

ACI 345.1R-16

Guide to Maintenance of Concrete Bridge Members

Reported by ACI Committee 345



American Concrete Institute
Always Learning



Documents

Document Sharing Hub



Guide to Maintenance of Concrete Bridge Members

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI via the errata website at <http://concrete.org/Publications/DocumentErrata.aspx>. Proper use of this document includes periodically checking for errata for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided “as is” without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

Order information: ACI documents are available in print, by download, on CD-ROM, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised ACI Manual of Concrete Practice (MCP).

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

Guide to Maintenance of Concrete Bridge Members

Reported by ACI Committee 345

Yail Jimmy Kim, Chair

Chris Carroll, Secretary

Jesse L. Beaver
Michael C. Brown
Andrew J. Foden
Oliver K. Gepraegs

Alan B. Matejowsky*
Rita K. Oglesby
Harold R. Sandberg
Johan L. Silfwerbrand

Michael M. Sprinkel
Paul J. St John
Ronald E. Vaughn
Richard E. Weyers

Mark Erik Williams

*Deceased

Consulting Members

James C. Anderson
Byron T. Danley

Fouad H. Fouad
Allan C. Harwood

Yash Paul Virmani
Jeffrey P. Wouters

This guide addresses typical problems and cost-effective maintenance techniques for highway bridges and their members, providing guidance to engineers and maintenance staff. Maintenance is crucial to a bridge's lifespan and continued functionality, as well as to the public safety. Continuous and systematic maintenance of a bridge will extend its service life and reduce its overall operating cost.

Concrete bridge maintenance is defined as those activities that are relatively inexpensive and repeatable, performed when a concrete member is still in good to fair condition, and are intended to prevent or minimize deterioration of the concrete. These activities include sealing, washing, caulking, crack repair, and other minor repairs intended to prolong functionality of bridge members. This guide does not cover major rehabilitation, reconstruction, or bridge inspection. Detailed methods of repairing and inspecting bridges are referenced wherever necessary throughout the guide relative to the subject matter.

Keywords: bridges; cementitious; coating; maintenance; placement; polymer; sealant.

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

CONTENTS

CHAPTER 1—INTRODUCTION AND SCOPE, p. 2

1.1—Introduction, p. 2

1.2—Scope, p. 2

CHAPTER 2—DEFINITIONS, p. 2

CHAPTER 3—MAINTENANCE OF BRIDGES, p. 2

3.1—Bridge maintenance, p. 2

3.2—Limitations, p. 3

3.3—Timing of maintenance, p. 3

CHAPTER 4—DETERIORATION OF BRIDGES, p. 3

4.1—Deterioration indicators, p. 3

4.2—Causes, p. 3

4.3—Contributing factors, p. 4

CHAPTER 5—CONSIDERATIONS IN BRIDGE DESIGN, p. 6

5.1—General, p. 6

5.2—Decks and curbs, p. 6

5.3—Deck joints, p. 7

5.4—Superstructure, p. 8

5.5—Substructures, p. 9

CHAPTER 6—DRAINAGE AND WASHING, p. 10

6.1—General, p. 10

ACI 345.1R-16 supersedes ACI 345.1R-06 and was adopted and published September 2016.

Copyright © 2016, American Concrete Institute.

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording, for distribution, reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietor.

- 6.2—Deck drainage, p. 10
- 6.3—Washing exposed surfaces, p. 10
- 6.4—Maintenance of deck drains, p. 10
- 6.5—Other drain considerations, p. 11

CHAPTER 7—SEALING, p. 11

- 7.1—General, p. 11
- 7.2—Purpose, p. 11
- 7.3—Sealing materials, p. 12
- 7.4—Suggested areas for sealing, p. 12
- 7.5—Recommended practice, p. 13
- 7.6—Product selection, p. 13

CHAPTER 8—MAINTENANCE PATCHING, p. 13

- 8.1—General, p. 13
- 8.2—Purpose, p. 14
- 8.3—Selecting durable patching materials, p. 14
- 8.4—Recommended patching procedures, p. 16

CHAPTER 9—JOINTS AND CRACKS, p. 16

- 9.1—General, p. 16
- 9.2—Maintenance of joints, p. 17
- 9.3—Cracks, p. 17
- 9.4—Crack repair, p. 17
- 9.5—Joint caulking, p. 19

CHAPTER 10—NOTABLE TECHNIQUES FOR BRIDGE MAINTENANCE, p. 19

- 10.1—General, p. 19
- 10.2—Corrosion inhibitors for use in maintenance, p. 19
- 10.3—Galvanic cathodic protection using sprayed zinc, p. 19
- 10.4—Discrete or spot anodes, p. 20

CHAPTER 11—SUMMARY, p. 20

CHAPTER 12—REFERENCES, p. 20

Authored documents, p. 21

CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Bridges represent a substantial investment of public funds and are expected to provide satisfactory performance and remain in service for many years. The longevity of constructed concrete bridges can be expected to be 75 to 100 years if proper maintenance action is executed in a timely manner. Structural concrete members that deteriorate over time and eventually lose functionality could become life-threatening to the public. Aggressive environmental conditions for bridges involve cycles of freezing and thawing and wetting and drying with or without the presence of chloride. Corrosion of reinforcing steel will usually result in spalling of concrete cover and reduction of the cross-sectional area of the reinforcing steel, which reduces the strength of the member. The time required for deterioration to occur varies considerably, depending on severity of the exposure conditions and characteristics of structural concrete and rein-

forcing steel. Traffic fatigue loading may become more dominant over time. Continuous and systematic maintenance of a bridge will extend its service life and reduce its overall operating cost. This guide presents various technical aspects related to bridge maintenance, including the sources of deterioration and technical action that can improve the performance of existing bridge members.

1.2—Scope

The contents discussed in this guide are classified into two categories: 1) deterioration of constructed bridges; and 2) maintenance activities to address potential problems associated with such bridges. The first category is dedicated to various distressful attributes influencing the performance of existing bridge members and their consequences, whereas the second category is concerned with timely preventive or corrective maintenance actions with an emphasis on drainage, sealing, patching, joint repair, and other relevant topics. The following is outside the scope of the present report: major rehabilitation, reconstruction, inspection, condition evaluation, and load rating.

CHAPTER 2—DEFINITIONS

ACI provides a comprehensive list of definitions through an online resource, <https://www.concrete.org/store/product-detail.aspx?ItemID=CT16>. Definitions provided herein complement that source.

bridge deck—structural concrete slab or other structure that is supported on the bridge superstructure and serves as the roadway or other traveled surface.

damage—various forms of disruption to a member (cracking, spalling, delamination, scaling, dissolution, and permanent deformation), such as result from environmental (freezing and thawing, erosion), chemical (alkali-silica reaction, sulfate attack), and physical (impact, overload, fatigue) stresses that disrupt its intended condition and function.

grout—mixture of cementitious materials and water, or other binding medium such as magnesium phosphate or epoxy, often mixed with fine aggregate to form a thin, coarse mortar that can be poured into narrow cavities to fill them and consolidate the adjoining objects into a solid mass

overlay—layer of hydraulic-cement concrete, mortar, or asphalt, seldom thinner than 1 in. (25 mm), placed on and usually bonded onto the worn or cracked surface of a concrete slab to either restore or improve the functionality of the previous surface, also a layer of polymeric concrete usually less than 0.4 in. (10 mm) thick.

superstructure—part of a bridge providing the horizontal span.

CHAPTER 3—MAINTENANCE OF BRIDGES

3.1—Bridge maintenance

Initial bridge deterioration occurs slowly and, therefore, is often overlooked. In later stages of deterioration, however, sudden catastrophic events could occur, demanding immediate action. Progressive deterioration can be avoided, sometimes avoided, if proper systematic preventive maintenance

nance is practiced (Carter and Kaufman 1990). Maintenance activities are often more cost-effective when the concrete is in relatively good condition (for example, structural members are sound with minor cracking or spalling). Maintenance should focus on those parts of a structure that face the most severe exposure conditions and on those whose deterioration may have the greatest impact on the functionality of the structure or the condition of adjacent members. Preventive maintenance focuses on the causes (as opposed to treatment) of potential deterioration and its effects. For example, sealing the deck surface reduces the infiltration of chloride. Refer to ACI 546R for technical details for sealing procedures. Proper preventive maintenance activities can reduce the rate of deterioration, extend service life, and reduce future repair costs (Carter 1989a). Responsive maintenance activities such as treatments to existing deck problems help to keep bridges operating safely and efficiently. These are treatments to existing deck problems.

Concrete bridge maintenance involves relatively inexpensive, repetitive activities that either: 1) prevent or minimize the deterioration of bridge members; or 2) extend the service of structural concrete members. Concrete bridge maintenance should be performed when the structural concrete member is still in excellent to fair condition, that is, has a condition appraisal rating of 5 (Federal Highway Administration 1995), including minor section loss, cracking, spalling, or scour, according to the nine-scale evaluation criteria of the National Bridge Inventory (Federal Highway Administration 1995). Maintenance can be subdivided into two categories: preventive and reactive.

3.1.1 Preventive maintenance—Procedures performed before significant deterioration is noticed and the structural concrete member is still in good condition are called preventive maintenance. These procedures, which may be planned at a design stage, include washing, sealing, caulking, and minor crack repair.

3.1.2 Reactive maintenance—Procedures performed in the early stages of the visible deterioration cycle, which are usually more extensive than preventive maintenance, are called responsive maintenance. These may include minor repairs, establishment of positive deck drainage systems, maintenance of deck joints, and similar activities that extend the service life of structural concrete members in bridges. Responsive maintenance can also apply to nonstructural members.

3.2—Limitations

Maintenance is not effective when applied to improperly designed and constructed concrete bridge members. Examples include inadequate or shallow concrete cover depths, and poor drainage characteristics that cause ponding.

3.3—Timing of maintenance

Whereas maintenance activities performed in a timely manner can be extremely cost-effective, the same activities conducted after extensive damage has occurred could become a poor investment. The objective of maintenance is to extend the service life of constructed concrete structures

by controlling the extent of damage nucleation and propagation. Knowledge of concrete deterioration mechanisms is crucial to foresee structural damage before it occurs, at a time when the concrete is still repairable. Damage, such as scaling, reinforcing steel corrosion, or spalling is easy to observe after it has occurred. Foresight involves the ability to identify the signs and symptoms that precede the development of damage. For example, an early signal of deterioration is the presence of leakage stains and cracking in concrete. Leakage stains induced by water leaking from deck slabs usually precede frozen bearings and rust stains, delamination, and spalling of reinforced concrete bridge superstructure and substructure members. Chapter 4 elaborates on the causes of bridge deterioration and contributing factors, which will be useful for making a timely maintenance decision.

CHAPTER 4—DETERIORATION OF BRIDGES

4.1—Deterioration indicators

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

- a) Water ponding because of improper deck drainage (Fig. 4.1a)
- b) Cracks, regardless of cause or type (Fig. 4.1b through 4.1d)
- c) Spalling due to inadequate reinforcing steel cover (Fig. 4.1e)
- d) Porous, debonded, or cracked asphalt wearing surfaces (Fig. 4.1f)
- e) Accumulation of deicing chemicals (Fig. 4.1g)
- f) Staining of concrete surfaces, regardless of cause or type (Fig. 4.1h)
- g) Erosion of headslope and sideslopes (Fig. 4.1i)

4.2—Causes

In general, the causes contributing to concrete bridge deterioration are moisture, reactive aggregates, chlorides, carbonation, acids, and other aggressive chemicals; cyclic changes in moisture and temperature; freezing; wear; and abrasion (ACI 201.1R; ACI 222R). The major cause of bridge concrete deterioration is exposure to moisture and chlorides, which is why exposed decks and curbs deteriorate sooner than sheltered superstructure members. Leaking joints, however, do not shelter superstructure members and can lead to earlier deterioration of these members. Early-age concrete cracking due to drying shrinkage, plastic shrinkage, and plastic settlement can be main reasons for initial deterioration because moisture and chloride ions penetrate the concrete through those channels (initial cracking).

Deterioration of concrete decks can also result from concrete fatigue. Tests (Suresh 2005) indicate that strength of concrete under cyclic loading may be reduced. Concrete bridge decks are often exposed to high by vehicle loads, which may result in cracking and accelerate the infiltration of chlo-



Fig. 4.1a—Water ponding from improper deck drainage.



Fig. 4.1b—Map cracking on underside of deck.

ride, resulting in progressive corrosion of reinforcement and disintegration of the deck slab.

4.3—Contributing factors

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

4.3.1 Design—Skeet and Kriviak (1994) found that design may be the primary determinant to the service life of bridge decks. 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. Some examples of problems that have occurred

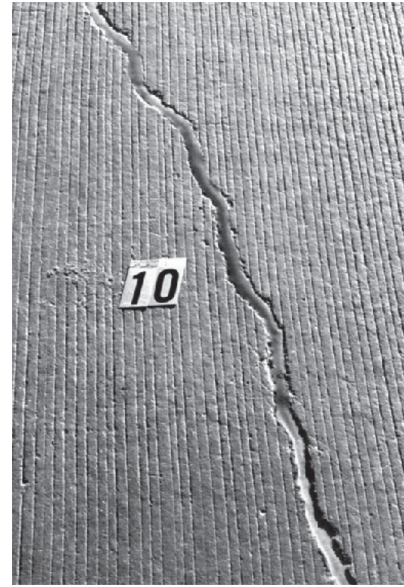


Fig. 4.1c—Transverse crack in deck.



Fig. 4.1d—Map cracking in parapet.



Fig. 4.1e—Shallow cover depth spalling.

by addressing initial construction costs without considering the impact on long-term maintenance include constructing bridges that are too flat, do not have deck drains, have inadequate cover over the reinforcing steel, or have deteriorated concrete. The structural system widely used in the 1950s and 1960s was simple-span bridges at grade separations in heavily deiced urban locations. These simple-span bridges require maintenance of deck joints. Without such maintenance, the superstructure and substructure members prematurely dete-



Fig. 4.1f—Deteriorated asphalt wearing surface.



Fig. 4.1g—Application of deicing chemicals to roadways.

riorate. Jointless integral bridges are erected in current practice to address potential problems induced by deck joints (Kim and Laman 2012; Lewis et al. 2014). Compared with earlier designs, current practice typically requires increased concrete cover, a reduced water-cementitious materials ratio (w/cm) and permeability, use of air-entrained concrete and nonreactive aggregates, and corrosion protection systems to enhance service life and durability.

4.3.2 Construction—Conditions that contribute to deterioration and reduced durability and service life include:

- a) Insufficient consolidation
- b) Inadequate air entrainment
- c) Inadequate cover over reinforcement
- d) Adding water to the concrete on site
- e) Improper surface finishing or overfinishing



Fig. 4.1h—Rust staining of curb.



Fig. 4.1i—Erosion and settlement of slopewall.

f) Inadequate or late curing

g) Concrete segregation due to poor casting or improper vibration

4.3.3 Materials—Material factors that contribute to deterioration include incompatibility between air-entraining and other admixtures, high- w/cm concrete, temperature differentials between deck concrete and supporting girders, and nondurable aggregates vulnerable to aggregate-alkali reactions and cycles of freezing and thawing. The amount of cement paste influences volumetric changes in a concrete and the degree of shrinkage as well as compressive strength and stiffness of the concrete. In the deck, high-slump concrete can be extremely detrimental, leading to more settlement over the top reinforcing bars that induces a plane of weakness and is the first section to crack (Darwin et al. 2012).

4.3.4 Environmental exposure conditions—Environment and climatic conditions contribute to rates of deterioration. For example, the deterioration of coastal bridges is different from that of high-elevation mountain bridges. Mountain bridges are subjected to snow, moisture, deicing chemicals (Fig. 4.1g), and cycles of freezing and thawing (Fig. 4.3.4), whereas coastal bridges may be exposed to chlorides from saltwater. The licensed design professional should consider the environmental and climate conditions in the design construction, and maintenance of bridges.



Fig. 4.3.4—Efflorescence from freezing-and-thawing deterioration.

Concrete maintenance materials are generally sensitive to ambient temperature and moisture conditions during application. Many products such as cementitious patches require moderate weather conditions and are unsuitable for application in extreme conditions (Carter 1989a; Department of Transport 1990; Federal Highway Administration 1995; Bean 1988).

CHAPTER 5—CONSIDERATIONS IN BRIDGE DESIGN

5.1—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 this chapter.

5.2—Decks and curbs

5.2.1 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.

5.2.2 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 not used. Curbs collect debris (Fig. 5.2.2a), snow, and salt from the riding surface, staying wet long after the riding surface has dried. They also stay wet when deck drainage systems become clogged (Fig. 4.1a and Fig. 5.2.2b). Vehicle impact is another attribute degrading the performance of constructed curbs. Because decks and curbs generally have high deterioration rates and repair and rehabilitation costs, maintenance activities that slow deterioration and delay expenditures are 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 when an asphalt-wearing surface is required by policy. Asphalt concrete overlays are used on bridge decks



Fig. 5.2.2a—Debris accumulation on curb.



Fig. 5.2.2b—Plugged deck drain.

because they provide smooth ride quality and protect wearing surfaces. Asphalt concrete overlays are more permeable than the underlying concrete. As asphalt deteriorates by oxidation and shrinkage cracking, permeability will increase, which traps 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 as stated by the Transportation Research Board (2012). Asphalt membranes should only be used at the end of the bridge life (40 to 50 years), and then the bridge is usually rehabilitated.

Untreated bridge deck cracks result in decreased service life and increased repair and rehabilitation cost; therefore, potential structural cracking needs to be addressed in the design phase. The use of larger-size aggregate can enhance the workability (in terms of optimized gradation) and durability of a concrete mixture. To accommodate such mixtures, sometimes the cover over the bottom mat of reinforcing steel should be increased slightly. Krauss and Rogalla (1996) correlated severity of cracking with large negative moments over the intermediate supports of continuous bridge design. AASHTO (2014) specifies the requirements for embedment length beyond the point of inflection for negative moment reinforcement at supports and for deck reinforcement in negative flexure regions of continuous spans. There is also a

direct correlation between severity of cracking and increase in beam spacing in the transverse direction (Buckler et al. 2000) and an increase in span length (Alampalli 2001). Krauss and Rogalla (1996) recommended using stiffer girders and a simply supported design to control bridge deck cracking, which conflict with present design trends.

5.2.3 Recommendations—Bridge designers should consider the exposure conditions likely to exist during the intended service life. Proper drainage systems should be included as a critical phase during design. Specific information on drainage systems is available in Chapter 6. Bridges exposed to chlorides should be designed with a corrosion protection system or systems that address the environmental exposure conditions and bridge serviceability requirements. Examples include low-permeability concrete, clear concrete reinforcement cover depths over reinforcement of at least 2.5 in. (63 mm), and corrosion-resistant reinforcement. The Transportation Research Board (2004) summarizes design and construction practices that have been used to improve the performance of concrete bridge decks. Bridge deck drainage should be considered during design. Drainage systems allow water to drain from driving surfaces and channel water away from bridge members 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 be allowed to flow over expansion joints because most joints leak, resulting in increased repair costs of superstructure and substructure members.

5.3—Deck joints

5.3.1 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.

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

5.3.3 Leakage—Failure to stop leakage may result in accelerated corrosion due to the constant exposure to moisture. This corrosion may lead to:

- a) Cracking and spalling around the corroding reinforcement, causing a reduction in the strength of the superstructure and substructure concrete members (Fig. 5.3.3)
- b) Section loss of steel girders induced by corrosion damage
- c) Corrosion seizing of the expansion bearings, which often creates cracks near anchor bolts and leads to further chloride absorption, deterioration, and loss of load-carrying capacity

5.3.4 Loss of freedom to move—Deck joints should always have the ability to move freely to avoid the transmission of

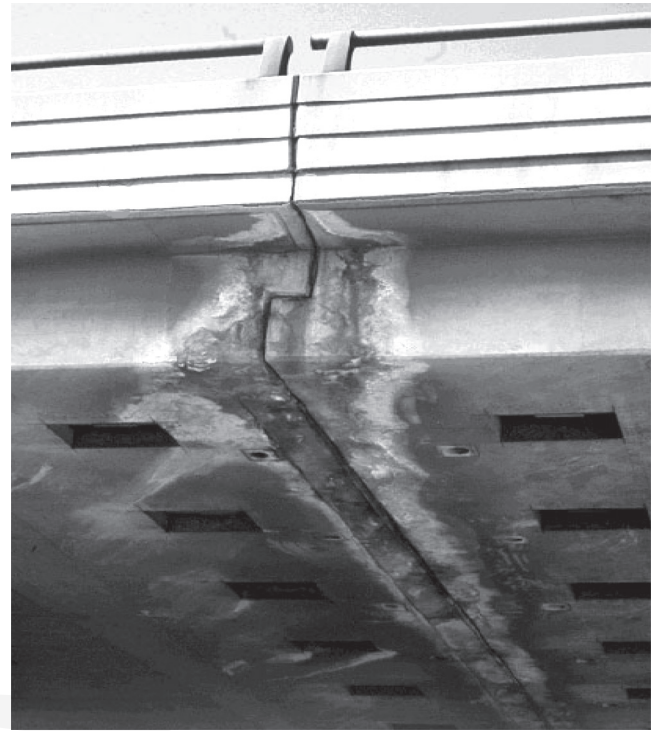


Fig. 5.3.3—Efflorescence from deck joint leakage.

undesirable stresses to the bridge superstructure members. Causes of movement restriction include the following.

5.3.4.1 Incompressible debris—Where deck joints become filled with incompressible debris, such as sand, gravel, and stone (Fig. 5.3.4.1), 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 could cause transverse movement of the deck, producing curb offsets and obstructing traffic. Debris-filled joints could be punctured and leak, and could also collect moisture and corrosive chemicals, thereby accelerating the deterioration of the adjacent deck area (NCHRP 1979).

5.3.4.2 Substructure settlement—Abutment settlement is typically accompanied by movement toward the bridge center, 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 might 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.

5.3.4.3 Misalignment—Impact forces on joints and their structurally-supporting members could be the result of a vertical misalignment between deck joints and adjoining riding surfaces (Fig. 5.3.4.3). The misalignment may be caused by rotation of the abutment due to settlement of fill material, by repaving the roadway approach, or by only is the bump a potential risk for the traveler, but the