An ACI / ICRI Manual

Guide to the Code for Assessment, Repair, and Rehabilitation of Existing Concrete Structures

A Companion to *ACI 562-19*

American Concrete Institute
Always advancing

ICRI CONCRETE REPAIR
Restore | Repurpose | Renew

Strategic Development Council
aciFoundation

MNL-3(20)

Guide to the Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures

ACI MNL-3(20)

Third Edition

Updated by Khaled Nahlawi, ACI Distinguished Engineer, under the review and approval of an ACI/ICRI review group consisting of Chair Keith E. Kesner and members Tarek Alkhrdaji, Eric L. Edelson, and Fred R. Goodwin

Guide to the Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures
ACI MNL-3(20)

Third Edition
First Printing: November 2020
ISBN: 978-1-64195-121-0

Managing Editor: Khaled Nahlawi, PhD, PE
Art Program: Claire Hiltz
Photo Editor: Ken Lozen, FICRI, FACI
Director, Events and Publishing Services: Lauren E. Mentz
Production Editors: Kaitlyn J. Dobberteen, Tiesha Elam, Hannah Genig, Kelli R. Slayden
Page Design & Composition: Ryan Jay
Front cover photos: copyright 2010 Mark Johnson Photography
Manufacturing: Marie Fuller
Printed in Eau Claire, WI

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

International Concrete Repair Institute
1000 Westgate Drive, Suite #252
St Paul, MN 55114
USA
www.icri.org

On the Cover

University of Houston East Garage Fire Emergency Response

2019 ICRI Award of Excellence – Parking Structures Category

The following summary is taken from the November/December 2019 issue of the ICRI *Concrete Repair Bulletin*.

The University of Houston's 2006 Campus Framework Plan included the addition of parking spaces to accommodate the growing population of students. The East Garage was designed to meet the needs of students, faculty, visitors, and residents of the nearby campus lofts (Fig. 1). Utilizing a "double zero" ramp configuration, the garage was designed to have "nested" visitor parking with the capability to use the upper levels for overflow parking.

In April 2018, a multiple-vehicle fire occurred on the third level of the four-level University of Houston East Garage (Fig. 2). Significant structural damage occurred to two columns, the framing of the level above, and the exterior signage (Fig. 3). Before a survey of the damage could be completed, shoring was installed as a precaution to prevent the possible collapse of damaged members (Fig. 4).

Inspection and Evaluation

Together with the Houston Fire Department, the Engineer performed an initial visual review. The extent of the fire damage was confined within the two bays adjacent to the garage expansion joint on the east side. Shoring and cleaning requirements for the damaged members were provided on-site on April 26, 2018, the same day that the fire occurred.

Available background information and plans were reviewed, and a follow-up visual assessment of the damage was conducted on May 2, 2018. Prior to the second visual evaluation, the structural members within the fire-damaged area were cleaned using dry ice blasting that allowed a closer look at the extent of the damage.

Fig. 1—University of Houston East Garage

Fig. 2—Fire damage on Level 3 of parking garage

Fig. 3—Fire damage at exterior of garage

Fig. 4—Shoring installed in affected areas

Fig. 5—Nondestructive testing performed at damaged column

Fig. 6—Concrete cracking and spalling due to fire

Fig. 7—Spandrel beam replacement

In addition to visual observations, a limited floor delamination survey was performed utilizing a chain dragging device to detect unsound concrete. An acoustical monitoring wheel and hammer sounding was used to detect delaminated concrete on the vertical and overhead elements.

Concrete testing was performed (compressive strength and petrographic examination) and nondestructive evaluation (NDE) methods were used to determine the severity of damage and repair approach. NDE methods included ground-penetrating radar (GPR) survey, ultrasonic pulse velocity (UPV) testing, and pulse-echo scanning (Fig. 5).

The visual reviews and delamination survey indicated that fire-related distress had occurred in the form of concrete cracking and spalling, including delaminations identified in several crucial structural beams and columns (Fig. 6). The concrete distress was more severe at members near the expansion joint. Core compressive strength testing did not show degradation of compressive strength as a result of the fire event. However, the petrographic examination of the concrete cores indicated the extent of surficial concrete damage as a result of exposure to fire-elevated temperatures was up to a depth of 0.4 in. (10 mm).

Significant carbonation and cracking were also observed in several core samples and correlated with the NDE (UPV and pulse echo) results at multiple locations at each structural member. GPR scanning of cracked double-tee beams with significant longitudinal cracking showed that these cracks were located along the prestressing strands, thus indicating possible debonding between the strand and concrete with subsequent reduction in structural capacity. The petrographic examinations also indicated that the concrete members were exposed to elevated temperatures up to 1400°F (800°C).

Site Preparation, Demolition, and Repairs

Repairs included replacement of members that experienced severe distress, along with localized repairs of members with moderate or minor distress. Repair drawings were issued on June 1, 2018.

Once mobilization took place, the perimeter of the precast double tees was saw-cut, creating separation of each member to be replaced prior to removal. In preparation of hoisting the existing damaged precast double tees, cores were drilled at each of the four pick points, allowing a sling to be wrapped around the stem for each double tee. A 350 ton (317,500 kg) crane was used to bring down each damaged precast double tee, with a total of six removed and four new double tees reinstalled. Two of the damaged double tees were found to be salvageable after removal. These members were temporarily placed on the ground, repaired, and

reinstalled in their original position. Two spandrel beams were hoisted down, removed from the site, and replaced with new members (Fig. 7). New replacement double tees were hoisted into place for final repairs (Fig. 8).

Other repair works included the repair of concrete columns supporting Level 4 (Fig. 9), spandrel beams on Levels 3 and 4, double-tee members on Level 4, topping slab replacement on Level 3, and waterproofing installation on Levels 3 and 4. The damaged expansion joint system on Level 3 was replaced and a new expansion joint system was installed on Level 4. Joints were tooled in the topping slab and sealed above the double-tee flange-to-flange joints, and construction joints were routed and sealed. Cove sealant was installed at the perimeter bumper wall and columns.

Safety

Emergency shoring addressed the initial safety concerns for assessing the damage and reduce the threat of a possible collapse. With student finals around the corner at the University of Houston, it was understood that the East Garage would need to remain in use on all undamaged levels. This presented another challenge to the construction team: safely making localized repairs to damaged elements with limited intrusion to occupants while considering the safety.

Logistics

The public garage proved to be a limited-space jobsite, leaving little room for repair materials and contractor use/laydown. While complexities were abundant, the project team worked efficiently to have the garage fully operational by the start of the fall semester. Ultimately, the team was able to come in under budget and ahead of schedule on repairs.

Fig. 8—New replacement double-tee beams at completion

Fig. 9—Column during repair (left) and after repair (right)

University of Houston East Garage Fire Emergency Response

OWNER
University of Houston
Houston, TX

PROJECT ENGINEER/DESIGNER
Walter P Moore & Associates, Inc.
Houston, TX

REPAIR CONTRACTOR
United Restoration and Preservation
Houston, TX

MATERIALS SUPPLIER/MANUFACTURER
BASF
Houston, TX

Acknowledgments

The development of "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings (ACI 562-13) and Commentary" and the first edition of the "Guide to the Code for Evaluation, Repair, and Rehabilitation of Concrete Buildings" were major milestones in the concrete repair industry. Prior to the publication of these documents in 2013, the industry lacked code requirements specific to the repair of concrete buildings, leading to inconsistent repair practices. To provide guidance to the repair community, yet maintain the flexibility necessary to address widely varying conditions, many of the repair code requirements took the form of performance requirements rather than the prescriptive requirements seen in many other concrete industry codes. Because of the performance nature of the requirements, however, there was significant room for interpretation when deciding whether a particular code requirement had been met.

Early in the development of ACI 562-13, the need was recognized for a document that would provide guidance and examples to assist engineers in understanding how to satisfy the Repair Code requirements. This was particularly important considering that ACI 562 was a new code that engineers would be using for the first time and with which they would have no prior experience.

The second edition of the repair code, "Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures (ACI 562-16) and Commentary," and corresponding guide to the repair code, were updated to address comments received from these first-time users. Chapters 1 and 4 were reorganized and properly defined the difference between evaluation and assessment. A new section in Chapter 7 addressed bond interface between an existing concrete substrate and a new concrete overlay. Appendix A was added to provide requirements in cases where a jurisdiction has not adopted a repair code, allowing ACI 562-16 to be used as a stand-alone code. If a jurisdiction had adopted a repair code, then the licensed design professional must use Chapter 4.

For the third edition of the repair guide, examples were updated to reflect the changes in ACI 562-19. The current edition of the repair code, "Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures (ACI 562-19) and Commentary," and this guide corresponding to the new repair code, have been updated to address comments received from users. The major revisions in ACI 562-19 are as follows:

(a) Text was added to simplify use of new materials that have the equivalent of an ICC-ES evaluation report in Chapter 1.
(b) The requirements for the basis of design report were simplified in Chapter 1.
(c) Clarified requirements related to detailing of existing reinforcing steel in Chapter 7.
(d) The commentary in Chapter 8 was updated to include a listing of exposure categories that may affect durability.

This edition contains updated chapters to reflect the changes in ACI 562-19, updated Examples 1 through 5, three new examples (Examples 6 through 8), and a new Appendix B, which provides an overview of the new "Specifications for Repair of Concrete in Buildings (ACI 563-18)."

"Vision 2020: A Vision for the Concrete Repair, Protection and Strengthening Industry" was published in 2006 with the facilitation of the Strategic Development Council (SDC) (a council of the ACI Foundation). One goal in Vision 2020 was the development of a concrete repair code. SDC also called for the development of documents in a more expedient manner than typically achieved in the volunteer committee development process. Their support of these goals continues with this document. ACI and ICRI would like to thank SDC for their vision in calling for the development of a concrete repair code and for providing financial support toward the development of the first two editions of this guide.

Finally, ACI and ICRI would like to thank the review group for this guide consisting of Chair Keith E. Kesner and members Tarek Alkhrdaji, Eric L. Edelson, and Fred R. Goodwin. Their careful review and dedication to the project on top of all their other volunteer time for both Institutes made it possible to develop and revise this guide in a timely manner while maintaining the quality expected by the industry.

Khaled Nahlawi
Managing Editor

Preface

Introduction to the ACI 562-19 Code

Advancements in the practice of assessment, repair, rehabilitation, and strengthening of concrete structures have developed through a collaboration of design professionals, contractors, suppliers, manufacturers, researchers, educators, and lawyers. The annual cost to owners for repair, protection, and strengthening of existing concrete structures is estimated between $18 and $21 billion (Vision 2020). Simply put, even sound concrete may require repair, rehabilitation, maintenance, or strengthening throughout the service life of a structure. Accordingly, from 2004 to 2006, the Strategic Development Council (SDC), an interindustry development group dedicated to supporting the concrete industry's strategic needs, facilitated the development of "Vision 2020: A Vision for the Concrete Repair, Protection, and Strengthening Industry" to establish a set of goals that would improve the efficiency, safety, and quality of concrete repair and protection activities. One of the goals established by Vision 2020 was to create a concrete repair and rehabilitation code by 2015. The ACI 562-13 standard, "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings and Commentary," is the end result of that initiative. ACI 562-19 is the third edition of the Code with revisions, additions, and reorganized information to enhance the Code, providing more clarity and additional, updated information to assist the design professional.

The purpose of the ACI 562 Code is to provide minimum material and design requirements for the assessment, repair, and rehabilitation of structural concrete members. Like other ACI codes, ACI 562 is organized in a dual-column format, with mandatory code provisions to the left of each page, and nonmandatory commentary to the right to provide additional guidance and information on the content presented in the Code provisions. Unlike other ACI standards, ACI 562 includes both prescriptive and performance requirements. The performance requirements provide great latitude and flexibility to the licensed design professional in satisfying the requirements of ACI 562. Accordingly, ACI 562 serves to unify and strengthen concrete assessment, repair, and rehabilitation projects while accommodating the diverse and unique strategies and materials used in the industry.

In general, the overall use and function of ACI 562, with respect to existing concrete structures, can be compared to that of ACI 318-19, "Building Code Requirements for Structural Concrete and Commentary," with new concrete construction. As with ACI 318 and the 2018 International Building Code (2018 IBC), plans are underway for ACI 562 an ANSI standard, to be adopted into the International Existing Building Code (IEBC) to address matters pertaining to assessment, repair, rehabilitation, and strengthening of concrete members within existing buildings. Local jurisdictions and building authorities can also adopt ACI 562 directly. Cities and states have both adopted ACI 562 and adopted use of ACI 562 on specific projects. Other jurisdictions are in the process of reviewing the Code for consideration and adoption. Accordingly, while ACI 562 currently defines the standard for the concrete assessment, repair, and rehabilitation industry, the code provisions of ACI 562 will likely then become mandatory requirements as part of the governing building codes that regulate work in existing buildings.

Overview of the guide to ACI 562 Code content

The primary purpose of this guide is to help licensed design professionals (LDPs) gain more knowledge, skill, and judgment to interpret and properly use the ACI 562 Code. Although specifically developed for LDPs, this guide also provides insight into the use and benefits of ACI 562 for contractors, material manufacturers, and building owners and building officials. To achieve this goal, the guide is separated into three main components: Chapter Guides including Appendix A, Project Examples, and Appendix B, providing an overall view of the new standard, ACI 563, "Specifications for Repair of Concrete in Buildings."

The Chapter Guides and Project Examples are provided in tandem for clarity and understanding of the relative portions of ACI 562 Code. The Project Examples illustrate the process of carrying out a concrete building assessment, repair, rehabilitation, or strengthening project from inception through completion. This guide, including the Project Examples, is intended as a supplement to the ACI 562 Code and not as a "how-to" manual for performing concrete assessment, repair, rehabilitation, or strengthening. Several additional documents are referenced in ACI 562 Commentary and this guide to assist in evaluating the various options and approaches to performing successful concrete assessment, repair, rehabilitation, or strengthening projects. The intent of each Project Example is not to be a prescriptive formula for each of the project scenarios presented, but to illustrate how various sections of ACI 562 are applied together to execute the project. For convenience, related provision numbers from ACI 562 are given at the top of each corresponding paragraph of the project example text. Eight Project Examples are included within the guide:

1. Typical parking structure repairs
2. Typical façade repairs
3. Repair of historic structure for adaptive reuse
4. Strengthening of two-way flat slab
5. Strengthening of double-tee stems for shear
6. Concrete beam repair by section enlargement
7. Concrete repair by steel jacket
8. Beam repair with fire protection analysis:
   a. Beam strengthening due to live load increase
   b. Beam with inadequate existing concrete cover

In the third edition of this repair guide, a new chapter, Appendix B, was added to address specifications. This is another goal by Vision 2020 to create a concrete repair specification standard. The ACI 563-18 standard, "Specification for Repair of Concrete in Buildings," is a reference standard that the LDP can apply to any construction repair and rehabilitation project involving structural concrete by citing

it in the Project Specifications. It provides direction to the contractor and clearly defines the responsibilities and scope of the repair, rehabilitation, or strengthening. The specifications detail the work, material, and installation required to complete a project the way the client wants.

The Chapter Guides follow the general organization of ACI 562, broken down by the corresponding sections of ACI 562. Section numbers in Chapters 1 to 10 and Appendix A of this guide correspond to the provision numbers in ACI 562. The Chapter Guides include background information and an explanation of the various ACI 562 provisions, with particular insight into how the particular chapter and section of the Code fit within the project. Where applicable, flowcharts are provided to illustrate how to navigate the various provisions of ACI 562. References to Project Examples are provided where applicable to illustrate how specific provisions within each chapter of ACI 562 are incorporated into the design process. In some instances, additional limited-scope examples are included to better illustrate a point that is not covered by the Project Examples.

The first edition of ACI 562 was published in 2013, and was not available when the work for the projects discussed in the Project Examples was actually performed. All Project Examples assume that ACI 562 was available and accepted by local jurisdiction when the example projects were performed.

The second edition of ACI 562, published in 2016, includes additional definitions used in the Code for consistency with 2018 IEBC and other similar standards for existing structures. The title of ACI 562-16 was changed by replacing the word "Evaluation" with "Assessment." The two terms, which are used interchangeably by other standards and the first version of this Code, have received distinct definitions in the second edition of ACI 562 (Stevens et al. 2016). Specific criteria requirements for assessment and design of repair and rehabilitation for varying levels of damage, deterioration, or faulty construction was added in Chapter 4 when using the Code with IEBC, and in Appendix A when using the Code as a stand-alone code. Chapters 1 and 4 were revised to include specific criteria requirements for assessment and design of repair and rehabilitation for varying levels of damage, deterioration, or faulty construction. Load combinations in Chapter 5, which define the minimum strength of a structure with unprotected external reinforcement, were revised. Chapter 6 directs the LDP to provide an assessment before rehabilitation of an existing structure. This chapter includes historical material property data to help the design professional in the assessment if existing documents related to the existing structure are not available or physical samples cannot be extracted, because of the historical value of the structure. The interface bond provisions in Chapter 7 were revised to provide specific requirements based on shear test, as well as when to provide interface reinforcement, and commentary in Chapter 8 was clarified.

The third edition of ACI 562, published in 2019, has:

(a) Added text to simplify use of new materials that have the equivalent of an ICC-ES evaluation report in Chapter 1;
(b) Simplified the requirements for the basis of design reported in Chapter 1;
(c) Clarified requirements related to detailing of existing reinforcing steel in Chapter 7; and
(d) Updated commentary in Chapter 8 to include a listing of exposure categories that may affect durability.

In addition, three new repair examples are added to demonstrate the flexibility of the Code and its applicability to different repair and strengthening methods. Example 6 is related to concrete beam repair by section enlargement, Example 7 addresses concrete frame strengthening by steel jacketing, and Example 8 focuses on the effect of fire on concrete members and possible protection based on two scenarios: scenario one—concrete structure subjected to increase in live load; and scenario two—reinforcement with low concrete cover.

Lastly, a summary of the various provisions of ACI 562, as well as the corresponding location where each provision is covered within the guide, is provided in the Provision Coverage Matrix at the end of this guide. This serves as a useful tool when searching for additional information to a specific provision of ACI 562.

Contents