Guide to Maintenance of Concrete Bridge Members

Reported by ACI Committee 374

ACI 345.1R-16

American Concrete Institute
Always advancing

First Printing
September 2016
ISBN: 978-1-945487-21-7

Guide to Maintenance of Concrete Bridge Members

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.

CONTENTS

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

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 reinforcing 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/productdetail.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 slowed, and sometimes avoided, if proper systematic preventive maintenance 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 cyclic loading, which may result in cracking and facilitate 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

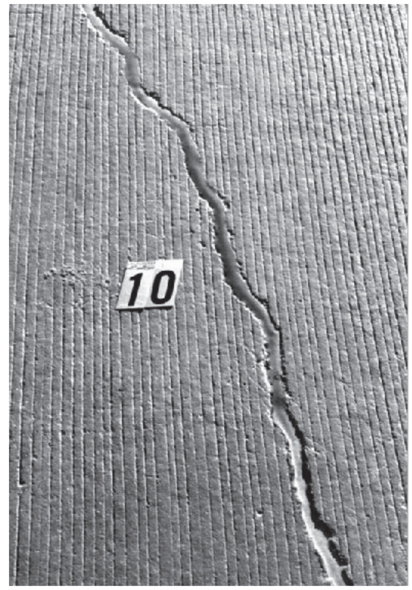

Fig. 4.1c—Transverse crack in deck.

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-