American Concrete Institute
Always advancing

ACI 364.10T-14
TechNote

Rehabilitation of Structure with Reinforcement Section Loss

Keywords: concrete cover; corrosion; load-carrying capacity; rehabilitation; reinforcement; repair.

Introduction

Integrity of reinforcement is fundamental to the strength, ductility, and safety of reinforced concrete structures. Determining the necessity of additional or replacement reinforcement is a primary concern in rehabilitation projects containing corrosion of reinforcing steel.

Question

How should an engineer address exposed and corroded reinforcement when repairing a conventionally reinforced concrete structure (Fig. 1), and should there be a concern if the loss of reinforcement is less than 10 percent of the cross-sectional area?

Fig. 1—Example of severe reinforcing steel deterioration due to corrosion in a reinforced concrete beam (courtesy of the Ministry of Transportation of Quebec).

Answer

After determining the condition of the reinforcement, remove unsound concrete, clean reinforcement, and provide additional reinforcement as needed. The structural consequences of a 10 percent cross-sectional area loss due to corrosion are usually minor for nonprestressed concrete components because there are usually redundancies in design.

Discussion

Begin by identifying the source, extent and level of activity of reinforcement corrosion (ICRI No. 310.1R; ACI 364.6T), and determining the overall condition and cross-sectional area of the affected reinforcing steel. Remove all unsound concrete; undercut the exposed corroded bars to provide clearance for under-bar cleaning and full bar embedment in the repair material; and secure the repair structurally, so as to ensure the required load-carrying capacity is achieved (Fig. 2). The clear space behind the reinforcing steel should be greater than 1/4 in. (6 mm), plus the dimension of the maximum-sized aggregate in the repair material (ACI 364.6T). Generally, a 3/4 to 1 in. (20 to 25 mm) gap is required to inspect and clean the bar. Place the repair material and encapsulate the bar with it.

Clean the reinforcement by means of wire brushing, sandblasting, shot-blasting, or water-blasting. Do not use solvents as they can penetrate the concrete, which may create a poor bond surface for repair materials. If the reinforcing bars are epoxy-coated, the epoxy in the area surrounding the exposed corrosion should be removed and the bar cleaned.

Measure the cross section. Use calipers to measure the reduced diameter of the reinforcing steel. If the loss of cross-sectional area is greater than 10 percent, additional (supplemental) reinforcement may be required (Fig. 3). If corrosion pits with depths greater than 25 percent of the bar diameter are observed, additional reinforcement could also be required.

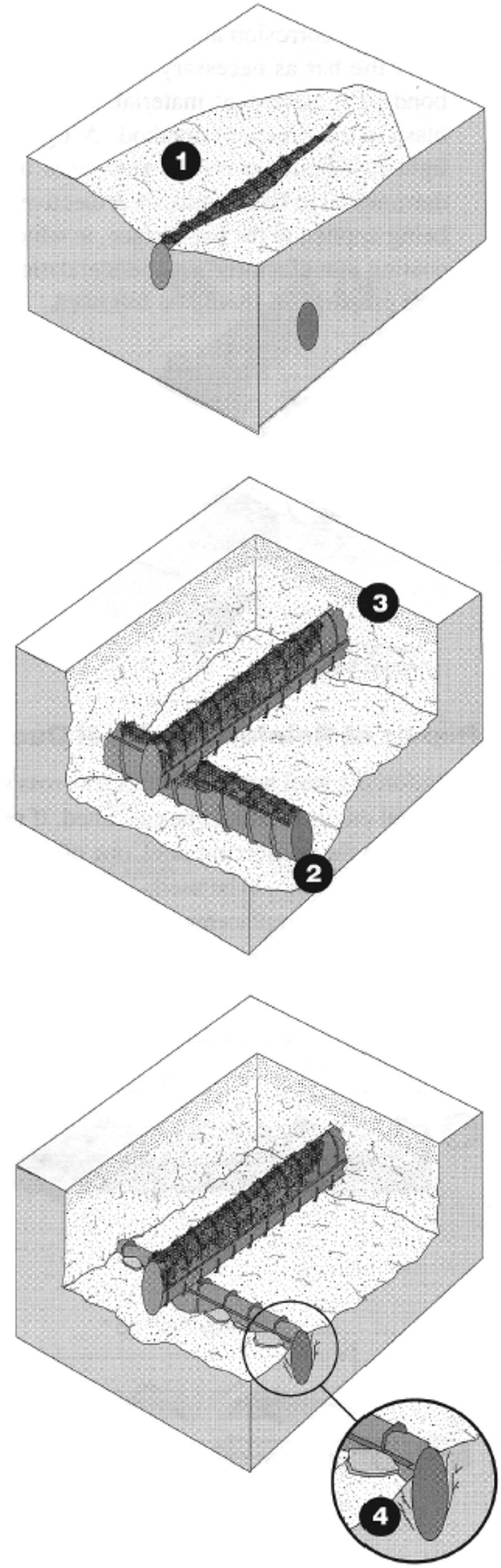
The structural consequences of a 10 percent cross-section area loss due to corrosion are usually minor for nonprestressed concrete components because of redundancies in design, as discussed in items (a) through (c) as follows. In practice, there is usually no concern with less than 10 percent loss of cross-sectional area.

(a) *Reinforcement reserve*—Steel reinforcement used in construction is typically larger than required by structural considerations. Extra steel is attributed to varying practical design requirements such as bar layout and spacing. Five to 10 percent more steel area is typically provided than is required by analysis.

(b) *Corrosion location*—Corrosion damage is often uneven throughout the member length and frequently may be at

These details are applicable to horizontal, vertical, and overhead locations. They are also applicable to removal by hydro-demolition, hydro-milling, and electric, pneumatic or hydraulic impact breakers.

1. Remove loose or delaminated concrete above corroded reinforcing steel.
2. Once initial removals are made, proceed with the undercutting of all exposed corroded bars. Undercutting will provide clearance for under bar cleaning and full bar circumference bonding to surrounding concrete, and will secure the repair structurally. Provide minimum $^3/_4$ inch (19 mm) clearance between exposed rebars and surrounding concrete or $^1/_4$ inch (6 mm) larger than largest aggregate in repair material, whichever is greater.
3. Concrete removals shall extend along the bars to locations along the bar free of bond inhibiting corrosion, and where the bar is well bonded to surrounding concrete.
4. If non-corroded reinforcing steel is exposed during the undercutting process, care shall be taken not to damage the bar's bond to surrounding concrete. If bond between bar and concrete is broken, undercutting of the bar shall be required.
5. Any reinforcement which is loose shall be secured in place by tying to other secured bars or by other approved methods.



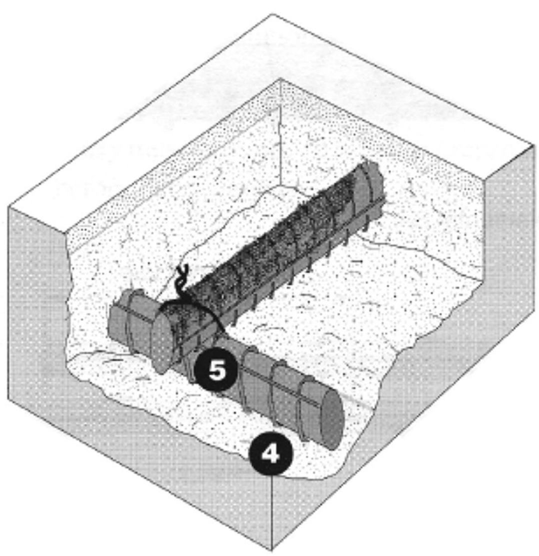


Fig. 2—ICRI recommendations for cleaning and undercutting of reinforcing steel prior to repair (ICRI No. 310.1R).

a location most distant from the critical design locations for maximum moments or maximum shear. In this case, evaluate the remaining area of reinforcement by calculating moment and shear at the affected sections.

(c) *ACI code provisions*—Provisions of Chapter 20 of ACI 318-11 may be used to modify the strength-reduction factor when the actual dimensions and material properties have been determined through measurements and testing. Moment redistribution provisions (ACI 318-11, Section 8.4) may be used to consider inelastic effects that may reduce the required capacity at the section under consideration.

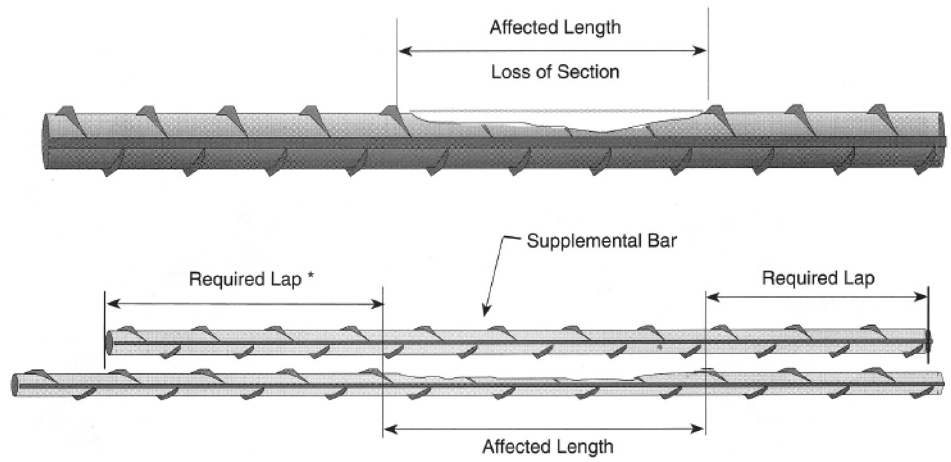


Fig. 3—Repair of reinforcing steel due to loss of section where the loss of section is greater than 10 percent (ICRI No. 310.1R).

Where a loss of 10 percent or more has been identified, check the original design to determine if the remaining reinforcement is adequate. Also, confirm the absence of design errors and that structure use remains the same.

If additional or replacement reinforcement is required, a new reinforcing bar may be lap spliced to the existing bar(s). Lap length is determined in accordance with ACI 318. Additional concrete removal may be necessary to properly splice the new steel reinforcing bar. Mechanical or welded splices that follow code provisions could also be used. Welding should conform to ANSI/AWS D1.4. Verify the structure's ability to carry construction loads during bar replacement or reinforcement. If mechanical splices are used, it may be necessary to shore the section before cutting the reinforcement to install a mechanical splice.

After placing the new reinforcement, place the repair material where concrete was removed. The repair material should be compatible dimensionally; permeability-wise; chemically; electrochemically; and, if required, aesthetically with the existing concrete.

If additional reinforcement is required, fiber-reinforced polymer (FRP) bars and strips may be considered as an alternative to placement of new steel reinforcing bars. ACI 440R discusses the use of FRP reinforcement. If FRP is used, fire code issues, softening of epoxy adhesive at 120 to 140°F (49 to 60°C), ductility, and other parameters should be carefully evaluated.

Although concrete normally provides reinforcement with excellent corrosion protection, corrosion is possible. For example, when the concrete fails to resist the ingress of corrosion-causing substances, if the structure was improperly designed for the service environment, where the environment was not as anticipated, or changes occurred during the service life of the structure. Mixture characteristics of the concrete, proper placement and curing, thickness of concrete cover over the reinforcing steel, crack-control measures, and implementation of measures designed specifically for corrosion protection are factors that help control the onset and rate of corrosion. Refer to ACI 222R for further discussion on the causes and prevention of reinforcement corrosion in concrete.

Summary

The loss of reinforcement section at less than 10 percent is generally accepted, provided the engineer is satisfied that the original design is adequate and no changes of use or demand issues have occurred (for example, changes in applied loads or environmental exposure). Understand the corrosion cause (for example, chloride exposure), to determine if the corrosion activity has slowed or stopped and to establish a timeframe for the corrosion deterioration process (ICRI No. 310.1R; ACI 364.6T). Generally, however, this answer cannot be applied to prestressing reinforcement.

References

Committee documents are listed first by document number and year of publication followed by authored documents listed alphabetically.

American Concrete Institute

ACI 222R-01—Protection of Metals in Concrete against Corrosion (Reapproved 2010)

ACI 318-11—Building Code Requirements for Structural Concrete and Commentary

ACI 364.6T-02—Tech-Note: Concrete Removal in Repairs Involving Corroded Reinforcing Steel (Reapproved 2011)

ACI 440R-07—Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures

American Welding Society
ANSI/AWS D1.4-11—Structural Welding Code–Reinforced Steel

International Concrete Repair Institute
No. 310.1R-2008—Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion (formerly No. 03730)

Reported by Committee 364

Fred R. Goodwin, Chair

James H. Loper, Secretary

Randal M. Beard
Benoit Bissonnette
Christopher D. Brown
Douglas Burke
Ryan Alexander Carris
Bruce A. Collins
Brian Lee Cope
Boris Dragunsky
Peter Emmons
Paul E. Gaudette
Timothy R. W. Gillespie
Zareh B. Gregorian
Pawan R. Gupta
John L. Hausfeld
Ron Heffron
Robert L. Henry
Kal R. Hindo
Charles J. Hookham
Lawrence F. Kahn
Ashok M. Kakade
Dov Kaminetzky
James M. Kasper
Keith E. Kesner
Erick N. Larson
Marjorie M. Lynch
Pritpal S. Mangat
Surendra K. Manjrekar
James E. McDonald
William R. Nash
Jay H. Paul
K. Nam Shiu
Thomas E. Spencer
John A. Tanner
Valery Tokar
David A. VanOcker
Alexander M. Vaysburd
Kurt F. von Fay
James Warner
Patrick M. Watson
David W. Whitmore

Consulting Members
Robert V. Gevecker
Stephen A. Johanson
Emroy L. Kemp
Howard H. Newlon, Jr.
Weilan Song
Dela Tharmabala
Robert Tracy
William F. Wescott

ACI 364.10T-14 was adopted and published July 2014.

For additional copies, please contact:
American Concrete Institute, 38800 Country Club Drive, Farmington Hills, MI 48331
Phone: 248-848-3700, Fax: 348-848-3701,
www.concrete.org