Guide for Maintenance of Concrete Bridge Members

Reported by ACI Committee 345

Richard E. Weyers, Chair

Paul D. Carter, Secretary

Gerald H. Anderson
Michael C. Brown
Robert J. Gulyas
Dena L. Guth
Alan B. Matejowsky
Harold R. Sandberg
Johan Silfwerbrand
Michael M. Sprinkel
Paul St. John
Jerzy Zemajtis

Bridges represent a substantial investment of public funds, and are expected to provide satisfactory performance and remain in service for many years. Design specifications typically require 75- or 100-year design life for new bridges. Neglecting or delaying bridge maintenance can result in reduced service life and increased costs due to repair, rehabilitation, or replacement at an early age. Another consequence of neglecting maintenance is that the condition of the bridge can become life-threatening to the public. It is believed that continuous and systematic maintenance of a bridge will extend its service life and reduce its overall operating cost.

This document addresses typical problems and presents potentially cost-effective maintenance techniques for concrete bridge elements. It provides guidance for engineers and maintenance staff. It does not cover repair, rehabilitation, reconstruction, or bridge inspection, and therefore, it does not include topics such as cathodic protection, repair with shotcrete, and deck overlays. Detailed methods of repairing and inspecting bridges may be found in the references.

Concrete bridge maintenance is defined as those activities that are relatively inexpensive and repeatable, performed when the concrete element is still in good to fair condition, intended to prevent or minimize deterioration of the concrete. These activities may include sealing, washing, caulking, crack repair, and other minor repairs intended to prolong the functionality of the bridge element.

Keywords: bridge decks; cementitious; coating; maintenance; placement; polymer; sealant.

CONTENTS

ACI 345.1R-06 supersedes ACI 345.1R-92 and became effective March 14, 2006.

CHAPTER 1—BRIDGE MAINTENANCE

1.1—Introduction

Bridges represent a substantial investment of public funds and are expected to function for many years. United States design specifications typically require a 75- or 100-year design life, and European specifications require a 120-year design life. Neglecting or delaying bridge maintenance can result in reduced service life and increased life-cycle costs due to repair, rehabilitation, or replacement at an early age. Another consequence of neglecting maintenance is that the condition of the bridge can become life-threatening to the public.

When exposed to sufficiently aggressive environmental conditions, structural concrete members will eventually deteriorate and lose strength. Aggressive environmental conditions for bridges involve cycles of freezing and thawing, and cycles of wetting and drying, with or without the presence of chloride. Corrosion of reinforcing steel spalls the cover concrete, reduces the cross-sectional area of the reinforcing steel, and therefore, its strength. The time required for deterioration to occur varies considerably, depending on the severity of the exposure conditions and the characteristics of the structural concrete. It is believed that continuous and systematic maintenance of a bridge will extend its service life and reduce its overall operating cost.

1.2—Concrete bridge maintenance

Bridge deterioration usually occurs slowly at first and is often overlooked. In later stages of deterioration, however, sudden catastrophic events can occur, demanding immediate action. Progressive deterioration can be retarded and sometimes avoided if proper systematic preventive maintenance is practiced (Carter and Kaufman 1990). Concrete bridge maintenance involves relatively inexpensive, repeatable activities that either prevent or minimize concrete life of bridge elements or are minor repairs that extend the service of the structural concrete members.

Concrete bridge maintenance is performed when the structural concrete member is still in good to fair condition, and can be subdivided into preventive and responsive maintenance.

1.2.1 *Preventive maintenance*—Preventive maintenance procedures are done before deterioration is visible and the structural concrete member is still in good condition, and are usually planned at the design stage and started accordingly. Procedures include sealing, washing, caulking, and crack repair. A procedure not planned is installing retrofit drains.

1.2.2 *Responsive maintenance*—Responsive maintenance procedures are usually more extensive, and are done in the early stages of the visible deterioration cycle. Procedures include small repairs, establishment of positive deck drainage systems, maintaining the functionality of deck joints, and similar activities to extend the service life of structural concrete members in bridges.

1.3—Purpose of maintenance

Maintenance activities are often more cost effective when the concrete is still in relatively good condition and is focused on those parts of a structure that face the most severe exposure conditions. Preventive maintenance addresses causes of the potential deterioration, as opposed to treatment, of the effects of deterioration. For example, sealing the deck surface reduces the infiltration of chloride. Proper preventive maintenance activities can reduce the rate of deterioration, extend service life, and reduce future repair costs (Carter 1989a). Responsive maintenance activities help to keep bridges operating safely and efficiently.

1.4—Limitations

Maintenance is no substitute for proper design and construction. Even proper maintenance will not produce desirable results when applied to improperly designed and constructed concrete bridge elements. Examples of improper design include insufficient reinforcing steel cover depths, excessive surface cracking, and poor drainage characteristics, such as ponding of chloride-contaminated water on a concrete bridge deck.

1.5—Timing of maintenance

Maintenance activities performed at the proper time are extremely cost effective. Similarly, maintenance activities conducted at the wrong time can be a poor investment. The wrong time for maintenance is after significant damage has occurred. Maintenance can prevent damage, but it cannot restore deteriorated concrete. Damage such as scaling, reinforcing steel corrosion, or spalling is easy for the untrained eye to see after it has occurred, but an understanding of concrete deterioration mechanisms is required to foresee damage before it occurs. Foresight involves the ability to identify the signs and symptoms that precede the development of damage. For example, an early signal is the presence of leakage stains. Leakage stains usually precede frozen bearings and rust stains, delamination, and spalling of reinforced concrete bridge superstructure and substructure elements.

CHAPTER 2—CONCRETE BRIDGE DETERIORATION

2.1—Deterioration indicators

The visual manifestation of concrete deterioration mechanisms is well documented in ACI 201.1R. Deterioration may be hastened by the synergistics of environmental conditions and mechanical loading forces. The following present some of the conditions relative to concrete bridges:

- Water ponding because of improper deck drainage (Fig. 2.1);
- Cracks, regardless of cause or type (Fig. 2.2, 2.3, and 2.4);
- Spalling due to inadequate reinforcing steel cover (Fig. 2.5);
- Porous, debonded, or cracked asphalt wearing surfaces (Fig. 2.6);
- Accumulation of deicing chemicals (Fig. 2.7);
- Staining of concrete surfaces, regardless of cause or type (Fig. 2.8); and
- Erosion of headslope and sideslopes (Fig. 2.9).

2.2—Causes

Factors contributing to concrete bridge deterioration are mainly moisture, chloride, acids and other aggressive chemicals, oxygen, cyclic changes in moisture and temperature, freezing, wear, and abrasion (ACI 201.1R and 222R). The most economically significant direct cause of bridge concrete deterioration is exposure to moisture and chlorides, which is why directly exposed decks and curbs deteriorate sooner than sheltered superstructure members. Leaking joints do not shelter superstructure elements.

Deterioration of concrete decks can also result from concrete fatigue. Tests (Suresh 2005) indicate that compressive strength of concrete under cyclic loading can be drastically reduced. Concrete bridge decks are often exposed to high cyclic loading, which may result in cracking, and which facilitates the infiltration of chloride and results in progressive corrosion of reinforcement and disintegration of the deck slab.

2.3—Contributing factors

In general, the causes and rates of deterioration depend on the relationship between design, construction, material selection, and exposure condition.

2.3.1 *Design*—Skeet and Kriviak (1994) found that design could be the primary determinant to service life of bridge deck overlays and other protection systems. It is easier and less expensive to maintain a bridge that has been designed with sufficient cover, protective systems, and positive drainage. Long-term maintenance costs are sometimes increased by focusing on low initial construction costs.

Fig. 2.1—Water ponding from improper deck drainage.

Fig. 2.2—Map cracking on underside of deck.

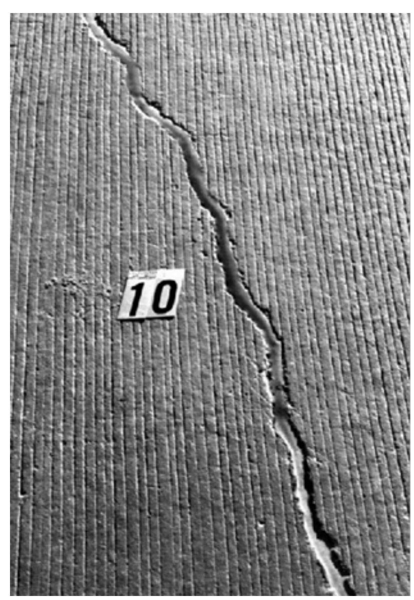

Fig. 2.3—Transverse crack in deck.

Fig. 2.4—Map cracking in parapet.

Fig. 2.5—Shallow cover depth spalling.

Fig. 2.6—Deteriorated asphalt wearing surface.

Simple examples are bridges that are flat, do not have deck drains, have inadequate cover over reinforcing steel, or have poor-quality concrete. Common examples, widely used in the 1950s and 1960s, were simple-span bridges used for

Fig. 2.7—Application of deicing chemicals to roadways.

Fig. 2.8—Rust staining of curb.

Fig. 2.9—Erosion and settlement of slopewall.

grade separations in heavily deiced urban locations. Simple-span bridges require maintenance of deck joints. Without such maintenance, the superstructure and substructure elements prematurely deteriorate. Present practice in northern regions of the U.S. is to reduce bridge maintenance costs by using continuous spans that reduce or avoid deck joints (Hambly and Nicholson 1990). Compared with earlier designs, bridge design codes typically require increased

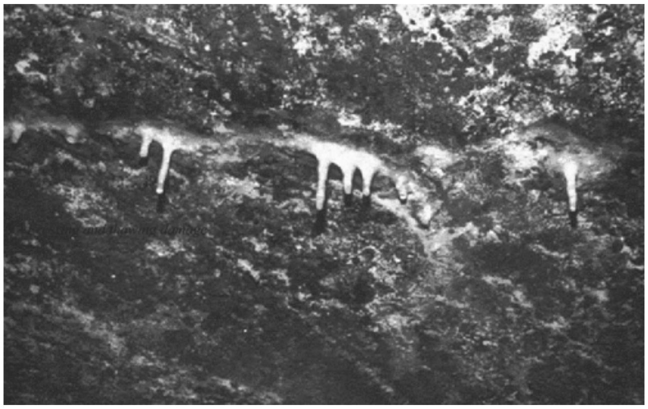

Fig. 2.10—Efflorescence from freezing-and-thawing deterioration.

concrete cover, a reduced water-cement ratio (*w/c*) and permeability, use of air-entrained concrete, corrosion protection systems, and eliminated simple spans and deck joints to increase service life and durability.

2.3.2 *Construction*—Improper construction techniques that contribute to deterioration include insufficient compaction, inadequate cover over the reinforcement, inadequately entrained air, or increases in the concrete's water-cementitious material ratio (*w/cm*) during placement. Improper surface finishing techniques, such as direct application of water to the surface, reduce durability and service life. Inadequate or late curing increases shrinkage cracking and permeability to chlorides.

2.3.3 *Materials*—Material factors that contribute to deterioration include incompatibility between air-entraining and other admixtures, high *w/cm* concrete, and nondurable aggregates vulnerable to aggregate-alkali reactions and cycles of freezing and thawing.

2.3.4 *Climate-related exposure conditions*—Environment and climatic conditions contribute to varying rates of deterioration. For example, the deterioration of coastal bridges is entirely different from that of high elevation mountain bridges. The mountain bridges are subjected to snow, moisture, cycles of freezing and thawing, and deicing chemicals (Fig. 2.10), whereas coastal bridges may involve chloride exposure from salt water. The design, construction, and maintenance of bridges in one environment and climate needs to take into account many conditions not relevant to another environment and climate. Concrete maintenance materials are generally sensitive to ambient temperature and moisture conditions during application. Many products require moderate weather conditions, and are not suitable for application in extreme conditions (Carter 1989a; Department of Transport 1990a; Federal Highway Administration 1994; Bean 1988).

CHAPTER 3—CONSIDERATIONS IN BRIDGE DESIGN

3.1—General

Good bridge design details prevent or delay component deterioration. Some design issues related to reducing future bridge repair and rehabilitation costs are discussed in the following sections.

Fig. 3.1—Debris accumulation on curb.

3.2—Decks and curbs

3.2.1 *Function*—Bridge decks support traffic and transmit structural loads to girders, bearings, and substructure components. Curbs, medians, and parapets define the limits of vehicular traffic on a bridge deck. They generally serve a dual purpose as both a safety barrier and a deck drainage tool, because installation usually includes gutters and drains.

3.2.2 *Typical problems*—Decks and curbs are generally the most exposed portions of a bridge, especially where drainage is inadequate, and protective systems such as overlays or membranes are lacking. Curbs collect debris, snow, and salt from the riding surface, staying wet long after the riding surface has dried (Fig. 3.1). They also stay wet when the deck drainage systems listed in Section 4.2 become clogged. Because decks and curbs generally have high deterioration rates and repair and rehabilitation costs, maintenance activities that slow deterioration and delay expenditures are especially appropriate. Deck-maintenance costs vary significantly due to different exposure conditions, amount and type of traffic, drainage characteristics, environment and climate, and design standards. An example of the influence of design standards on deterioration is an asphalt-wearing surface. Asphalt concrete overlays are often used on bridge decks because they provide a smooth riding surface and are used as a protective wearing surface covering membranes. Asphalt concrete overlays are more permeable than the underlying concrete. The process of asphalt deterioration includes oxidation, shrinkage cracking, and increased permeability with time. Asphalt overlays trap chloride-laden water, thereby promoting and accelerating concrete deterioration (Skeet and Kriviak 1994). To protect the concrete, a membrane should be applied to the concrete surface before placing the asphalt.

Untreated bridge deck cracks result in decreased service life and increased repair and rehabilitation cost, and therefore, potential structural cracking needs to be addressed in

Fig. 3.2—Efflorescence from deck joint leakage.

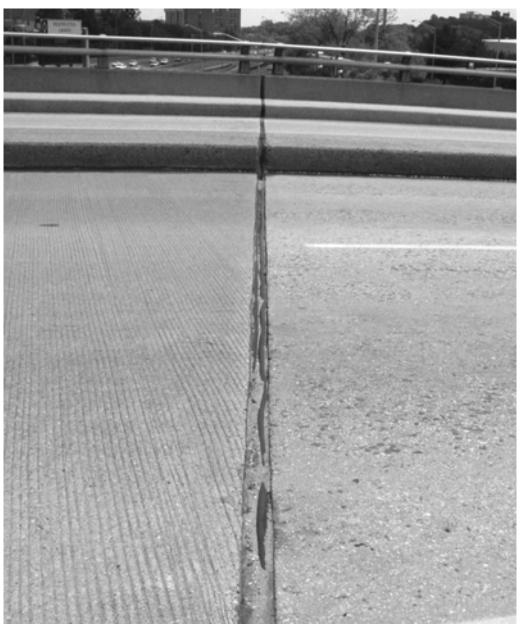

Fig. 3.3—Incompressible debris-filled deck joint.

the design phase. Krauss and Rogalla (1996) correlated severity of cracking with large negative moments over the intermediate supports of continuous bridge design. There is also a direct correlation between severity of cracking and increase in transverse beam spacing (Buckler et al. 2000) and an increase span in length (Alampalli 2001). Krauss and Rogalla (1996) recommended using stiffer girders and a simply supported design to control bridge deck cracking, which conflicts with present design trends.

Bridge deck drainage should be considered during design. Drainage systems allow water to drain from driving surfaces and channel water away from bridge elements and crossing features below the bridge. They should be designed to minimize potential blockage from roadway debris (Chen and Duan 2000). Surface water on a bridge deck should not flow over expansion joints because most joints leak, which results in increased repair costs of superstructure and substructure members.

3.2.3 *Recommendations*—Bridge design should take into account the exposure conditions likely to exist during the intended service life. Proper drainage systems should be included as a critical phase during design. Life-cycle cost analysis should be done to select the best alternative designs in terms of the total long-term costs. Bridges exposed to chlorides should be designed with a corrosion protection system, or systems, fulfilling environmental exposure conditions and bridge serviceability requirements. Examples include low-permeability concrete, clear concrete reinforcement cover depths over 2 in. (51 mm), and corrosion-resistant reinforcement. Bridges should be designed to provide safe access for future inspection and maintenance. Provisions should be made for replacing individual components, such as bearings and deck joints.

3.3—Deck joints

3.3.1 *Function*—Bridge deck joints are structural breaks in the deck that accommodate length changes due to concrete shrinkage, temperature- and moisture-related longitudinal expansion and contraction of the bridge, rotational movement due to live-load deflections, and substructure movements.

3.3.2 *Maintenance significance*—Joints should protect underlying structural elements from leakage of chloride-laden water. Areas below joints are generally highly stressed and structurally important. No leakage should be allowed onto the bearings, ends of girders, or substructure elements (Hambly and Nicholson 1990; Vaysburd 1990a,b).

3.3.3 *Leakage*—Failure to stop leakage may result in:

1. A reduction in the strength of the superstructure and substructure concrete elements and ends of steel girders. The constant exposure to moisture accelerates the corrosion of reinforcing and prestressing steel, especially where freezing and thawing are encountered (Fig. 3.2); cracking; and subsequent spalling. The exposure to moisture also contributes to the corrosion and the subsequent section loss of steel girders; and
2. Corrosion seizing of the expansion bearings often creates cracks near anchor bolts and leads to further chloride absorption, deterioration, and loss of load-carrying capacity.

3.3.4 *Loss of freedom to move*—Deck joints should always be able to freely move so as not to transmit undesirable stresses to the bridge superstructure elements. Causes of movement restriction include:

1. **Incompressible debris.** Where deck joints become filled with incompressible debris such as sand, gravel, and stone (Fig. 3.3), the deck, girder ends, or both, may crack or spall in warm weather when expansion is restrained. On some bridges, especially concrete spans built on a skew, this condition may cause transverse movement of the deck, producing curb offsets and obstructing traffic. Debris-filled joints may be punctured and leak, and may also collect moisture

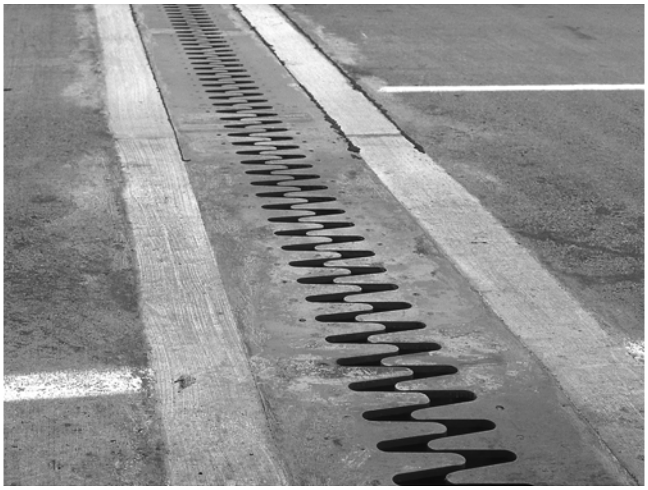

Fig. 3.4—Vertical misalignment of steel finger joint.

and corrosive chemicals, thereby accelerating the deterioration of the adjacent deck area (NCHRP 1979);

2. **Substructure settlement.** Abutment settlement is typically accompanied by movement towards the center of the bridge, which reduces the intended gap in deck joints, thereby restricting the allowable range of joint movement. At high temperatures, the gap closes, resulting in pressure on both the abutment backwall and the joint anchorage. On older flat plate-type joints, the plates can be trimmed to relieve the pressure. Steps may also be needed to relieve the settlement pressure that caused the abutment movement. Concrete pavement creep caused by pavement joints clogged with incompressible material during expansion cycles also reduces deck joint gap, resulting in undesirable high pressures on abutments, beams, and bearing anchorage; and

3. **Misalignment.** Impact forces on joints and their structurally supporting elements can result from vertical misalignment between deck joints and adjoining riding surfaces (Fig. 3.4). The misalignment may be caused by rotation of the abutment due to settlement of fill material, by repaving the roadway approaches, or by settlement. Not only is the bump an annoyance or possible harm for the traveling public, but the resulting impact can accelerate deterioration of the members supporting the deck joint.

3.3.5 *Design recommendations*—The future traffic volumes and types of loads should be considered when selecting durable bridge deck joints. Cover plates or other protection should be used when excessive amounts of incompressible road debris are likely to be tracked into the joints. The number of intermediate joints should be minimized when using continuous spans. When possible, integral or semi-integral abutments should be used to eliminate end joints. Concrete pavement stress-relief joints should be installed.

3.4—Superstructure

3.4.1 *Definition and function*—The superstructure is the structural system that is supported by the substructure. Its components include main structural members, floor system, secondary members, and bearing elements (Fig. 3.5 and 3.6). Main members are those whose failure would result in

Fig. 3.5—Concrete superstructure elements.

Fig. 3.6—Steel superstructure elements.

collapse or significantly impair the load-carrying capacity of the structure, including concrete, steel, or timber girders; and truss chords, diagonals, and vertical members. Floor systems include members that transmit loads from the deck to the main members. Secondary members add stiffness to the main members. Failure of the floor system members would usually only have local effects. Bearings are mechanical devices that transfer the loads from main members to the substructure, and also accommodate the main member longitudinal, transverse, and rotational movement (NCHRP 1979).

3.4.2 *Problems*—Due to their sheltered condition, properly designed concrete superstructure members, other than the bridge deck, do not usually deteriorate rapidly or require much maintenance. They should not be exposed to direct chloride-laden water, such as may occur at locations below leaky deck joints, gutterline gratings, or poorly extended deck drains. The most prominent maintenance issue with concrete superstructure members is control of cracking. The use of smaller reinforcing bars at moderate spacing provides more effective crack control than larger bars at larger spacings (Chen and Duan 2000).

3.5—Substructures

3.5.1 *Functions*—Substructure elements transmit loads from the superstructure to the supporting soil or bedrock

Fig. 3.7—Bridge substructure pier.

Fig. 3.8—Soil slopewall.

Fig. 3.9—Pier cap deterioration due to deck joint leakage.

(Fig. 3.7). They include two types: abutments and intermediate supports. Intermediate supports can usually be further classified as bents or piers. Intermediate support members are the cap, columns or piers, and foundations. Abutment components include backwall, face wall, shelf, and foundation. Soil and protected slope walls are considered to be nonstructural elements (Fig. 3.8). Stone, concrete, and concrete block are used to protect soil slopewalls.

3.5.2 *Problems*—Dirt and debris often accumulate on the substructure members below open bridge deck joints, and can become saturated with moisture and deicing chemicals (Fig. 3.9). If permitted to remain for extended periods of time, deicing chemicals will penetrate the concrete, causing corrosion of the reinforcing steel with subsequent spalling of the cover concrete. Leaking end joints result in erosion of soil slope walls, the exposing of foundation slabs and piles, and erosion of support soils from protected slopewalls.

A large number of bridges are built in, or adjacent to, chloride-rich brackish water or sea water. These structures are particularly vulnerable to chloride contamination and subsequent corrosion of reinforcing steel (Sagues 2001). Substructure protection measures, such as low permeable concrete, increased clear concrete cover depth, cathodic protection, corrosion inhibitors, coatings, and encasements should be considered during design.

For structures built adjacent to stream or river crossings and in flood plains, scour protection measures should be considered in the design process. Scour protection measures are generally either scour reduction techniques or structural measures. Substructure settlement often causes movement related maintenance activities. Due to the inability to completely eliminate settlement, designers often estimate the amount of movement that will be induced by applied loads and design accordingly (Barker and Puckett 1997).

CHAPTER 4—DRAINAGE AND WASHING

4.1—General

Accumulation of dirt saturated with water and chemicals on bridge decks, beams, bearing, and other concrete elements accelerate concrete deterioration. While adequate drainage should reduce the need for cleaning, drainage systems can still become plugged and require maintenance. Short of replacing leaking deck joints or installing drain troughs to collect leakage, salt-exposed substructure areas should be cleaned and, if necessary, the concrete sealed to protect against deicing chemicals (Federal Highway Administration 1994).

4.2—Deck drainage

A bridge drainage system (including deck drains, scuppers, pipe, downspouts, and drain troughs) transports rainwater, ice, and snow meltwater away from the structural elements of the bridge. Scuppers that allow runoff water to cascade over superstructure and substructure elements should be avoided.

4.2.1 *Function*—Drainage devices, such as drains and downspouts, prevent ponding of water on properly sloped decks. Deck drainage is important for several reasons. Water on decks reduces skid resistance and increases the danger of vehicles hydroplaning or skidding on ice. Water on decks increases the rates of most concrete deterioration mechanisms, thereby reducing service life. Chlorides diffuse more quickly through saturated concrete, and reinforcing steel corrosion is usually accelerated.

Fig. 4.1—Plugged deck drain.

4.2.2 *Problems*—Drainage problems result from plugged drain inlets and piping systems and from structural causes as well (Fig. 2.1). These include long-term creep and changes in camber of girders, settlement of substructure footings, and repaving of decks. All of these may alter drainage patterns and result in the ponding of salt-laden water. They may also misdirect drainage onto structural elements (NCHRP 1979).

4.3—Washing exposed surfaces

Besides removing dirt and debris, one of the main purposes of washing is to remove chlorides from the concrete surface, thereby reducing their rate of ingress. Annual cleaning and flushing of concrete decks, drains, piping, expansion joints, substructure caps, bearings, and other members is recommended. The most cost-effective frequency of such work should be determined by the site conditions that will vary considerably due to climatic, environmental, and roadway differences. Bridges in cold climates often collect grit used in winter to promote roadway traction and are subjected to deicing salt use. Bridges on unpaved roads collect debris more quickly than those on paved roads.

To remove the salt-laden dirt and debris, washing and flushing requires shovels, brooms, sweepers, compressed air, trash pumps, mobile cleaners, or water under pressure.

4.4—Maintenance of deck drains

Debris and paper products can plug even properly designed deck drainage systems (Fig. 4.1). Plugged drains are a direct cause of concrete deck deterioration and skid-resistance reductions. Blockages often occur when items such as plastic cups, bottles, cans, and other rubbish accumulate within drains.

4.4.1 *Clearing of drains and piping*—Short, straight drains that discharge directly beneath the deck can usually be cleared with plumbing equipment. Drainage systems that consist of long piping that change direction may require tools and equipment suited to their geometry.

4.4.2 *Extending drains*—On older bridges, the existing drains may be too short to prevent exposing bottom flanges of girders or substructure elements to rainwater and chloride-laden meltwater (Fig. 4.2). The cost of extending drains is usually low, and can result in substantial savings in future repairs to the exposed elements.

Fig. 4.2—Short deck drainpipe.

Fig. 4.3—Installation of retrofit deck drain.

4.4.3 *Other maintenance*—Leaks and corrosion damage to drain pipes should be repaired regularly to prevent deterioration to adjacent concrete members. Corroded members should be repaired with corrosion-resistant alloy steels, such as 316LN stainless steel.

4.4.4 *Retrofitting drains*—Deck-drainage characteristics often change with time, and decks that are suspected of having inadequate drainage should be observed shortly after a rain for signs of poor drainage. The depth of standing water can be used to establish the low spots where new drains will function best, and areas where additional drains are warranted should be marked. Holes may be cored through the deck, and a round drain pipe installed (Fig. 4.3). The diameter of the hole should be appropriate for the pipe. Drilling holes through structural elements, such as concrete girders or steel stringer flanges, should be avoided. The drain pipe should be recessed into the deck, and should be aligned to direct water away from below-deck structural members.

Discharge of water onto roadways, railroads, or waterways underneath should be avoided. The pipe opening should contain a cross bar to prevent possible injury to inspectors, pedestrians, and the bike-riding public on or underneath the bridge. The pipe should be secured to the deck and structural elements. After the pipe is aligned and secured, the perimeter of the opening should be externally grouted or sealed with a material to fill voids and prevent moisture seepage into the deck. Where chlorides are present, noncorrosive drainpipe materials, such as 316LN stainless steel or fiber-reinforced polymers, are preferred.

4.5—Other drain considerations

While maintaining proper deck drainage is very important, it is equally important to maintain the drainage system. Improper drainage at the ends of the bridge or at ends of intermediate drain pipes can caused soil erosion and loss of foundation support at abutments and intermediate supports. Maintenance of open-channel flow structures to prevent tipping and settlement is necessary, including removal of debris and vegetation.

Settlement problems may also occur at abutments and wingwalls where impaired drainage systems through these bridge elements exist. Excessive hydrostatic pressures behind these bridge elements may also occur. Regular inspection and cleaning of weep holes is necessary. If soil plugging of granular material behind the weep holes occurs, removal and replacement of granular materials with new granular materials may be required. Preventative measures may be used, such as protective screening to prevent animal intrusion and geotextile materials to prevent soil plugging of granular fill material behind weep holes.

Stream and river channel maintenance may be necessary to prevent excessive soil erosion at wingwall areas. Riprap or gabions can be placed along upstream locations to prevent continued bank erosion. Debris should be removed from stream and river channels to prevent excessive lateral forces of the structure during high flow occurrences or fire damage should debris under the bridge catch fire.

CHAPTER 5—SEALING

5.1—General

Since the early 1900s, various sealers have been used to protect concrete by reducing the permeability of its surface to moisture and deleterious chemical intrusions.

5.2—Purpose

Concrete will absorb water and chemicals, such as chlorides and sulfates, that readily dissolve in water. Almost all of the various deterioration mechanisms for concrete involve internal moisture and accelerate with increased moisture. Sealing and caulking slow the absorption of deleterious chemicals that penetrate cracks or migrate through the concrete surface to cause corrosion of the reinforcing steel, deteriorate the concrete, or both. The process of treating concrete to reduce absorption is called damp-proofing (Fig. 5.1). Waterproofing is defined as treatment to prevent all water from penetrating. Damp-proofing by use of sealers is more economical than waterproofing. The purpose of sealing is to extend the service life of highly exposed concrete surfaces where rapid deterioration leading to failure is expected to occur without sealing. Sprinkel et al. (1991) compared rapid repair techniques and concluded that sealing was the most cost effective of the protection systems evaluated. Other systems evaluated included overlays and membranes.

Fig. 5.1—Newly sealed concrete curb surface.

The application and purpose of a concrete sealer is similar in principle to that of painting steel, except that paints for steel do not need to be vapor-permeable and often contain corrosion inhibitors. In contrast, sealers for concrete should allow escape of internal moisture vapor without creating blisters and debonding of the coating.

5.3—Sealing materials

Sealing materials can be divided into two general categories: coatings and penetrating sealers. Surface coatings can be further subdivided into clear and colored categories. Penetrating sealers can be further subdivided into the older inert pore plugging materials and the newer, chemically reactive products. Sealers are useful on surfaces exposed to cyclic wetting and drying. They are not recommended in continually submerged areas. ACI 515.1R provides more detailed information and guidance on this topic.

5.3.1 *Surface coatings*—Coatings sometimes create a glossy appearance and have limited ability to allow internal concrete moisture to escape, but they have relatively good damp-proofing characteristics. As the application rate of these products is increased, the ability to allow moisture to escape is reduced while the damp-proofing performance improves. Applying too much material can cause moisture to build up behind them, resulting in blistering and peeling.

5.3.1.1 *Types*—Coatings include acrylics, epoxies, and urethanes.

5.3.1.2 *Uses*—Coatings are generally used on vertical surfaces or horizontal surfaces not exposed to traffic. When properly applied, they can prevent or slow various concrete deterioration mechanisms, such as chloride absorption, which leads to corrosion of reinforcing steel, acid rain attack, and sulfate attack. They can also reduce the rate of absorption of carbon dioxide, a cause of concrete carbonation, which also leads to corrosion of reinforcing steel. They may reduce the ingress of moisture into the concrete, thereby reducing freezing-and-thawing damage, salt scaling, and alkali-aggregate reaction (Pfiefer and Scali 1981; Forbes and Carter 1986; Aitkin and Litvan 1989; Bean 1988; Pfeifer et al. 1987; Department of Transport 1990b; Carter 1994; Kamel et al. 1993; Curra 1990; Smith 1986; Weyers et al. 1994; Carter 1991; Carter 1989b; National Research Council 1993; Cady 1995).

5.3.2 *Penetrating sealers*—These products can be subdivided into inert, pore-plugging products and chemically reactive products that have to be reapplied periodically. Chemically reactive products are generally more durable than pore-plugging products. Normally, penetrating sealers do not significantly change the visual appearance of the concrete. They have much higher vapor permeability than surface coatings, especially when heavy application rates are required. Subsequent treatments often require only minor surface preparation. Penetrating sealers will not work if they cannot penetrate the surface due to previous coatings, contaminants, or moisture.

For concrete penetrating sealers to be effective, the general performance properties are (Filice and Wong 2001): damp-proofing ability; breathability (gas exchange between the concrete and the surrounding environment); resistance to chemicals; ultraviolet ray penetration and deterioration; low toxicity; low volatility; resistance to freezing and thawing; and resistance to deicing salt scaling.

5.3.2.1 *Types*—Types of penetrating sealers include linseed oil, siloxanes, silanes, and siloxane-silane combinations in various concentrations and in various carriers. Silicates that have good penetration are not considered sealers.

5.3.2.2 *Uses*—When properly applied, penetrating sealers are useful in reducing ion penetration such as chloride and sulfate (Fig. 5.2). Silane sealers are effective in damp-proofing concrete deck-wearing surfaces without reducing skid resistance. Water-based or pure silanes are possible options for use in jurisdictions where there are stringent limits on volatile organic compounds (VOC). Penetrating sealers should penetrate to perform adequately, and their ability to penetrate is influenced by factors such as the permeability of concrete, moisture content near the concrete surface, and the surface preparation required to remove contaminants such as form oils, curing compounds, previously applied surface sealers, or roadway oils (Carter 1989b; Kamel et al. 1993). The deepest penetration occurs when the concrete surface is clean, dry, and porous. Sealers may not significantly improve the protection provided by high-performance, low-permeability concrete. The depth of penetration can be determined by extracting and examining cores.

Fig. 5.2—Application of penetrating concrete sealer.

5.4—What and when to seal

In general, the following areas should be considered for sealing:

- All concrete surfaces exposed to cyclic wetting and drying, to chloride-laden waters and spray, to other aggressive ions, or to leakage from deck joints and drains. These may include curbs, barriers, medians, deck-wearing surfaces and undersides, wingwalls, piers, girders, and abutments;
- Areas where significant penetration of carbonation has been identified by testing;
- Surfaces where alkali-aggregate reaction has been identified; and
- New concrete surfaces that are expected to be exposed to chlorides and freezing within a month or so of construction.

Filice and Wong (2001) have presented the following guidelines for the use of three silane penetrating sealer types for concrete bridges when the concrete surfaces are 28 days or older and clean and dry:

1. Solid contents of 14 to 32% may be used in sheltered areas where the concrete relative humidity is less than 55%;

2. Solid contents of 25 to 33% may be used on traffic-bearing and exposed areas where the concrete relative humidity is less than 75%; and

3. Solid contents of 65 to 72% may be used on precast concrete that has been steam-cured for 1 to 5 days and the concrete humidity is less than 85%.

5.5—Recommended practice

Recommended practice for sealing depends on the type of product used, but generally it includes the following:

- Manufacturer's application instructions should be followed;
- The concrete surfaces to be sealed should be sound, clean, and dry. Low internal concrete moisture content promotes deeper penetration of sealers and prevents blistering of coatings. Wet concrete should be allowed to dry for several days after the surface appears dry. A surface-dry condition does not guarantee good concrete sealing performance (Kamel et al. 1993);
- Surface preparation should remove all surface contaminants, curing compounds, form oils, and loose or incompatible previous coatings;
- New concrete should be allowed to cure before sealing. Sealing performance generally increases with concrete

age, and it is recommended that sealing not be done until the concrete is at least 2 weeks of age and after deck grooving;

- The sealer application rate should vary with the surface texture and permeability of the concrete, and several coats may be needed because the treatable surface area increases with texture and permeability;
- Smooth, dense concrete will require less sealer than rough, porous concrete, but both will benefit from sealing when exposed to chloride;
- Because different sealers perform differently, it is important to verify performance and identity of the specific product being used. On large jobs, solids content tests and spectrographic analysis can be done to verify the sealer identity. An indication of performance can usually be obtained from suppliers and users. Permeability records for applications similar to those intended should be given the most consideration;
- Proper equipment, usually low-pressure sprayers or paint rollers, should be used; and
- Field tests, such as ASTM D 6489, should be done after application at construction to measure acceptance of damp-proofing performance and as a follow-up to determine the service life of the sealer.

Sealing programs should be done on a regular cycle, such as every 5 to 10 years, depending on the sealer. A survey of U.S. highway agencies concluded that the service life of bridge concrete sealers was 5 to 10 years (Weyers et al. 1994).

5.6—Product selection

General selection guidelines include:

- Deck-wearing surfaces may be sealed with water-repelling, penetrating products, such as silanes or siloxanes, which provide a hydrophobic surface that does not reduce skid resistance, rather than pore-blocking products that may reduce skid resistance;
- Non-wearing, vertical surfaces may be sealed with coatings or pore-blocking or water-repelling sealers. If additional damp-proofing performance is needed, non-water-based coatings may be applied over a prime coat of penetrating material;
- Pigmented coatings are available that provide good appearance as well as resistance to penetration of moisture and ions; and
- Sealer product selection should never be based on generic type alone because there is substantial variation among similar products within any generic group. The manufacturer should be consulted to verify the product performance claims in the given conditions, and independent approval testing is recommended. Sealer testing consists of using standard concrete test samples to measure the desired sealer characteristics of damp-proofing, vapor transmission, penetration depth, and durability in certain conditions. Examples are in the *NCHRP Report* No. 244 (Pfeifer and Scali 1981) and the Province of Alberta, Canada approval test programs (Carter 1989b, 1994).

The damp-proofing performance that results from sealing concrete is dependent on three main groups of factors: sealer characteristics, concrete characteristics, and the workmanship in cleaning the surface and applying the sealer.

Sealer performance varies significantly from one situation to another, and field testing is recommended. Field-performance tests should be done routinely to monitor the actual performance of the sealer. This will provide valuable information to verify that the desired results are being obtained. It will also allow problems in performance to be identified and improvements in materials and procedures to be implemented. Several departments of transportation have performance-based sealing specifications using a field-test method on cores taken from the sealed concrete. ASTM D 6489 may also be used. When measuring sealer performance on deck-wearing surfaces, it is recommended to consider both damp-proofing performance and penetration depth (Carter 1994; Kamel et al. 1993; Curra 1990; Smith 1986; Carter 1991; Carter 1989b; National Research Council 1993; Cady 1995; Whiting et al. 1993; Emmons 1993).

CHAPTER 6—MAINTENANCE PATCHING

6.1—General

This chapter covers procedures for the routine patching of relatively small areas of concrete damage. Patching, defined herein as repairs that average 2 in. (51 mm) or less in depth, are generally made with prepackaged, proprietary materials, including polymer-modified products that have the potential for better adhesion and curing. Prepared packaged materials may not be practical for deeper repairs because of the high cost. Ready-mixed concrete may be more practical and may be more compatible with the substrate. Bridge deck patches need to resist live loads, impact, and abrasion. For concrete superstructures, particularly prestressed members, attention should be given to cracks or spalls that indicate structural distress. Structural expertise should be consulted before beginning structural maintenance or repair. Where water and deicers are expected to be present, maintenance actions for damaged areas and cracks may be accomplished by the use of an appropriate sealer, sealant, crack repair, corrosion inhibitor, or repair material.

6.2—Purpose

Maintenance patching is intended as a quick, and sometimes temporary, repair to restore the rideability and appearance of concrete. Patching is often done under adverse field conditions, such as temperature extremes (Fig. 6.1 and 6.2). Riding-surface defects and spalls create danger to the public. They trap water and chlorides and result in increased live-load impact forces that may accelerate the failure of adjacent deck areas. Unless stopped, this damage will develop into full-depth holes that cannot be ignored. Because full-depth repairs require forms on the underside of the deck, they are slow and costly to construct, disruptive to traffic, and potentially dangerous to workers and the traveling public. Patching is sometimes needed to repair overhead damages to overpasses or vertical surfaces where non-sag, cohesive materials are needed. Due to the differences in the applica-

Fig. 6.1—Prepared surface for temporary deck patch.

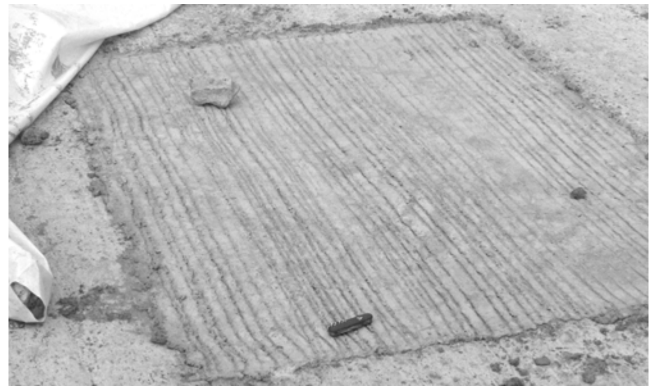

Fig. 6.2—Newly placed deck patch.

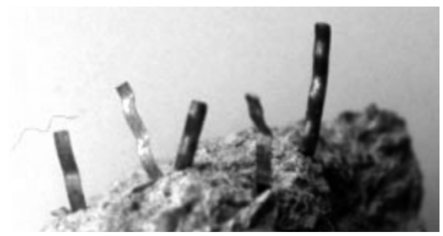

Fig. 6.3—Steel fiber reinforcement.

tion properties needed to place durable patches in areas subject to different exposure conditions, several typical types of patching are described.

6.3—Selecting durable patching materials

When selecting a patching material, the recommended procedure is to first identify the cause of the original damage or deterioration. The user should then select a material that has resistance to the original cause of deterioration, one with physical properties of high bond strength and low shrinkage, and having application characteristics that meet the weather conditions, needs, and constraints of the site. User-friendliness, as in prepackaged materials, should always be considered in product selection, and practical experience with the product is advantageous. Independent test data or field experience is preferable to information supplied on a manufacturer's data sheet. Note that no single patching material is suitable for all types of work and exposure conditions. Compatibility with the substrate may be important (Emmons 1992). An example of potential incompatibility is the use of a nonbreathable patch on a bridge approach slab. The patch inhibits the normal movement of moisture through the substrate concrete. Refer to ACI 546R for typical properties, advantages, limitations, and applicable standards for the various categories of repair materials.

6.3.1 *Physical properties*—The basic material characteristics needed to produce a durable repair are good bond strength, low shrinkage, compatibility with the substrate, and ease of application. Cement-based patching materials that are similar in handling, mixing, and behavior to the hydraulic concrete being repaired are more likely to be compatible and easy to apply than special materials like polymer concrete. Economics usually also favor these materials. Polymer concrete or polymer-modified concrete has potential applications in areas where patch material volume is low and material cost is low in comparison to labor cost.

6.3.1.1 *Compressive strength*—Compressive strength is not the most appropriate physical property to consider when selecting patching materials. High compressive strength is often associated with high cement content and high heat of hydration temperatures during setting. These may result in excessive long-term drying shrinkage, consequent tensile stresses, and possible debonding from the substrate. The probability of these problems occurring increases as the thickness of the patch increases.

6.3.1.2 *Shrinkage*—Shrinkage is always a potential problem with patching materials. Patching mortars usually have a high potential for shrinkage because of their high paste content and lack of coarse aggregate. Shrinkage test data from independent sources or field experience with the product are recommended as sources of information for product selection and use. All patching products should be cured in accordance with manufacturer's instructions. In adverse drying conditions, the potential for plastic shrinkage cracking of cementitious materials will increase unless proper curing is provided (ACI 308R). Adverse drying conditions result from any combination of air temperature, relative humidity, concrete temperature, and wind velocity that promotes rapid evaporation of moisture. Repair mortars should be extended with coarse aggregate where possible to reduce drying shrinkage. Proper wet-curing techniques will also reduce early drying shrinkage (Emmons 1993).

6.3.2 *Special material properties*—Bridge deck surfaces require high-quality repairs due to the severity of the conditions to which patches are exposed. These include frequent live loads and impacts, temperature cycling, wet-and-dry cycling, and exposure to chlorides. Deck patches are generally subjected to these severe conditions before they are fully cured. Normal wet-curing methods for concrete may be impractical for use on deck patches. Liquid membrane curing materials are often used. Patching in northern climates should be done with products possessing adequate salt-scaling and freezing-and-thawing resistance.

6.3.2.1 *Fiber*—Fibers can be added to repair concrete to limit cracking and increase toughness (Fig. 6.3) (Ezeldin and

Fig. 6.4—Deteriorated vertical pier surface.

Fig. 6.5—Shotcreted vertical pier surface.

Fig. 6.6—Improper feather-edged patch.

Lowe 1991). Bridge deck patches are generally subjected to frequent vehicle impact forces, leading to cracking and eventual disintegration of the patch. Fiber reinforcement has the potential to significantly improve the durability of concrete exposed to impacts and cyclic loading. Refer to the report(s) of ACI Committee 544 for information on the relative merits of both steel and synthetic fibers.

6.3.2.2 *Low-temperature patching*—Cementitious patching materials are normally designed to be placed at temperatures of approximately 50 °F (10 °C) or greater. Because bridge deck spalls often develop during winter conditions, patching materials are often needed that will set and cure at temperatures between 20 and 40 °F (–5 and +5 °C). Some patching materials, such as magnesium phosphate cement-based materials, will set and cure at temperatures at and below freezing (ACI 546R). The risk of a problem increases as the thickness of the patch and the ability to protect the patch decreases. The alternative of heating the area being patched is not usually practical or economical. Low-temperature patching materials must have good bond strength and resistance to freezing and thawing and scaling. Temporary asphalt patching to improve deck rideability is an alternative to more permanent concrete patching during winter months. Concrete patching can then be done in more favorable weather conditions.

6.3.2.3 *Rapid-setting patching*—Routine deck patching in high traffic areas requires rapid-setting materials to reduce the risk of traffic accidents during lane closures and traffic delays. A compressive strength of approximately 3000 psi (21 MPa) is recommended before allowing traffic on the patch. Materials that comply with R3 performance requirements (ASTM C 928) must exhibit this strength level at 3-hour ages. Rapid-setting products may sacrifice some long-term durability, but are usually the best option for high-traffic areas. To prevent drying-shrinkage cracks, the patch must be properly cured. The manufacturer's instructions should be followed as usual. These materials should have good abrasion resistance usually related to 28-day compressive strength.

Some rapid-setting materials are susceptible to sulfate attack, and should not be used in marine environments. Other patch materials may not be compatible with future maintenance activities, such as polymer concrete overlays. Suppliers should be consulted to verify that the desired performance is achievable in the intended environmental conditions.

6.3.2.4 *Overhead and vertical patching*—Zero-slump, nonsagging patching materials do not generally need the freezing-and-thawing or salt-scaling durability of deck patches unless they are in areas expected to become saturated or subject to heavy salt exposure (Fig. 6.4 and 6.5). Properties necessary for a good repair include good bond strength, low drying shrinkage, and ability to match the appearance of concrete because they are often in visible locations on grade separation structures. Curing is generally done with curing compound rather than burlap to reduce labor costs.

6.4—Recommended patching procedures

6.4.1 *Feather-edging*—Thin or feather-edged patches are not as durable as thicker patches, and feather edging is not recommended, especially in areas where cyclic water and freezing conditions occur (Fig. 6.6). Feather-edging of most patching materials will reduce their service life. Most repair materials contain some coarse aggregates that cannot be

Fig. 6.7—Saw-cutting perimeter of patch.

feathered easily. The smaller the maximum aggregate size in the patching material, the higher the potential drying shrinkage.

6.4.2 *Surface preparation*—Proper surface preparation is one of the most important steps in the repair process. Surface preparation may require surface roughening, exposure of coarse or fine aggregate, removal of a thin layer of damaged concrete, or simply cleaning of the concrete surface (ACI 546R). The surface should be moist unless recommended otherwise by the manufacturer.

6.4.3 *Saw-cutting*—Edges should be saw-cut to a depth compatible with the coarse aggregate size and the manufacturer's recommendations (Fig. 6.7). Unless specified otherwise, a minimum depth of 0.4 in. (10 mm) should be used and chipped inward at an approximate angle of 45 degrees to a minimum depth of 1 in. (25 mm).

6.4.4 *Other items*—The manufacturer's instructions should be followed regarding prewetting, bonding agents, minimum patching depth, and curing procedures. All these factors are important in obtaining durable patches.

CHAPTER 7—JOINTS, CRACKS, AND CONTROL JOINTS

7.1—General

Leaking joints and cracks in concrete are detrimental to bridge elements exposed to chlorides. Cracks reduce the service life of chloride-exposed concrete bridge elements (Sprinkel 1992a,b). Control joints allow for movement between elements, but if not maintained, allow for the infiltration of chloride.

7.2—Maintenance of joints

Maintenance activities are intended to help joints continue to accommodate thermal and live-load movement of the superstructure, while preventing leakage through the joint.

7.2.1 *Cleaning*—Filled expansion joints should be cleaned periodically as often as necessary to remove incompressible materials. At a minimum, debris should be removed after winter maintenance and before moderating temperatures.

7.2.2 *Sealing*—Joint sealing materials should retain their elastic properties over a wide range of temperatures to accommodate movement of the deck. Possible replacement joint materials include butyl rubber, polyurethane, and silicone. Deck joints consisting of steel members housing a strip seal are generally durable as long as the range of movement is not greater than 3 in. (76 mm).

7.2.3 *Reducing impact*—Impact forces generally result from vertical misalignment between the joint and the deck or the approach. High-impact forces reduce the life of the joint and its supporting elements. The misalignment can be corrected by raising the joint, welding additional plates, repairing with concrete or other cementitious materials, or replacing the joint at the proper elevation. Proper alignment of the approach pavement should also be maintained at the bridge ends.

7.3—Cracks

Structural concrete is a material that is durable and strong in compression, but relatively weak in tension. Steel is highly susceptible to corrosion, but strong in tension, and steel relies on the alkalinity of concrete to remain chemically stable in a corrosive environment. Concrete cover is the term for the layer of concrete that protects the reinforcing steel from the environment. Cracks may destroy the corrosion protection that the concrete cover is intended to provide, thereby reducing the service life of the structural member.

Cracks occur when the tensile, diagonal tensile, or flexural tensile stress exceed the tensile strength of the concrete. While some cracks appear shortly after casting due to plastic shrinkage and drying shrinkage, even uncracked mature concrete may be subjected to shrinkage stresses near the surface. When these stresses are combined with other stresses from live loads or temperature change, cracks may appear later. Once a crack has developed in a bridge member, it often propagates with time due to cyclic loading. For the purposes of bridge maintenance, cracks can be categorized as either structural or nonstructural. Each requires different repair techniques. Typically, structural cracks are repaired to restore structural integrity, and nonstructural cracks are sealed to minimize the potential for increased cracking.

7.3.1 *Structural cracks*—Structural cracks are originally created by stress due to live load and dead load and thermal and shrinkage strains (Fig. 7.1). Thermal cracks tend to be straight in orientation, and may open at night and close during the day, making them harder to detect and repair. On bridge decks, they are often located directly above a reinforcing bar, exposing the bar to moisture and chlorides. Structural cracks include diagonal tension, shear, and flexural tension cracks in concrete girders. Transverse and longitudinal cracks in decks and substructure cracks may also be caused by a lack of proper reinforcing or seized bearings.

7.3.2 *Nonstructural cracks*—Nonstructural cracks are generally not straight, may be superficial in depth, and take on various patterns depending on their cause (Fig. 7.2). They result primarily from nonstructural causes such as plastic drying, autogenous and thermal shrinkage, or alkali-aggregate reaction. They are generally unaffected by live loads, making them easier to repair or seal.

Fig. 7.1—Structural deck cracking.

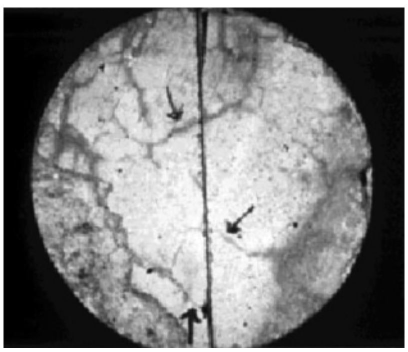

Fig. 7.2—Nonstructural cracking.

Fig. 7.3—Crack repaired by routing and sealing.

7.4—Crack repair

Cracks are a long-term maintenance concern when they occur in bridge elements exposed to chlorides. ACI 224.1R provides additional information on causes, evaluation, and repair of cracks.

7.4.1 *Active cracks*—Active cracks are those that open and close often when the bridge is carrying traffic. Depending on the location, some cracks open under live load, while others close. It is as difficult to predict the amount of movement as it is to predict the types of future loads. Some thermal cracks are active cracks, closing during the day and widening during the night. Most structural cracks are active cracks, while most nonstructural cracks are not active cracks.

Fig. 7.4—Epoxy injection of cold joint or crack.

7.4.1.1 *Routing and sealing*—Deck cracks may be repaired by routing, sandblasting, priming the bond surfaces, and filling the resulting groove with a relatively firm but flexible material, usually a two-component urethane (Fig. 7.3). The material should have a tensile elongation capability (ASTM D 638) of more than 200%, and the elongation capability should not be significantly affected by temperature. Poor surface preparation or inadequate elongation capability can result in bond failure at the edge of the groove.

7.4.1.2 *Bonded versus debonded repairs*—Rout and seal crack repairs may involved the sealant being either bonded or debonded from the bottom of the groove surface. Bonded repair requires a material with at least a 300% tensile elongation capability by ASTM D 638. Debonding may be achieved in several ways, such as placing a layer of fine sand or smooth-sided tape in the bottom of the routed groove. It is important to achieve good bond to the sides of the groove.

7.4.1.3 *Expanding urethane foam*—Expanding urethane foam may be injected into prewetted cracks after sealing the exposed surfaces of the cracks. The material reacts chemically with water to create significant expansion, and quickly flows through the crack. The resulting repair is flexible, and will prevent the penetration of moisture and chlorides. This method is generally reserved for moving cracks that remain moist and normally not used on decks, but might be used on piers or abutments.

7.4.1.4 *Epoxy injection*—One-hundred-percent solid, high-strength, low-viscosity, moisture-tolerant, structural epoxy resins are suitable for repairing cracks in substructure and superstructure members (Fig. 7.4). They are generally

Fig. 7.5—Routed and caulked crack.

not used for deck cracks due to the high cost of sealing the underside of the deck.

7.4.2 *Dormant cracks*—These cracks are generally easier to repair than active cracks. Shrinkage cracks can be sealed because they only move with changes in temperature. Methods include gravity fill, topical applications of sealers, rout and seal, and epoxy injection.

7.4.2.1 *Gravity fill*—Low viscosity, slow setting, water, and air-displacing resins are particularly suited for the repair of pattern shrinkage cracks in horizontal surfaces such as decks. Products include high molecular weight methacrylate, epoxy, and urethane. The material may leak through full-depth cracks, and arrangements need to be made to either seal the bottom of the crack or to collect the leaking material (Sprinkel 1992a).

7.4.2.2 *Topical applications of sealers*—Hydrophobic penetrating sealers may be used to treat dormant cracks in decks and pier caps to reduce intrusion of moisture and chloride solution. The procedure works best on cracks less than 0.01 in. (0.3 mm) in width.

7.4.2.3 *Routing and sealing*—Deck cracks may be repaired by routing, sandblasting, priming the bond surfaces, and filling the resulting groove with a relatively firm, but flexible, material.

7.4.2.4 *Epoxy injection*—Epoxy injection is sometimes used for structural repair of cracks or to seal and restore the protection to steel reinforcing.

7.5—Joint caulking

The purpose of caulking is to prevent the penetration of deleterious materials into joints in concrete construction or exposed joints between concrete and steel members, such as bearings (Fig. 7.5). Bridges are often designed with various types of movement joints, where maintenance caulking can easily be carried out. These joints can have various purposes, such as to reduce restraint and allow movements to occur, to allow shrinkage to occur without cracking, or as part of the construction casting sequence (ACI 504R; Panek 1986; Palmer 1992; Beech 1986).

Manufacturer's instructions should be followed, but in general, procedures involve cleaning the bond surface and allowing it to dry before caulking or applying a bonding primer. The design of the joint usually involves maximizing the bond strength of caulk to concrete by increasing the surface area and creating a reduced cross section of caulk between the bond surfaces to promote necking of the caulk when movement occurs.

CHAPTER 8—POTENTIALLY PROMISING TECHNIQUES FOR BRIDGE MAINTENANCE

8.1—General

This chapter presents some promising maintenance techniques that currently lack substantial field-performance data to support their use. Independent evaluations, such as the Strategic Highway Research Program reports, suggest potential life-cycle cost savings (Weyers et al. 1993; Sagues and Powers 1994). On the other hand, a recently completed corrosion-inhibitor project was inconclusive (Sprinkel 2003).

8.2—Corrosion inhibitors for use in maintenance

While the use of corrosion inhibitors for the protection of metallic substances is not a new technique, their use as part of a maintenance program for reinforced concrete structures is a more recent development. The Strategic Highway Research Program SHRP-S-666 (Weyers et al. 1994) evaluated several corrosion-inhibiting materials and identified some promising ones from both laboratory and field-testing data.

There are several types of corrosion inhibitors with different types of protection mechanisms. They come in two forms: admixtures for new concrete, and surface treatments for existing concrete.

8.2.1 *Admixtures*—Some admixture forms of corrosion inhibitor may be beneficial when added to concrete repair material used for replacing deteriorated concrete surrounding previously corroded reinforcing steel. Applications could include proprietary patching materials that contain an inhibitor (Weyers et al. 1993).

8.2.2 *Surface treatments*—Surface treatments may be potentially useful in the following applications: for treating wide cracks in concrete bridge elements exposed to chlorides (Weyers et al. 1993) or for protecting reinforcing steel in carbonated concrete, especially areas with inadequate concrete cover depth (Sagues and Powers 1994). To be effective, surface treatments involve either penetration through cracks or absorption and migration through concrete to reach the steel. The drier and more porous the substrate and the thinner the cover depth, the more likely the treatment will have value. The concrete permeability and the ambient weather conditions are factors that should also be considered. Previous coatings that prevent absorption should be removed. Shot or grit blasting can be used to remove water-repelling sealers. Pore blocker sealers may have to be removed by grinding the surface. Product selection should involve getting evidence of previously successful applications. Manufacturer's guarantees should be considered.

8.2.3 *Corrosion-inhibiting surface treatment*—Corrosion-inhibiting surface treatment may be injected into transverse deck cracks that are located directly above reinforcing steel to temporarily reduce the rate of corrosion. This method is relatively new, and its effectiveness is not known. The method may be suited to treat transverse deck cracks where other types of repair are either too expensive or ineffective. A sealer may be used after the inhibitor treatment, as most corrosion inhibitors are water soluble and may be flushed out of cracks during rain storms.

8.3—Galvanic cathodic protection using sprayed zinc

This maintenance method involves the use of steel metallizing technology to stop corrosion in reinforced concrete. There are two versions: impressed current, which is outside the scope of this document, and galvanic or passive cathodic protection. In the galvanic system, the zinc layer is applied directly on the surface of the concrete. If the concrete is sufficiently electrically conductive, the zinc is progressively sacrificed as current flows through the concrete to the steel being protected. To complete the galvanic circuit, the coating should be connected electrically in several locations to the reinforcement that is being protected. As in all cathodic protection systems, the underlying reinforcement should be electrically continuous to avoid creating anodic areas on the reinforcement that will corrode more rapidly than without the cathodic protection.

8.3.1 *Applications*—The system has been used in humid, salt-exposed environments where the concrete has good conductivity. The system does not work in dry climates or on nonconductive concrete.

8.3.2 *Recommended practice*—Bond strength of coating to concrete is important, and should generally be greater than 145 psi (1 MPa). Several procedures have been shown to result in maximum bond strength (Fanson and Cohen 1991). These procedures include:

- Lightly sandblasting the bond surfaces before applying coating without exposing too much coarse aggregate, because the zinc bonds better to cement paste (parallel construction);
- Cleaning all dust and contaminants from the surface after sandblasting;
- Maintaining the metallizing nozzle approximately 6 in. (150 mm) from the surface;
- Ensuring that all bond surfaces are dry before metallizing;
- Applying coating at temperatures of 68 °F (20 °C) or greater;
- Preheating bond surfaces with a propane torch to remove moisture and reduce thermal stress on the coating;
- Using multiple passes of approximately 0.002 in. (0.05 mm) each to progressively build up the coating; and
- Performing bond tests during initial phases of the work to establish adequate spray patterns and procedures.

The thickness should be approximately 0.016 in. (0.4 mm), and can be measured by a wet film thickness gauge or by eddy-current equipment. Because specialized equipment and expertise are needed for this type of maintenance, properly qualified contractors should do the work.

CHAPTER 9—REFERENCES

9.1—Referenced standards and reports

The standards and reports listed below were the latest editions at the time this document was prepared. Because these documents are revised frequently, the reader is advised to contact the proper sponsoring group if it is desired to refer to the latest version.

American Concrete Institute

201.1R Guide for Making a Condition Survey of Concrete in Service
222R Protection of Metals in Concrete Against Corrosion
224.1R Causes, Evaluation, and Repair of Cracks in Concrete Structures
308R Guide to Curing Concrete
504R Guide to Joint Sealants for Concrete Structures
515.1R Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete
546R Concrete Repair Guide

ASTM International

C 928 Standard Specification for Packaged, Dry, Rapid-Hardening Cementitious Materials for Concrete Repairs
D 638 Standard Test Method for Tensile Properties of Plastics
D 6489 Standard Test Method for Determining the Water Absorption of Hardened Concrete Treated With a Water Repellent Coating

These publications may be obtained from these organizations:

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
www.concrete.org

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428
www.astm.org

9.2—Cited references

Aitkin, C. T., and Litvan, G. G., 1989, "Laboratory Investigation of Concrete Sealers," National Research Council of Canada.

Alampalli, S., 2001, "Correlation Between Bridge Vibration and Bridge Deck Cracking: A Qualitative Study," FHWA/NY/SR-01/136, New York State Department of Transportation, Albany, N.Y.

Barker, R. M., and Puckett, J. A., 1997, *Design of Highway Bridges*, John Wiley & Sons, Inc., New York, 1192 pp.

Bean, D. L., 1988, "Surface Treatments to Minimize Concrete Deterioration: Survey of Field and Laboratory Application and Available Products," U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Beech, J. C., 1986, "A Review of Test Methods for the Assessment of the Movement Capability of Building Sealants," *Joint Sealings and Bearing Systems for Concrete Structures*, SP-94, V. 1, American Concrete Institute, Farmington Hills, Mich., pp. 203-221.

Buckler, J. G.; Barton, F. W.; Gomez, J. P.; Massarelli, P. J.; and McKeel, W. T., 2000, "Effects of Girder Spacing on Bridge Deck Response," VTRC01-R6, Virginia Transportation Research Council, Charlottesville, Va., 22 pp.

Cady, P. D., 1995, "Sealers for Portland Cement Concrete Highway Facilities," *NCHRP Synthesis* 209, Transportation Research Board, Washington, D.C.

Carter, J., and Kaufman, J. J., 1990, "Value Engineering Study of Bridge Deck-Maintenance, Repair, and Protection," *Report* No. FHWA-TS-90-041, Federal Highway Administration, McLean, Va.

Carter, P. D., 1989a, "Preventive Maintenance of Concrete Bridge Decks," *Concrete International*, V. 11, No. 11, Nov., pp. 33-36.

Carter, P. D., 1989b, "The Use of Penetrating Sealers on Concrete Bridge Decks," *Structural Materials—Proceedings of Structures Congress '89*, American Society of Civil Engineers, New York, pp. 292-302.

Carter, P. D., 1991, "Sealing to Improve Durability of Bridge Infrastructure Concrete," *Concrete International*, V. 13, No. 7, July, pp. 33-36.

Carter, P. D., 1994, "Evaluation of Dampproofing Performance and Effective Penetration Depth of Silane Sealers in Concrete," *Concrete Bridges in Aggressive Environments*, Philip D. Cady International Symposium, SP-151, R. E. Weyers, ed., American Concrete Institute, Farmington Hills, Mich., pp. 95-117.

Chen, W. F., and Duan, L., 2000, *Bridge Engineering Handbook*, CRC Press, Washington, D.C.

Curra, W., 1990, "Evaluation of Sealers for Concrete Bridge Decks," *Report* DHT-21, Texas State Department of Highways and Public Transportation, Austin, Tex., Apr., 41 pp.

Department of Transport, 1990a, "Impregnation of Concrete Highway Structures," *Departmental Advice Note* BA 33/90, London, 9 pp.

Department of Transport, 1990b, "Criteria and Material for the Impregnation of Concrete Highway Structures," *Departmental Standard* BD 43/90, London, Apr., 12 pp.

Emmons, P. H., 1992, "Selecting Concrete Repair Materials for Long-Term Durability Based on Available Test Data," *Concrete Repair Bulletin*, International Concrete Repair Institute, Des Plaines, Ill.

Emmons, P. H., 1993, *Concrete Repair and Maintenance—Illustrated*, Construction Publishers, Kingston, Maine, 295 pp.

Ezeldin A. S., and Lowe, S. R., 1991, "Mechanical Properties of Steel Fiber Reinforced Rapid-set Materials," *ACI Materials Journal*, V. 88, No. 4, July-Aug., pp. 384-389.

Fanson J., and Cohen, E., 1991, "Lincoln Park Bridge Restoration," *Concrete International*, V. 13, No. 6, June, pp. 50-52.

Federal Highway Administration, 1994, "Bridge Maintenance Training Manual," FHWA-HI-94-034, U.S. Department of Transportation, May.

Filice, J., and Wong, J., 2001, "Best Practice Guidelines for Selecting Concrete Bridge Deck Sealers," Alberta Department of Transportation, Alberta, Canada.

Forbes, A. J., and Carter, P. D., 1986, "Comparative Evaluation of the Waterproofing and Durability Performance of Concrete Sealers," Alberta Transportation and Utilities, 90 pp.

Hambly, E. C., and Nicholson, B. A., 1990, "Prestressed Beam Integral Bridges," *Structural Engineer*, London, V. 68, No. 23, Dec., pp. 474-478.

Kamel, A.; Kalluri, P.; and Bush, T. D., 1993, "Effect of Field Variables and Test Procedures on Silane Weatherproofing Performance," Oklahoma Department of Transportation, Norman, Okla., June, 91 pp.

Krauss, P. D., and Rogalla, E. A., 1996, "Transverse Cracking in Newly Constructed Bridge Decks," *NCHRP* 380, Transportation Research Board, NRC, Washington, D.C.

National Research Council, 1993, "Condition Evaluation of Concrete Bridges Relative to Reinforcement Corrosion, Volume 5: Methods for Evaluating the Effectiveness of Penetration Sealers," *Strategic Highway Research Program*, SHRP-S-327, National Research Council, Washington, D.C., 59 pp.

NCHRP Synthesis No. 67, 1979, "Bridge Drainage Systems," Transportation Research Board, Washington, D.C., pp. 2-4; 10; 29-35.

Palmer, M., 1992, "How to Seal Joints in Concrete Structures," *Concrete Construction Online*, Nov. 1, http://www.concreteconstruction.net, 4 pp.

Panek, J. R., 1986, "A Comparison of Sealant Specifications," *Joint Sealings and Bearing Systems for Concrete Structures*, SP-94, V. 1, American Concrete Institute, Farmington Hills, Mich., pp. 193-202.

Pfeifer, D. W.; Landgren, J. R.; and Zoob, A., 1987, "Protective Systems for New Prestressed and Substructure Concrete," *Report* No. FHWA/RD-86/193, Federal Highway Administration, Washington, D.C., 133 pp.

Pfeifer, D. W. and Scali, M. J., 1981, "Concrete Sealers for Protection of Bridge Structures," *NCHRP Report* No. 244, Transportation Research Board, Washington, D.C., 137 pp.

Sagues, A., 2001, "Metallurgical Effects of Chloride Ion Corrosion Threshold of Steel in Concrete," *WPI* No. 0510806, Florida Department of Transportation, Tallahassee, Fla.

Sagues, A., and Powers, R., 1994, "Sprayed Zinc Galvanic Anodes for Concrete Marine Bridge Substructures," SHRP-S-405, Strategic Highway Research Program, National Research Council, Washington, D.C.

Skeet, J., and Kriviak, G., 1994, "Service Life Prediction of Protective Systems for Concrete Bridge Decks in Alberta," ABTR/RD/RR-94/01, Alberta Transportation and Utilities, Edmonton, Canada, 106 pp.

Smith, M. D., 1986, "Silane Chemical Protection of Bridge Deck," *Report* No. FHWA/OK 86 (4), Research & Development Division, Oklahoma Department of Transportation, 66 pp.

Sprinkel, M. M., 1992a, "Use of High Molecular Weight Methacrylate Monomers to Seal Cracks in Bridge Decks, Retard Alkali-Silica-Aggregate Reactions, and Prime Bridge Surfaces for Overlays," *Transportation Research Record* No. 1347, pp. 29-36.

Sprinkel, M. M., 1992b, "Twenty-Year Performance of Latex-Modified Concrete Overlays," *Transportation Research Record* No. 1335, pp. 27-35.

Sprinkel, M. M.; Weyers, R. E.; and Sellars, A. R., 1991, "Rapid Techniques for the Repair and Protection of Bridge

Decks," Virginia Transportation Research Council, Charlottesville, Va., 31 pp.

Sprinkel, M. M., 2003, "Evaluation of Corrosion Inhibitors for Concrete Bridge Deck Patching and Overlays," FHWA/VTRC 03-R14, Virginia Transportation Research Council, Charlottesville, Va., 37 pp.

Suresh, S., 2005, *Fatigue of Materials*, 2nd Edition, Cambridge Press, 700 pp.

Vaysburd, A. M., 1990a, "Rehabilitation of an Elevated Roadway Bridge," *Concrete International*, V. 12, No. 9, Sept., pp. 45-50.

Vaysburd, A. M., 1990b, "Deterioration and Rehabilitation of the Elevated Roadway Bridge at Baltimore/Washington International Airport," *Paul Kleiger Symposium on Performance of Concrete*, SP-122, D. Whiting, ed., American Concrete Institute, Farmington Hills, Mich., pp. 401-426.

Weyers, R.; Fitch, M.; Larsen, E.; and Al-Qadi, I., 1994, "Service Life Estimates," SHRP-S-668, Strategic Highway Research Program, National Research Council, Washington, D.C.

Weyers, R.; Prowell, B.; Sprinkel, M.; and Vorster, M., 1993, "Concrete Bridge Protection, Repair, and Rehabilitation Relative to Reinforcement Corrosion: A Methods Application Manual," SHRP-S-360, Strategic Highway Research Program, National Research Council, Washington, D.C.

Whiting, D.; Ost, B.; and Nagi, M. 1993, "Methods for Evaluating the Effectiveness of Penetrating Sealers," SHRP-S-327, V. 5, Strategic Highway Research Program, National Research Council, Washington, D.C.