

ACI 423.4R-14

Report on Corrosion and Repair of Unbonded Single-Strand Tendons

Reported by Joint ACI-ASCE Committee 423



American Concrete Institute
Always advancing



Report on Corrosion and Repair of Unbonded Single-Strand Tendons

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

Report on Corrosion and Repair of Unbonded Single-Strand Tendons

Reported by Joint ACI-ASCE Committee 423

H. R. Trey Hamilton III, Chair

Carin L. Roberts-Wollman, Secretary

Theresa M. Ahlborn
Robert W. Barnes
Florian G. Barth
Roger J. Becker
Kenneth B. Bondy*
Charles W. Dolan
James P. Donnelly*
Martin J. Fradua*
William L. Gamble
Harry A. Gleich
Shawn P. Gross
Pawan R. Gupta
William M. Hale

Mohammad Iqbal
L. S. Paul Johal
Donald P. Kline
Larry B. Krauser
Jason J. Krohn
Mark E. Moore†
Theodore L. Neff
Sami H. Rizkalla
James Rogers
Bruce W. Russell
David H. Sanders
Thomas C. Schaeffer
Andrea J. Schokker

Morris Schupack*
Richard W. Stone
Amy M. R. Trygestad
Miroslav F. Vejvoda
Jeffery S. Volz
H. Carl Walker
Zuming Xia
Paul Zia

Steven R. Close
Henry J. Cronin Jr.
Ward N. Marianos Jr.
Hani Melhem
Antoine E. Naaman
Thomas E. Nehil

*Chair of subcommittee responsible for preparation of report.

†Member of subcommittee responsible for preparation of report.

Consulting Members

Robert N. Bruce Jr.
Ned H. Burns
Chunsheng "Steve" Cai

This report gives general information regarding evaluating corrosion damage in structures reinforced with unbonded single-strand post-tensioning tendons. Historical development of those parts of the building code dealing with durability and corrosion protection is explained. Evolution of the types and components of unbonded tendons is described. Specific aspects of corrosion in unbonded single-strand tendons are described, and common problems in structures reinforced with these tendons are discussed. Methods are presented for repairing, replacing, and supplementing tendons.

Keywords: allowable stresses; anchorage; carbonation; concrete construction; corrosion; corrosion protection; cover; durability; embrittlement; external post-tensioning; post-tensioned concrete; prestressed concrete; sheathing; single-strand tendons; unbonded post-tensioning.

CONTENTS

CHAPTER 1—INTRODUCTION, p. 2

- 1.1—General, p. 2
- 1.2—Background, p. 2
- 1.3—Scope, p. 3
- 1.4—Limitations, p. 3

CHAPTER 2—DEFINITIONS, p. 3

- 2.1—Definitions, p. 3

CHAPTER 3—REVIEW OF CODE REQUIREMENTS AND CHANGES, p. 3

- 3.1—General, p. 3
- 3.2—Cover requirements for unbonded tendons, p. 3
- 3.3—Allowable tensile stresses in concrete, p. 4
- 3.4—Protection of unbonded tendons, p. 4

CHAPTER 4—UNBONDED TENDONS, p. 6

- 4.1—Historical development of unbonded tendons, p. 6
- 4.2—Sheathing problems, p. 7
- 4.3—Detailing practices, p. 7
- 4.4—Storage, handling, and construction problems, p. 9

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.

ACI 423.4R-14 supersedes ACI 423.4R-98 and was adopted and published November 2014.

Copyright © 2014, 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 sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietors.

- 4.5—Deterioration mechanisms, p. 10
- 4.6—Performance record, p. 11

CHAPTER 5—CONDITION ASSESSMENT AND TESTING, p. 12

- 5.1—General, p. 12
- 5.2—Condition surveys of concrete, p. 12
- 5.3—Condition surveys of tendons, p. 13
- 5.4—Nondestructive testing, p. 13
- 5.5—Exploratory openings, p. 14
- 5.6—Strand removal, p. 15
- 5.7—Other testing and investigative procedures, p. 16

CHAPTER 6—REPAIR METHODS, p. 16

- 6.1—General, p. 16
- 6.2—Tendons with observable corrosion, p. 16
- 6.3—Spliced repair of strand, p. 17
- 6.4—Strand replacement, p. 18
- 6.5—Tendon replacement, p. 18
- 6.6—External post-tensioning, p. 18
- 6.7—Continuous acoustic monitoring, p. 19
- 6.8—External nonprestressed reinforcement or support, p. 19
- 6.9—Total demolition and replacement, p. 20

CHAPTER 7—SUMMARY, p. 21

CHAPTER 8—REFERENCES, p. 21

- Authored documents, p. 22

CHAPTER 1—INTRODUCTION

1.1—General

This report provides general information on the evaluation of known or suspected corrosion problems in unbonded single-strand tendons, historical information on the types and components of unbonded tendons and on the durability and corrosion protection provisions in the building code, and describes typical repair methods in use today. Expertise in design, construction, evaluation, and repair of structures using single-strand unbonded tendons is strongly recommended for a team undertaking evaluation and repair of corrosion problems.

Historically, there have been corrosion problems with other types of pre- and post-tensioning systems (Nehil 1991); however, certain aspects of corrosion of unbonded single-strand tendons are unique. The causes and effects of corrosion of unbonded single-strand tendons are, in several respects, different from those of bonded conventional reinforcing or other post-tensioning (PT) systems, so the methods for evaluating and repairing corrosion of single-strand tendons are also different. For example, because the tendons are largely isolated from the surrounding concrete, they may not be affected by deleterious materials such as chlorides and moisture in the concrete. The surrounding concrete does not stop corrosion alone because, if water gains access to the inside of the sheathing, PT coating is rendered ineffective. Measures taken to repair and protect

the surrounding concrete may not repair or reduce deterioration of the prestressing steel where corrosion has been initiated. The tendons usually require separate evaluation and repair.

1.2—Background

Unbonded PT systems were introduced to North America in the 1950s. At that time, there were no accepted standards for design or material specifications for prestressing steels. Guidance came in the form of tentative recommendations from Joint ACI-ASCE Committee 323 (1958), Bureau of Public Roads (1954), or Structural Engineers Association of Northern California (SEA/NC) (1959). Unbonded tendons in the early systems used bundles of wires or strands, sometimes inaccurately called cables, of various diameters, and were assumed to be protected by PT coating and paper sheathing that were sometimes applied by hand (Nehil 1991; Schupack 1991a).

The use of unbonded tendons became more common during the late 1950s and early 1960s, as progress was made in establishing design and materials standards. Acceptance of the concept was regional at first and was largely the result of sales efforts and design tutoring by tendon suppliers. The use of post-tensioning increased rapidly during the late 1960s and 1970s as advantages of the system were demonstrated. For many types of structures, these advantages included shorter construction time, reduced structural depth, increased stiffness, and savings in overall cost. In addition to their use in enclosed buildings, unbonded PT systems were used in parking structures and slabs-on-ground, and bonded post-tensioning was used on water tanks, bridges, dams, and soil tie-back systems. Unbonded multi-wire and multi-strand tendons have been used extensively in nuclear power structures.

Incidents of corrosion of unbonded single-strand tendons began to surface during the 1970s. It was believed that corrosion protection would be provided by the PT coating during shipping, handling, and installation, and by the concrete thereafter. The early PT coatings, however, often did not provide the corrosion-inhibiting characteristics that are presently required in ACI 423.7 or PTI M10.2. In the early 1980s, the Post-Tensioning Institute (PTI) recognized the structural implications of corrosion and began implementing measures to increase the durability of unbonded PT systems (Post-Tensioning Institute 1985). Relying on the experience and practice of the nuclear industry's use of corrosion-inhibiting hydrophobic grease, similar performance standards for grease were adopted. In 2000, PTI published the second edition of its "Specification for Unbonded Single Strand Tendons (PTI M10.2-00)." In ACI 318-89, measures were incorporated that related the required protection of the tendons and the quality of the concrete to the environmental conditions that could promote corrosion of the post-tensioning.

In 2007, ACI published ACI 423.7, which provides detailed specifications for PT coating. With the adoption of this specification, the term "grease" was replaced with the more generic term "PT coating" to address other mate-

rials used as protection systems inside the sheathing. These improved coatings were introduced by **PTI M10.2** long before the publication of **ACI 423.7**. Structures built before the adoption of these standards, especially those in aggressive environments, are more likely to experience corrosion of the PT system than those designed and built since then.

Tendons that are broken or damaged by corrosion can be repaired or supplemented by several methods. The more difficult task is determining the extent of corrosion damage and degree to which tendon repairs are needed. This report provides guidance on the evaluation of suspected or known corrosion problems and describes repair methods currently in use.

1.3—Scope

This report reviews the following:

- a) Codes and code changes affecting unbonded PT tendons
- b) Past and present corrosion protection systems and how they have changed to enhance corrosion protection
- c) Types of corrosion damage found in prestressing steel
- d) Methods for evaluating structures that are suspected of, or known to have, corrosion damage in the PT system
- e) Basic repair options

1.4—Limitations

This report presents a summary of typical problems experienced with unbonded PT systems and includes general guidelines for evaluating and repairing single-strand tendons. While the methods presented are general in nature, they are not universally applicable. Standard specifications and details are not included because each structure is unique and should be analyzed accordingly.

This report is not intended to be included as a part of specifications for investigations and repairs. Presently, there is no practical method to determine the total extent of damage to a PT system. The unpredictable nature of tendon failures exhibited by inadequately protected, corroding strand makes estimating tendon life uncertain.

A wide variation exists in the durability and rate of deterioration of older PT systems. This is due, in part, to the composition of the parts of the tendon: strand, anchors, PT coating, and sheathing, and in part to the quality of the surrounding concrete, environmental exposure, and type of maintenance performed on the structure. The investigator should rely on available information on the historical performance of similar structures and should be experienced in interpreting external evidence that may give an indication of latent internal problems.

CHAPTER 2—DEFINITIONS

2.1—Definitions

ACI provides a comprehensive list of definitions through an online resource, “ACI Concrete Terminology,” <http://www.concrete.org/Tools/ConcreteTerminology.aspx>. Definitions provided herein complement that resource.

post-tensioning (PT) coating—material used to protect the prestressing steel against corrosion and reduce friction

between prestressing steel and sheathing; this term has been adopted to refer to grease or other materials, or a combination of both, that may be used inside the sheathing to protect the strand.

CHAPTER 3—REVIEW OF CODE REQUIREMENTS AND CHANGES

3.1—General

When evaluating corrosion damage in post-tensioned structures with unbonded tendons, the investigator should consider the age of the structure and the standards of practices available to the licensed design professional and contractor at the time of construction.

Although ACI published building regulations for reinforced concrete as early as 1920, **ACI 318-47** was the first to acknowledge the significance of environmental exposure. **ACI 318-47**, **ACI 318-51**, and **ACI 318-56** also recognized the importance of clear cover and concrete quality in providing adequate corrosion protection to the nonprestressed bonded reinforcement.

Joint ACI-ASCE Committee 323 (1958) addressed the protection of prestressing steel in three areas of recommended practice: concrete cover; allowable tensile stresses; and, for unbonded systems, protection of the strand or wire with PT coating and a sheathing material. Since 1958, provisions for prestressed concrete have included requirements for corrosion protection. The PT coating and sheathing were viewed, by most, primarily as a lubricant and bond breaker, and secondarily as a corrosion deterrent during shipping, handling, and placing. Long-term corrosion protection was viewed by some as being provided by the uncracked concrete cover.

Prestressed concrete was first included in **ACI 318-63** with provisions for concrete cover, allowable tensile stresses, and strand protection. These items were modified occasionally, but the substantive change came in **ACI 318-89** when durability was emphasized.

3.2—Cover requirements for unbonded tendons

ACI 318-63 required the following:

- a) The following minimum thickness of concrete cover shall be provided for prestressing steel, ducts, and nonprestressed steel:

Cover, in. (mm)

Concrete surface in contact with ground.....2 (50)

Beams and girders:

Prestressing steel and main reinforcing bars 1.5 (40)

Stirrups and ties 1 (25)

Slabs and joists exposed to weather 1 (25)

Slabs and joists not exposed to weather 75 (20)

- b) In extremely corrosive atmosphere or other severe exposures, the amount of protection shall be suitably increased.

Eight years later, in **ACI 318-71**, the cover requirements for prestressed members cast against and permanently exposed to earth increased from 2 in. (50 mm) to 3 in. (75 mm). In