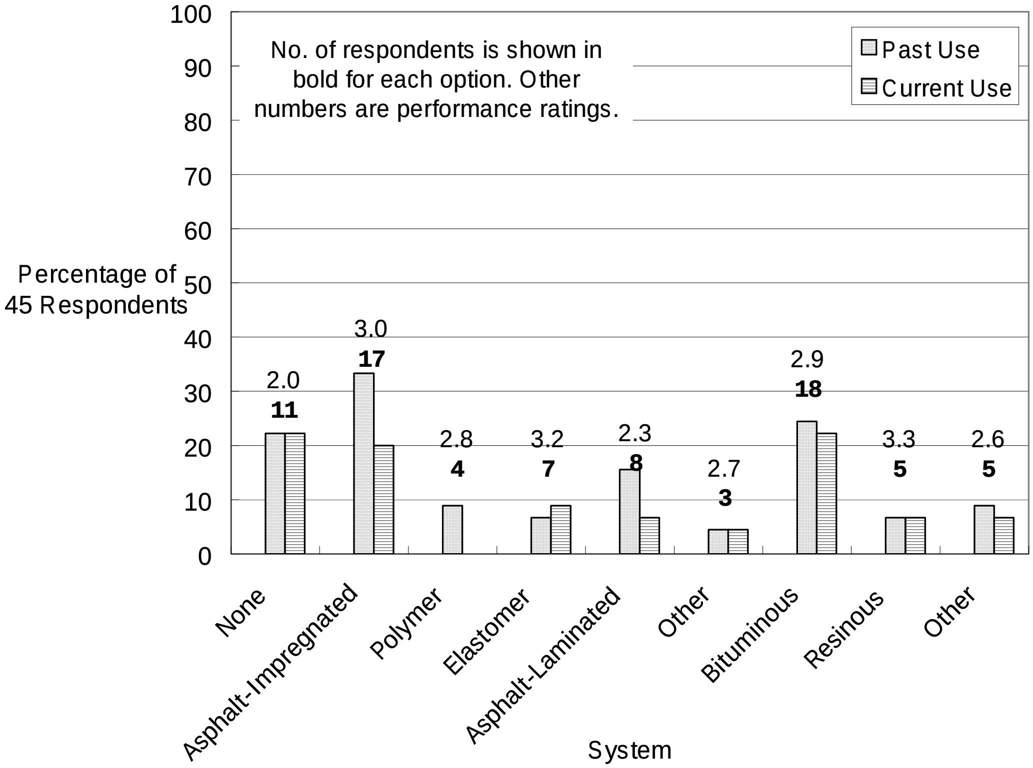
SECTION E—PROTECTIVE SYSTEMS

E1. Which of the following overlay systems has your agency used in the past and which does your agency currently use? For each overlay system that your agency has used, please rate its performance on a scale of 1 to 5, where 1 = excellent and 5 = poor.

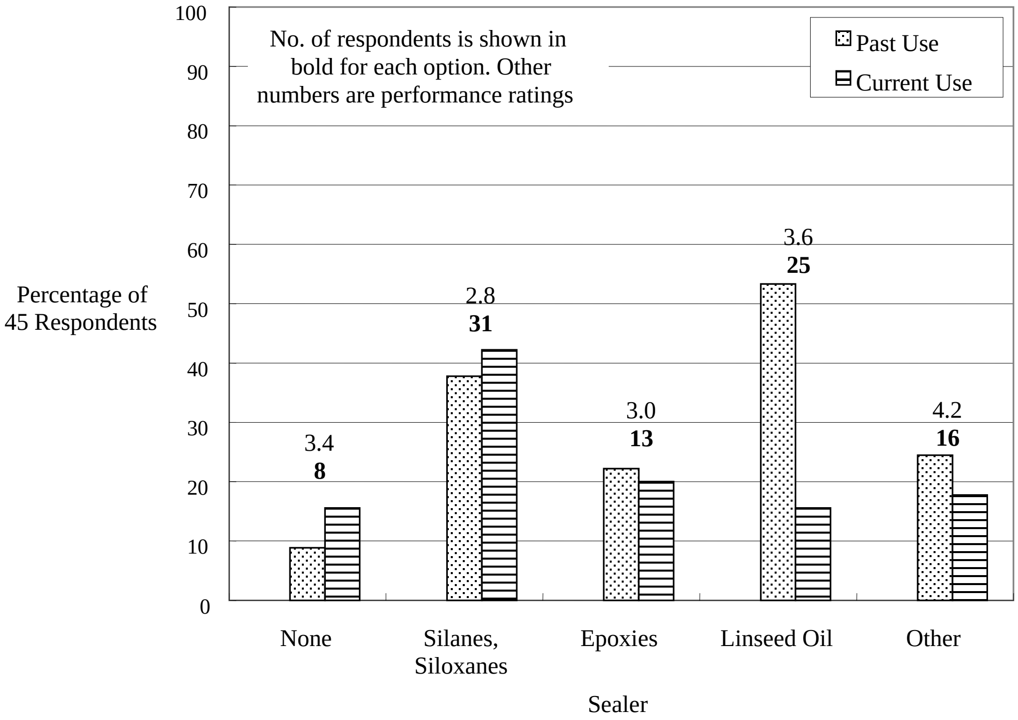


E2. Which of the following waterproofing membrane systems has your agency used in the past and which does your agency currently use?

For each waterproofing membrane system that your agency has used, please rate its performance on a scale of 1 to 5, where 1 = excellent and 5 = poor.



E3. Which of the following sealers has your agency used in the past and which does your agency currently use. For each sealer that your agency has used, please rate its performance on a scale of 1 to 5, where 1 = excellent and 5 = poor.



E4. If your agency has used cathodic protection systems in the past, please provide the name of the system(s) and describe how successful it was:

State/Province	Description
Alaska	Norton Corrosion was not successful because the system was not maintained.
California	Coke breeze, metallized zinc, conductive polyester concrete.
Delaware	One bridge deck using a nonoverlay grid anode system consisting of primary (platinum wire) and secondary (carbon strand) anodes installed in sawed slots (3/4 in. x 3/4 in.) backfilled with conductive polymer concrete grout. Installed in 1986 by Matco, Inc., of Doylestown, PA.
Dist. of Columbia	One cathodic protection system placed on an Interstate ramp and worked well.
Georgia	Not used.
Illinois	Elgard and Corrpro—Never evaluated, probably forgotten.
Indiana	Impressed current system; to date successful.
Iowa	Three bridges total; two with Raychem, both shut off in less than 5 years. Elgard is still working, but bridge is scheduled for replacement.
Kansas	Corrpro anode mesh depressed current installed in 2001. Too recent to assess. Vector Galvashield XP embedded anode system. Too recent to assess. Zinc Hydrogel—installed on an abutment and portion of concrete box girder in 2002.
Maryland	Cathodic protection systems installed at 12 sites. Ongoing electrical problems have provided limited success.
Minnesota	Two test installations—system didn't operate with enough reliability to make final conclusions.
Montana	Two installations—Neither very successful.
Nebraska	The name of the system is unavailable. High degree of success.

Nevada	Two bridges were constructed with a Raychem system consisting of a grid of carbon strands/conductive grout and platinum wire in 1986. It was encased in a low-slump concrete overlay. It was removed in 2002 as part of a widening project. The low-slump overlay debonded and the grid system was damaged beyond repair. It is not known how well the CP system worked. The bridges had been in service for 20 years prior to the CP system being installed and there is no record of the deck's condition at that time.
New Hampshire	System name unknown. Not maintained and no data on success.
New Jersey	Have used titanium mesh system, mounded conductive polymer system, and flexible conductive polymer system.
Oklahoma	Harco Corp. system installed on one bridge by Good-All Electric, Inc. We had problems with maintenance and vandalism. A report is available*: Cathodic Protection for Reinforced Concrete Bridge Decks*, dated 1988.
Texas	Currently using sacrificial galvanic anodes marketed by Vector Corrosion Technologies on a limited basis. However, not enough field data to assess reliability of system. TxDOT currently participating in CERF evaluation of this product.
Utah	Name of the system unknown. The system and performance were unreliable.
Virginia	Used only on some experimental projects.
Alberta	1. Used a titanium mesh system embedded in concrete overlay on a number of bridges about 10 years ago. Systems still appear to be working. However, initial costs were high and systems require continuing monitoring and maintenance. 2. Conductive paint system used on underside of deck on one bridge. The resistance of system increased over time and it was not possible to maintain voltage potential required.
Nova Scotia	Cathodic protection was used on one structure in the early 1980s. The impressed current system used coke breeze layer over the deck in conjunction with silicon iron and pancake type anodes buried in the deck. The system appears to be effective as no repairs have been conducted on the structure since its installation.
Ontario	Conductive asphalt system was used until late 1980s, but performance was very poor. From early 1990s, titanium mesh system with normal concrete overlay has been used and the performance has been good so far.
Quebec	Partial experimentation—three zones of deck rehabilitation in 1989 (5,800 ft^2). Mesh Elgard 210 + latex-modified overlay (25 mm). Important reduction of corrosion activity and consequently less deterioration. Operation of the system has been discontinuous (human resource and logistic problems).
Saskatchewan	Ferex—not successful; Elgard—worked adequately.

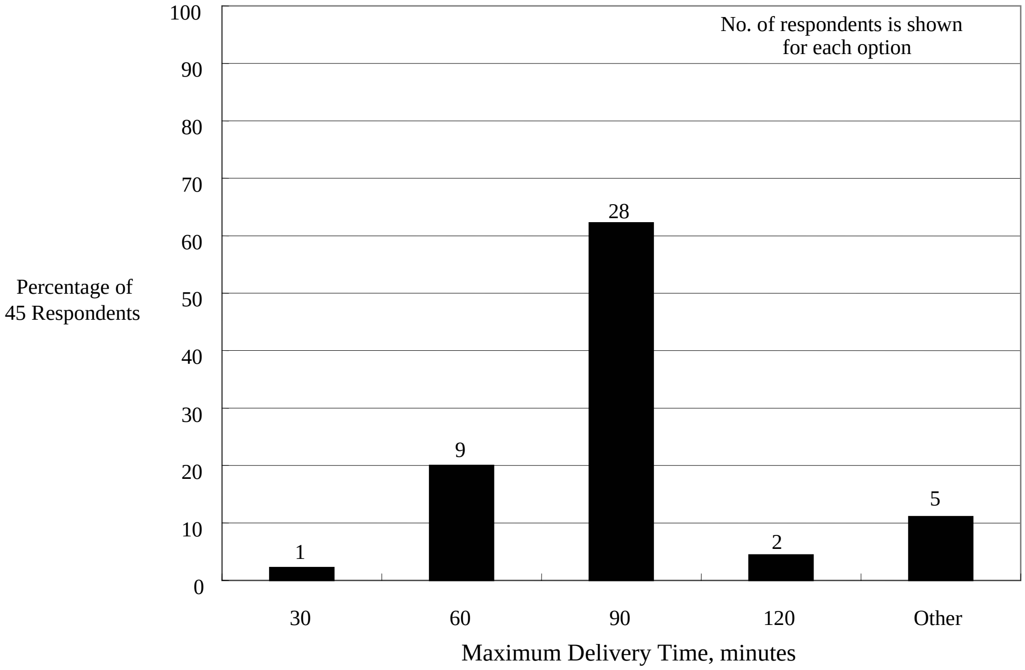
E5. Describe your agency's experience with protective systems.

State/Province	Response
Alabama	Not applicable.
Alaska	Success with asphalt overlay with waterproofing membrane and silica fume overlays.
Arkansas	Not applicable.
California	Good.
Connecticut	Preformed sheet systems bonded poorly to bridge decks and were discontinued. The current woven glass fabric hot mopped system bonds well and seems to waterproof well, but is very difficult to remove for resurfacing. Extra cover of 1/2 in. was recently added to accommodate milling to remove it. Liquid applied systems (Sterling Lloyd's Eliminator) work well but are very expensive and therefore not competitive. Silica fume concretes and latex-modified overlays have very limited use to date. Latex-modified overlay seems to work well and may see more future use. HPC decks are difficult to cure and have had some cracking problems. However, there will probably be more use of bare HPC decks in the future. Cathodic protection has limited use and requires maintenance of the system, which is sometimes lacking. Sealants have not been tried extensively and seem of limited use.
Georgia	With adequate cover, we do not need protective systems. Georgia aggregate coupled with a few freeze-thaw cycles in the state is very successful.
Hawaii	None.
Indiana	For the most part a positive experience.
Iowa	The asphalt overlay was tried on only a few bridges. Although a latex-modified overlay is permissible, contractors prefer the low-slump Iowa mix, and few latex-modified overlays have been constructed. In the future, Iowa plans to seal HPC decks for 6 to 8 months until permeability matures.
Kansas	No success with BM-2 when laid without a membrane. Varied success when laid with a membrane. Sealers work only if applied every year. Low-slump, silica fume, and latex overlays work well if cured properly (or cracking problems occur). Not experienced any problems with epoxy-coated bars on decks 20 to 25 years old.
Minnesota	Tremendous experience with low-slump dense concrete overlays for rehabilitation and new construction. Have built 12 bridges with full-depth (9 in.) silica fume decks. Have had construction problems on four of the bridges.
Nebraska	Cathodic protection has been the best active system.
Nevada	Protective systems have been used on bridges when they did not have epoxy-coated reinforcement. See question A7 for description of systems no longer in use. Our current protection system is the polyester-styrene overlay developed by Caltrans. We have been using this system for about 10 years with very good performance. It has been placed on about 50 bridges. We have had only one major failure and it was not due to the system but the deck under the overlay failing. Minimum thickness is 0.75 in. The system works well in Nevada owing to our dry climate in summer, which is beneficial to polymers.
New Hampshire	Continuing process of trial and error going from one system to the next as problems are encountered with each.
New Jersey	Overall performance was good—see answer to question E4.
North Dakota	None.
Ohio	Application of concrete sealers is standard practice on new construction. Many districts use on rehabilitation projects.
Oklahoma	The sealers appear to be helping.
South Carolina	Overall, minor.
Tennessee	Epoxy-coated reinforcement with 2-1/2 in. clear cover is our best system for new construction. Asphalt/sandwich seal are the next best and most cost-effective system. PMC overlays are good alternative in conjunction with scarifying away the top 1 in. of existing contaminated deck when avoiding the need to raise existing expansion joints. When eliminating joints, we prefer scarifying the top 1 in. of existing deck and placing 4-1/2 in. of 4 ksi concrete overlay with one mat of epoxy-coated reinforcing. This works well with widening without adding girders or widenings where cross-slope changes are required or crown locations are moved. Had poor results with low-slump dense overlays bonding, attributed to lack of contractor expertise and heavy screed rollers.

Texas	Not enough field data to comment on performance of system. In aggressive environments, TxDOT is specifying the use of HPC.
Newfoundland	Nil.
Ontario	The single most cost-effective protective system is the waterproofing membrane. It generally lasts about 25 years before replacement. Recently, study on decks has shown very little chloride penetration through the waterproofing after 18 to 20 years in service.
Saskatchewan	Iowa method, high-density overlays, epoxy-coated bars, high-performance concrete, and asphalt with hot applied rubber membrane.

SECTION F—CONSTRUCTION PRACTICES FOR FULL-DEPTH DECKS

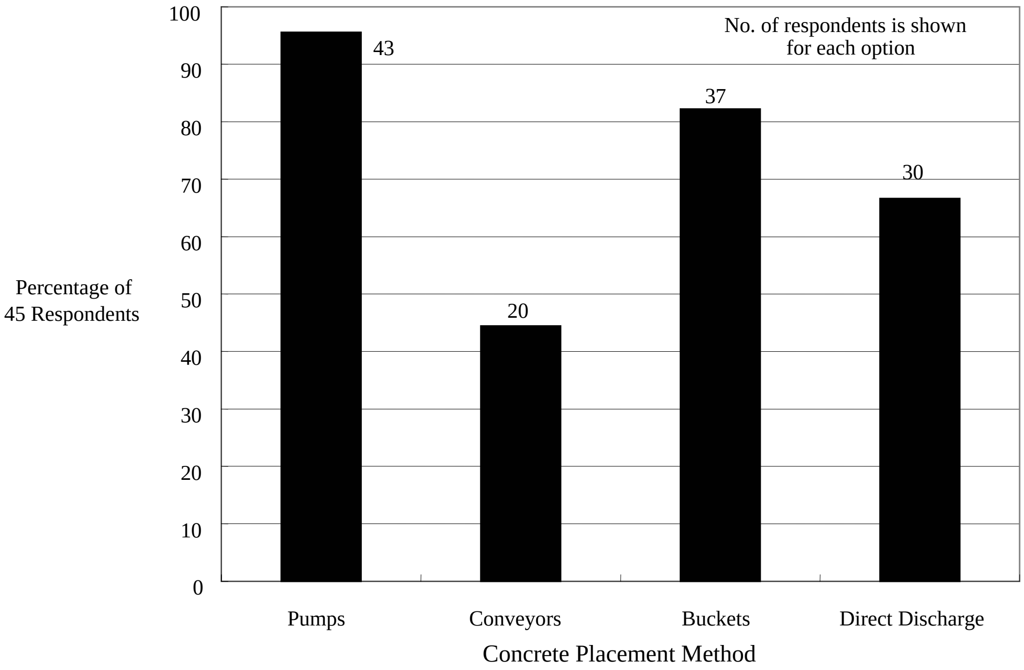
F1. What maximum delivery time after batching does your agency specify?



F2. Does your agency specify the concrete placement method?

Yes—7 respondents or 16%
No—36 respondents or 80%

F3. What methods of concrete placement are used?



F4. Under what conditions does your agency require fogging systems?

State/Province	Conditions
Alabama	Hot weather, low humidity.
Alaska	Throughout finishing process.
Arkansas	Not specified.
California	Not required, but is an option.
Connecticut	Fogging shall start immediately after initial set and continue until cotton mats are in place.
Delaware	Specifications require conformance to ACI 305R “Hot Weather Concreting.”
District of Columbia	Some precast units.
Georgia	Not specified.
Hawaii	All bridge decks are required to be water cured, which includes fogging. Specifications do not require fogging during concrete placement.
Illinois	Evaporation rate $\geq$0.1 lb/ft^2/h. Equipment required for all projects.
Indiana	Only when using QC/QA superstructure concrete with silica fume and when evaporation rates >0.1 lb/ft^2/h.
Iowa	May be used if evaporation rate >0.2 lb/ft^2/h.
Kansas	Based on chart. Required for overlays.
Kentucky	With silica fume concrete.
Maryland	Misting equipment must be on site for all deck placements. If concrete is not covered with burlap within 30 min of placement, misting must start and continue until burlap is placed.
Massachusetts	Evaporation chart provided. Fogging required when rate exceeds 0.15 lb/ft^2/h.
Minnesota	Only for silica fume concrete.
Mississippi	Thin bridge deck overlays.
Montana	All deck placements.
Nebraska	Evaporation rate $\geq$0.15 lb/ft^2/h.
Nevada	Every deck placement.
New Hampshire	Not specified.
New Jersey	Per Standard Specifications 2001 NJDOT 501.12 Item 5.
New Mexico	Fog spray reduces rate of evaporation. Specifications provide graphs when additional measures required.
New York	None. Fogging has been inappropriately used with excess water used as finishing aid—scaling resulted.
North Carolina	Conditions not specified. Require fogging equipment on site capable of placing enough moisture to curb effects of rapid evaporation.
North Dakota	When water-saturated covers are not on before concrete surface begins to dry.
Ohio	None.
Oklahoma	Require fogging then curing on fresh deck concrete.
South Carolina	All deck concrete.
Texas	Advised to start at evaporation rates of 0.10 lb/ft^2/h, but not specified. Shrinkage cracks generally occur at rates above 0.25 lb/ft^2/h.
Utah	When combination of air temperature, humidity, and wind velocity have the potential to impair the concrete quality.
Virginia	Excessive evaporation, delay in covering.
Washington	None.
Wisconsin	Decks more than 100 ft long.
Alberta	For 50 MPa HPC.
New Brunswick	All conditions for a deck. Concrete usually placed at night or early morning.
Newfoundland	All conditions.
Ontario	Required for HPC and immediately after finishing.
Quebec	Always after placement by automatic finisher.
Saskatchewan	Not yet used.

F5. What surface finish does your agency specify for deck concrete?

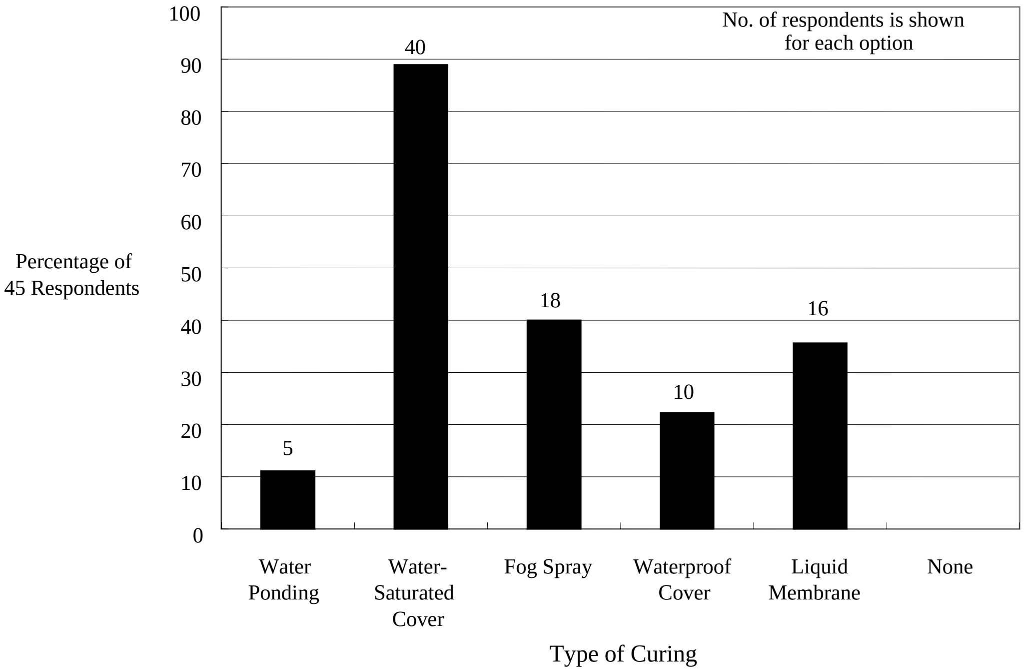
State/Province	Surface Finish
Alabama	Saw grooved after curing.
Alaska	Sawcut groove.
Arkansas	Burlap drag followed by tining.
California	Friction coefficient at least 0.35, profile counts, no high point above 6.36 mm.
Connecticut	Float finish is standard practice because decks are overlaid. In rare instances of bare decks, a tined finish is required.
Delaware	DelDOT Standard Specifications Section 602.20.c: mechanical grooving (0.1 in. wide, 1/8 in. deep, cut at 1.5 in. centers or cut at random centers) and manual texturing (broom 0.1 in. wide, 0.2 in. deep, at 1/2 to 3/4 in. centers). The use of mechanical grooving allows the placement of curing compound soon after the finishing machine has passed an area.
District of Columbia	Diamond saw cutting.
Georgia	Belt finish.
Hawaii	Float finish with a finishing machine. Final surface is textured with metal tines to produce transverse grooves.
Idaho	Longitudinal tined surface.
Illinois	Burlap or artificial turf carpet drag. Tining done after curing is completed.
Indiana	Finished and tined in accordance with Standard Specification 704.05. For details go to www.in.gov/dot/div/contracts/standards/book/sep03/sep.htm.
Iowa	For standard “C” mix, pan drag with burlap followed by a transverse rake texture. For HPC, pan drag with Astroturf. (Longitudinal grooves cut later.)
Kansas	Tined.
Kentucky	Transverse tining after deck finished with Bidwell machine.
Maryland	Transverse grooves.
Massachusetts	For exposed decks: artificial turf drag and transverse sawcut grooves. For decks to be overlaid with bituminous concrete: smooth surface.
Minnesota	Metro area: surface planing. Other areas: carpet drag and transverse wet tining.
Mississippi	Broom finish, then mechanically grooved.
Montana	Burlap then transverse sawcut grooves.
Nebraska	Tined.
Nevada	Whatever the Bidwell produces. Grooves cut after the deck is cured.
New Hampshire	CSP 5 or less.
New Jersey	Per Standard Specifications 2001 NJDOT 501.15 deck slab surface finish.
New Mexico	Broom finish during finishing. Grooving after curing.
New York	Astroturf drag while concrete is plastic with sawcut grooving 1/4 in. deep, 1/4 in. wide at 1.5 in. spacing after curing.
North Carolina	Burlap drag or broom finish and grooving required.
North Dakota	Tining.
Ohio	Screed or bullfloat and cover with burlap then diamond bladed grooving.
Oklahoma	Tined.
South Carolina	Random transverse grooves at 1/2 to 1-1/8 in. spacing.
Tennessee	For design speeds <40 mph, burlap drag. For design speeds ≥40 mph, sawed transverse grooving.
Texas	Bare surfaces require a grooved steel tine finish applied to the fresh concrete. For asphaltic overlays, a broom finish is required.
Utah	Machine finish and transverse texturing.
Virginia	Burlap during screeding and sawcut grooves on hardened concrete.
Washington	Nail broom 3/16 in. deep, 1/8 in. wide at 1/2 in. spacing.
Wisconsin	Turf drag then tined.
Alberta	Magnesium floated.
New Brunswick	Free from voids and protrusions, acceptable for peel and stick waterproofing.
Newfoundland	Broom finish.

Nova Scotia	Textured finish free of ridges, depressions, undulations, and blemishes. When tested with 3-m-long straight edge, no gap greater than 8 mm in any direction.
Ontario	Mechanical finishing followed by burlap drag. No hand finishing except at deck edges where machine does not reach.
Quebec	Trowel finish—good quality in order to install membrane afterwards.
Saskatchewan	Broomed.

F6. Under what conditions does your agency require the use of evaporation retardants prior to initiation of curing?

State/Province	Condition
Alabama	Hot weather placement.
Alaska	None.
Arkansas	Application of clear curing compound immediately after final finishing and before application of covers.
California	Not required, but is an option.
Connecticut	None.
Delaware	DelDOT requires evaporative retardants when silica fume is used in the concrete.
District of Columbia	None.
Georgia	Not specified.
Hawaii	None.
Illinois	Not allowed.
Indiana	Only with QC/QA superstructure concrete per the special provisions.
Iowa	For standard “C” mix, if wet burlap is not on within 15 min. For HPC, if wet burlap not on within 10 min.
Kansas	Always.
Kentucky	Set retarders used on bridge deck concrete.
Maryland	Not applicable.
Massachusetts	Only for unavoidable delays during placement.
Minnesota	Not allowed.
Montana	Not used.
Nebraska	Allowed, but not required. White pigmented curing compound is required.
Nevada	Every project.
New Hampshire	Not applicable.
New Jersey	Evaporation retarders not generally used.
New Mexico	Not required.
New York	None.
North Carolina	None.
North Dakota	None.
Ohio	At air temperature above 60°F with ASTM C494 Type A or D.
Oklahoma	Minimum air temperature of 70°F and rising.
South Carolina	All deck concrete.
Texas	Membrane is used as an interim cure. Membrane applied after free moisture disappears. Evaporation retardants are not required.
Utah	Contractor’s decision—based on temperature, humidity, wind, etc.
Virginia	Allowed if excessive evaporation is present.
Wisconsin	Allowed—contactor’s choice.
New Brunswick	Have stopped using due to abuse during finishing. Once finishing completed, fogging starts.
Newfoundland	All conditions.
Nova Scotia	Only with HPC.
Ontario	Not normally required or specified.
Quebec	Not applicable.
Saskatchewan	Always.

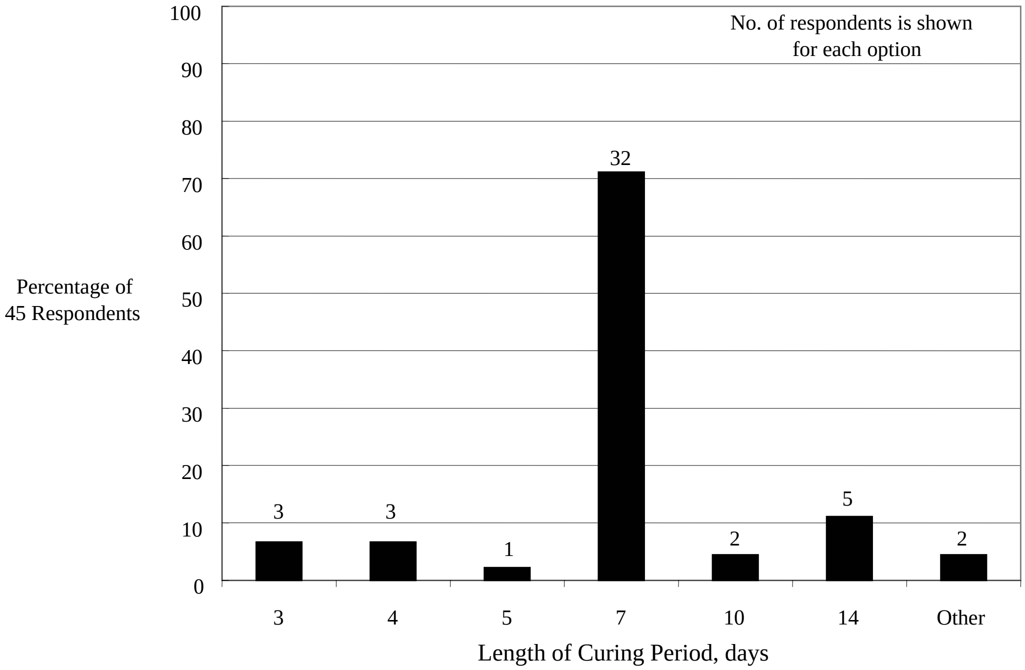
F7. What type of curing does your agency specify?



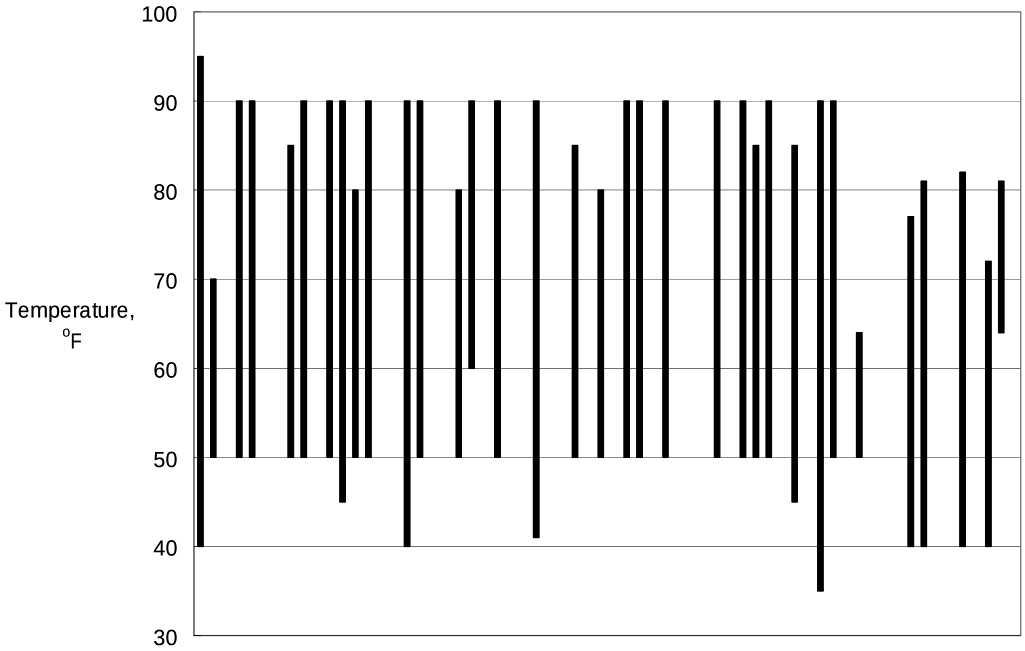
F8. When does your agency specify that curing must begin?

37 or 82% of the respondents replied "Immediately after finishing any portion of the deck." The other respondents had other criteria.

F9. What length of curing period does your agency specify?



F10. What range of initial concrete temperature does your agency permit?



F11. What value, if any, does your agency specify for maximum temperature of deck concrete during the curing period?

The majority of respondents replied that they do not specify a maximum value. Exceptions were

Massachusetts: 154°F

Alberta: 140°F

Ontario: 158°F

New Brunswick: 140°F

F12. How frequently are the following tests made for quality control during deck placement?

Responses to this question indicated a wide range of practices. Some agencies reported that tests were made on the first delivery of concrete and at a regular frequency thereafter. Others reported a regular frequency of testing. This frequency varied from every 20 yd^3 to every 400 m^3. Tests for slump, air content, and initial concrete temperature were generally measured at the same frequency. Measurement of unit weight was performed by fewer respondents than the other fresh concrete tests. Water content was only measured by a few agencies. The frequency of compressive strength measurements varied from one set per 20 yd^3 to one set per 400 m^3. The most common response was one set per 50 yd^3.

F13. Does your agency conduct tests of the hardened in-place concrete to check end-product performance?

Yes—6 respondents or 13%
No—23 respondents or 51%
Sometimes—16 respondents or 36%; mainly related to low concrete strengths or observed deficiencies.

F14. Does your agency use any in-place sensors or instrumentation for quality control during construction?

Yes—10 respondents or 22%
No—34 respondents or 76%

In the United States, use of maturity meters was reported by four states. In Canada, the use of temperature sensors was reported by five provinces.

F15. When staged construction is used, does your agency require that the freshly placed concrete be isolated from traffic-induced vibrations in adjacent open traffic lanes?

Yes—12 respondents or 27%
No—35 respondents or 78%

Two respondents replied Yes and No.

F16. Does your agency require repair of cracks if they occur during construction?

Yes—35 respondents or 78%
No—9 respondents or 20%

F17. What methods are used to repair cracks?

The two predominant methods were epoxy injection and the use of methyl methacrylate or other sealant.

F18. Explain which repair methods are most effective in prolonging deck service life:

Epoxy injection and overlays were considered to be the most effective.

SECTION G—MAINTENANCE

G1. Does your agency repair cracks when they occur in bridge decks?

State/Province	Yes	No	Sometimes	Explanation
Alabama	X			
Alaska	X			
Arkansas		X		
California	X			
Connecticut			X	Most cracks are not repaired but are sealed with a membrane. Large open cracks may be repaired by injection.
Dist. of Columbia			X	Depends on extent of cracking.
Georgia	X			
Hawaii			X	Cracks are recommended to be repaired if structural or they compromise structural reinforcement.
Idaho	X			
Illinois		X		
Iowa		X		
Kansas			X	Large cracks—may fill with HMWM or epoxy injection.
Maryland	X			
Massachusetts			X	Depends on severity. Narrow infrequent cracks not repaired. Wider more frequent cracks are repaired.
Minnesota	X			
Mississippi		X		
Montana		X		
Nebraska			X	Eight districts. Each district approaches the problem in its own way. Cracks must be obvious before treated.
Nevada	X			
New Hampshire	X			
New Jersey	X			
New Mexico			X	New construction: HMWM. Existing: Do not generally seal cracks.
New York			X	Recently initiated a program to treat cracks using state personnel.
North Carolina	X			
North Dakota		X		
Ohio	X			
Oklahoma			X	New decks: Seal cracks the following summer with a sealing contract that includes the cracks and a silane treatment. Old decks: usually do not do anything—have done a flood coat with a HMWM or epoxy alternate.
South Carolina			X	Depends on severity.
Tennessee			X	Excessive or >0.125 in. methyl methacrylate. Abnormal working structural cracks are epoxy injected.
Texas			X	Discretion of Engineer with jurisdiction over bridge. Will consult with District Bridge Engineer or Bridge Division for recommendations.
Utah			X	Preventive maintenance program.
Virginia	X			
Washington		X		
Wisconsin	X			
Alberta			X	Depends on width and extent.
New Brunswick			X	If construction method contributed to cracks—then repaired.
Newfoundland		X		

Nova Scotia			X	Depends on severity.
Ontario			X	Depends on crack width, repair if >0.3 mm.
Quebec		X		
Saskatchewan	X			

G2. What methods does your agency use to repair cracks?

Alabama: Sealants for hairline, epoxy injection for larger.

Alaska: Fill cracks with HMWM resin.

Arkansas: We don't repair surface cracks, we use epoxy to seal surface cracks.

California: Methacrylate, epoxy-inject (rarely).

Delaware: Seal with Pronto 19. Mill and overlay with LMC.

District of Columbia: Approved job-specific epoxy crack sealer.

Georgia: General sealants, epoxy, concrete overlays.

Hawaii: Sealer or epoxy injection.

Idaho: Methacrylate, epoxy.

Kansas: Large cracks—may fill with HMWM or epoxy injection.

Maryland: Epoxy injection.

Massachusetts: Epoxy injection, methyl methacrylate.

Minnesota: Sweep, blast, epoxy crack sealer.

Nebraska: Low-viscosity, high-density polymers.

Nevada: Methacrylate resins.

New Hampshire: Methyl methacrylate.

New Jersey: SIKA Pronto 19.

New Mexico: HMWM.

New York: Gravity feed ultra-low viscosity polymers.

North Carolina: Cleaning cracks most important—use torch to burn out oil, fill hole with two parts epoxy (with aggregate for wear resistance); e.g., "Final Fix CRS" for small holes, "Duracal Fast Set" for large holes. Experimenting with "SR2000."

Ohio: HMWM CMS 705.15 SRS Supplemental 841.

Oklahoma: Epoxy injection, flood coat with HMWM or epoxy alternate.

South Carolina: Epoxy injection, partial, and full-depth patching.

Tennessee: Excessive or >0.125 in. methyl methacrylate. Abnormal working structural cracks—epoxy inject.

Texas: Very low viscosity epoxy or HMWM, then entire surface is sealed, grooving and sealing individual cracks with low modulus epoxy adhesive.

Utah: Polymer overlay.

Virginia: Low-viscosity epoxy, polyurethanes, MMA, liquid asphalt.

Wisconsin: Low-viscosity epoxy.

Alberta: Epoxy injection, gravity-fed epoxy, rout, and seal.

New Brunswick: Low-viscosity repair (Sika, 3M), no injection.

Nova Scotia: Epoxies mainly.

Ontario: Epoxy injection.

Saskatchewan: Epoxy.

G3. Which crack repair methods are most effective in prolonging bridge deck life?

Alabama: Epoxy injection.

Alaska: Sealing cracks with HMWM resin.

Delaware: Overlay with LMC.

Georgia: Epoxy overlays, concrete overlays.

Hawaii: Depends on cause. Epoxy most effective, also more costly.

Idaho: Epoxy.

Kansas: Sealing type and effectiveness depends on crack width.

Minnesota: Epoxy.

New Hampshire: Methyl methacrylate.

New Jersey: SIKA Pronto 19.

New Mexico: HMWM.

North Carolina: Final Fix CRS and Duracal Fast Set (Like Set 4S—very effective).

South Carolina: Partial and full-depth patching.

Tennessee: Methyl methacrylate, epoxy injection.

Texas: Either method properly installed.

Utah: Depends on type of cracking.

Virginia: Depends on the crack.

Alberta: Non-moving cracks—epoxy injection.

Ontario: Epoxy injection.

G4. What methods does your agency use to repair freeze-thaw surface damage?

Alaska: Use chipping hammer to remove delaminated concrete. Replace with rapid set concrete mix.

Connecticut: None. Bridges are typically overlaid.

Delaware: <2 in. patch with epoxy. >2 in. saw cut, remove unsound concrete, clean rebar, remove concrete 1 in. below rebar, and use Class D concrete for repairs.

District of Columbia: Low-chloride-permeability concrete thin overlay.

Georgia: Concrete overlays.

Illinois: Removal and replacement.

Iowa: Surface damage is not specifically repaired.

Kansas: Ignore unless really bad, then mill and overlay.

Maryland: Latex overlay.

Massachusetts: Chip out deteriorated concrete and recast with new concrete.

Minnesota: Occurs so seldom to have standard repair.

Nebraska: Polymer asphaltic materials, bituminous patching, portland cement concrete patching most frequent. Cementitious-based repair materials sometimes used for early opening.

New Hampshire: Remove damaged concrete.

New Jersey: Spalls, cracks, and scaling. Use quick set deck patching material.

New York: Not a problem.

North Carolina: Final Fix CRS and Duracal Fast Set (Like Set 4S—very effective).

Ohio: Scaling—Sealer per supplement 864 or 841. Overlays per supplement 847 or 848.

Tennessee: Rarely have this type of damage. Might use PMC overlay or sandwich seal.

Texas: Remove loose concrete by chipping, sawing, and/or scarifying. Repaired with portland cement concrete or proprietary repair material. Overlays also used.

Virginia: Overlays.

Wisconsin: Partial depth repair.

Alberta: Routing and sealing of concrete surfaces on 4-year cycle, unless severe.

New Brunswick: Partial or full-depth repair.

Newfoundland: Chip out and patch or overlay.

Nova Scotia: Chip and replace.

Ontario: Partial depth removal and patch, waterproof, and pave. Extensive—overlay, waterproof, and pave.

G5. Which surface repair methods are most effective in prolonging bridge deck life?

Alabama: Epoxy injection.

Alaska: Remove and replace delaminated concrete.

Arkansas: The surface repair method is to patch holes using a rapid set type concrete.

Connecticut: Partial and full-depth patching with cementitious materials are performed during periodic resurfacings.

Delaware: Overlay with LMC.

District of Columbia: Low-chloride-permeability concrete thin overlay.

Georgia: Concrete overlays.

Iowa: Low-slump dense concrete overlay (Iowa method).

Kansas: Sealing and placing a concrete overlay on the bad deck.

Maryland: Latex overlay.

Massachusetts: Depends on overall deck condition and workmanship of repair.

Mississippi: Hydroblasting and latex-modified concrete overlay.

Montana: Latex overlays.

Nebraska: Asphalt overlays.

Nevada: Overlays such as low-slump concretes and polyester styrene.

New Hampshire: Remove deteriorated concrete and seal up the surface as best you can—not real successful!

New Jersey: Quick set patch materials prolong deck life.

New Mexico: New—HMWM crack sealer and saline water repellant treatment.
Existing—Nothing.

New York: Any operation that waterproofs the decks. Repairing not as important as bridging the gap with an impermeable material.

North Carolina: Sealer coats on concrete decks seal stuff out but also seal contaminants in.

Ohio: Overlays per supplement 847 or 848 have lasted more than 20 years.

Oklahoma: High-density overlay.

South Carolina: Patching with overlays.

Tennessee: PMC overlays or sandwich seals.

Texas: Replacement only as good as substrate concrete, which may continue to deteriorate.

Virginia: Overlays.

New Brunswick: Waterproofing and asphalt coating.

Newfoundland: Chip out and patch or overlay.

Ontario: Partial depth removal of deteriorated concrete, overlay, waterproof, and pave.

Quebec: “Patch” type method only one used.

G6. What deicing agents are used on bridge decks by your agency?

Alaska: Magnesium chloride, urea.

Arkansas: Calcium chloride.

Connecticut: Salt.

Georgia: Sand, sodium chloride, (salt), calcium chloride.

Idaho: Magnesium chloride.

Illinois: Salt brine, rock salt.

Iowa: Rock salt or brine solution of 23% salt (abrasives also may be used when temperatures are cold).

Kansas: Salt and sand, liquid chloride, calcium magnesium acetate.

Maryland: Sodium chloride, “ice ban” material.

Massachusetts: Calcium chloride, sodium chloride.

Minnesota: Salt, magnesium chloride.

Montana: Ice-ban, magnesium chloride, calcium chloride, sodium chloride.

Nebraska: Sodium chloride, magnesium chloride, KAc, Caliber 1000, Caliber 2000, NaCl, and a corn-based material—80% NaCl and 20% agricultural byproduct.

New Hampshire: Calcium chloride.

New Jersey: Calcium chloride broadcast over deck area.

New York: Salt, almost exclusively.

North Carolina: One Division Bridge Maintenance Engineer (DBME) said they let Road Maintenance use their normal sodium chloride rock salt on the bridge. One DBME said he uses sand/salt mix for deicing and then washes the bridge down ASAP to prevent damage to the bridge.

North Dakota: Sodium chloride, sand, salt brine.

Ohio: Ranges per season from fewer than 5 tons per lane-mile to more than 36 tons per lane-mile. New policy also requires brine pretreatment for any temperature below 35°F to prevent black ice.

Oklahoma: Salt, magnesium chloride.

South Carolina: Sand/salt mixture.

Tennessee: Rock salt or brine water.

Texas: Salt, magnesium chloride, calcium magnesium acetate-limited.

Alberta: Salt, magnesium chloride.

New Brunswick: Calcium chloride.

Newfoundland: Sodium chloride.

Quebec: Salt (sodium chloride) (mostly).

Saskatchewan: Calcium chloride.

SECTION H—LESSONS LEARNED

H1. Of all the strategies and methods that your agency has used to improve bridge deck performance, please list those that were effective, those that were not effective, and those for which the verdict is unknown. Explain the reasons, if known, or provide additional documentation about the outcomes. Specific case studies would be useful for the synthesis.

Alaska: 1. Asphalt overlay and waterproofing membrane (minimal chloride contamination and concrete delaminations after 20 years of service life—Port Access Bridge No. 455).
2. Silica fume overlay (f_c' > 8 ksi, permeability < 1,000 coloumbs).

Arkansas: Bridge deck sealants—project not complete.

Connecticut: Best results have been with membranes combined with epoxy-coated reinforcement. This seems to provide good protection, but requires periodic maintenance. Membranes can be difficult to remove for resurfacing, and removal can result in damage and loss of cover from deck surface. Bare HPC decks have been tried, but finishing is difficult and significant cracking has been difficult to avoid. Cathodic protection systems are generally not well maintained and so lose effectiveness.

Georgia: Effective cover—most effective, 70 years service (still effective).
Epoxy-coated reinforcement—unknown, 25 years service.
Linseed oil sealant—unknown, appears to be effective for 2 years.
Concrete overlay—effective, 15 years service.
Epoxy overlay—unknown, 5 years service.
Epoxy injection of cracks—unknown, 20 years service.

Hawaii: The jury is still out as far as effectiveness of methods currently being used, such as the use of shrinkage-reducing admixtures. Our study so far indicates that use of the admixture reduces the shrinkage of concrete by more than 50%.

Idaho: Use of fly ash has improved the decks in regions of the state that have alkali-silica reactive aggregates. Wet cure has reduced cracking.

Illinois: Epoxy-coated reinforcement has greatly improved performance of bridge decks.

Iowa: About 10 years ago the Iowa DOT changed from requiring a “D” mix to a “C” mix. The lower cement content in the “C” mix has reduced cracking. Timely curing also has been important in reducing cracking. The specifications have set an evaporation limit of 0.2 lb/ft^2/h.
The Iowa DOT recently developed an HPC deck mix with a permeability less than 1,500 coulombs that includes GGBFS and fly ash (but not silica fume). When the mix has been cured promptly for 7 days, there has been no noticeable cracking other than one crack that apparently was caused by reasons other than design and construction of the deck. The HPC specifications limit evaporation rate to 0.1 lb/ft^2/h.

Kansas: We ask about our present practice of silica fume overlay and epoxy rebar with 3-in. clear cover. See K-Tran report. We are interested in solid stainless rebar with 2.5-in. clear cover. See K-Tran report.

Massachusetts: The materials and methods used to construct decks as identified herein have only recently been adopted. They are based upon the reported good performance of simular materials and methods in other states. More time is needed to evaluate performance.

Minnesota: Most successful—3 in. cover, low-slump overlays, epoxy-coated reinforcement.

Nebraska: Fogging and wet curing.

Nevada: Performance-based specifications are much better than “how to” specifications. Make the contractor responsible for the end product and specify what he will have to do if he does not meet certain requirements. The “how to” approach results in too many poor decks. We also believe the curing should start as soon as possible after the concrete is finished.

New Hampshire: The use of performance specifications as an off-shoot of our earlier HPC experiences has proven to be the most effective solution. This has also been combined with a concerted focus on providing proper curing. If anything is crucial to preventing cracks, the issue of curing cannnot be emphasized enough.

New Jersey: Latex-modified overlay—20-year service life at best. Silica fume concrete overlay effective, acceptable coulomb values—placement problems.

New Mexico: HMWM provided good results. Silane—good short-term, little data. Epoxy sand overlays for the late 1970s did not work.

New York: A bridge deck task force is investigating transverse cracking of decks mainly on steel beam bridges. Cracking seems to be caused by tension stress from

a. autogeneous shrinkage,
b. locked in thermal stresses created as the concrete gains strength at a higher temperature than the steel,
c. thermal stresses due to temperature gradients after construction (*NCHRP Report 380*), and
d. live load stress in the negative moment areas.

North Carolina: Not effective—deck sealers (see G5), asphaltic plugs (no sealer or adhesive used), liquid asphalt-type fills, concrete to patch concrete.

Effective—washing the salt, sand, and other deicers off the bridge as soon as possible.

Promising: SR2000—Southgate Resin Co.

North Dakota: Epoxy-coated reinforcing steel—20+ years in use, no problems.

2-1/2 in. clear cover for top reinforcement improves deck performance.

Ohio: Utilization of epoxy-coated reinforcement, development of HPC, development of quality assurance/quality control concrete specification.

Oklahoma: Concrete overlays seem to do the best. Asphalt overlays with membranes do best on lower-volume highways where there is not a great deal of truck traffic. Our practice of constructing new bridge decks using 2-1/2 in. cover with a silane sealer and epoxy-coated reinforcement is working well.

South Carolina: Patching with overlay—best long-term solution for structural repairs and rideability.

Tennessee: New construction—epoxy-coated reinforcement with 2-1/2 in. cover.

Sandwich seals or PMC work well on existing decks (uncoated reinforcement and minimum cover).

Good curing practice enhances deck life, but specifications not well enforced by inspectors.

Texas: Effective: A large number of the 25 TxDOT Districts use fly ash in their deck concrete mix designs. The goal, however, is to produce high-quality concrete. In aggressive environments, TxDOT is increasingly using prescriptive HPC specifications.

Ineffective—The use of high-strength concrete bridge decks, as well as post-tensioned bridge decks has been problematic. Asphaltic membrane with asphalt concrete pavement has also caused problems.

Unknown—The use of corrosion inhibitors for the protection of reinforcing steel. The performance of epoxy-coated reinforcement is also unknown due to lack of long-time performance history.

Virginia: Most effective—low-permeability concrete, cover depth.

Wisconsin: Not effective: Type K and HPC. (See A7 and D5.)

Alberta: Waterproofing membranes have been effective in keeping chloride ions out of deck. However, the ACP on the membrane has a definite life and replacing ACP is a future maintenance cost.
For exposed concrete decks, concrete sealers have been very cost-effective in reducing the amount of chlorides getting into the deck.
Epoxy-coated reinforcement also appears effective in increasing the time for deck reinforcement corrosion.
Silica fume is very effective in the decreasing of the permeability of concrete decks. However, there is often cracking of the concrete, which negates the decreased permeability.

Newfoundland: High-performance silica fume concrete thought to improve service life—unknown for our agency.

Nova Scotia: To improve bridge deck performance, Nova Scotia is tending to go towards the use of HPC and increased cover over the top mat. In addition, Nova Scotia will continue to use a waterproofing protection system, which appears to be more effective in reducing chloride intrusion.

Ontario: Use of hot-applied waterproofing membranes has been extremely effective; since an end-result specification was introduced, with provisions for testing quality and thickness of waterproofing materials, quality overall has been very good and we are satisfied with the current system.
Concrete cover is specified as 70 ± 20 mm; we feel by increasing depth of cover we have increased the time required for chlorides to penetrate to the level of the steel.

Quebec: Effective methods; high-strength concrete (50 MPa); automatic finisher (to obtain good tranverse profile and a good clear cover); asphalt preformed torch-applied sheet (with automatic machine); deck joint only if required; improved deck joint to limit the water infiltration.

Saskatchewan: Proper mix design, control of placement conditions, and moist curing are the most important.

H2. Please list any research in progress by your agency related to concrete bridge deck performance:

Arkansas: Evaluation of bridge deck sealants.

Connecticut: Corrosion inhibitors.

Delaware: Monitoring high-performance concrete bridge deck projects.

Hawaii: Field evaluation of shrinkage-reducing admixtures.

Illinois: Evaluation of low-permeability concrete mixes for bridge decks.

Indiana: Field investigations of a concrete deck designed by the empirical method.
Long-term durability of rapid-set cement-based materials.
Transversely prestressed concrete bridge decks.
Bridge deck cracking in various superstructure systems.
Performance-related specifications.

Kansas: Construction of crack-free bridge decks (pooled fund study with other states).

Massachusetts: Performance evaluation and economic analysis of combinations of durability enhancing admixtures for concrete for bridge applications in the northeast.

Minnesota: Trial placements of silica fume concrete.

Nebraska: Tining versus turf drag finish.

New Jersey: High-performance concrete mix designs.

New York: Concrete deck material properties.

North Dakota: Performance evaluation and monitoring of low-permeability concrete bridge decks.

Ohio: Deck cracking.

Oklahoma: Corrosion inhibitors.

Texas: Methods to control drying shrinkage cracks in concrete bridge decks.
Effects of wet mat curing and early loading on long-term durability of bridge decks.

Virginia: Concrete shrinkage and creep.
Service life of epoxy-coated reinforcement.
Bridge deck service life prediction.
End-result specifications.
Use of stainless steel clad reinforcement.
Fiber-reinforced concrete.
Lightweight high-performance concrete.
Electro-chemical chloride extraction.

Wisconsin: Stainless steel clad reinforcement.

Alberta: Analysis of 25 years of deck testing and rehabilitation methods.

Ontario: High-performance concrete and stainless steel reinforcement.

Quebec: Ternary blend cements with different combinations of supplemental materials.

H3. Please list any recommendations for future research:

Alaska: Performance of full-depth silica fume decks.

Arkansas: Impermeable concrete. Salt-resistant reinforcement or concrete.

Delaware: Analyze shrinkage values of concrete mixtures. Study the interface between concrete and reinforcement during the first 24 to 49 h. Examine the effect of different reinforcement surfaces due to material and coating differences.
DelDOT is concerned that high-strength concrete and high cement content are assumed to be the best way to attain high durability. There is a need to evaluate the concrete’s modulus, its susceptibility to failure due to brittleness.

Georgia: None—We feel that if you get adequate concrete cover on construction and use quality concrete, then you will have a long-lasting bridge deck.

Indiana: 1. Compatibility of patching materials and substrate concrete in bridge decks. 2. Vibration-induced cracks in bridge decks.

Kansas: Complete the pooled fund study TPF-5(051) first.

Massachusetts: Effect of adjacent stage construction vibration on concrete deck quality.

New Jersey: Permeability test methods for concrete with quick results. AASHTO T277 reliability is questionable.

North Carolina: Trouble repairing deck spalls—most hot and cold weather concrete patches do not work.

Ohio: Concrete sealers in reducing chloride content—expansion of *NCHRP Report 299*. Monitoring methods and assessments to optimize timing for deck overlays to create a sacrificial surface that protects the structural deck from chlorides.

Virginia: End result specifications.

Newfoundland: Use of supplementary cementitious materials, including tertiary cement, effects on concrete construction, and service life. Develop library or central website, available to all agencies, to disseminate information from all completed research.

Ontario: Fast-track repair and construction methods, particularly those using precast concrete technology.

APPENDIX D

Research in Progress

Responses to the questionnaire for this synthesis listed the following research projects:

Arkansas: Evaluation of bridge deck sealants.

Connecticut: Corrosion inhibitors.

Delaware: Monitoring high-performance concrete bridge deck projects.

Hawaii: Field evaluation of shrinkage-reducing admixtures.

Illinois: Evaluation of low-permeability concrete mixes for bridge decks.

Indiana: Field investigations of a concrete deck designed by the empirical method.
Long-term durability of rapid-set cement-based materials.
Transversely prestressed concrete bridge decks.
Bridge deck cracking in various superstructure systems.
Performance-related specifications.

Kansas: Construction of crack-free bridge decks (pooled-fund study with other states).

Massachusetts: Performance evaluation and economic analysis of combinations of durability enhancing admixtures for concrete for bridge applications in the northeast.

Minnesota: Trial placements of silica fume concrete.

Nebraska: Tining versus turf drag finish.

New Jersey: High-performance concrete mix designs.

New York: Concrete deck material properties.

North Dakota: Performance evaluation and monitoring of low-permeability concrete bridge decks.

Ohio: Deck cracking.

Oklahoma: Corrosion inhibitors.

Texas: Methods to control drying shrinkage cracks in concrete bridge decks.
Effects of wet mat curing and early loading on long-term durability of bridge decks.

Virginia: Concrete shrinkage and creep.
Service life of epoxy-coated reinforcement.
Bridge deck service life prediction.
End-result specifications.
Use of stainless steel clad reinforcement.
Fiber-reinforced concrete.
Lightweight high-performance concrete.
Electro-chemical chloride extraction.

Wisconsin: Stainless steel clad reinforcement.

Alberta: Analysis of 25 years of deck testing and rehabilitation methods.

Ontario: High-performance concrete and stainless steel reinforcement.

Quebec: Ternary blend cements with different combinations of supplemental materials.

Abbreviations used without definition in TRB Publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation

SURVEY SECTION A

Question A1. What strategies does your agency currently use to provide a low-permeability concrete?

State/Province	None	Minimum Cementitious	Minimum Cement	Maximum w/cm	Fly Ash	Silica Fume	GGBFS	Rapid Chloride Perm.	Ponding	Other	Most Effective	Least Effective	Comment
Alabama			Y	Y	Y		Y				Max. w/c ratio and fly ash		
Alaska		Y	Y	Y	N	Y	N	Y	N		Silica fume	All effective	
Arkansas		Y	Y	Y	N	N	N	N	N		Max. w/c ratio	Min. cementitious materials content	
California		Y	Y	Y	Y								
Colorado		Y		Y		Y		Y		Y			Fly ash & perm. testing only some concrete types
Connecticut	N	Y	N	Y	N	N	N	N	N		No data – always used together		
Delaware	Y		Y	Y				Y					Rapid chloride test only for HPC
DC		Y	Y	Y	N	N	N	N	N	Y	Min. chloride perm. 1500 coulombs	None	Specify min. chloride perm. 1500 coulombs
Georgia	N	Y	Y	Y	Y	Y	N	Y	N	N	Low permeability on HPC projects only. All successful	Low permeability for deck <1000 coulombs difficult to obtain in field	
Hawaii	N	N	Y	Y	N	N	N	N	N		Not conclusive	Not conclusive	
Idaho	Y												
Illinois	N	N	Y	Y	N	N	N	N	N	Y	Cementitious materials	Min. cement content	Fly ash and GGBFS may be used in bridge decks. SF and high-reactivity metakoolin have been used in bridge decks (experimental)
Indiana	N	Y	Y	Y	N	N	N	N	N	Y	Min. cementitious and Type A or D chem ad with slump restriction	w/cm ratio -because difficult to measure	Class C concrete requires Type A or D chemical admixture
Iowa		Y	Y	Y	Y		Y	Y			GGBFS—permeability of 1300 coulombs or less	Silica fume (one deck)—learning curve too steep for contractors	
Kansas		Y		Y		Y				Y	w/cm w. proper curing	Silica fume overlays-cracking. GGBFS abused-overdosed w. retarder. Surface cracking even in post-tensioned concrete	Epoxy-coated rebar
Kentucky		Y	Y	Y	Y	Y	N	N	N		Min. cement content	Too much silica fume—deck cracking	
Maryland			Y	Y						Y			HPC mix with fly ash or GGBFS or SF and polyproylene fibers

Question A1. (*Continued*)

Massachusetts	N	Y	N	Y	Y	Y	N	Y	N	N			
Minnesota	N	Y	Y	Y	Y	N	N	N	N	N	2" low slump overlay		SF in limited cases
Mississippi	N	N	N	Y	N	N	N	N	N	N	Permeability tests not performed		
Montana		Y	Y	Y									
Nebraska		Y		Y							Min. cementitious materials, max. w/cm		
Nevada			Y	Y	Y								At this time we have not constructed any concrete with low permeability requirement. Developing spec for low permeability that will include SF
New Hampshire				Y				Y		Y	Performance spec.		Performance spec: max. pay factor with perm. 1500-2500 coulombs
New Jersey	N	N	N	Y	Y	Y	Y	Y	N		Combination fly ash and SF for low permeability concrete	Low w/cm without a pozzolan	
New Mexico					Y			Y					
New York	N	N	N	Y	Y	Y	Y	N	N	Y	HPC mix shows improvements to reduce cracking—but cracking not eliminated		HPC mix - 20% fly ash or GGBFS and 6% SF - established using T 277 - but test not done routinely
North Carolina		Y	Y	Y	Y	Y	Y	Y	N		Day-to-day: fly ash. selected applications: SF	Not enough data	Silica fume, GGBFS, perm. testing used in selected applications
North Dakota		Y	Y	Y	N	N	N	N	N				
Ohio				Y	Y	Y	Y	Y			4 HPC mixes allowed – Spec. 511.4 (2002) data being collected		Fly ash or SF
Oklahoma		N	Y	Y	Y	Y	Y	N	N		Don't know	Don't know	Allow substitution of fly ash, SF, GGBFS - do not require
South Carolina	N	Y	Y	Y	Y	Y	N	N	N	N	Silica fume and fly ash		
Tennessee	N	Y	Y	Y	N	N	N	N	N	Y	All		Allow fly ash, GGBFS substitutes for cement 76% mixes have pozzolans. Reduces permeability
Texas	N	N	Y	Y	N	N	N	N	N	Y	Some Dist. Offices replace some cement with fly ash	Limited to non-existent use of GGBFS and SF	TxDOT is using prescriptive HPC specs that require the use of fly ash, GGBFS, or silica fume on selected projects

Question A1. (*Continued*)

Utah		Y	Y	Y	N	N	N	N	N		Don't know		
Virginia		Y	Y	Y	Y	Y	Y	Y	N		Pozzolans or slag	Specify min. cement content	
Washington	N	Y	Y	Y	Y	N	N	N	N	N			
Wisconsin	N	Y	Y	Y	Y	N	Y	N	N	N	Used in combination		To clarify our requirements, require use of either 15-30% fly ash or GGBFS in mixes
Alberta		Y	Y	Y	Y	Y		Y			Low w/cm. Addition of SF		Fly ash—special provisions
New Brunswick		Y		Y		Y		Y					
Newfoundland	N	N	N	Y	N	Y	N	Y	N	N	Silica fume	Unknown	
Nova Scotia		Y		Y	Y	Y		Y	N		Fly ash and SF in HPC		
Ontario						Y		Y			HPC w. silica fume, rapid chloride perm. max. 1000 coulombs		
Quebec	N	Y	Y	Y	Y	Y	Y	N	N		SF w. slag or fly ash + max. w/cm		Tests for rapid chloride perm. and ponding not specified—verified in control procedure
Saskatchewan		Y	Y	Y	N	Y		N	N		Cementitious materials content, SF	No comment	

Question A2. What strategies does your agency currently use to provide a concrete that is resistant to freeze-thaw damage and deicer scaling?

State/Province	None	Air Content	Air Void Parameters	Freeze-Thaw Test	Deicer Scaling Test	Other	Most Effective	Least Effective	Comments
Alabama		Y					Freeze-thaw no problem in AL		
Alaska		Y	N	N	N		Air content	None	
Arkansas		Y	N	N	N		Air content		
California		Y		Y					
Colorado		Y				Y			Strength. Some concrete types, perm. testing
Connecticut	N	Y	N	N	N		No data		
Delaware		Y					NB: DelDOT recommends deicer salt applications be delayed until concrete has reached sufficient strength in conformance with ACI recommendations; difficult to enforce		
DC	N	Y	N	N	N	N	Air content	None	
Georgia	N	Y	N	N	N	N	Air content	n/a	
Hawaii	Y	N	N	N	N	N	n/a in HI		
Idaho		Y							
Illinois	N	Y	N	N	N		Air content	n/a	
Indiana	N	Y	Y	N	N	Y	Approved AEA in concrete having sufficient air content in the plastic state at point of placement	Air void system analysis done for HRWR and HRWR admixture systems. Provides reasonable values for VPI, specific surface area, and distance between air void; but air content does not agree with result in plastic state	Maintain approved list of AEA, which have been tested according to AASHTO M 154 and found to be in compliance
Iowa		Y							
Kansas		Y					Proper air content and curing	Cold weather, frozen or bad cure	
Kentucky		Y	N	N	N		Air content	Only specify one	
Maryland		Y							
Massachusetts	N	Y	N	N	N	N			
Minnesota		Y					Few problems using 5.5 to 6.5%		
Mississippi	N	Y	N	N	N	N	Air content	n/a	
Montana		Y							
Nebraska		Y							
Nevada		Y							
New Hampshire		Y				Y	Combination of specified range and perf. spec.	Spec. range w/o $ penalty	Performance spec.
New Jersey	N	N	N	Y	Y		Specify freeze-thaw and deicer scaling testing	Specify air content only	
New Mexico			Y	Y					
New York	N	Y	N	N	N	N	Air content easiest to do—timely results	Air void, freeze-thaw, and scaling tests performed when evaluating new products in the lab and/or when field samples taken from pilot projects but acceptance testing is not performed using these methods	

Question A2. (*Continued*)

North Carolina		Y	N	N	N		Air entrained concrete		Note
North Dakota		Y	N	N	N				
Ohio		Y					No data		CMS 499.03.2B
Oklahoma		N	N	Y	N		Freeze-thaw durability to approved coarse aggregate sources (use of concrete mix design with approved source only)		
South Carolina	N	Y	N	N	N	N	Freeze-thaw no problem in SC		
Tennessee	N	Y	N	N	N	N	Air content		
Texas	N	Y	N	N	N	Y	Entrained air required on all bridge decks	Not sure if sealers are effective long-term	Seal deck with linseed oil or silane
Utah		Y	N	N	N				
Virginia		Y	N	N	N		Specify air-void parameters	No action	
Washington	N	Y	N	N	N	N			
Wisconsin	N	Y	N	N	N	N	Need to do more in this area		Only used one strategy
Alberta		Y	Y				Air content 5-8%, voids less than 230		
New Brunswick		Y	Y	Y		Y	ERS contracts		Air voids on ERS contracts. Freeze-thaw if parameters are outside accepted hardened air parameters
Newfoundland	N	N	Y	N	N	N	Air void parameters	Not applicable	
Nova Scotia		Y	Y				Air void parameters		
Ontario			Y		Y		Air content and air void parameters		
Quebec	N	Y	Y	N	N				Freeze-thaw and deicer scaling tests not specified—verified
Saskatchewan		Y	N	N	N		Air content		

Question A3. What strategies does your agency currently use to provide abrasion resistant concrete?

State/Province	None	High-Strength Concrete	Abrasion Testing	Other	Comment
Alabama	Y				
Alaska		Y	N		
Arkansas	Y				
California				Y	Overlays
Colorado				N	Nothing specific to abrasion other than mod high strength. SF for some concrete types
Connecticut	Y				
Delaware	Y				
DC	N	N	N	Y	Specify abrasion resistant aggregates
Georgia	Y	N	N	N	
Hawaii	Y	N	N		
Idaho	Y				
Illinois	Y	N	N		
Indiana	N	N	N	Y	Class C concrete. Tining—min/max depth requirement
Iowa	N				
Kansas				Y	Specify type of coarse agg. for wearing surfaces
Kentucky	Y				
Maryland	Y				
Massachusetts	N	N	N	Y	Use silica fume modified concrete
Michigan					
Minnesota	Y				
Mississippi	N	N	Y	N	
Montana	Y				
Nebraska	Y				
Nevada	Y				
New Hampshire	Y				
New Jersey	N	N	Y		
New Mexico	Y				
New York	Y	N	N	N	
North Carolina		Y	Y		HSC-selected appl. Abrasion testing—aggregates only
North Dakota	N	N	N		
Ohio					None
Oklahoma	N				
South Carolina	N	N	N	N	
Tennessee	Y				
Texas	N	N	Y	N	Abrasion specified for aggregate tests
Utah	Y	N	N		
Virginia	Y	N	N	Y	Nonpolishing aggs
Washington	Y	N	N	N	
Wisconsin	N	Y	N	N	
Alberta		Y			
New Brunswick	Y				
Newfoundland	N	N	N	N	
Nova Scotia	Y				
Ontario	Y				
Quebec	Y	N	N		NB: Most of decks not concrete apparent
Saskatchewan	Y				

Question A4. What strategies does your agency currently use to minimize cracking in bridge decks?

State/Province	None	Maximum Cementitious Materials	Maximum Strength	Maximum Temperature	Maximum Slump	Wind Breaks	Evaporation Retardants	Fogging	Minimum Curing	Other	Most Effective	Least Effective	Comments
Alabama				Y	Y		Y	Y			Fog curing in hot weather	Min. comp. strength of 4000 psi	
Alaska		N	N	N	Y	N	N	Y	Y		3-day wet cure for sf. 7-days for conv. concrete	None	
Arkansas		N	N	Y	Y	N	N	N	Y		Min. curing times	Max. slump	
California		Y	N	Y	Y	N	Y	Y	Y				
Colorado		Y					Y	Y	Y	Y	Low wind placement requirements		
Connecticut	N	N	N	Y	Y	Y	N	Y	Y	Y	No data		Cotton mats after fogging
Delaware				Y	Y				Y				NB: DelDOT requires conformance to ACI 305R re max. evaporative rate—allows for options of wind breaks, evaporative retardants, and fogging. When using SF, contractor required to use an evaporative retardant
DC	N	N	N	Y	Y	N	N	N	Y	N	Max. slump	None	
Georgia	N	Y	N	Y	Y	N	N	Y	Y		Fogging and curing	n/a	
Hawaii		N	N	N	Y	N	N	Y	Y		Fogging or wet curing for the duration of the curing period (not less than 7 days). Have also used shrinkage-reducing admixtures; e.g. Tetraguard, Eclipse—good results. These products may have limitations with freeze-thaw.	Not sure	

Question 4A. (*Continued*)

Idaho				Y	Y				Y	Y	Combination effective. Difficult to differentiate between items		Max. evaporation rate specified
Illinois	N	Y	N	Y	Y	N	N	Y	Y	Y	Unknown	Unknown	Cotton mats after finishing. Then soaked
Indiana	N	Y	N	N	Y	N	N	N	Y	N	Min. cure time	Max. cementitous content	Min. pour rate for 2 adjacent spans based on set time for concrete
Iowa		Y		Y	Y		Y		Y	Y	For the standard “C” mix—wet burlap on the deck 15 min (with discretion) after final finishing. Finishing includes a rake texture and sprayed curing compound. For HPC—wet burlap on deck within 10 min	Wind breaks have been discussed but never specified because they are unlikely to be effective under many field conditions	Max. evap. rate 0.2 lb/sf/hr
Kansas					Y		Y	Y	Y		Fogging and curing time	Slump	
Kentucky		Y	Y	Y	Y	N	Y	Y	Y		Specifying mix parameters—slump, air, strength, etc.	Fogging—when used as finishing aid, useful when used correctly	
Maryland				Y				Y	Y	Y			Min. cementitious material content
Massachusetts	N	Y	N	Y	Y	Y	N	Y	Y	Y	Wet burlap curing and starting early	Wind breaks—local eddys inc. evap.	Specify max. time before wet burlap curing
Minnesota					Y			Y	Y	Y	Longer curing periods—keep surface damp		Rapid application of curing compound
Mississippi	N	N	N	Y	Y	N	N	N	Y	N	Max. slump		
Montana					Y			Y	Y				
Nebraska				Y	Y	Y	Y	Y	Y		Fogging very effective—minimizes cracking		90ºF conc temp at time of placement, wind breaks, retardants, fogging depend on atmoferit table. 96 hr wet curing

Question A4. (*Continued*)

Nevada				Y	Y		Y	Y	Y	Y	Make contractor resp. for crack repair by epoxy injection. Eliminate tining behind Bidwel and groove deck after curing		
New Hampshire		Y							Y	Y	Combination of all three	Any one alone	Wet burlap or cotton mat cure
New Jersey	N	Y	N	Y	N	Y	Y	Y	Y	N	Specifying min. continuous wet curing time of 7 days	Specifying evaporation retardants	
New Mexico				Y	Y	Y		Y		Y			Monitor evap.—require wind breaks, night time placement if required
New York	N	N	N	Y	Y	Y	N	N	Y	Y	Cure within 30 min.	Retardants, wind breaks, etc.—misused	Cure within 30 min. max. w/cm 0.40
North Carolina		Y	N	Y	Y	N	N	Y	Y		All acting together		
North Dakota		N	N	Y	Y	N	N	N	Y				
Ohio				Y	Y				Y	Y	Cracking still an issue under study		Drying shrinkage test ASTM C 157
Oklahoma		N	N	Y	Y	N		Y	Y		Min. curing time		
South Carolina	N	Y	N	Y	Y	Y	N	Y	N	N	Max. cementitious materials content, max. conc. temp. Require wind breaks, fogging		
Tennessee	N	N	N	Y	Y	Y	Y	Y	Y		Proper curing		Wind breaks if evap. rate > 0.2 gal/hr/sy
Texas	N	N	N	Y	Y	N	N	Y	Y	Y	Fogging, wet cotton mats applied early		Interim cure w/membrane before wet mat cure
Utah		Y	N	Y	Y	N	N	N	Y		Do not know		
Virginia		N	N	Y	Y	Y	Y	Y	Y		Good curing, don't let surface of concrete dry	Specify max. slump	
Washington	N	Y	N	N	Y	N	N	N	Y	N			
Wisconsin	N	N	N	Y	Y	N	N	Y	Y	Y	Don't know—all applied together		1-1/2" max. coarse agg.
Alberta				Y	Y			Y	Y	Y	Casting from 6 pm to 10 am—no rain or wind		Specify time frame for casting
New Brunswick				Y				Y	Y				ERS contracts

Question A4. (*Continued*)

Newfoundland	N	Y	N	Y	Y	N	Y	Y	Y	N	Curing	Max. conc. temp	
Nova Scotia			Y	Y	Y				Y				Concrete temp., curing
Ontario				Y	Y			Y	Y		4 days wet cure—normal conc. Fog mist + 7 days wet for HPC	Curing compounds	
Quebec		N	N	Y	Y	N	N	Y	Y	Y	Fogging (note some projects use wind breaks)	Evaporation retardants	Night time concreting
Saskatchewan		N	N	Y	Y	Y	Y	N	Y		Max. slump, evap. retardants. Min. time for moist curing	Wind breaks not effective	

Question A5. What strategies does your agency currently use to prevent corrosion of reinforcement in bridge decks?

State/Province	None	Low Permeability	Corrosion Inhibitor	Epoxy Coated	FRP	Metallic Coated	Stainless Steel	Other Reinforcement	No Reinforcement	High-Strength Concrete	Clear Cover	Protective Barrier	Other	Combinations	Most Effective	Least Effective	Notes
Alabama											Y				Fly ash. Silica fume near salt water		
Alaska		Y	N	Y	N	N	N	N	N	N	Y	Y			SF+epoxy (sf deck), asphalt overlay, waterproofing membrane, epoxy rebar (conv. deck)	None	
Arkansas		N	N	Y	N	N	N	N	N	N	Y	N		Min. cover and epoxy rebar	Epoxy rebar	Min. cover	
California		Y	N	Y	N	N	N	N	N	N	Y	N					
Colorado		Y		Y						Y	Y	Y	Y				Waterproofing membrane w/ asph., silane-bare riding surface
Connecticut	N	N	N	Y	N	N	N	N	N	N	Y	Y		Epoxy coated bars in combo w/woven glass fabric waterproofing (hot mop bituminous w/woven fiberglass mat) under bituminous wearing surface. NB: Corrosion inhibitors under study by The U. of CT and CT DOT. Experimental, has not been used in a project	No data—used in combination		

Question A5. (*Continued*)

Delaware		Y		Y							Y				Non-coated bars—see note	See note	NB: Non-coated reinforcement performing well after many years of service. Concern that the epoxy coating is not a guarantee that steel is protected, since inadequate coating and handling damage can void the expected protection. If the epoxy coating affects the interface between the concrete and the reinforcement during early stages (first 24–49 h) that may allow more concrete cracking
DC	N	Y	N	Y	N	N	N	N	N	Y/N	Y/N	N	N	Epoxy rebar + 2-1/2" cover	Listed combination	None	
Georgia	N	N	N	Y	N	N	N	N	N	N	Y	N	Y	Clear cover and linseed oil treatment used in the northern 1/3 of state. Epoxy coated rebar, clear cover and linseed oil treatment used on interstate bridges in northern 1/3 of state	Clear cover	Linseed oil deck sealant	Linseed oil
Hawaii		Y	Y	N	N	N	N	N	N	Y	Y	N		Corrosion inhibitor, more cover, higher strength concrete	Concrete cover	Not conclusive	
Idaho				Y							Y						
Illinois	N	Y	N	Y	N	N	N	N	N	N		Y	Y	Epoxy rebar, clear cover, linseed oil	Epoxy rebar	Boiled linseed oil	Linseed oil—temporary barrier

Question A5. (*Continued*)

Indiana	N	Y	N	Y	N	N	N	N	N	N	Y	Y		Low perm. concrete, epoxy rebar, cover distance, protective barrier	Epoxy rebar	Surface sealers	
Iowa		Y		Y							Y			Standard “C” mix: epoxy-coated reinforcement and 2 1/2 inches top cover. HPC: 1500 coulomb specification, epoxy-coated reinforcement, and 2 1/2 inches top cover		Research in Iowa has shown the epoxy coating to be effective even over cracked areas of decks (with minor problems). There has been no spalling after 25 years, and the decks have an expected life of 40 to 50 years	
Kansas		Y		Y							Y	Y		Epoxy rebar top and bottom & SF overlay, 3" clearance	Epoxy + curing	HSC overlays crack	
Kentucky		Y	N	Y	N	N	N	N	N	Y	Y/N			Class AA (4,000 psi)+epoxy+2-1/2" cover	Combination as listed	Use Class AAA (5,500 psi) with sf — cracking. No real data only 5-8 yr	$f_c' = 4{,}000$ to 5,500 psi
Maryland				Y						Y	Y						$f_c' = 4{,}500$ psi
Massachusetts	N	Y	Y	Y	N	N	N	N	N	N	Y	Y	N	All yeses	Epoxy rebar and clear cover distance. Low perm. and corrosion inhibitors recent addition		
Minnesota		Y		Y							Y		Y	2" low slump overlay. epoxy both mats, 3 in. clear cover	3" clear cover		High density, low slump overlay 2" thick
Mississippi	N	N	N	Y	N	N	N	N	N	N	Y	N	N	Not rated			
Montana				Y							Y						
Nebraska				Y											Epoxy-coated rebar		
Nevada				Y						Y	Y	Y		Epoxy-coated rebar, HSC, clear cover	Protective barriers	HSC	$f_c' = 4{,}500$ psi
New Hampshire		Y		Y	Y		Y				Y	Y		More top rebar cover, protective liquid spray barrier membrane, epoxy-coated rebar	Combination as listed	Black steel w. sheet membrane	
New Jersey	N	Y	Y	Y	N	Y	N	N	N	N	Y	Y		Epoxy+corrosion inhibitor, corrosion-protected rebar always	Epoxy-coated rebar —good. Low perm. looks good—need more data	No opinion	

Question A5. (*Continued*)

New Mexico		Y		Y							Y						
New York	N	Y	Y	Y	N	Y	N	N	N	N	Y	N	N	Low perm, epoxy-top only, 75 mm cover, inhibitors occasionally. Galv. stainless clad and stainless progressing - not standard	Low perm, epoxy-rebar top only, 75 mm cover penetrating sealers		
North Carolina		Y	Y	Y	N	N	N	N	N	Y	Y	N		Extreme: low permeability, corrosion inhibitor, epoxy-rebar, clear cover distance. Coastal: corrosion inhibitor, epoxy-rebar, clear cover distance	All		
North Dakota		N	N	Y	N	N	N	N	N	N	Y	N		Cover, epoxy-rebar	Epoxy rebar		
Ohio		Y	Y	Y						Y	Y			HPC (511.04) low perm, high strength, epoxy rebar, cover	Epoxy rebar and cover since early 80s		f_c'= 4500 psi inhibitor for prestressed concrete products
Oklahoma		N	Y	Y	N	N	N	Y	N	Y	Y	Y		Cover and poxy-coated reinforcement with water repellant treatment. Cover and epoxy-coated reinforcement with corrosion inhibitor (precast deck panel)	Cover and epoxy coated reinforcement with WRT (Silane)	HSC only	f_c' = 4000 psi. Corrosion inhibitor is used in precast deck panels only. MMFX (corrosion-resistant reinforcement) used experimentally on one project. Protective barriers are sealers (silanes - water repellant treatment)
South Carolina	N	Y	Y	N	N	Y	Y	N	N	N	Y	N	N	Corrosion inhibitor & metallic coated rebar (Galv)	Stainless steel	Too early to tell	Galvanized metallic coated
Tennessee	N	N	N	Y	N	N	N	N	N	N	Y	N	N	Epoxy-coated rebar and 2-1/2 in. cover	Above combination satisfactory		
Texas	N	Y	Y	Y	Y	N	N	Y	N	Y	Y	Y	Y	2 in. clear cover, coated/uncoated rebar, PC/standard concrete, corrosion inhibitor, protective barrier/deck sealer	Clear cover distance with low permeability concrete will most likely be the most effective	The protective barrier is least effective over life of structure - lack of maintenance. Only one experimental FRP reinforced concrete deck has been constructed	f_c'= 8000. Sacrificial galvanic anodes on limited basis

Question A5. (*Continued*)

Utah		N	N	Y	N	N	N	N	N	N	Y	N		Do not know			
Virginia		Y	N	Y	N	N	N	N	N	N	Y	Y		Low perm. concrete, cover depth, overlays	Low perm. concrete, cover depth, overlays		
Washington	N	N	N	Y	N	N	N	N	N	N	Y	N	N				
Wisconsin	N	Y	N	Y	N	N	N	N	N	N	Y	Y	N	Low perm PCC + epoxy coated rebar + cover depth + silane sealer. We are also now trying stainless clad bar on limited pilot projects note	Don't know - all used together		
Alberta		Y		Y			Y	Y		Y	Y	Y		HSC, epoxy-coated rebar, hot applied water-proofing membrane, and ACP wearing surface.	Membrane and ACP		f_c'= 35 or 50 MPa
New Brunswick		Y	Y								Y	Y		All those checked	Above cominabiton		45 MPa
Newfoundland	N	Y	N	N	N	N	N	N	N	Y	Y	Y	N	Low perm., HSC, and clear cover	Clear cover	Protective barriers	45 MPa
Nova Scotia		Y		Y					Y	Y	Y		Y	Low perm. concrete, epoxy rebar, increased cover	Waterproof and pave decks, increased cover	High strength	
Ontario		Y		Y			Y			Y	Y	Y		Strategic highways: stainless steel + HPC + 70 mm cover + waterproofing membrane. Others: epoxy rebar + 70 mm cover + waterproofing membrane. Epoxy rebar under review	Increased cover + waterproofing membrane	Epoxy rebars in exposed decks - premature deterioration	
Quebec	N	Y	N	N	N	Y	N	N	N	Y	Y	Y		For average daily circulation flow > 500 vehicles: high strength concrete (50 MPa) is used. Usual combination = HSC (50 MPa), galvanized reinforcement, clear cover 60 mm top reinforcement, membrane, asphalt (65 mm)			f_c'= 50 MPa
Saskatchewan		N	N	N		N				N	N	N		Low perm. concrete w/clear cover + waterproofing system	Low perm. concrete with adequate cover + waterproofing system	No comment	

Question A6. What strategies does your agency currently use to provide a protective barrier for the deck concrete?

State/Province	None	Overlays	Membranes	Sealers	Other	Most Effective	Least Effective	Comments
Alabama	Y	Y				Thin polymer overlay—not new construction	Sealers	
Alaska		Y	Y	N		Asphalt overlay w/membrane	None	
Arkansas		N	N	Y		Sealers		
California		Y						
Colorado		Y	Y	Y				Either membrane w/overlay or sealer w/bare riding surface
Connecticut	N	Y	Y	N	N	There has been limited use of latex modified overlays, but woven glass membranes are standard practice and are considered most effective at this time		
Delaware		Y						
DC	N	Y	N	Y	N	Low perm. concrete overlays and sealers used only when cracks noted	None	
Georgia	N	N	N	Y	N	n/a	n/a	
Hawaii	Y	N	N	N		n/a	n/a	
Idaho		Y	Y	Y				
Illinois	N				Y	Concrete overlay	Sealers	Overlays with rehab, linseed oil new
Indiana	N	N	N	Y	N		Sealers	
Iowa		Y				In general, Iowa does not use overlays on new construction. However, since 1973 for 12+ major bridges, Iowa has used a two-course deck. In a few cases the two-course deck has been used for a better ride, but in most cases the two-course deck has been used for reinforcement protection. The method has been effective. The 1990 final report for HR-502, however, indicates that the two-course deck would not achieve a 50-year life, and that epoxy-coated steel would be more effective		
Kansas		Y	Y	Y		Low slump dense concrete overlays and SF overlays	Sealers that bead water but let chloride penetrate sealer	
Kentucky	Y				N	Overlays on existing decks—last about 20 yrs		Overlays on existing decks for rehabs
Maryland				Y				
Massachusetts	N	N	Y	N	Y	Both above		Full depth microsilica decks where exposed concrete decks used
Minnesota		Y				2" low slump concrete overlays		
Mississippi	Y							
Montana		Y		Y				
Nebraska		Y						

Question A6. (*Continued*)

Nevada		Y				Polyester-styrene overlay—Caltrans spec.	Sealers	
New Hampshire			Y			Liquid spray membrane	Sheet membrane	
New Jersey	N	Y	Y	Y	N	Overlays. 20-year protective measure	Membranes. Hides concrete—don't know what's happening	
New Mexico		N	N	Y		NM uses monomeric alkyltrialoxy silane sealers		
New York	N	Y	Y	Y	N	Sealers applied to green concrete placed late season (a large percentage of deck placements) from early ingress of chlorides. Sealers applied before deck opened to traffic. Maintenance—re-seal decks every 4-5 yrs. Sealers used as remediation to minor cracking resulting from improper construction practices. This requires contractor to provide multiple applications sealer		
North Carolina		Y						Occasionally on precast decks
North Dakota		Y	N	Y		Overlay used as rehabilitation strategy for decks in 20-30 yr range		
Ohio		Y		Y		Concrete overlay decks w/LMC, SDC or microsilica after spall & delaminations are 15-30% of deck area. Overlays can last up to 20 years.	Epoxy overlays last short time only	Have used silane, HMWM, SRS
Oklahoma		N	N	Y		Overlays were applied to new concrete bridge decks in the mid-70's (high density and latex). Some membrane overlays with asphalt were applied to new bridge decks in the mid-70s. Sealers apply to silanes	A combination of sealers, increased cover, and epoxy-coated rebar	
South Carolina	N	Y	Y	N	N	Overlays		
Tennessee	N							
Texas	N	N	Y	Y	N	Neither are effective over the life of the structure	Membranes (2 coarse asphalt surface treatment with 1 ½ in. HMACP) have a tendency to trap contaminants that promote concrete deterioration. Sealers are also not effective because they usually do not get reapplied after initial construction application	
Utah		N	N	N		Membranes and overlays		
Virginia		Y	N	Y		Overlays	Sealers	
Washington	N	Y	Y	N	N			
Wisconsin						No response		
Alberta		Y	Y	Y		Sealers probably most cost-effective		
New Brunswick			Y					
Newfoundland	N	N	Y	Y	N	Membranes	n/a	

Question A6. (*Continued*)

Nova Scotia		Y				Asphalt overlay		
Ontario			Y			Waterproofing membrane		
Quebec	N	N	Y	N	Y	Satisfied with torch-applied pre-formed sheet		Asphalt (bituminous concrete)—wearing surface
Saskatchewan		N	N			Waterproofing	Overlay	

Question A7. What strategies has your agency used in the past to enhance bridge deck performance but no longer uses? Explain why they are not used currently.

State/Province	Used but No Longer Uses
Alabama	Linseed oil coating. Lasted only 6 months – not worth cost.
Alaska	Latex modified concrete overlay – difficult to mix and place.
Arkansas	None
California	
Colorado	Minimum cement content w/o a maximum. Maximum w/c ratio w/o minimum (I think). Lower doses of silica fume. Restrictions on fly ash content.
Connecticut	Various sheet membranes were previously used, but often did not bond sufficiently to the deck. These were discontinued and the woven glass system substituted. There have been no debonding problems with the current system.
Delaware	
DC	Membranes were used in the distant past when asphalt cover was routinely used on bridge decks. We abandoned the use of asphalt on bridge decks 25 years ago, so the use of membranes was discontinued.
Georgia	None
Hawaii	None
Idaho	
Illinois	Not applicable
Indiana	Asphalt deck membrane, bad performance in the past. Use of No. 3 longitudinal reinforcement above the top mat of steel, the steel was not epoxy coated and depth of cover was minimal so delaminations resulted.
Iowa	Iowa has tried an ACC overlay above a waterproofing membrane. The membrane bubbled due to outgassing of the concrete deck, and the bubbling caused debonding problems. Overall the construction process was difficult.
Kansas	HSC (4A) f'c = 5 ksi. Cracking, too much cement. Siloxes and silanes just don't work.
Kentucky	HSC Class AAA (5500 psi) with silica fume. Transverse cracking in decks—suspended until further testing conducted.
Maryland	Cathodic protection—stopped because of maintenance and cost factor.
Massachusetts	LMC—FHWA no longer supports its use.
Minnesota	Haven't changed strategy in 20+ years. Didn't have much success using bituminous overlays with membranes.
Mississippi	None
Montana	
Nebraska	Sealers, membrane covering.
Nevada	1. Waterproof Membranes: Required an overlay on bridge, minimum 3 in. to keep the membrane in place. Required repaving and new membranes every 8 to 15 years. Some studies indicated membranes were effective. We had fair to good performance for protecting decks. 2. Latex Modified Concrete Overlays: Late 1970s and early 1980s. Used on about 5 bridges. Overlays debonded, had to be removed from all bridges. Low humidity and high temperatures identified as a problem. 3. Low Slump Concrete (Iowa): Late 1970s and 1980s. 50 bridges. Fair performance as far as debonding and surface cracking. 20%—significant debonding problems requiring repair. 90%—some level of surface cracking. 25% of these sealed (methacrylate). Surface cracking (10%) observed within one month of construction. Most (90%) surface cracking observed after overlay went into service. Low humidity and high temperatures identified as a problem.
New Hampshire	1. Rewarded contractors for increasing permeabilities down to as low as they could achieve. Decks cracked with the high cementitious contents. Changed our permerability target values. 2. Sheet membranes performed poorly. Bubbled up with moisture trapped below them.
New Jersey	2 course deck. Second course used to be LMC or SF overlay. Now require all decks to be HPC with permeability prime performance measure.
New Mexico	Epoxy sand overlays used late 70s early 80s—separated from concrete.
New York	
North Carolina	Coating with linseed oil—deemed ineffective.
North Dakota	Linseed oil discontinued—switched to silane.
Ohio	Moving away from asphalt overlays w/membrane. Membrane integrity impossible to control.
Oklahoma	In the 1970s, we did a few new bridge decks with high density concrete overlays and some decks with membranes. This practice was discontinued because of the expense and because of the development of sealers.
South Carolina	Bridge deck sealers and epoxy-coated rebar not effective.
Tennessee	3-in. asphalt overlay with sandwich seal. Sealant membrane placed between 2 layers of sand-asphalt mix (E-mix). Top 1 in. used as top lift on approach roadway. System worked well, but only 10-yr life—increased dead loads. Still use sandwich seal when repairs to bridge decks with black reinforcing bars and less cover. Protection very good.
Texas	Specified deck concrete with $f_c' = 8000$ psi. No longer specifying high strength decks due to cracking. Post-tensioned decks. Construction problems outweighed benefits.
Utah	
Virginia	Linseed oil. Slippery surface when placed on old concrete.
Washington	
Wisconsin	We tried pilot decks with Type K cement for about 5 years in early 90s for reduction of cracking, but quit because of problems with scaling, low strength and high permeability on some decks. (Due to additional water needed to activate expansive component in Type K product.) Note that it WAS very effective in stopping deck cracking, though.
Wyoming	

Question A7. (*Continued*)

Alberta	Deck concrete cast to grade. Often had full-depth transverse cracks at 1.2 to 2.0 m spacing.
New Brunswick	Epoxy rebar to limited extent. Not considered effective by other agencies.
Newfoundland	Not applicable
Ontario	Epoxy-coated rebars under review.
Quebec	Bituminous mastic as waterproofing membrane. Too brittle in cold temperatures.
Saskatchewan	High density concrete overlays no longer used. Only 20-yr life before rehabilitation—ride not good.

Question A8. Please supply any information about life-cycle costs for the different strategies that your agency has used.

State/Province	Attached	Fax	Separate Mail	Email	Reference	None	Comments
Alabama						X	
Alaska						X	
Arkansas						X	
California						X	
Colorado						X	
Connecticut						X	
Delaware							
DC						X	
Georgia						X	
Hawaii						X	
Idaho							
Illinois						X	
Indiana						X	
Iowa						X	
Kansas					X		K-Tran Reports
Kentucky						X	
Maryland							
Massachusetts						X	
Minnesota						X	
Mississippi						X	
Montana							
Nebraska						X	
Nevada						X	
New Hampshire						X	
New Jersey						X	
New Mexico							
New York						X	
North Carolina						X	
North Dakota						X	
Ohio							
Oklahoma						X	
South Carolina						X	
Tennessee						X	
Texas						X	
Utah						X	
Virginia						X	
Washington						X	
Wisconsin	X	X	X				
Alberta						X	
New Brunswick						X	
Newfoundland						X	
Nova Scotia						X	
Ontario						X	
Quebec						X	
Saskatchewan		X					

Question A9. Does your agency require any warranties for bridge decks?

State/Province	Yes	No	Details
Alabama		N	
Alaska		N	
Arkansas		N	
California		N	
Colorado		N	
Connecticut		N	
Delaware		N	
DC		N	
Georgia		N	
Hawaii		N	
Idaho		N	
Illinois		N	
Indiana		N	
Iowa		N	
Kansas		N	
Kentucky		N	
Maryland		N	
Massachusetts		N	
Minnesota		N	
Mississippi		N	
Montana			
Nebraska		N	
Nevada		N	
New Hampshire		N	
New Jersey		N	
New Mexico		N	
New York		N	
North Carolina		N	
North Dakota		N	
Ohio	Y		Supplemental Spec 894 & 898, see www.dot.state.oh.us/construction/oca/specs/
Oklahoma		N	
South Carolina			
Tennessee		N	
Texas		N	
Utah		N	
Virginia		N	
Washington		N	
Wisconsin		N	
Alberta	Y		2-year warranty
New Brunswick		N	
Newfoundland	Y		1 year from substantial performance, general warranty with all contract work
Nova Scotia		N	
Ontario	Y		1 yr general warranty for everything
Quebec		N	
Saskatchewan		N	

SURVEY SECTION B

Question B1. What design live loads does your agency use for bridge decks?

State/Province	HS20	HS25	MS18	HL93	Other	Note
Alabama	X					
Alaska		X		X		
Arkansas	X					
California					X	16 k load
Colorado				X		
Connecticut	X					
Delaware				X		
DC	X	X				
Georgia	X					
Hawaii				X		
Idaho				X		
Illinois	X					
Indiana	X					
Iowa	X	X				
Kansas			X	X		
Kentucky		X				
Maryland		X				
Massachusetts		X				
Minnesota		X		X		
Mississippi	X					
Montana		X		X		
Nebraska				X		
Nevada	X	X		X		X
New Hampshire		X				
New Jersey				X		
New Mexico	X	X				
New York		X				
North Carolina	X		X			
North Dakota		X				
Ohio		X				
Oklahoma	X					
South Carolina		X		X		
Tennessee	X			X		
Texas	X	X	X			
Utah	X					
Virginia	X					
Washington				X		
Wisconsin		X				
Alberta					X	YES
New Brunswick					X	
Newfoundland					X	YES
Nova Scotia					X	
Ontario					X	
Quebec					X	YES
Saskatchewan					X	YES

Question B2. What minimum deck thickness does your agency require?

State/Province	None	6 in.	6.5 in.	7 in.	7.5 in.	8 in.	8.5 in.	9 in.	10 in.	Other
Alabama				X						
Alaska	X									
Arkansas					X					
California			X							
Colorado						X				
Connecticut							X			
Delaware						X				
DC							X			
Georgia	X									
Hawaii	X									
Idaho						X				
Illinois					X					
Indiana						X				
Iowa						X				
Kansas						X				
Kentucky						X				
Maryland							X			
Massachusetts						X				
Minnesota								X		
Mississippi					X					
Montana					X					185 mm
Nebraska					X					
Nevada						X				
New Hampshire						X				
New Jersey						X				
New Mexico										7.25 in.
New York										9.5 in.
North Carolina						X				
North Dakota						X				
Ohio							X			
Oklahoma						X				
South Carolina						X				
Tennessee						X				
Texas						X				
Utah						X				
Virginia										7.5–8.5 in.
Washington					X					
Wisconsin						X				
Alberta								X		
New Brunswick								X		
Newfoundland								X		
Nova Scotia							X			
Ontario								X		
Quebec						X				
Saskatchewan						X				

Question B3. What is the minimum clear cover that your agency specifies for the top layer of reinforcement?

State/Province	1.5 in.	2 in.	2.25 in./ 60 mm	2.5 in.	2.75 in./ 70 mm	3 in.	Notes
Alabama		X					
Alaska				X			
Arkansas		X					
California		X					
Colorado						X	2.5 in. with asphalt, 3 in. with bare
Connecticut				X			
Delaware		X					
DC				X			
Georgia		X					
Hawaii		X					
Idaho				X			
Illinois			X				2.25 in. ± 0.25 in.
Indiana				X			
Iowa				X			
Kansas				X			
Kentucky				X			
Maryland				X			
Massachusetts		X					
Minnesota						X	
Mississippi				X			
Montana			X				
Nebraska				X			
Nevada				X			
New Hampshire				X			
New Jersey				X			
New Mexico		X					
New York						X	
North Carolina				X			
North Dakota				X			
Ohio				X			
Oklahoma				X			
South Carolina				X			
Tennessee				X			
Texas		X					
Utah		X					
Virginia		X					
Washington				X			
Wisconsin				X			
Alberta		X					
New Brunswick						X	
Newfoundland				X			
Nova Scotia		X					
Ontario					X		
Quebec			X				
Saskatchewan					X		

Question B4. What is the minimum clear cover that your agency specifies for the bottom layer of reinforcement?

State/Province	1 in.	1.25 in.	1.5 in.	2 in.	2.5 in.
Alabama	X				
Alaska	X				
Arkansas	X				
California	X				
Colorado	X				
Connecticut	X				
Delaware				X	
DC	X				
Georgia	X				
Hawaii		X			
Idaho	X				
Illinois	X				
Indiana	X				
Iowa	X				
Kansas	X				
Kentucky	X				
Maryland	X				
Massachusetts			X		
Minnesota	X				
Mississippi			X		
Montana	X				
Nebraska	X				
Nevada	X				
New Hampshire		X			
New Jersey	X				
New Mexico	X				
New York			X		
North Carolina		X			
North Dakota	X				
Ohio			X		
Oklahoma	X				
South Carolina	X				
Tennessee	X				
Texas		X			
Utah			X		
Virginia	X				
Washington	X				
Wisconsin			X		
Alberta			X		
New Brunswick				X	
Newfoundland			X		
Nova Scotia			X		
Ontario			X		
Quebec			X		
Saskatchewan				X	

Question B5. What is the maximum bar size that your agency uses for deck reinforcement?

State/Province	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	Other
Alabama			X					
Alaska				X				
Arkansas			X					
California					X			
Colorado				X				
Connecticut			X					
Delaware				X				X
DC				X				
Georgia				X				
Hawaii				X				
Idaho				X				
Illinois			X					
Indiana				X				
Iowa							X	
Kansas				X				
Kentucky				X				
Maryland			X					
Massachusetts			X					
Minnesota				X				
Mississippi								X
Montana			X					
Nebraska			X					
Nevada				X				
New Hampshire				X				
New Jersey				X				
New Mexico			X					X
New York				X				
North Carolina					X			
North Dakota				X				
Ohio			X					
Oklahoma			X					
South Carolina				X				
Tennessee				X				
Texas			X					
Utah		X						
Virginia			X					
Washington				X				
Wisconsin				X				
Alberta				X				
New Brunswick								X
Newfoundland								35 mm
Nova Scotia				X				
Ontario						X		X
Quebec				X				
Saskatchewan						X		

Question B6. What is the maximum spacing for longitudinal bars?

State/Province	3–6 in.	6.1–9 in.	9.1-12 in.	12.1–15 in.	15.1–20 in.	Other
Alabama				X		
Alaska	X					
Arkansas					X	
California					X	
Colorado		X				
Connecticut			X			
Delaware		X				X
DC				X		
Georgia				X		
Hawaii					X	
Idaho			X			
Illinois			X			
Indiana			X			
Iowa				X		
Kansas			X			
Kentucky			X			
Maryland					X	
Massachusetts			X			
Minnesota					X	
Mississippi			X			
Montana			X			
Nebraska			X			
Nevada				X		
New Hampshire			X			
New Jersey			X			
New Mexico	X					
New York					X	
North Carolina			X			
North Dakota				X		
Ohio						AASHTO
Oklahoma			X			
South Carolina					X	
Tennessee					X	
Texas		X				
Utah			X			
Virginia		X				
Washington		X				
Wisconsin			X			
Alberta			X			
New Brunswick			X			
Newfoundland			X			
Nova Scotia			X			
Ontario			X			
Quebec			X			
Saskatchewan					X	

Question B7. What is the maximum spacing for transverse bars?

State/Province	3–6 in.	6.1–9 in.	9.1–12 in.	12.1–15 in.	15.1–20 in.	Other
Alabama	X					
Alaska	X					
Arkansas		X				
California				X		
Colorado		X				
Connecticut			X			
Delaware			X			X
DC		X				
Georgia		X				
Hawaii			X			
Idaho			X			
Illinois			X			
Indiana	X	X				5–7 in.
Iowa			X			
Kansas		X				
Kentucky			X			
Maryland		X				
Massachusetts	X	X				5–8 in.
Minnesota		X				
Mississippi				X		
Montana			X			230 mm
Nebraska			X			
Nevada		X				
New Hampshire		X				
New Jersey			X			
New Mexico	X					
New York			X			
North Carolina		X				
North Dakota			X			
Ohio						AASHTO
Oklahoma			X			
South Carolina			X			
Tennessee	X					
Texas	X					
Utah			X			
Virginia		X				
Washington		X				
Wisconsin		X				
Alberta			X			
New Brunswick			X			
Newfoundland			X			
Nova Scotia			X			
Ontario			X			
Quebec			X			
Saskatchewan					X	

SURVEY SECTION C

Question C1. What grade of reinforcement does your agency specify for deck reinforcement?

State/Province	40	60	75
Alabama	X		
Alaska		X	
Arkansas		X	
California		X	
Colorado		X	
Connecticut		X	
Delaware	X	X	
DC		X	
Georgia		X	
Hawaii		X	
Idaho		X	
Illinois		X	
Indiana		X	
Iowa		X	
Kansas		X	
Kentucky		X	
Maryland		X	
Massachusetts		X	
Minnesota		X	
Mississippi		X	
Montana		X	
Nebraska		X	
Nevada		X	
New Hampshire		X	
New Jersey		X	
New Mexico		X	
New York		X	
North Carolina		X	
North Dakota		X	
Ohio		X	
Oklahoma		X	
South Carolina		X	
Tennessee		X	
Texas		X	
Utah		X	
Virginia		X	
Washington		X	
Wisconsin		X	
Alberta		X	
New Brunswick		X	
Newfoundland		X	
Nova Scotia		X	
Ontario		X	
Quebec		X	
Saskatchewan		X	

Question C2. Does your agency specify epoxy-coated reinforcement?

State/Province	Deck Top Layer	Deck Bottom Layer	Projecting from Girder	Notes
Alabama	N	N	N	
Alaska	Y	Y	Y	
Arkansas	Y	Y	Y	
California	Y	Y	Y	
Colorado	Y	Y	Y	
Connecticut	Y	Y	Y	
Delaware	Y	Y	Y	
DC	Y	Y	Y	
Georgia	Y	N	N	
Hawaii	N	N	N	
Idaho	Y			
Illinois	Y	Y	N	
Indiana	Y	Y	Y	
Iowa	Y	Y	N	MMFX project and a new project w/bulb tee-girder rebar projecting into deck.
Kansas	Y	Y	Y	
Kentucky	Y	Y	Y	
Maryland	Y	Y		
Massachusetts	Y	Y	Y	
Minnesota	Y	Y	Y	
Mississippi	N	N	N	
Montana	Y	Y	N	
Nebraska	Y	Y	N	
Nevada	Y	Y	Y	
New Hampshire	Y	Y		
New Jersey	Y	Y	N	
New Mexico	Y	Y	Y	
New York	Y	N	N	
North Carolina	Y	Y	N	Bottom layer, severe coastal environment.
North Dakota	Y	Y	N	
Ohio	Y	Y	Y	
Oklahoma	Y	Y	Y	
South Carolina	N	N	N	
Tennessee	Y	Y	N	
Texas	Y	Y	N	
Utah	Y	Y	N	
Virginia	Y	Y	Y	
Washington	Y	N	N	
Wisconsin	Y	Y	Y	
Alberta	Y	Y	N	
New Brunswick	N	N	N	
Newfoundland	N	N	N	
Nova Scotia	Y	Y		
Ontario	Y	N	Y	
Quebec	N	N	N	
Saskatchewan	N	N	N	

Question C3. What types of reinforcement with metallic coating has your agency used?

State/Province	None	Zinc Coated	Stainless Clad	Other	Effect on Deck Performance
Alabama	X				
Alaska	X				
Arkansas	X				
California	X				
Colorado	X				
Connecticut			X		Too soon
Delaware	X				
DC	X				
Georgia	X				
Hawaii			X		SS clad specified, got solid. No performance history
Idaho					
Illinois	X				
Indiana	X				
Iowa		X			1967: 2 bridges w/galv. rebar. 1992: Some corrosion below cracks. Otherwise performed well.
Kansas				X	Let galv. rebar. Not constructed. Proposed solid stainless
Kentucky			X	X	Too soon
Maryland	X				
Massachusetts	X				
Minnesota		X			1970s no information
Mississippi	X				
Montana	X				
Nebraska	X				
Nevada	X				
New Hampshire			X		No data
New Jersey		X	X		Expect coatings to enhance life expectancy of decks.
New Mexico	X				
New York		X			In some cases, scaling of concrete surface due to formation of hydrogen gas bubbles, which are trapped under the top surface.
North Carolina	X				
North Dakota			X		1 bridge, experimental. Too soon.
Ohio		X		X	Research on a few bridges w/galv. or FRP.
Oklahoma	X				
South Carolina		X			Good
Tennessee	X				
Texas	X				
Utah			X		Too soon
Virginia		X			
Washington	X				
Wisconsin	X				
Alberta			X		Too soon
New Brunswick	X				
Newfoundland	X				
Nova Scotia		X			
Ontario			X		2000, SS clad bars—experimental. Inconsistencies in manufacture. No further use.
Quebec		X			Good performance against corrosion. Good price.
Saskatchewan		X			Worked well

Question C4. Has your agency used solid stainless steel reinforcement?

State/Province	Solid Stainless	Effect
Alabama	N	
Alaska	N	
Arkansas	N	
California	N	
Colorado	N	
Connecticut	N	
Delaware	N	
DC	N	
Georgia	N	
Hawaii	Y	SS clad specified, got solid—Type 316.
Idaho	N	
Illinois	N	
Indiana	N	
Iowa	N	Propose project—TEA-21
Kansas	N	Future use. Clad has field problems.
Kentucky	N	
Maryland	Y	Stainless steel on bascule portion of Woodrow Wilson bridge—A955 Grade 60 Type 2205 or Type 316LN. Under construction.
Massachusetts	N	
Minnesota	N	
Mississippi	N	
Montana	Y	Too soon
Nebraska	N	
Nevada	N	
New Hampshire	Y	Grade A316 LN recent, no data.
New Jersey	Y	Permitted. Costs too high.
New Mexico	N	
New York	N	
North Carolina	N	
North Dakota	N	
Ohio	N	
Oklahoma	N	
South Carolina	Y	Pilot project, 2 years old. Too soon.
Tennessee	N	
Texas	N	
Utah	N	
Virginia	Y	Ongoing experimental. Too soon.
Washington	N	
Wisconsin	N	
Alberta	Y	Grade 316LN or 2205 Duplex. Too soon.
New Brunswick	N	
Newfoundland	N	
Nova Scotia	N	
Ontario	Y	Grade 316 LN or 2205 Duplex. No corrosion to date, steel passive. High cost a problem.
Quebec	N	
Saskatchewan	N	

Question C5. Has your agency used fiber-reinforced polymer (FRP) reinforcement?

State/Province	FRP	Effect
Alabama	N	
Alaska	N	
Arkansas	N	
California	N	
Colorado	Y	Too soon
Connecticut	N	
Delaware	N	
DC	N	
Georgia	N	
Hawaii	N	
Idaho	Y	In latex modified concrete overlays. Satisfactory.
Illinois	N	
Indiana	N	
Iowa	N	Proposed project—TEA-21
Kansas	N	Minimal design for maintenance salt shed—not constructed.
Kentucky	Y	Too soon
Maryland	N	
Massachusetts	N	
Minnesota	N	
Mississippi	N	
Montana	N	
Nebraska	N	
Nevada	N	
New Hampshire	Y	Deck has performed well for 3 years.
New Jersey	N	
New Mexico	N	
New York	N	As fiber additive not as rebar. Too soon (2001)
North Carolina	N	
North Dakota	N	
Ohio	Y	No data
Oklahoma	N	
South Carolina	N	
Tennessee	N	8 years ago—FRP on 12 bridges. No help in absence of proper curing, with proper curing did not reduce cracking
Texas	Y	2-year old deck with FRP. Too soon
Utah	N	
Virginia	Y	Recently awarded. Too soon
Washington	N	
Wisconsin	N	
Alberta	N	
New Brunswick	N	
Newfoundland	N	
Nova Scotia	Y	Used in curb and parapet wall in the one steel-free bridge in NS.
Ontario	Y	CFRP used. No data yet
Quebec	Y	5 experimental project. No problems so far. Looking for good results.
Saskatchewan	N	

SURVEY SECTION D

Question D1. For each of the following items, please list maximum and minimum values that your agency specifies and typical values used or achieved.

State/		Cementitious Materials lb/cu yd				Water-Cementitious Materials Ratio				Cement Content, lb/cu yd				Fly Ash Content			
Province	General Notes	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes
Alabama		620		620			0.44								20-30		%. 1:1 substitute
Alaska		710	710	710			0.33	0.33		658	658	658	lb/cu yd	0	0	0	
Arkansas		611					0.44			611					20		%, 1:1 replacement by weight
California		674	801	590				0.43				75%				25	%
Colorado																	
Connecticut		658					0.53									No	
Delaware		705		705	When history of low material quality variation, contractor may reduce cement to 658	0.38	0.42	0.4	Weight based				See cementitious materials content			0	Optional, but not in addition to SF or GGBFS
DC		658	None	X		0.44				60%	100%				15		%
Georgia		635	—	635		—	0.445	0.445		635	—	635		—	15	15	%
Hawaii							0.49	0.45		610	800	610					
Idaho		560					0.44			467				20			%
Illinois		N/A	N/A	N/A		0.32	0.44	0.44		605	605	605		0	15	15	%, 1.5:1 replacement
Indiana		658	718				0.443			526	718			0	25	25	20% reduction with 1.25:1 replacement
Iowa	"C" mix except as noted	624		624			0.488		0.42 for HPC			530				94 lb/ cu yd	15% allowed
Kansas		626				0.37			%	582							
Kentucky																	
Maryland		615		658			0.45	0.42						15	25		%
Massachusetts		655	705	655-705		0.35	0.40	0.35-0.40		556	600	556-600		15	30	15	% of cementitious
Minnesota	Low slump concrete overlay	800	N/A	800		0.32	0.32	0.32		800	800	800		0	0		Don't use in low slump concrete
Mississippi				658		0.45				75		80	%		25	20	%
Montana		615					0.42										
Nebraska		658		658			0.42	0.40		507					164	151	lb/cu yd
Nevada		611	752	725		—	0.44	0.44		611	752	725		—	—		Required when aggregates have ASR as an addition
New Hampshire		—	—	610	Contractor designs mixes	—	—	—	Contractor designs mixes	—	—	—	Contractor designs mixes	25			Fly ash or slag
New Jersey	*controlled by mix design verification process, placement conditions (time of year, etc.)				*	0.30	0.40						*		15		%

Question D1. (*Continued*)

New Mexico		—	—			—	—							20 or 25			20% for Class F, 25% for Class C by weight of cement
New York				675	Prescriptive mix			0.40				500				135	
North Carolina		639	715	Varies	Cement only, no pozzolan in mix. Cement and fly ash Min: 511 c + 126 FA. Max: 572 c + 172 FA	—	0.426	0.40		639	715	Varies		—	20	Varies	Replacement 1.2 lb FA/lb cement
North Dakota		517	541	503		0.44	0.51	0.47		517	611	564			30		Cement replacement
Ohio	See CMS 2002 Section 499 and 511																
Oklahoma							x			x					x		
South Carolina	Class D, 4000	611		611			0.40	0.40		611		611					Optional
South Dakota	HPC Class E, 6500	782		782			0.37	0.37		600		600		140		140	lb/cu yd
Tennessee		620		620			0.40	0.40		620					20 to 25	20-25	20% for Class F 25% for Class C
Texas		—	—				0.44			611				20	35	20	
Utah																	
Virginia		635		635-658			0.45	0.44						15	30	20 to 25	%
Washington																	
Wisconsin		565		565			0.45	0.42					70-85% of total cementitious				15-30% of total cementitious
Alberta							0.45				590				35		% by weight of cement
New Brunswick		674		708		0.37		0.37	see table								
Newfoundland		N/A	809	710-758		N/A	0.37	0.36-0.37	0.37 for 40 MPa 0.36 for 45 MPa	N/A	N/A	691		N/A	N/A	N/A	
Nova Scotia		699					0.40								20		%
Ontario					No limits, mix design by contractor				No limits				No limits		10-25		25% for HPC, 10% normal. Rarely used
Quebec		691	N/A		Ternary blend (Cement + SF + FA + GGBFS) = 450 kg/cu m	0.34	0.38					75	% of cementitious materials		20		%
Saskatchewan				576				0.40				539				0	

Question D1. (*Continued*)

State/Province	Silica Fume Content				GGBFS Quantity				Coarse Aggregate Minimum Size, in.				Water Reducer Quantity			
	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes
Alabama		8		Rarely used in slabs	25	50		%, Use allowed	0.75	1						Can be used in approved mix
Alaska	52	52	52	lb/cu yd	0	0	0		1	1.5	1				71	oz
Arkansas				Not specified		25		1:1 replacement by weight		1.5	1.25	AHTD standard AASHTO M 43 # 57				Per mfg. recommendations
California		10		%	—		—		0.375	1.5	1					Not specified Contractor's option
Colorado																
Connecticut			No				No			0.75						Not specified
Delaware			7	Optional, but not in addition to fly ash or GGBFS			35-50	Optional, but not in addition to fly ash or SF	1		1	AASHTO #57			2-5%	ASTM 494
DC		5		%		40		%	1	1.5						As needed
Georgia	—	—	—		—	50	30	%		1.5	1.5					Mfg. recommendations
Hawaii										0.75	0.75					
Idaho	7.5			Only in overlays					1							
Illinois	N/A	N/A	N/A		0	25	25	1:1 replacement	0.75	1.5						Used
Indiana					0	30	30	30% reduction with 1:1 replacement	0.75	1						Mfg. recommendations
Iowa			N/A					35% allowed	0.75	1.5	1				By product	Only when retarder not used
Kansas	44			lb/cu yd				35% allowed	0.75							
Kentucky																
Maryland	5	7		%		50	25-35	%		1.5	1.5				2-4	oz
Massachusetts	5	7	6	% of cementitious	25	40	40	% of cementitious		0.75	0.75					Mfg. recommendations
Minnesota	0	0			0	0				0.375		Overlay thickness 2 in.				Maximum allowable
Mississippi						50	50	%		1	1					Mfg. recommendations
Montana									0.75	0.75						
Nebraska		25	25	lb/cu yd overlay only	—	—	—			1	0.75				Varies	
Nevada	—	—			—	—				1			0	0		ASTM C 494 per mfg. recommendations
New Hampshire	—	—			50			Fly ash or slag		0.75						
New Jersey			7.5	%		30			1	0.375						*
New Mexico	5	12		% by weight of cement	25	50		By weight of cement	0.75	2			—	—		

Question D1. (*Continued*)

New York			40				135	Used as an alternative to fly ash—not in combination			1.5				v	For workability beyond max. w/c ratio
North Carolina	4	8	Limited use ~7	% by weight of cement lb for lb	35	50	35	% by weight of cement lb for lb	0.75	1.5	1					Mfg. recommendations
North Dakota				N/A				N/A			1					N/A
Ohio																
Oklahoma		x				x				x				x		
South Carolina	—	—			—	—						No. 56, 57, 67				As necessary
South Dakota	42		42	lb/cu yd	—		—					No. 56, 57, 67				As necessary
Tennessee						25		Not used much		1	1					Mfg. recommendations
Texas		10		%	35	50		%	0.75	1.5		Nominal Sizes	2	25		fl oz/100 lb mfg. dependent
Utah																
Virginia	3	10	7	%	25	50	40	%	0.75	1	1					Depends on product and need
Washington																
Wisconsin				None				15-30% of total cementitious as alternate to FA	1.5						3	oz/cwt
Alberta		10		% by weight of cement						0.79						
New Brunswick	7	10		%							0.79					Mfg. recommendations
Newfoundland	7	10	8	% by mass of cement	N/A	N/A	N/A		N/A	0.8	0.75		N/A	N/A	2-3	l/cu m of concrete
Nova Scotia		10		%		N/A				0.79				Varies		
Ontario			8	%. HPC only as blended cement		25		%, Depends on geographic location. 25% common in large part of ON		0.75		13 mm for overlay concrete				No limits, use mfg. recommendations
Quebec		10		%		20		%		0.5		14 mm				Not specified
Saskatchewan			37									1050 kg/cu m			y	Recommended dosage

Question D1. (*Continued*)

State/ Province	High Range Water Reducer Quantity				Retarder Quantity				Corrosion Inhibitor Quantity				Air Content Percentage			
	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes
Alabama				Can be used in approved mix				Can be used in approved mix				Rarely use calcium nitrite	4	6		
Alaska			71	oz							none					
Arkansas				Considered job-to-job. Per mfg. recommendations				Per mfg. recommendations				Not specified	4	8		
California								Not specified Contractor's option				Not used	0	6	4	
Colorado																
Connecticut				Not specified				For 50-60% increase in setting time					5	7	Yes	
Delaware				Optional			1-2%	ASTM 494				Not used	4	7	5	
DC				As needed				As needed				Not used	5	7.5		
Georgia				Mfg. recommendations				Mfg. recommendations	N/A	N/A	N/A		3.5	7	5	
Hawaii											5	gal/cu yd	2	4	3	
Idaho													5	8		
Illinois				Used				When concrete or air temp. > 65°F	N/A	N/A	N/A		5	8	6.5	
Indiana							> 65°F	Mfg. recommendations					5	8		Mix design at 6.5% target
Iowa			N/A					As required for placement			N/A		5.5	7.5	6.5	5.5 to 8.5 for HPC
Kansas													5	8		
Kentucky																
Maryland			N/A				4-8	oz			N/A		5	8		
Massachusetts	5	25		oz/cwt	2	8		oz/cwt	3	5	3	calcium nitrite, gal/cu yd	6	8	7	
Minnesota	0	0			0	0			0	0			4.8	8.2	6.5	
Mississippi				Mfg. recommendations				Mfg. recommendations					3	6	4	
Montana													5	7		
Nebraska			Varies				Varies	1 hour delay if T > 60°F			None		5	7.5	5.5-6.0	% by volume
Nevada	0	0		ASTM C 494 per mfg. recommendations	—	—		Not specified	—	—		Not specified				
New Hampshire				Contractor designs mixes									5	9		PWL calc
New Jersey				*				*			2 gal/cu yd		5.5	8.5		
New Mexico	—	—			—	—			—	—			4.5 to 6.5	9 to 10		Depends on risk zone

Question D1. (*Continued*)

New York			None	HRWR not allowed			v	Minimum to keep concrete plastic for placement			Varies	4.0 gal/yd general. 5.4 gal/yd severe environments (salt water)	5	8		
North Carolina				Mfg. recommendations				Mfg. recommendations	1 gal/cu yd	5.4 gal/cu yd	2-3 gal/cu yd		1.5	7.5	6	Specified as 6.0 ± 1.5%
North Dakota				N/A				Mfg. recommendations				N/A	5	8	6	% of total volume
Ohio																
Oklahoma		x												x		
South Carolina				As necessary				As necessary	—	—			3	6	4.5 ± 1.5	
South Dakota				Required per mfg. recommendations				As necessary				Required per mfg. recommendations	3	6	4.5± 1.5	
Tennessee				Mfg. recommendations				Mfg. recommendations				Not used	4	8	6	
Texas				Rarely used in decks	3	6		fl oz/cwt mfg. dependent	2	3	3	gal/cu yd	5	7		
Utah																
Virginia				Depends on product and need				Depends on product and need				Depends on product and need	5	8	6.5	
Washington																
Wisconsin				None				3				None	4.5	7.5	6	
Alberta													5	8		
New Brunswick				Mfg. recommendations				Mfg. recommendations			15	l/cu m	5	8		
Newfoundland	N/A		4 l/cu m	Max. slump of 230 mm	N/A	N/A	1.5 l/cu m	When used	N/A	N/A	N/A		5	8	6	
Nova Scotia		Varies				Varies				N/A			5	7		
Ontario				No limits, use mfg. recommendations. Max. slump of 230 mm				No limits, use mfg. recommendations. Extended retarder specified in some contracts				Not used	4			% in hardened concrete
Quebec				Not specified				Requested but not specified				N/A	5	8		
Saskatchewan								N/A					5	7	6	

Question D1. (*Continued*)

State	Freeze-Thaw Resistance				Deicer Scaling Resistance				Abrasion Resistance				
Province	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes	Other
Alabama				Only on HPC				Only on HPC				Only on HPC	
Alaska			None				None				None		
Arkansas													
California				Not specified				Not specified				Not specified	
Colorado													
Connecticut				Not specified				Not specified				Not specified	
Delaware				Not tested				Not tested				Not tested	For HPC typical w/c = 0.35
DC				Not specified				Not specified				Abrasion resistant aggregates only	
Georgia	N/A	N/A	N/A		N/A	N/A	N/A		N/A	N/A	N/A		
Hawaii													Shrinkage-reducing admixture—Tetraguard or Eclipse
Idaho													
Illinois	N/A	N/A	N/A		N/A	N/A	N/A		N/A	N/A	N/A		Coarse aggregate quality—40% max loss with AASHTO T 96
Indiana													
Iowa			N/A				N/A				N/A		
Kansas													
Kentucky													
Maryland			N/A				N/A				N/A		
Massachusetts			N/A				N/A				N/A		FA and GGBFS individually to the limits shown, in combination at reduced rates but permeability and strength limits satisfied and trial batches approved
Minnesota	N/A				N/A				N/A	N/A			
Mississippi													
Montana													
Nebraska				Not specified				Not specified				Not specified	
Nevada				Not specified				Not specified				Not specified	
New Hampshire													
New Jersey	80			Relative dynamic modulus of elasticity	3				1.016			mm	
New Mexico	85 to 95			Depends on risk zone									
New York													
North Carolina				Not specified				Not specified				Not specified	
North Dakota				N/A				N/A				N/A	
Ohio													
Oklahoma	x												
South Carolina													
South Dakota		—	—		—	—			—				

Question D1. (*Continued*)

Tennessee													
Texas													
Utah													
Virginia													
Washington													
Wisconsin				Not specified				Not specified				Not specified	
Alberta													
New Brunswick				ASTM C 666A									Low alkali cement < 0.6%
Newfoundland				N/A				N/A				N/A	
Nova Scotia													
Ontario				Not specified				Modified test for some pre-cast elements. (Quantitative assessment of mass loss due to scaling)				Not specified	
Quebec				Not specified		0.8	<0.5	kg/cu m				Not specified	
Saskatchewan				N/A				N/A				N/A	

Question D1. (*Continued*)

State/	Compressive Strength, psi				Tensile Strength, psi				Slump, in.				Rapid Chloride Permeability, coulombs			
Province	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes	Min.	Max.	Typical	Notes
Alabama	4000	None						None specified		3.5						Only on HPC
Alaska			None				None			7				1000	1000	
Arkansas		4000							1	4						
California	3600		3600					Not specified	1	8	4					Not specified
Colorado																
Connecticut	4000							Not applicable	1.5	3						Not specified
Delaware	4500		5500					Not tested	2	4		8 in. for Type F or G admixture				HPC, deck concrete is required to have test value < 1500 coulombs.
DC	4500	N/A						Not specified	2	3				1500		
Georgia	3500	5000	3500		N/A	N/A	N/A		2	4	3		N/A	N/A	N/A	
Hawaii			4000													
Idaho	4000									4						
Illinois		N/A	N/A		N/A	N/A	N/A		2	4	4	7 in. for HRWR	N/A	N/A	N/A	
Indiana					550			Field cure strength, or 15-18 days	1	4						
Iowa	3500			5000 min. for HPC					1	4	3.25					1300 for HPC, 56 days < 1000
Kansas									2	5						
Kentucky																
Maryland	4500						N/A		2	5	4				N/A	
Massachusetts	5000		5000						3	6	5-6			1500	<1000	
Minnesota	5600		5600		N/A				0.5	1	0.75		N/A			
Mississippi	4000									3						
Montana	4496								1.6	3.1						
Nebraska	4000							Not specified	0.75	4	≥4	May be exceeded w/water reducer				Not specified
Nevada	4500		5000		—	—		Not specified	1	2.5						
New Hampshire	4000							Not specified								
New Jersey	5400	>5400		56 days	0	0			2	4				1000		
New Mexico	4000	—		Min. 1200 psi over-design	—	—			2.5	4.5				2000 to 3000		Depends on risk zone

Question D1. (*Continued*)

New York				Designed for 3000 psi—but strength not specified					3	5						
North Carolina	4500	—	4500		—	—	—			3.5	3.5					Not specified
North Dakota			4000				N/A			3						N/A
Ohio																
Oklahoma	x				x					x						
South Carolina			4000		—	—			1	4			—	—		
South Dakota			4000						1	4						
Tennessee	4000	—							2	4	6	Allow 6 in. w/HRWR				
Texas	4000			28 days	570			7 days flexural strength		4	3		1000	2500	2000	
Utah																
Virginia	4000		5000						2	4	4			2500	1500	
Washington																
Wisconsin	4000		5000					Not specified		4					1500	
Alberta	5076	7252		7250 psi where FA used					2.0	2.8				1000		
New Brunswick	6526		7977						2.8	7.1	5.5				1000	
Newfoundland	5788	N/A	6511	40 MPa and 45 MPa	N/A	N/A	N/A		N/A	N/A	0.75 to 2.0	Each mix design	N/A	1000	N/A	ASTM C 1202
Nova Scotia		5076							2.4	3.9				600		At 91 days
Ontario			Varies	30, 35, 50 MPa typical for structural work				Not specified		9.1		For superplasticized concrete		1000		
Quebec	7252		8992						5.5	7.9	6.7			<1000		HPC only
Saskatchewan			4351					N/A	3.2	3.9						N/A

Question D2. What types of cement does your agency allow?

State/Province	Notes	I	II	III	IV	V	IA	IIA	IIIA	IS	IP	I(PM)	I(SM)	P	IS(MH)	IP(MH)	I(PM) (MH)	I(SM) (MH)	P(LH)	IS(MS)	IP(MS)	P(MS)	I(PM) (MS)	I(SM) (MS)	GU	MH	HE	LH	MS	HS
Alabama		X	X	X							X																			
Alaska		X	X				X																							
Arkansas		X									X	X	X																	
California			X	X		X					X	X				X	X													
Colorado																														
Connecticut		X	X	X						X	X																			
Delaware		X	X												X					X										
DC		X	X																											
Georgia		X	X																											
Hawaii		X									X																			
Idaho		X	X																											
Illinois		X	X	X	X	X	X	X	X	X	X	X	X							X	X									
Indiana		X	X	X						X	X																			
Iowa		X	X							X	X		X																	
Kansas			X								X																			
Kentucky																														
Maryland		X	X								X	X																		
Massachusetts		X	X				X	X																						
Minnesota		X	X	X			X	X	X	X	X																			
Mississippi		X	X							X	X		X							X	X									
Montana		X	X	X	X	X																								
Nebraska		X	X								X																			
Nevada			X	X		X					X																			
New Hampshire			X								X																			
New Jersey		X	X	X																										
New Mexico	II low alkali		X								X																			
New York		X	X								X		X																	
North Carolina	IS 35-50% req'd. IP 19-23% req'd.	X	X	X						X	X																			
North Dakota							X	X																						
Ohio	Limited use of AASHTO M 240	X	X	X			X						X																	
Oklahoma		X	X	X		X				X	X	X	X	X											X					
South Carolina		X	X				X						X											X			X			
South Dakota																														
Tennessee		X											X																	
Texas		X	X							X	X																			
Utah		X	X			X					X										X									X

Question D2. (*Continued*)

Virginia		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
Washington		X	X																											
Wisconsin		X	X							X	X		X																	
Alberta		X				X																								
New Brunswick																														
Nova Scotia		X		X																										
Ontario																														
Quebec																														
Saskatchewan	Type 10, 30, 50 w/low alkali																													

Question D3. What fly ash and pozzolan types does your agency allow?

State/Province	Class C	Class F	Class N
Alabama	X	X	
Alaska			
Arkansas	X	X	
California		X	X
Colorado			
Connecticut			
Delaware	X	X	
DC		X	
Georgia	X	X	
Hawaii			
Idaho		X	
Illinois	X	X	
Indiana	X	X	
Iowa	X	X	
Kansas			
Kentucky			
Maryland	X	X	
Massachusetts		X	
Minnesota	X	X	
Mississippi	X	X	
Montana			
Nebraska		X	
Nevada	X	X	X
New Hampshire		X	
New Jersey	X	X	
New Mexico	X	X	
New York	X	X	
North Carolina	X	X	
North Dakota	X	X	
Ohio	X	X	
Oklahoma	X		
South Carolina	X	X	
South Dakota			
Tennessee	X	X	
Texas	X	X	
Utah		X	X
Virginia		X	X
Washington		X	
Wisconsin	X		
Alberta	X	X	
New Brunswick			
Nova Scotia		X	
Ontario	X		
Quebec			
Saskatchewan		X	

Question D4. Does your agency have information of situations when the use of specific materials or test values was beneficial to enhancing the bridge deck performance?

State/Province	Yes	No	Explanation
Alabama		X	
Alaska	X		Silica fume overlay tested per AASHTO T 227 (705, 722 coulombs)
Arkansas		X	
California			
Colorado			
Connecticut		X	
Delaware		X	No values but testing of hardened air, shrinkage, and brittleness would be valuable
DC		X	
Georgia		X	
Hawaii		X	
Idaho			
Illinois		X	
Indiana	X		Recently adopted QC/QA for superstructure concrete through special provisions that require better quality control than Class C concrete. See www.in.gov/dot/div/contracts/standards/rsp/sep03/sep.htm
Iowa		X	
Kansas	X		Use of silica fume gave lower permeability values than low water-cement ratio high-density overlay
Kentucky			
Maryland	X		HPC mix with polypropylene fibers, chloride permeability test, corrosion inhibitors, w/cm = 0.40, and 4200 psi minimum
Massachusetts		X	
Minnesota		X	
Mississippi		X	
Montana		X	
Nebraska	X		All materials must be tested and approved before use
Nevada		X	
New Hampshire		X	
New Jersey		X	
New Mexico			
New York		X	
North Carolina	X		On Manteo Bypass, mix design specifications were based on chloride permeability values obtained by laboratory testing.
North Dakota	X		The use of fly ash and GGBFS for permeability and durability of concrete. (Research project)
Ohio		X	
Oklahoma			
South Carolina		X	
South Dakota			
Tennessee		X	
Texas		X	Research ongoing at U of T Austin
Utah		X	
Virginia		X	
Washington			
Wisconsin		X	
Alberta	X		Performance monitoring has proven that the use of specific materials is beneficial
New Brunswick			
Nova Scotia	X		Use of HPC reduced the number of girders required on one project. Use of waterproofing membranes and increasing the cover increased time between repairs.
Ontario			
Quebec	X		Use of ternary blend of cementitious materials plus fogging as a method of intermediate curing Placement of concrete by finisher (Gomaco type) Placing concrete at night with lower temperatures
Saskatchewan		X	

Question D5. Does your agency have information of situations when the use of specific materials or test values was not beneficial to enhancing bridge deck performance?

State/Province	Yes	No	Explanation
Alabama		X	
Alaska		X	
Arkansas		X	
California			
Colorado			
Connecticut		X	
Delaware			
DC		X	
Georgia		X	
Hawaii		X	
Idaho			
Illinois		X	
Indiana	X		Type K cement, DCI and Postrite corrosion inhibitors, slag cement, and Flexolith epoxy overlay do not meet design life.
Iowa	X		Silica fume and a superplasticizer in a deck mix. Slump and air contents were inconsistent. Pumping caused loss of air.
Kansas			
Kentucky			
Maryland		X	
Massachusetts		X	
Minnesota		X	
Mississippi		X	
Montana		X	
Nebraska		X	
Nevada		X	
New Hampshire		X	
New Jersey		X	
New Mexico			
New York		X	
North Carolina		X	
North Dakota		X	
Ohio		X	
Oklahoma			
South Carolina		X	
South Dakota			
Tennessee		X	
Texas	X		High-strength concrete due to cracking.
Utah		X	
Virginia		X	
Washington			
Wisconsin	X		20 decks with a specification requiring a maximum w/cm of 0.40 and mandatory use of HRWR—high level of early cracking on several decks—dropped use of specification.
Alberta		X	
New Brunswick			
Nova Scotia		X	
Ontario			
Quebec	X		Evaporation retardants not effective. Daytime concreting produced temperature problems.
Saskatchewan		X	

SURVEY SECTION E

Question E1. Which of the following overlay systems has your agency used in the past and which does your agency currently use? For each overlay system that your agency has used, please rate its performance on a scale of 1 to 5, where 1 = excellent and 5 = poor.

	None			Asphalt			Low Slump Dense Concrete			Latex Modified Concrete			Fly Ash Concrete			Silica Flume Concrete		
State/Province	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.
Alabama										X		4						
Alaska					X	1				X		3					X	1
Arkansas				X		5	X	X	3									
California																		
Colorado																		
Connecticut	X		5	X	X	2				X	X	2						
Delaware				X			X			X	X					X	X	
DC	X		5	X		5		X	1		X	1					X	3
Georgia	X	X	1	X		5												
Hawaii		X	3	X	3													
Idaho				X	X	3					X	?					X	2
Illinois				X	X	3	X	X	3	X	X	2	X	X	2	X	X	2
Indiana				X		5	X		1		X	2			4		X	3
Iowa				X		4	X	X	1	X	X	2	X	X	2			
Kansas	X		3	X		4	X		2	X		2				X	X	3
Kentucky		X	2				X		1	X		1						
Maryland				X		5	X		3	X	X	2						
Massachusetts										X		2				X	X	2
Minnesota							X	X	1									
Mississippi								X	2									
Montana							X			X	X							
Nebraska				X		3	X		2	X		2					X	2
Nevada							X		3	X		5						
New Hampshire		X	3		X	3	X		3	X		4		X	3		X	2
New Jersey				X		4				X		3		X	2		X	2
New Mexico											X							
New York							X		4	X		4		X	3		X	2
North Carolina				X	X					X	X		X	X				
North Dakota				X		5		X	2	X		2						
Ohio				X		3	X	X	1	X	X	2				X	X	1
Oklahoma				X	X	4	X	X	2	X	X	2					X	2
South Carolina				X		5	X	X	1	X	X	1						
South Dakota																		
Tennessee				X		4	X		4	X	X	2	X	X	2	X	X	2
Texas				X	X	4	X	X	3		X	3		X	2			
Utah				X		3	X		3	X		3				X		3
Virginia				X		4	X		5	X	X	2		X	2		X	2
Washington					X	4	X		4		X	2		X	2		X	2
Wisconsin					X	3	X	X	5									
Alberta				X		4	X		1	X		5		X	?	X	X	1
New Brunswick	X		5	X	X	2											X	1
Newfoundland	X	X	3	X	X	3												
Nova Scotia					X	2										X		3
Ontario				X	X					X	X	1				X	X	2
Quebec				X	X	3	X		2		X	2						
Saskatchewan					X	3	X		3								X	3

Question E1. (*Continued*)

	Epoxy			Polyester			Other			
State/Province	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.	Notes
Alabama	X	X	3							
Alaska										
Arkansas										
California				X	X	2				
Colorado										
Connecticut										
Delaware										
DC										
Georgia								X	1	Fast track concrete overlay
Hawaii										
Idaho										Asphalt used with membrane. Latex modifed allowed but not generally used
Illinois							X	X	2	Thin polymer overlay and high-reactive metakaolin—infrequently
Indiana		X	1							
Iowa										
Kansas	X	X	1				X		5	Wax beads, chloride extraction and polymer filling
Kentucky										
Maryland										
Massachusetts	X	X	1							
Minnesota										
Mississippi										
Montana	X			X						
Nebraska										
Nevada				X		1				
New Hampshire										
New Jersey										
New Mexico										
New York		X	2					X	2	HPC mix w/20% fly ash and 6% SF
North Carolina	X	X								Ratings unavailable
North Dakota										
Ohio	X		5							Performance based on duration of riding surface condition
Oklahoma										Asphalt/membrane (rating of 5 w/o membrane)
South Carolina										
South Dakota										
Tennessee		X	1	X		5				
Texas		X	4							
Utah										
Virginia	X	X	3							
Washington	X		4		X	2				
Wisconsin										
Alberta	X	X	2				X		5	Pyrament cement
New Brunswick	X		3				X	X	2	Rosphalt 50
Newfoundland										
Nova Scotia	X		4				X		4	
Ontario									1	Normal concrete
Quebec										
Saskatchewan		X	4							

Question E2. Which of the following waterproofing membrane systems has your agency used in the past and which does your agency currently use? For each waterproofing membrane system that your agency has used, please rate its performance on a scale of 1 to 5, where 1 = excellent and 5 = poor.

State/Province	General notes	None			Asphalt-Impregnated Fabric			Polymer			Elastomer		
		Past	Current	Perform.	Past	Current	Perform.	Past	Current	Perform.	Past	Current	Perform.
Alabama		X	X										
Alaska												X	1
Arkansas		X	X										
California					X	X	2						
Colorado													
Connecticut					X		4						
Delaware					X								
DC					X		5				X		5
Georgia		X	X	1									
Hawaii		X	X	3									
Idaho	Asphalt-impregnated most common					X	3						
Illinois													
Indiana					X		4	X		5			
Iowa	Elastomer was butyl rubber										X		5
Kansas		X		2				X		2			
Kentucky			X	2									
Maryland													
Massachusetts					X	X	2						
Minnesota	Haven't used such systems in 20+ years												
Mississippi													
Montana		X	X										
Nebraska								X		2			
Nevada					X		2				X		2
New Hampshire					X		4						
New Jersey				X									
New Mexico													
New York													
North Carolina		X	X										
North Dakota		X	X										
Ohio	Current practice Type D per 512.08 or Type 3 per 512.09 of CMS 2002												
Oklahoma					X	X	3						
South Carolina					X	X	2						
South Dakota													
Tennessee	30 yrs ago used asphalt overlays on all new decks. With clear cover of 2-1/2 in. and epoxy steel, sandwich seals used only on older decks with black steel and less cover as needed.				X	X	2						
Texas		X	X										
Utah					X		2	X		2			
Virginia					X	X	4						
Washington						X	3						
Wisconsin												X	
Alberta					X		3						
New Brunswick												X	3
Newfoundland													
Nova Scotia													
Ontario		X	X										
Quebec					X	X	2						
Saskatchewan												X	2

Question E2. (*Continued*)

State/Province	Asphalt-Laminated			Other				Bituminous			Resinous			Other			Notes
	Past	Current	Perform.	Past	Current	Perform.	Notes	Past	Current	Perform.	Past	Current	Perform.	Past	Current	Perform.	
Alabama										5							
Alaska																	
Arkansas														X	X	3	Boiled linseed oil/kerosene mix
California																	
Colorado																	
Connecticut									X	1		X	1				
Delaware								X									
DC								X		3							
Georgia																	
Hawaii																	
Idaho		X							X			X					Bituminous w/asphalt roofing
Illinois				X	X	2	Coal tar inner layer w/fiberglass reinforcement							X		4	Methyl methylacrylate and urethene polymers
Indiana								X		5							
Iowa				X		4	Protecto wrap/asphaltic										
Kansas	X		2					X	X	2							
Kentucky																	
Maryland																	
Massachusetts														X		4	Asphaltic emulsion
Minnesota																	
Mississippi																	
Montana																	
Nebraska											X		5				
Nevada																	
New Hampshire					X	2	Torch applied								X	1	
New Jersey									X	3							
New Mexico																	
New York																	
North Carolina																	
North Dakota																	
Ohio																	
Oklahoma																	
South Carolina								X		3							
South Dakota																	
Tennessee	X	X															
Texas								X	X	4							
Utah								X		2							
Virginia	X	X	3					X		4	X		4				
Washington									X	3							
Wisconsin																	
Alberta								X	X	1	X	X	3				
New Brunswick																	
Newfoundland	X		4					X		2							
Nova Scotia	X								X	2							
Ontario	X								X	2				X	X	1	Hot applied rubberized asphaltic membrane
Quebec	X		4					X		4							
Saskatchewan									X	2							

Question E3. Which of the following sealers has your agency used in the past and which does your agency currently use? For each sealer that your agency has used, please rate its performance on a scale of 1 to 5, where 1 = excellent and 5 = poor.

		None			Siloxanes			Epoxies			Gum Resins and Mineral Spirits			Linseed Oil		
State/Province	General Notes	Past	Current	Perform.	Past	Current	Perform.	Past	Current	Perform.	Past	Current	Perform.	Past	Current	Perform.
Alabama					X		2	X	X	4				X		1
Alaska																
Arkansas	Use silanes, siloxanes only when specified					X	4							X	X	3
California					X	X	2							X		5
Colorado																
Connecticut					X		4							X		4
Delaware					X											
DC														X		5
Georgia						X	2							X	X	3
Hawaii		X	X	3												
Idaho			X	3	X	2										
Illinois														X	X	5
Indiana						X	2		X	3				X		4
Iowa														X		3
Kansas					X		4	X		3				X		3
Kentucky			X	2												
Maryland														X	X	
Massachusetts		X	X	5	X		3							X		4
Minnesota					X		3							X	X	4
Mississippi						X	4		X	4						
Montana						X								X		
Nebraska			X		X		4							X		3
Nevada					X	X	4									
New Hampshire						X	3	X		4		X	3		X	3
New Jersey								X	X	4						
New Mexico						X		X								
New York		X		4		X	1									
North Carolina																
North Dakota						X	2							X		4
Ohio	See Supplement Spec. 864 and 841					X	1		X	1						
Oklahoma						X	1							X		4
South Carolina					X		3							X		5
South Dakota																
Tennessee					X		4	X	X	2						
Texas								X	X	4				X	X	3
Utah					X		3	X		3						
Virginia					X	X	3	X	X	2	X		4	X		4
Washington			X	X												
Wisconsin						X	5							X		3
Alberta					X	X	1	X	X	2				X		4
New Brunswick																
Newfoundland						X	2							X		3
Nova Scotia					X		3							X		2
Ontario	MTO applies silanes, siloxanes or blends of silanes and siloxanes as a primer followed by application of acrylic top coat. Therefore we can not rate performance of each individually.				X	X										
Quebec		X	X													
Saskatchewan						X	2									

Question E3. (*Continued*)

	Sterates			Acrylics			Silicates and Fluorosilicates			Urethanes and Polyurethanes			Polyesters			Chlorinated Rubber		
State/Province	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.
Alabama																		
Alaska																		
Arkansas																		
California							X		5	X		5	X		5	X		3
Colorado																		
Connecticut																		
Delaware																		
DC																		
Georgia																		
Hawaii																		
Idaho																		
Illinois																		
Indiana																		
Iowa																		
Kansas																		
Kentucky																		
Maryland																		
Massachusetts																		
Minnesota																		
Mississippi																		
Montana					X													
Nebraska	X		5															
Nevada																		
New Hampshire																		
New Jersey																		
New Mexico																		
New York																		
North Carolina																		
North Dakota																		
Ohio											X	1						
Oklahoma																		
South Carolina																		
South Dakota																		
Tennessee																		
Texas																		
Utah										X		3						
Virginia										X	X	3						
Washington																		
Wisconsin																X		4
Alberta				X	X	1												
New Brunswick																		
Newfoundland																		
Nova Scotia																		
Ontario				X	X													
Quebec																		
Saskatchewan																		

Question E3. (*Continued*)

	Silicones			Vinyls			Other			
State/Province	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.	Past	Cur-rent	Per-form.	Notes
Alabama										
Alaska										
Arkansas										
California										
Colorado										
Connecticut										
Delaware										
DC								X	3	Methyl methacrylate
Georgia										
Hawaii										
Idaho										
Illinois										
Indiana										
Iowa										
Kansas										
Kentucky										
Maryland										
Massachusetts										
Minnesota										
Mississippi										
Montana										
Nebraska										
Nevada										
New Hampshire										
New Jersey										
New Mexico										
New York										
North Carolina										
North Dakota										
Ohio								X		Soluble reactive silicate (SS 841)
Oklahoma										
South Carolina										
South Dakota										
Tennessee										
Texas										
Utah										
Virginia										
Washington										
Wisconsin										
Alberta										
New Brunswick										
Newfoundland										
Nova Scotia										
Ontario										
Quebec										
Saskatchewan										

Question E4. If your agency has used cathodic protection systems in the past, please provide the name of the system(s) and describe how successful it was.

State/Province	Description
Alabama	
Alaska	Norton Corrosion was not successful since the system was not maintained.
Arkansas	
California	Coke breeze, metallized zinc, conductive polyester concrete.
Colorado	
Connecticut	
Delaware	One bridge deck using a non-overlay grid anode system consisting of primary (platinum wire) and secondary (carbon strand) anodes installed in sawed slots (3/4 x 3/4 in.) backfilled with conductive polymer concrete grout. Installed in 1986 by Matco, Inc. of Doylestown, PA.
DC	One cathodic protection system placed on an Interstate ramp and worked well.
Georgia	
Hawaii	
Idaho	
Illinois	Elgard and Corrpro. Never evaluated, probably forgotten.
Indiana	Impressed current system; to date successful.
Iowa	Three bridges total; two with Raychem both shut off in less than five years. Elgard is still working, but bridge is scheduled for replacement.
Kansas	Corrpro anode mesh depressed current installed in 2001. Too recent to assess. Vector Galvashield XP embedded anode system. Too recent to assess. Zinc Hydrogel—installed on an abutment and portion of concrete box girder in 2002.
Kentucky	
Maryland	Cathodic protection systems installed at 12 sites. Ongoing electrical problems have provided limited success.
Massachusetts	
Minnesota	Two test installations—system didn't operate with enough reliability to make final conclusions.
Mississippi	
Montana	Two installations. Neither very successful.
Nebraska	The name of the system is unavailable. High degree of success.
Nevada	Two bridges were constructed with a Raychem system consisting of a grid of carbon strands/conductive grout and platinum wire in 1986. It was encased in a low-slump concrete overlay. It was removed in 2002 as part of a widening project. The low-slump overlay debonded and the grid system was damaged beyond repair. It is not known how well the CP system worked. The bridges had been in service for 20 years prior to the CP system being installed and there is no record of the deck's condition at that time.
New Hampshire	System name unknown. Not maintained and no data on success.
New Jersey	Have used titanium mesh system, mounded conductive polymer system, and flexible conductive polymer system.
New Mexico	
New York	
North Carolina	
North Dakota	
Ohio	
Oklahoma	Harco Corp. system installed on one bridge by Good-All Electric, Inc. We had problems with maintenance and vandalism. A report is available: "Cathodic Protection for Reinforced Concrete Bridge Decks," dated 1988.
South Carolina	
Tennessee	
Texas	Currently using sacrificial galvanic anodes marketed by Vector Corrosion Technologies on a limited basis. However, not enough field data to assess reliability of system. TxDOT currently participating in CERF evaluation of this product.
Utah	Name of the system unknown. The system and performance were unreliable.
Virginia	Used only on some experimental projects.
Washington	
Wisconsin	
Alberta	1. Used a titanium mesh system embedded in concrete overlay on a number of bridges about 10 years ago. Systems still appear to be working. However, initial costs were high and they require continuing monitoring and maintenance. 2. Conductive paint system used on underside of deck on one bridge. The resistance of system increased over time and it was not possible to maintain voltage potential required.
New Brunswick	
Newfoundland	
Nova Scotia	Cathodic protection was used on one structure in the early 1980s. The impressed current system used coke breeze layer over the deck in conjunction with silicon iron and pancake type anodes buried in the deck. The system appears to be effective as no repairs have been conducted on the structure since its installation.
Ontario	Conductive asphalt system was used until late 80s, but performance was very poor. From early 90s, titanium mesh system with normal concrete overlay has been used and the performance has been good so far.
Quebec	Partial experimentation—three (3) zones of deck rehabilitation in 1989 (5800 ft²). Mesh Elgard 210 + latex modified overlay (25 mm). Important reduction of corrosion activity and consequently less deterioration. Operation of the system has been discontinuous (human resource and logistic problems).
Saskatchewan	Ferex—not successful. Elgard—worked adequately.

Question E5. Describe your agency's experience with protective systems.

State/Province	Response
Alabama	Not applicable
Alaska	Success with asphalt overlay with waterproofing membrane and silica fume overlays.
Arkansas	Not applicable
California	Good
Colorado	
Connecticut	Preformed sheet systems bonded poorly to bridge decks and were discontinued. The current woven glass fabric hot mopped system bonds well and seems to waterproof well, but is very difficult to remove for resurfacing. Extra cover of 1/2 in. was recently added to accommodate milling to remove it. Liquid applied systems (Sterling Lloyd's Eliminator) work well but are very expensive and therefore not competitive. Silica fume concretes and latex modified overlays have very limited use to date. Latex modified seems to work well and may see more future use. HPC decks are difficult to cure and have had some cracking problems. However, there will probably be more use of bare HPC decks in the future. Cathodic protection has limited use and requires maintenance of the system which is sometimes lacking. Sealants have not been tried extensively and seem of limited use.
Delaware	
DC	
Georgia	With adequate cover, we do not need protective systems. Georgia aggregate coupled with a few freeze-thaw cycles in the state is very successful.
Hawaii	None
Idaho	
Illinois	See E1 through E4
Indiana	For the most part a positive experience.
Iowa	The asphalt overlay was tried on only a few bridges. Although a latex-modified overlay is permissible, contractors prefer the low-slump Iowa mix, and few latex-modified overlays have been constructed. In the future, Iowa plans to seal HPC decks for 6 to 8 months until permeability matures.
Kansas	No success with BM-2 when laid without a membrane. Varied success when laid with a membrane. Sealers work only if applied every year. Low slump, silica fume and latex overlays work well if cured properly (or cracking problems occur). Not experienced any problems with epoxy-coated bars on decks 20 to 25 years old.
Kentucky	
Maryland	
Massachusetts	
Minnesota	Tremendous experience with low-slump dense concrete overlays for rehabilitation and new construction. Have built 12 bridges with full-depth (9 in.) silica fume decks. Have had construction problems on four of the bridges.
Mississippi	
Montana	
Nebraska	Cathodic protection has been the best active system.
Nevada	Protective systems have been used on bridges when they did not have epoxy-coated reinforcement. See question A7 for description of systems no longer in use. Our current protection system is the polyester-styrene overlay developed by Caltrans. We have been using this system for about 10 years with very good performance. It has been placed on about 50 bridges. We have had only one major failure and it was not due to the system but the deck under the overlay failing. Minimum thickness is 0.75 in. The system works well in Nevada due to our dry climate in summer which is beneficial to polymers.
New Hampshire	Continuing process of trial and error going from one system to the next as problems are encountered with each.
New Jersey	Overall performance was good—see answer to E4.
New Mexico	
New York	
North Carolina	
North Dakota	None
Ohio	Application of concrete sealers is standard practice on new construction. Many districts use on rehabilitation projects.
Oklahoma	The sealers appear to be helping.
South Carolina	Overall—minor
Tennessee	Epoxy-coated reinforcement with 2-1/2 in. clear cover is our best system for new construction. Asphalt/sandwich seal are the next best and most cost-effective system. PMC overlays are good alternative in conjunction with scarifying away the top 1 in. of existing contaminated deck when avoiding the need to raise existing expansion joints. When eliminating joints, we prefer scarifying the top 1 in. of existing deck and placing 4-1/2 in. of 4 ksi concrete overlay with one mat of epoxy-coated reinforcing. This works well with widening w/o adding girders or widenings where cross-slope changes are required or crown locations are moved. Had poor results with low-slump dense overlay bonding, attributed to lack of contractor expertise and heavy screed rollers.
Texas	Not enough field data to comment on performance of system. In aggressive environments, TxDOT is specifying the use of HPC.
Utah	

Question E5. (*Continued*)

Virginia	
Washington	
Wisconsin	
Alberta	
New Brunswick	
Newfoundland	Nil
Nova Scotia	
Ontario	The single most cost-effective protective system is the waterproofing membrane. It generally lasts about 25 years before replacement. Recently, study on decks has shown very little chloride penetration through the waterproofing after 18 to 20 years in service.
Quebec	
Saskatchewan	Iowa method, high density overlays, epoxy-coated bars, high performance concrete, and asphalt with hot applied rubber membrane.

SURVEY SECTION F

Question F1. What maximum delivery time after batching does your agency specify?

State/Province	30	60	90	120	Other	Notes
Alabama					X	45 min. if temp > 30°C, 60 min if < 30°C
Alaska			X			
Arkansas			X			
California			X			
Colorado						
Connecticut		X				
Delaware		X				
DC			X			
Georgia		X				
Hawaii			X			
Idaho			X			
Illinois			X			With retarder
Indiana			X			From time of batching to discharge
Iowa			X			
Kansas		X				
Kentucky			X			
Maryland			X			
Massachusetts			X			
Minnesota		X				
Mississippi			X			
Montana			X			
Nebraska	X		X			30 min. with non-agitating truck. 90 min. with agitating truck
Nevada			X			
New Hampshire			X			
New Jersey			X			
New Mexico			X			
New York			X			
North Carolina					X	Depends on air and concrete temp. and if retarder used
North Dakota		X				
Ohio			X			
Oklahoma		X				
South Carolina				X		
Tennessee					X	60 min. if ambient temp > 90°F. 90 min. if ambient temp < 90°F
Texas		X				For agitated concrete with temp. between 75 and 90°F at point of placement and no retarder
Utah			X			
Virginia			X			
Washington					X	320 revolutions of concrete drum
Wisconsin			X			
Alberta			X			
New Brunswick			X			
Newfoundland				X		
Nova Scotia					X	
Ontario			X			
Quebec			X			
Saskatchewan		X				

Question F2. Does your agency specify the concrete placement method?

State/Province	Yes	No		
Alabama		X		
Alaska	X			
Arkansas		X		
California		X		
Colorado				
Connecticut				
Delaware		X		
DC		X		
Georgia		X		
Hawaii		X		
Idaho		X		
Illinois		X		
Indiana		X		
Iowa		X		
Kansas		X		
Kentucky		X		
Maryland		X		
Massachusetts		X		
Minnesota		X		
Mississippi		X		
Montana		X		
Nebraska		X		
Nevada		X		
New Hampshire		X		
New Jersey	X			
New Mexico	X			
New York		X		
North Carolina		X		
North Dakota		X		
Ohio		X		
Oklahoma		X		
South Carolina		X		
Tennessee		X		
Texas	X			
Utah	X			
Virginia		X		
Washington		X		
Wisconsin		X		
Alberta	X			
New Brunswick		X		
Newfoundland		X		
Nova Scotia		X		
Ontario		X		
Quebec	X			
Saskatchewan		X		

Question F3. What methods of concrete placement are used?

State/Province	Pumps	Conveyors	Buckets	Direct Discharge	Notes
Alabama	X	X	X	X	
Alaska	X	X		X	
Arkansas	X		X		
California	X	X	X	X	
Colorado					
Connecticut	X		X	X	
Delaware	X	X	X	X	
DC	X	X	X	X	
Georgia	X		X	X	
Hawaii	X		X	X	
Idaho	X		X	X	
Illinois	X	X	X	X	
Indiana	X	X	X	X	
Iowa	X	X	X	X	Buckets not common. Direct discharge used at end of bridge when outside pumping range.
Kansas	X	X	X	X	
Kentucky	X		X	X	
Maryland	X		X	X	
Massachusetts	X				
Minnesota	X	X	X		
Mississippi	X	X	X	X	
Montana	X		X	X	
Nebraska	X		X	X	
Nevada	X				
New Hampshire	X		X		
New Jersey	X	X	X	X	
New Mexico	X				
New York	X	X	X	X	
North Carolina	X		X		
North Dakota	X	X			
Ohio	X	X	X	X	
Oklahoma	X		X	X	
South Carolina					
Tennessee	X		X	X	
Texas	X	X	X		
Utah	X		X		
Virginia	X	X	X	X	
Washington	X			X	
Wisconsin	X	X	X		
Alberta	X		X	X	
New Brunswick	X		X		
Newfoundland	X	X	X	X	
Nova Scotia	X		X	X	
Ontario	X	X	X	X	
Quebec	X		X		
Saskatchewan	X		X	X	

Question F4. Under what conditions does your agency require fogging systems?

State/Province	Conditions
Alabama	Hot weather low humidity
Alaska	Throughout finishing process
Arkansas	Not specified
California	Not required but is an option
Colorado	
Connecticut	Fogging shall start immediately after initial set and continue until cotton mats are in place.
Delaware	Specifications require conformance to ACI 305R "Hot Weather Concreting."
District of Columbia	Some precast units
Georgia	Not specified
Hawaii	All bridge decks are required to be water cured, which includes fogging. Specifications do not require fogging during concrete placement.
Idaho	
Illinois	Evaporation rate $\geq$ 0.1 lb/sq ft/hr. Equipment required for all projects.
Indiana	Only when using QC/QA superstructure concrete with silica fume and when evaporation rates > 0.1 lb/sq ft/hr.
Iowa	May be used if evaporation rate > 0.2 lb/sq ft/hr.
Kansas	Based on chart. Required for overlays.
Kentucky	With silica fume concrete
Maryland	Misting equipment must be on site for all deck placements. If concrete is not covered with burlap within 30 minutes of placement, misting must start and continue until burlap is placed.
Massachusetts	Evaporation chart provided. Fogging required when rate exceeds 0.15 lb/sq ft/hr.
Minnesota	Only for silica fume concrete
Mississippi	Thin bridge deck overlays
Montana	All deck placements
Nebraska	Evaporation rate $\geq$ 0.15 lb/sq ft/hr.
Nevada	Every deck placement
New Hampshire	Not specified
New Jersey	Per Standard Specifications 2001 NJDOT 501.12 Item 5
New Mexico	Fog spray reduces rate of evaporation. Specifications provide graphs when additional measures required.
New York	None. Fogging has been inappropriately used with excess water used as finishing aid—scaling resulted.
North Carolina	Conditions not specified. Require fogging equipment on site capable of placing enough moisture to curb effects of rapid evaporation.
North Dakota	When water-saturated covers are not on before concrete surface begins to dry.
Ohio	None
Oklahoma	Require fogging then curing on fresh deck concrete
South Carolina	All deck concrete
Tennessee	
Texas	Advised to start at evaporation rates of 0.10 lb/sq ft/hr but not specified. Shrinkage cracks generally occur at rates above 0.25 lb/sq ft/hr.
Utah	When combination of air temperature, humidity, and wind velocity have the potential to impair the concrete quality
Virginia	Excessive evaporation, delay in covering
Washington	None
Wisconsin	Decks over 100 ft long
Alberta	For 50 MPa HPC
New Brunswick	All conditions for a deck. Concrete usually placed at night or early morning.
Newfoundland	All conditions
Nova Scotia	
Ontario	Required for HPC and immediately after finishing.
Quebec	Always after placement by automatic finisher
Saskatchewan	Not yet used

Question F5. What surface finish does your agency specify for deck concrete?

State/Province	Surface Finish
Alabama	Saw grooved after curing
Alaska	Sawcut groove
Arkansas	Burlap drag followed by tining
California	Friction coefficient at least 0.35; profile counts; no high point above 6.36 mm
Colorado	
Connecticut	Float finish is standard practice because decks are overlaid. In rare instances of bare decks, a tined finish is required.
Delaware	DelDOT Standard Specifications Section 602.20.c: mechanical grooving (0.1 in. wide, 1/8 in. deep, cut at 1.5 in. centers—or cut at random centers) and manual texturing (broom 0.1 in. wide, 0.2 in. deep, at 1/2 to 3/4 in. centers). The use of mechanical grooving allows the placement of curing compound sooner after the finishing machine has passed an area.
DC	Diamond saw cutting
Georgia	Belt finish
Hawaii	Float finish with a finishing machine. Final surface is textured with metal tines to produce transverse grooves.
Idaho	Longitudinal tined surface
Illinois	Burlap or artificial turf carpet drag. Tining done after curing is completed.
Indiana	Finished and tined in accordance with Standard Specifications 704.05. For details go to www.in.gov/dot/div/contracts/standards/book/sep03/sep.htm
Iowa	For standard “C” mix, pan drag with burlap followed by a transverse rake texture. For HPC, pan drag with Astroturf. (Longitudinal grooves cut later)
Kansas	Tined
Kentucky	Transverse tining after deck finished with Bidwell machine
Maryland	Transverse grooves
Massachusetts	For exposed decks: artificial turf drag and transverse sawcut grooves. For decks to be overlaid with bituminous concrete: smooth surface
Minnesota	Metro area: surface planing. Other areas: carpet drag and transverse wet tining
Mississippi	Broom finish, then mechanically grooved
Montana	Burlap then transverse sawcut grooves
Nebraska	Tined
Nevada	Whatever the Bidwell produces. Grooves cut after the deck is cured.
New Hampshire	CSP 5 or less
New Jersey	Per Standard Specifications 2001 NJDOT 501.15 deck slab surface finish
New Mexico	Broom finish during finishing. Grooving after curing.
New York	Astroturf drag while concrete is plastic with sawcut grooving 1/4 in. deep, 1/4 in. wide at 1.5 in. spacing after curing
North Carolina	Burlap drag or broom finish and grooving required.
North Dakota	Tining
Ohio	Screed or bullfloat and cover with burlap then diamond bladed grooving
Oklahoma	Tined
South Carolina	Random transverse grooves at 1/2 to 1-1/8 in. spacing.
Tennessee	For design speeds < 40 mph: burlap drag. For design speeds ≥ 40 mph: sawed transverse grooving
Texas	Bare surfaces require a grooved steel tine finish applied to the fresh concrete. For asphaltic overlays, a broom finish is required.
Utah	Machine finish and transverse texturing
Virginia	Burlap during screeding and sawcut grooves on hardened concrete
Washington	Nail broom 3/16 in. deep, 1/8 in. wide at 1/2 in. spacing
Wisconsin	Turf drag then tined
Alberta	Magnesium floated
New Brunswick	Free from voids and protrusions. Acceptable for peel and stick waterproofing.
Newfoundland	Broom finish
Nova Scotia	Textured finish free of ridges, depressions, undulations, and blemishes. When tested with 3-m long straight edge, no gap greater than 8 mm in any direction.
Ontario	Mechanical finishing followed by burlap drag. No hand finishing except at deck edges where machine does not reach.
Quebec	Trowel finish—good quality in order to install membrane afterwards.
Saskatchewan	Broomed

Question F6. Under what conditions does your agency require the use of evaporation retardants prior to initiation of curing?

State/Province	Conditions
Alabama	Hot weather placement
Alaska	None
Arkansas	Application of clear curing compound immediately after final finishing—before application of covers
California	Not required but is an option
Colorado	
Connecticut	None
Delaware	DelDOT requires evaporative retardants when silica fume is used in the concrete.
DC	None
Georgia	Not specified
Hawaii	None
Idaho	
Illinois	Not allowed
Indiana	Only with QC/QA superstructure concrete per the Special provisions.
Iowa	For standard “C” mix, if wet burlap is not on within 15 minutes. For HPC, if wet burlap not on within 10 minutes.
Kansas	Always
Kentucky	Set retarders used on bridge deck concrete
Maryland	Not applicable
Massachusetts	Only for unavoidable delays during placement.
Minnesota	Not allowed
Mississippi	
Montana	Not used
Nebraska	Allowed, but not required. White pigmented curing compound is required.
Nevada	Every project
New Hampshire	Not applicable
New Jersey	Evaporation retarders not generally used
New Mexico	Not required
New York	None
North Carolina	None
North Dakota	None
Ohio	At air temperature above 60°F with ASTM C 494 Type A or D
Oklahoma	Minimum air temperature of 70°F and rising
South Carolina	All deck concrete
Tennessee	
Texas	Membrane is used as an interim cure. Membrane applied after free moisture disappears. Evaporation retardants are not required.
Utah	Contractor's decision—based on temperature, humidity, wind, etc.
Virginia	Allowed if excessive evaporation is present
Washington	
Wisconsin	Allowed—contactor's choice
Alberta	
New Brunswick	Have stopped using due to abuse during finishing. Once finishing completed, fogging starts.
Newfoundland	All conditions
Nova Scotia	Only with HPC
Ontario	Not normally required or specified.
Quebec	Not applicable
Saskatchewan	Always

Question F7. What type of curing does your agency specify?

State/Province	Water Ponding	Water-Saturated Cover	Fog Spray	Waterproof Cover	Liquid Membrane	None	Notes
Alabama		X	X		X		
Alaska		X	X				
Arkansas		X		X	X		Initial
California		X			X		
Colorado							
Connecticut		X	X				
Delaware		X					
DC		X			X		
Georgia		X	X	X			
Hawaii	X	X	X		X		
Idaho		X			X		
Illinois		X					
Indiana		X					
Iowa		X					
Kansas		X	X	X	X		
Kentucky		X		X	X		
Maryland		X					
Massachusetts		X					
Minnesota		X			X		
Mississippi		X					
Montana		X	X				
Nebraska		X					
Nevada					X		
New Hampshire		X					
New Jersey		X	X				
New Mexico					X		
New York		X					
North Carolina		X		X			7-day wet burlap under polyethylene sheets
North Dakota		X	X				Fog when cannot get covers on—See F4
Ohio		X					Method per 511.17 CMS 2002. Water and curing membrane after 7 days.
Oklahoma	X	X	X	X			
South Carolina			X	X	X		
Tennessee		X			X		
Texas	X	X			X		
Utah		X					
Virginia		X	X				
Washington		X			X		
Wisconsin		X					
Alberta	X	X	X				
New Brunswick			X				
Newfoundland		X	X	X			
Nova Scotia	X	X	X		X		
Ontario		X	X	X			
Quebec		X	X	X			
Saskatchewan		X					

Question F8. When does your agency specify that curing must begin?

State/Province	Immediately After Finishing Any Portion	Immediately After Finishing Whole Deck	No Later than 4 hours After Finishing the Deck	Next Morning	Other	Notes
Alabama	X					
Alaska	X					
Arkansas	X					
California	X					
Colorado						
Connecticut	X					
Delaware	X					
DC	X					
Georgia	X					
Hawaii	X					
Idaho	X					
Illinois	X					
Indiana					X	After texturing—as soon as surface can support without deforming
Iowa	X					
Kansas	X					
Kentucky	X					
Maryland	X					
Massachusetts					X	No later than 15 min. after concrete deposited
Minnesota	X					
Mississippi	X					
Montana	X					
Nebraska					X	3 hours after curing compound
Nevada	X					
New Hampshire	X					
New Jersey	X					
New Mexico	X					
New York	X				X	Within 30 min. of placing
North Carolina					X	Prior to initial set
North Dakota	X					
Ohio	X					
Oklahoma	X	X				
South Carolina	X					
Tennessee					X	Liquid membrane behind screen, with wet burlap or burlene as soon as concrete sets enough to pull mats onto deck.
Texas					X	Interim curing on completion of final finish including tining. Water curing ASAP without damaging surface finish.
Utah	X					
Virginia	X					
Washington	X					
Wisconsin	X					
Alberta	X					
New Brunswick	X					
Newfoundland	X					
Nova Scotia					X	
Ontario	X					
Quebec	X					
Saskatchewan	X					

Question F9. What length of curing does your agency specify?

State/Province	3	4	5	7	10	14	Other	Notes
Alabama				X				
Alaska	X			X				
Arkansas				X				
California				X				
Colorado								
Connecticut				X				
Delaware				X				
DC				X				
Georgia			X					
Hawaii	X							
Idaho					X			
Illinois				X				
Indiana				X				
Iowa				X				
Kansas				X				
Kentucky				X				
Maryland				X				
Massachusetts						X		
Minnesota		X						
Mississippi				X				
Montana						X		
Nebraska		X						
Nevada				X				
New Hampshire				X				
New Jersey				X				
New Mexico				X				
New York						X		
North Carolina				X				
North Dakota				X	C			10 days when pozzolans exceed 10%
Ohio				X				Followed by curing compound
Oklahoma				X				
South Carolina				X				
Tennessee	X							
Texas					X		X	8 days with Type I cement, 10 days with Type II + fly ash
Utah				X				
Virginia				X				Followed by curing compound
Washington						X		
Wisconsin				X				
Alberta				X		X		14 days on some projects
New Brunswick				X				
Newfoundland				X				Plus 7 days of air drying
Nova Scotia							X	
Ontario		X		X				4 days for normal concrete. 7 days for HPC
Quebec				X				
Saskatchewan				X				

Question F10. What range of initial concrete temperature does your agency permit?

State/Province	Min. Temp. °F	Max. Temp. °F	Range °F	Notes
Alabama	40	95	55	
Alaska	50	70	20	
Arkansas	50	90	40	
California	50	90	40	
Colorado				
Connecticut	60			Max temp of water—150°F
Delaware	50	85	35	
DC	50	90	40	
Georgia	50	90	40	
Hawaii	45	90	45	
Idaho	50	80	30	
Illinois	50	90	40	
Indiana				Based on concrete & air temp—related to cold weather or if mix must be retarded in initial set time
Iowa		90		
Kansas	40	90	50	
Kentucky	50	90	40	
Maryland	50	80	30	
Massachusetts	60	90	30	
Minnesota	50	90	40	
Mississippi				
Montana	41	90	49	
Nebraska		100		
Nevada		90		At delivery
New Hampshire	50	85	35	
New Jersey	50			
New Mexico	50	80	30	
New York		90		
North Carolina	50	90	40	At placement
North Dakota	50	90	40	
Ohio		90		
Oklahoma	50	90	40	
South Carolina	50	90	40	
Tennessee	50	90	40	
Texas	50	85	35	
Utah	50	90	40	
Virginia	45	85	40	
Washington				
Wisconsin	50	90	40	When concrete temp. exceeds 80°F, measures must be taken to minimize mix temps. If concrete temp. > 85°F, ice is required in mix
Alberta	50	64	14	
New Brunswick	40	77	37	
Newfoundland	40	81	41	
Nova Scotia				CSA A23.1-00/A23.2-00
Ontario	40	82	42	For HPC, maximum initial temp. is 77°F
Quebec	40	72	32	
Saskatchewan	64	81	17	

Question F11. What value, if any, does your agency specify for maximum temperature of deck concrete during the curing period?

State/Province	Maximum Concrete Temperature
Alabama	95°F
Alaska	None
Arkansas	None
California	32°C
Colorado	
Connecticut	None
Delaware	None
DC	85°F
Georgia	Not specified
Hawaii	NS.—water curing to maintain concrete in acceptable range. Temp spec not less than 45°F for 3 days, 40°F for final 4 days
Idaho	
Illinois	Not specified
Indiana	None
Iowa	None
Kansas	None specified. Supposedly cannot freeze
Kentucky	No max. Min. is 45°F for 3 days and 40°F for 4 days
Maryland	N/A
Massachusetts	154°F
Minnesota	None
Mississippi	
Montana	
Nebraska	
Nevada	None
New Hampshire	100°F
New Jersey	89°F
New Mexico	None
New York	Not specified
North Carolina	Air temp. surrounding concrete 50-90°F
North Dakota	N/A
Ohio	Not specified. Heat of hydration testing per CMS 511.23 C
Oklahoma	90°F
South Carolina	None
Tennessee	90°F
Texas	None
Utah	None
Virginia	Not specified
Washington	
Wisconsin	None
Alberta	60°C
New Brunswick	60°C with 20°C difference
Newfoundland	N/A
Nova Scotia	CSA A23.1-00/A23.2-00
Ontario	For 7 days after placing, concrete temp. shall not fall below 10°C or exceed 70°C
Quebec	None
Saskatchewan	Not specified

Question F12. How frequently are the following tests made for quality control during deck placement?

State/Province	Slump	Air Content	Unit Weight	Initial Concrete Temp.	Water Content	Compressive Strength	Other and Notes
Alabama							
Alaska	Daily at startup & 20 cu yd	Daily at startup & 20 cu yd	Daily startup	None		Daily at startup & 20 cu yd	
Arkansas	QC	QC		Inspector's discretion		QC	QC per 100 cu yd
California	Penetration test of two per day	Min. 1 in 4 hours + test specimens	Min. of 2 per mix design	Engineer's option		1set cylinders per 250 cu m	QA only. No QC
Colorado							
Connecticut							
Delaware	Initial load & every 100 cu yd	Initial load & every 100 cu yd	None	Initial load & every 100 cu yd	None	Initial load and every 100 cu yd	
DC							
Georgia	50 cu yd	50 cu yd	None	50 cu yd	None	50 cu yd	None
Hawaii	As needed	As needed	As needed	As needed	As needed	150 cu yd not less than 1 per day. Tests for 7 and 28 days	As needed by testing laboratory
Idaho	60 cu yd	60 cu yd	60 cu yd	60 cu yd	60 cu yd	60 cu yd	Yield and cement factor every 60 cu yd
Illinois	50 cu yd	Every truck	None	As needed	None	250 cu yd	
Indiana	1 per day & 100 cu yd	First load, 2 in first 50 cu yd, and 1 for every 50 cu yd	Part of relative yield. 1/week	None	w/cm—1 per week	Not for Class C	Flexural strength beams cast each day to control load application and traffic
Iowa	1 per 30 cu yd	1 per 30 cu yd		Initial		Set of 3 per placement	
Kansas	Every 65 cu yd	Every 65 cu yd	Every 65 cu yd	Every 65 cu yd		1 set per placement	
Kentucky	50 cu yd	50 cu yd	None when cylinder strengths tested	50 cu yd		50 cu yd	Start-up test—2 of first 6 trucks—incl. slump, air, temp
Maryland	50 cu yd	50 cu yd	N/A	50 cu yd	50 cu yd	50 cu yd	
Massachusetts	*	*	*	*	None	Not less than once per day or every 150 cu yd	*Depends on amount of concrete placed, as needed to control operations
Minnesota	1 at start, every 15 sq m or cu yd	1 at start, every 15 sq m or cu yd	None	1 at start, every 15 sq m or cu yd	None	1 min. and 1 per 30 cu m or cyl.	
Mississippi	50 cu yd	50 cu yd	400 cu yd	50 cu yd	Initial field verification	100 cu yd	
Montana	Every truck	Every truck				3 cyl.< 150 cu m. 6 cyl. < 300 cu m	
Nebraska	1 per day min.	1 per day min.	n	1 per day min.	None	7, 28 days min.	
Nevada	< 100 cu yd, 1 per 25 cu yd. > 100 cu yd, 1 per 50 cu yd	< 100 cu yd, 1 per 25 cu yd. > 100 cu yd, 1 per 50 cu yd	200 cu yd	< 100 cu yd, 1 per 25 cu yd > 100 cu yd, 1 per 50 cu yd	None	1 min. and every 100 cu yd	
New Hampshire	Every load				None	N/A	
New Jersey	At time of deck placement	At time of deck placement	At time of deck placement	At time of deck placement	At time of deck placement	28 days	
New Mexico	First three trucks and every third truck	First three trucks and every third truck	First three trucks and every third truck	First three trucks and every third truck	None	First three trucks and every third truck	First three trucks and every third truck. Air loss through pump

Question F12. (*Continued*)

New York	50 cu yd	50 cu yd	None	Start and 200 cu yd	None*	1 set per 200 cu yd	*Water recorded for every batch, retempering monitored to maintain w/c ratio
North Carolina	First load and every fourth truck	Every load*		Every load	Check tickets for amount to be added at site	1 set cyl. + 1 set per 100 cu yd	*Air—AASHTO T 199 or T 152 reject by T 152
North Dakota	First load and every 25 cu yd up to 100 cu yd then every 50 cu yd	First load and every 25 cu yd up to 100 cu yd then every 50 cu yd	First load and every 25 cu yd up to 100 cu yd then every 50 cu yd	First load and every 25 cu yd up to 100 cu yd then every 50 cu yd	Once per day for aggregate and check batch tickets every load.	First load and every 25 cu yd up to 100 cu yd then every 50 cu yd	
Ohio	Every load	Every load	Every load			CMS 2002 511.06. Varies with deck size	
Oklahoma	4 tests per 200 cu yd					4 tests per 200 cu yd	Deck cracking—4 tests per 200 cu yd. Use AASHTO M 157 as appropriate
South Carolina		50 cu yd		50 cu yd	Truck	50 cu yd	
Tennessee	First 50 cu yd then 1 every 150 cu yd	First 50 cu yd then 1 every 150 cu yd	QC at plant as need	First 50 cu yd then 1 every 150 cu yd	None	First 50 cu yd then 1 every 150 cu yd	
Texas	First few loads then every third load (same load as test specimens)	First few loads then every third load (same load as test specimens)	None	Every truck	None	2 cyl. per 60 cu yd or fraction	
Utah	Every 400 cu m	Every 400 cu m				3 cyl. per 400 cu m	
Virginia	First 3 loads and every third load	First 3 loads and every third load	None	First 3 loads and every third load	None	1 set per 100 cu yd	Permeability per comp. strength
Washington							
Wisconsin	Every 50 cu yd	Every 50 cu yd		Every 50 cu yd		Every 50 cu yd	
Alberta	Every truck	Every truck		Every truck		10 cu m	
New Brunswick		Every truck	Every truck	Every truck	Start of each placement and moisture content is changed ERS	2 sets cyl. to 50 cu m, 3 sets 51-100 cu m, 4 sets 101-200 cu m	
Newfoundland	Each truck until control established. Then every other truck	Each truck until control established. Then every other truck	1 test per 100 cu m of concrete type. Min. of 1 test/type/day	Each truck until control established. Then every other truck	None	1 test per 100 cu m of concrete type. Min. of 1 test/type/day	
Nova Scotia	Each load until control established. Then every other load	Each load until control established. Then every other load	N/A	Each load until control established. Then every other load	N/A	Every 50 cu m	
Ontario	Each truck until control established.	Each truck until control established.	Not required	Each truck until control established.	Not required	Cyl. cast per statistically based sampling program (random on sublots)	
Quebec	First 2 trucks. If correct every third truck	First 2 trucks. If correct every third truck	None	First 2 trucks. If correct every third truck	None	Every lot of 75 cu m	
Saskatchewan	Per truck	Per truck	Every third truck	Per truck	N/A	Every third truck	

Question F13. Does your agency conduct tests of the hardened in-place concrete to check end-product performance?

State/Province	Yes	No	Sometimes	Explanation for Sometimes	Explanation for Yes
Alabama	X				
Alaska		X			
Arkansas		X			
California		X			
Colorado					
Connecticut		X			
Delaware			X	Problems noticed-comp. strength, air void tests on cores	
DC			X	Deficient concrete suspected—coring	Coring for compressive testing
Georgia			X	Cylinder strengths not met	Swiss hammer—cores for strength. Usually verify cyl. strengths.
Hawaii			X	Problems	Swiss hammer, Coring. “unacceptable” results—rarely—remedial measures recommended. Small pours only removal.
Idaho			X	Cylinder strengths not met	
Illinois		X			
Indiana	X	X		If job control testing fails to meet the specification requirement the concrete in question is considered a failed material. An investigation is done to determine the degree of non-compliance and assess the loss in servicability of the structure containing the deficient concrete.	Strength issues resolved by coring—measure comp. strength. Air content evaluated from cores-tested for air content by ITM 401 "High Pressure Air Content of Hardened Portland Cement Concrete" or air viod system using ASTM C 457. Depth of cover with a pacometer or R-meter, coring provides direct measurements. Results for all tests vary. Some indicate to problem, some confirm problems. Deck material typically not removed—left in place at reduced cost or overlayed with latex modified concrete at contractors expense.
Iowa			X	Problem during placement	
Kansas			X	On suspect concrete or cyl. test failure	Core w/compression test. Maybe air void or freeze-thaw
Kentucky		X			
Maryland		X			
Massachusetts		X			
Minnesota			X	If problem develops	Linear transverse—variable results
Mississippi		X			
Montana		X			
Nebraska			X	Problems—cyl. breaks low	
Nevada		X			
New Hampshire	X			Permeability 1000-2000 coulombs. Concrete cover with GPR—good results	
New Jersey			X	Failure of initial results. Coring	Coring. No accurate data.
New Mexico		X			
New York			X	Problems	Freeze-thaw and scaling, possibly hardened air tests
North Carolina			X	Cyl. fail	Swiss hammer, winsor probe,—results vary depending on knowledge of tester. Confirm if cyl. results valid.
North Dakota		X			
Ohio			X	Low strength verifications	
Oklahoma		X			
South Carolina		X			
Tennessee			X	Low strength verifications	4 in. dia. cores. Swiss hammer
Texas	X				Texture depth after hardening. One/placement
Utah		X			
Virginia			X	Problems	
Washington		X			
Wisconsin		X			
Alberta			X	Visual examination for surface cracks	
New Brunswick	X				
Newfoundland		X			
Nova Scotia		X			
Ontario	X			Air-void parameters on cores of hardened concrete. Rapid chloride permeability on HPC on cores.	
Quebec		X			
Saskatchewan		X			

Question F14. Does your agency use any in-place sensors or instrumentation for quality control during construction?

State/Province	Yes	No	Explanation
Alabama		X	
Alaska		X	
Arkansas		X	
California		X	
Colorado			
Connecticut		X	
Delaware		X	
DC		X	
Georgia		X	
Hawaii		X	
Idaho		X	
Illinois		X	
Indiana		X	
Iowa		X	
Kansas		X	
Kentucky	X		Use high/low thermometers in cold weather
Maryland		X	
Massachusetts		X	
Minnesota		X	
Mississippi		X	
Montana		X	
Nebraska		X	
Nevada		X	
New Hampshire		X	
New Jersey	X		Maturity meters being studied
New Mexico		X	
New York		X	
North Carolina		X	
North Dakota		X	
Ohio		X	Tried maturity meters, heat of hydration testing per CMS511.23C
Oklahoma		X	
South Carolina		X	
Tennessee		X	
Texas	X		Maturity method for concrete strength in some locations
Utah		X	
Virginia		X	
Washington		X	
Wisconsin	X		Maturity permiited but rarely used by contractors
Alberta	X		Temperature sensors cast into deck to monitor conformance
New Brunswick	X		
Newfoundland	X		Thermocouples
Nova Scotia	X		Temperature sensors and probes
Ontario	X		Thermocouples for temperature during curing. Corrosion sensors, electrodes for cathodic protection systems, and long-term reseach or trial installations
Quebec	X		Thermocouples sometimes
Saskatchewan		X	

Question F15. When staged construction is used, does your agency require that the freshly placed concrete be isolated from traffic-induced vibrations in adjacent open traffic lanes?

State/Province	Yes	No	Explanation
Alabama		X	
Alaska	X		Limit speed of adjacent traffic to below 10 mph
Arkansas		X	
California		X	
Colorado			
Connecticut	X		Diaphragms sometimes disconnected to isolate stages
Delaware		X	Traffic is slowed to reduce “bouncing” before deck sets and gains initial strength
DC		X	
Georgia		X	Use pour strips to separate new sections from traffic vibrations
Hawaii		X	
Idaho	X		Lane closures if possible
Illinois		X	
Indiana		X	
Iowa		X	
Kansas		X	
Kentucky		X	
Maryland	X		Must reach min. of 40 hours before new work can begin
Massachusetts		X	
Minnesota		X	
Mississippi		X	
Montana		X	
Nebraska		X	
Nevada		X	
New Hampshire	X	X	Disconnect diaphragms if possible. Vibrations carry over regardless.
New Jersey	X		Speed restriction
New Mexico	X	X	Traffic removed from area, or as far away as possible
New York	X		Closure pour
North Carolina		X	No requirement but consider if unusual circumstances
North Dakota		X	
Ohio		X	Use closure pours, cut cross framing to accommodate differential deflections > 1/4 in.
Oklahoma		X	
South Carolina	X		Closure pours between stages (3-5 ft). Diaphragm between stages not connected until closure pour
Tennessee		X	
Texas		X	
Utah		X	
Virginia		X	Has not been a problem
Washington		X	
Wisconsin		X	
Alberta		X	
New Brunswick	X		Bridge closed 2-3 days, or traffic slowed
Newfoundland	X		If possible, practical and economical: Temporary closure, bypass constr., isolate portions of deck by separation with small gaps
Nova Scotia		X	
Ontario		X	
Quebec	X	X	Yes for new bridges by constructing in 3 stages. No for new deck on existing girders: sometimes nighttime concreting, no trucks, and speed limits are used.
Saskatchewan		X	

Question F16. Does your agency require repair of cracks if they occur during construction?

State/Province	Yes	No	Notes
Alabama	X		
Alaska	X		
Arkansas	X		
California	X		
Colorado			
Connecticut	X		
Delaware	X		
DC	X		
Georgia	X		
Hawaii	X		
Idaho	X		
Illinois	X		
Indiana	X		
Iowa		X	
Kansas	X		
Kentucky	X		
Maryland		X	
Massachusetts	X		
Minnesota	X		
Mississippi		X	
Montana		X	
Nebraska	X		
Nevada	X		
New Hampshire	X		
New Jersey	X		
New Mexico	X		
New York	X		
North Carolina	X		If related to plastic shrinkage
North Dakota		X	
Ohio	X		Warranty specification 894/898
Oklahoma	X		
South Carolina	X		
Tennessee	X		
Texas	X		
Utah		X	
Virginia		X	
Washington	X		
Wisconsin		X	
Alberta	X		
New Brunswick	X		
Newfoundland	X		
Nova Scotia		X	
Ontario	X		
Quebec	X		
Saskatchewan	X		

Question F17. What methods are used to repair cracks?

State/Province	Method
Alabama	Sealant or epoxy injection
Alaska	Fill with HMWM resin, 2 applications for 1/16 in. or wider. Coat wetted surface with sand
Arkansas	Epoxy injection, silane sealer
California	Methacrylate
Colorado	
Connecticut	Tight cracks: membrane waterproofing. Large cracks: application of sealer or epoxy injection
Delaware	Sealant into or over cracks—epoxies and methacrylates
DC	Approved epoxy crack sealers
Georgia	General sealants or epoxy injection
Hawaii	Depends on size and cause of cracks, structural or non-structural. Epoxy sealer—narrow. Epoxy injection—wider
Idaho	Epoxy methacrylate
Illinois	Gravity—methacrylate, urethane or epoxy. Epoxy recommended.
Indiana	Severe: milled, overlayed with latex modified concrete. Minor: low-viscosity epoxy or asphalt material
Iowa	Rare cases: methacrylate penetrating sealers or epoxy injection.
Kansas	Large: may use HMWM or epoxy injection
Kentucky	Excessive: penetrating crack sealer—short term effect
Maryland	
Massachusetts	Epoxy injection, methyl methacrylate
Minnesota	Repair requirements vary—likely a methyl methacrylate
Mississippi	
Montana	
Nebraska	Seal with HMWM
Nevada	Minor: methacrylate sealer. Changing to require epoxy injection. Severe: polyester-styrene overlay
New Hampshire	Methyl methacrylate flooding of cracks
New Jersey	SIKA Pronto 19
New Mexico	HMWM
New York	< 0.004 in. nothing. < 0.007 in. silane sealer. Non-working crack 0.004 to 1/8 in. epoxy injection or methyl methacrylates. Larger cracks: route, seal with silicone
North Carolina	Epoxy filled pressure injected or gravity if minor. Deck milling and overlay if severe
North Dakota	
Ohio	HMWM for 0 to 20% deck surface. LCM or microsilica for greater than 20% deck surface
Oklahoma	HMWM or epoxy alternate (SSI deck sealer). Sealers are epoxy pounding, silicone, asphalt mortar and/or bituminous joint sealer
South Carolina	Epoxy sealer
Tennessee	Excessive or > 0.125 in. methyl methacrylate. Abnormal working structural cracks—epoxy inject
Texas	At discretion of engineer—based on severity and/or significance of cracks.
Utah	
Virginia	
Washington	
Wisconsin	
Alberta	Epoxy injection. Gravity fed epoxy
New Brunswick	
Newfoundland	Epoxy
Nova Scotia	
Ontario	Epoxy injection
Quebec	Low viscosity resin placed by gravity
Saskatchewan	Cracks filled with epoxy

Question F18. Explain which repair methods are most effective in prolonging deck service life.

State/Province	Repair Method
Alabama	Epoxy injection
Alaska	Sealing cracks with HMWM resin
Arkansas	Epoxy injection
California	
Colorado	
Connecticut	Routine cracks adequately repaired by sealing with membrane
Delaware	
DC	Approved job specific epoxy crack sealers
Georgia	Not known
Hawaii	No history. Opinion: epoxy injection of wider cracks prefered
Idaho	
Illinois	Based on literature, it is believed is the best (See F17)
Indiana	Overlay
Iowa	
Kansas	Sealing and placing concrete overlay on the bad deck
Kentucky	
Maryland	
Massachusetts	Data not available
Minnesota	
Mississippi	
Montana	
Nebraska	Delamination repair and overlay
Nevada	Methacrylate sealer—less effective but far less costly than epoxy injection. Polyester-styrene overlay 20-30 year protection
New Hampshire	Methyl methacrylate flooding of cracks
New Jersey	Sealing prolongs service life
New Mexico	HMWM
New York	
North Carolina	Overlays and pressure injection
North Dakota	
Ohio	
Oklahoma	Epoxy flood coat with SSI. Need more experience with the product.
South Carolina	Latex overlay
Tennessee	Both methods in F17
Texas	Crack sealing with epoxy
Utah	
Virginia	
Washington	
Wisconsin	
Alberta	Gravity fed epoxy
New Brunswick	
Newfoundland	Unknown
Nova Scotia	
Ontario	Epoxy injection
Quebec	
Saskatchewan	