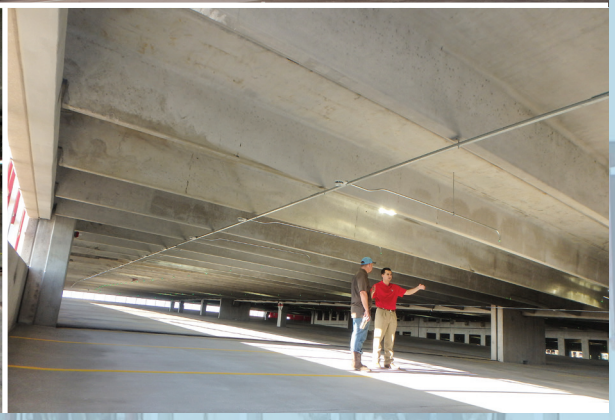
An ACI / ICRI Manual

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

A Companion to *ACI 562-19*







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Guide to the Code 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

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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
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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

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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

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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 salvaged after removal. These members were temporarily placed on the ground, repaired, and

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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

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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

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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

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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.

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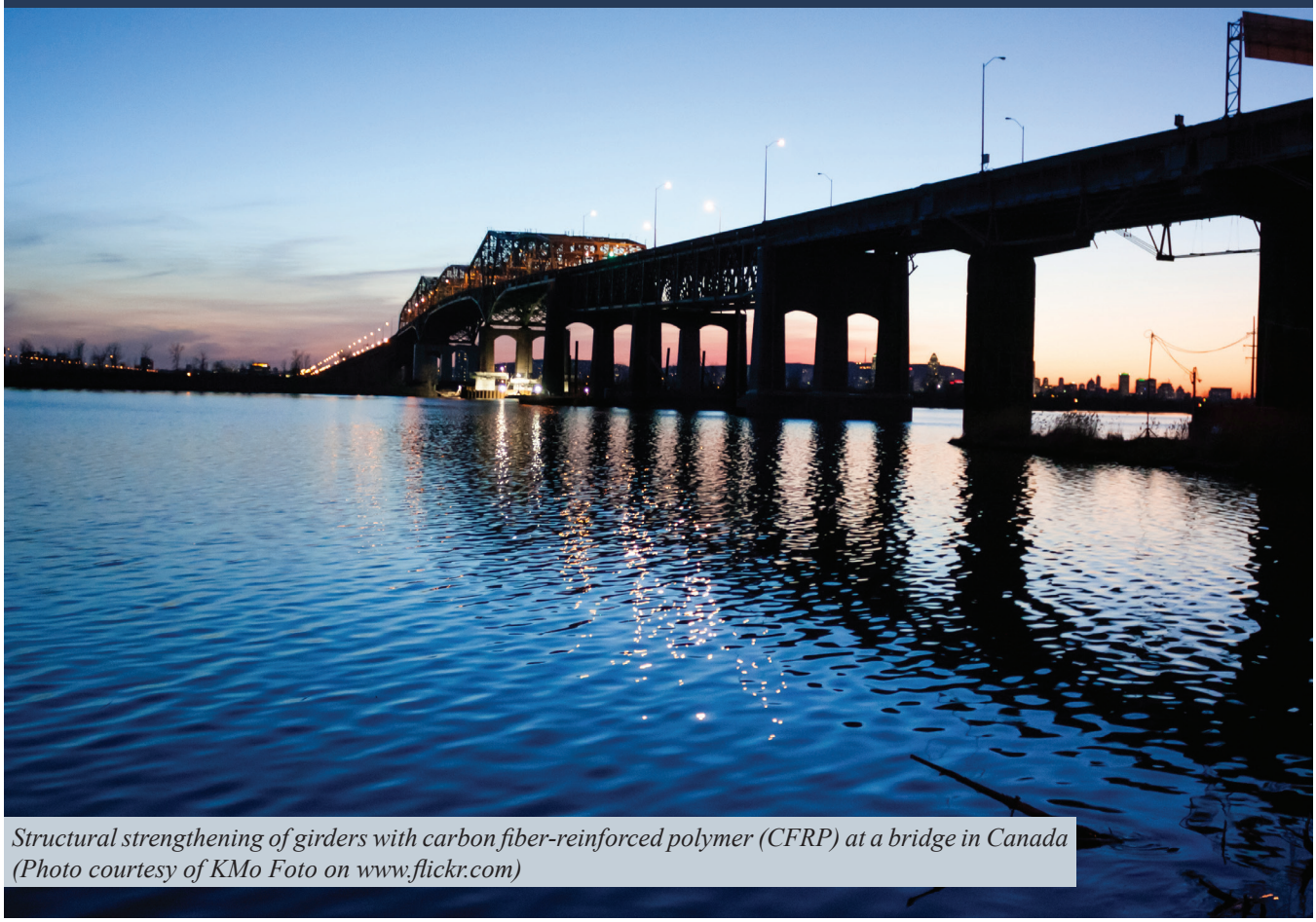
The Chapter Guides in Chapters 1 to 11 and Appendix A of this guide correspond to the identically numbered sections of ACI 562-19, "Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures." Related ACI 562 provision numbers are included at the top of each corresponding paragraph of the Project Example text in Examples 1 to 8.

This Guide is intended to provide examples and guidance for how licensed design professionals may satisfy the performance provisions of ACI 562. It does not, however, purport to represent the only suitable way to satisfy the requirements for every project. Engineering judgment must be applied to the unique requirements of individual projects.

This edition added Appendix B, which provides an overall view of ACI 563-18, "Specifications for Repair of Concrete in Buildings."

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Chapter 1—General Requirements



Structural strengthening of girders with carbon fiber-reinforced polymer (CFRP) at a bridge in Canada (Photo courtesy of KMo Foto on www.flickr.com)

Overview

Chapter 1 of ACI 562 specifies the applicability of ACI 562, including review of the various building codes that might affect the repair design, as well as selecting the building code for the repair design; applicability of the code; responsibilities of the licensed design professional including submittals to building officials and the owner; and development of maintenance recommendations. Chapter 1 also specifies the requirements for performing a preliminary assessment by examining the available information and determining if the proposed changes, imposed changes, or both, are safe, followed by how the structure will be affected by these changes.

1.1—General

ACI 562 Code is written to the licensed design professional (LDP) and provides guidance and consistency when assessing, designing, repairing, and rehabilitating concrete structures. It is intended to supplement the International Existing Building Code (IEBC), as part of a locally adopted code governing existing buildings or structures, or as a stand-alone code for existing concrete structures. The intent of the Code is to address minimum safety requirements and provide some uniformity and standardization to the industry for assessing existing concrete structures. The requirements based on performance, which encompass the majority of the requirements in ACI 562 Code, direct the design professional to satisfy specific requirements, while providing some leeway, flexibility, and direction with the repair and rehabilitation of concrete structures. Concrete structures constructed before 1971 that require repair, rehabilitation, or strengthening were probably designed based on the

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allowable stress approach, whereas the demand and capacity requirements of ACI 562 are based on strength design. The LDP is encouraged to consider strength design provisions of this Code as a check when assessing existing structures originally designed with allowable stress methods.

An existing structure, as defined in Chapter 2, is one for which a legal certificate of occupancy has been issued, or one that is finished and permitted for use. If no certificate of occupancy has been issued, or the building has not been permitted for use, the building is still considered new construction, and existing design provisions of ACI 318 will govern.

Licensed design professional—The LDP, as defined in the Code and consistent with ACI Concrete Terminology (CT), refers to an individual for a project who is licensed to provide design services as defined by the statutory requirements of professional licensing laws of the state or jurisdiction in which the project is to be executed, and who is in responsible charge of the structural assessment, rehabilitation design, or both. The LDP should exercise sound engineering knowledge, experience, and judgment when interpreting and applying ACI 562.

1.2—Criteria for the assessment and design of repair and rehabilitation of existing concrete structures

Determination of applicable building codes—Before performing an assessment, repair, rehabilitation, or strengthening of an existing concrete building or concrete structural element, the LDP of the project should first determine the building codes applicable to the project, understand their relevance to assessment and repair, rehabilitation, and strengthening design decisions, and the relationship between the different standards. Per ACI 562, the LDP should identify the following codes per the specific section numbers of ACI 562:

a. *Current building code* (1.2.2)
b. *Original building code* (1.2.3)
c. *Existing building code* (1.2.1)
d. *Design-basis code* (1.2.4)

In the United States, the *current building code* is usually based on an edition of the International Building Code (IBC), which was first published in 2000; a few large cities have their own customized building codes. The *current building code* establishes the design and construction regulations for new construction and provides limits that need not be exceeded if designing new construction or assessing and designing repairs and rehabilitation of existing structures. For the design and construction of new concrete structures, IBC references ACI 318. The code used to initially design the building is referred to as the *original building code* and is typically identified in the construction documents, or may be obtained by contacting the local jurisdiction and requesting information regarding the building code in effect at the time of original construction. The most common original codes prior to the IBC in the U.S. include the Building Officials Code Administrators National Building Code (BOCA/NBC), the Uniform Building Code (UBC), and the Standard Building Code (SBC) that typically reference previous versions of ACI 318 with modification. An existing concrete building may undergo several alterations, additions, rehabilitations, repairs, or strengthening during its service life, spanning several code cycles, and more than one code type may have been applied. Therefore, the LDP should determine the original building code for each of the alterations, additions, rehabilitations, repair, or strengthening, during the preliminary assessment and apply the specific original code for the area where work will be done.

There are cases of existing concrete structures where alterations, additions, rehabilitations, repair, or strengthening were completed prior to the adoption of a building code by the jurisdiction where the structure is located. The LDP should, in this case, research available standards and practices in effect at the time of construction. The Historic American Engineering Record, a program of the United States Park Service, has information on construction and preservation of historic structures (**https://www.nps.gov/hdp/haer/index.htm**).

In the U.S., the *existing building code* is most often based on an edition of the IEBC, which was first published in 2003. As of January 2016, the IEBC has been adopted in approximately 80 percent of the United States, Guam, and Puerto Rico (International Code Council 2014). Chapter 34 of the IBC, before the 2015 edition, also covers existing structures and has similar provisions as IEBC that permit the use of the original code for rehabilitations, and when it is required to upgrade an existing structure to the current code. Chapter 34 has since been deleted from the 2015 IBC. The intent of ACI 562 is that *existing building code* refers to the IEBC and not sections of other *current building codes* that contain provisions pertinent to existing construction. For jurisdictions that have not adopted an edition of the IEBC or the IBC with Chapter 34 version before 2015, that jurisdiction is considered to have no *existing building code*. In this case, the provisions of Appendix A of ACI 562 and any chapters in the *current building code* that address existing buildings must be met.

Once the *original building code* and *current building code* have been identified, the LDP can use the flowchart presented in Fig. 1.2 as a guide to determine the *design-basis code* for repair, rehabilitation, or strengthening design. The *design-basis code* is dependent on the adoption of an *existing building code* within the jurisdiction of the project. If a jurisdiction has not adopted an *existing building code*, Appendix A of ACI 562 is used to determine the *design-basis code*. In jurisdictions that have adopted an *existing building code*, the *design-basis code* is determined in accordance with Chapter 4 of ACI 562. The Project Examples included within this guide illustrate how Fig. 1.2 is used to determine the *design-basis code*. Chapter 4 and Appendix A provide the design-basis criteria for the repair and rehabilitation work. Designing new members and their connections to existing structures must be based on ACI 318.

The LDP may forego the determination of the design-basis code based on Chapter 4 or Appendix A and select the current building code for assessment criteria. This is a conservative approach and may result in expensive repair or strengthening options. The LDP should, therefore, review this option with the owner before proceeding with the assessment.

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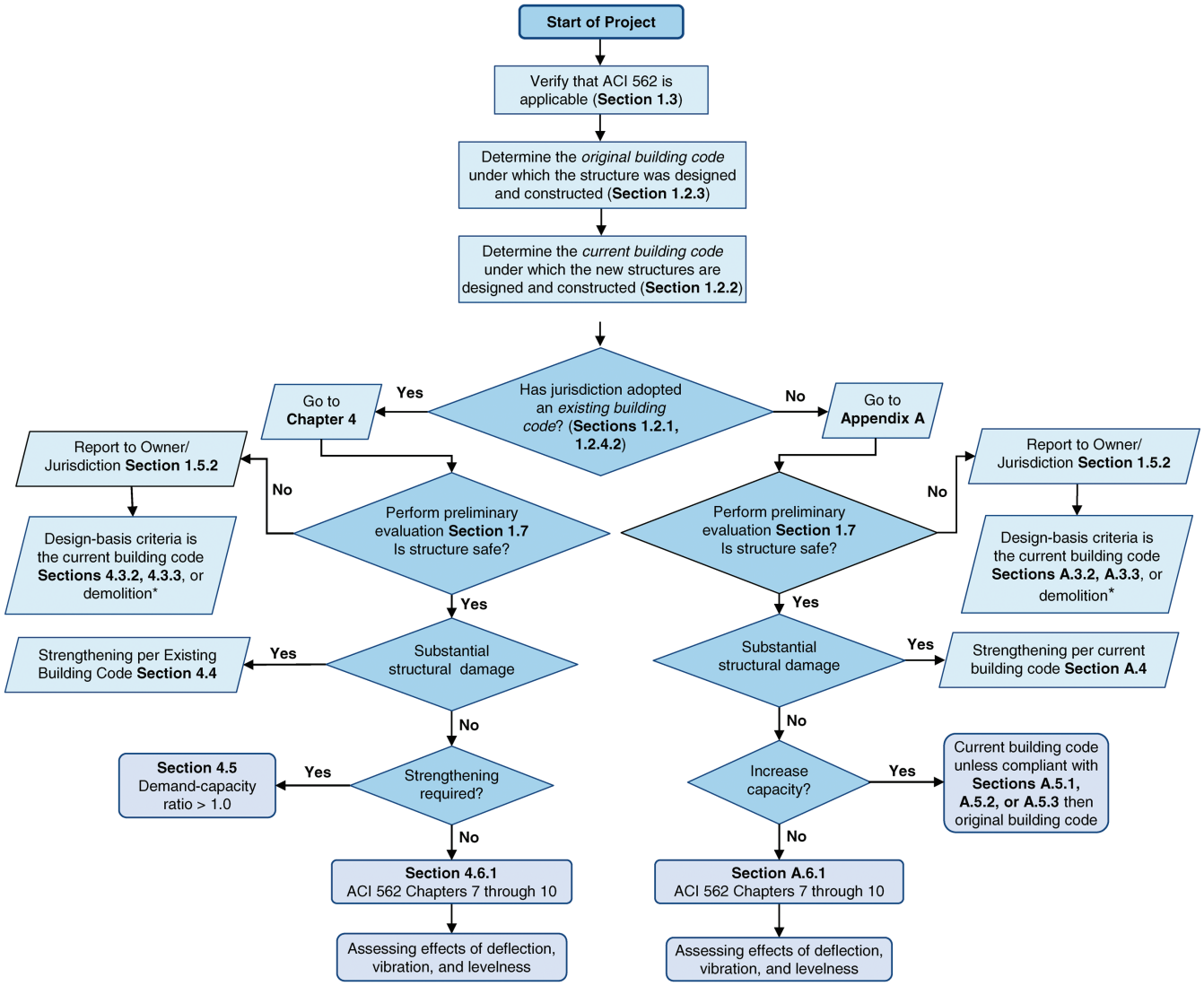


Fig. 1.2—Flowchart for determination of design basis code in ACI 562-19.

1.3—Applicability of the Code

Owners are required to maintain existing structures to prevent unsafe conditions from occurring, or repair potentially dangerous conditions that are present. ACI 562 is applicable to existing concrete structures including the concrete elements of buildings; nonbuilding structures; building foundation members, both plain and reinforced concrete; soil-supported structural slabs; concrete portions of composite members; and prestressed and precast concrete structures including cladding, which transmits lateral loads to diaphragms or bracing members. ACI 562 includes provisions specific to performing assessment, repair, rehabilitation, and strengthening of existing concrete elements of buildings or nonbuilding concrete structures. These provisions provide minimum level of repair for an existing building and typically address these unsafe and potentially dangerous conditions. The LDP can exceed the minimum requirements of ACI 562, such as those for progressive collapse resistance, redundancy, or integrity provisions. Regulations of the current building code, however, need not be exceeded when assessing, designing repair and rehabilitation work, or installing remedial work of existing structures. The Code applies to nonstructural concrete or for aesthetic improvements, if there is a potential for these materials to fail resulting in a potentially dangerous condition.

Provisions for seismic resistance—ACI 562 refers to the *existing building code* for the evaluation of seismic resistance and seismic rehabilitation design. If an existing building code has not been adopted, ACI 562 requires that the LDP use ASCE/SEI 41 for voluntary seismic retrofits supplemented by ACI 369.1. These references provide guidance for the LDP regarding forces, analysis and modeling procedures, and seismic rehabilitation design. The effect of repairs or rehabilitations to existing concrete buildings should be considered in the assessment of the structure's seismic response per ACI 562, 6.7.4.

ACI 562 permits voluntary retrofit for seismic resistance if the existing building code or ACI 562 do not require rehabilitation for existing buildings. If IEBC is adopted, then IEBC and ACI 562 are used for voluntary retrofit for seismic resistance. If, however, an existing building code has not been

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Which ACI Code Governs?

The assessment, repair, and rehabilitation of existing concrete structures present several unique considerations as compared to the design and construction of new concrete structures. Accordingly, ACI 562 provides directions for how existing structures are treated with respect to various building codes. For example, repairs, additions, or alterations to structures may result in the redistribution of moments in continuous flexural members. ACI 562 provisions address these effects and allow the analysis of existing structures to consider the actual state of redistributed moments, even if they exceed the moment distribution permitted in ACI 318 (ACI 562, R6.5.4).

Some of the provisions, calculations, and methods presented in ACI 318 are also applicable to the design of repair and rehabilitation measures for existing concrete structures. In these instances, ACI 562 provides direction regarding the scope and applicability of ACI 318 provisions for use with existing structures. For example, horizontal shear and shear-friction provisions presented in ACI 318 are applicable for force transfer at the interface between existing members and repair materials, and designing supplementary reinforcement for repairs (ACI 562, 7.3.2 and 7.4.1). Similarly, post-installed anchors and dowels are often used in repairs of existing concrete members. Accordingly, the provisions provided in ACI 318 Chapter 17 are applicable for the design of post-installed anchors in existing structures (ACI 562, 7.6.5).

Chapter 1 of ACI 562 describes how ACI 562, ACI 318, and other codes adopted by the local jurisdiction are used by the licensed design professional in the assessment, repair, and rehabilitation of existing concrete structures.

adopted, then ACI 562 directs the LDP to use the current building code supplemented by ASCE/SEI 41 and ASCE/SEI 7 to design seismic retrofits.

1.4—Administration

This Code, unless in conflict with the IEBC or jurisdiction authority regulations, will govern in the assessment and repair or rehabilitation of existing concrete structures. If ACI 562, however, is in conflict with requirements in referenced standards in thie ACI 562, then this Code will govern. ACI 562 permits the use of repair design or construction systems that do not conform to ACI 562, provided such systems are approved by the building official based on successful use, analysis, or testing in accordance with ACI 562, 1.4.2.

1.5—Responsibilities of licensed design professional

The LDP for the project is responsible for the repair process, from assessing a structure to designing and specifying repair materials, developing details to producing quality assurance programs covering the repairs, and advising the owner on future maintenance requirements to maintain a durable structure.

ACI 562, 1.5.2, requires the LDP to report observations of exposed structural defects within the work area representing obvious conditions requiring immediate attention to the owner and should alert the contractor of potentially dangerous conditions that require urgent action that may be discovered during construction to protect the public. Some jurisdictions may require the LDP to report potentially dangerous conditions directly to them. The LDP should be aware of thoese requirements when working in such a jurisdiction.

The LDP should document these findings in a report that includes a summary of the assessment of the existing structure, and a summary of or reference to the construction documents used for rehabilitation. These findings may be presented to the owner and jurisdictional authorities in form of a basis of design report. The items to be included in a basis of design report are summarized in the following titled text box "Basis of design report example."

The Project Examples presented in this guide provide specific examples of the responsibilities of the LDP, including the responsibility for notifying and communicating information to the owner through the duration of the assessment, repair, and rehabilitation. Specifically, Project Example 4 presents the reporting of potentially dangerous structural conditions.

1.6—Construction documents

Construction documents need to clearly communicate the information necessary to perform the repair, rehabilitation, or strengthening work, and the material specified must satisfy ACI 562 and the local jurisdictional authority. The LDP may perform calculations necessary to evaluate the structure and design the repairs. Computer analyses and model analysis may be used. Pertinent calculations are required to be submitted to the building official if required. The LDP will furnish the owner with copies of the project documents, including reports, repair documents, construction submittals, field reports, and locations of completed repairs to the extent of the LDP's contractual obligations. The Project Examples presented in this guide provide specific examples of the types of information that are to be specified in the construction documents, as well as any additional information that should be delivered to the owner, the building official, or both throughout the duration of the assessment, repair, and rehabilitation. Essential information that should be included in the construction documents is listed in the following titled text box "Construction document example."

1.7—Preliminary assessment

A preliminary assessment is the first step in the repair process in which the LDP reviews plans, construction data

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Basis of design report example*

1. Building description including:
   a. Address
   b. Date of construction
   c. Structural systems
   d. Original building code
   e. Past and current uses
2. Documenting of potentially dangerous structural conditions in the work area, as determined in the assessment
3. Documenting of substantial structural damage in the work area
4. History of concrete repairs and rehabilitations
5. Members and systems of the work area requiring increase in capacity beyond the demand of the original building code
6. Modifications such as additions, alterations, or changes in occupancy
7. Conditions and details of the proposed rehabilitation work
8. Assessment criteria and findings
9. Design-basis code criteria and basis of rehabilitation design
10. Material selection parameters
11. Shoring needs
12. Quality assurance and quality control (QA/QC) requirements
13. Types and frequency of future inspection
14. Types and frequency of future maintenance

*A basis design report should include, but is not limited to, this information.

Construction document example*

1. Name and date of issue of building code and supplements to which the assessment, repairs, or rehabilitation conforms
2. Design-basis code criteria used for conditions addressed by the documents
3. Design assumptions and construction requirements, including specified properties of existing and remedial materials used for the project and the strength requirements at stated ages or stages of construction
4. Details, locations, and notes indicating the size, configuration, reinforcement, anchors, repair materials, preparation requirements, and other pertinent information to implement the repairs, strengthening, or rehabilitation of the structure
5. Magnitude and location of prestressing forces†
6. Anchor details for prestressing reinforcement†
7. Development length of reinforcement and length of lap splices
8. Type and location of mechanical or welded splices of reinforcement†
9. Shoring or bracing criteria necessary before, during, and at completion of the assessment, repair, or rehabilitation projects†
10. Quality assurance program including specific inspections and testing requirements

*A construction document should include, but is not limited to, this information.

†Items not required on every project.

reports, local jurisdictional codes, and other available documents of the existing structure to assess the damage, capacity, or load thresholds that will determine the *design-basis code.* The preliminary assessment is done to determine if visibly dangerous structural conditions are present. If present, the LDP must report these conditions to the owner, contractor, or both (ACI 562, Section 1.7.2). For additions and alterations, the preliminary assessment will generally include the determination of the effect of the work on live and dead loads and the capacity of members. The level of damage to an existing structure is also an important determining factor in selecting the *design-basis code* and, therefore, a preliminary assessment is carried out to assess the level of structural damage, to determine that the structure is in compliance with the original design code, and that the structure is safe.

Chapter 4 applies if a jurisdiction has adopted the IEBC and defines the design-basis code criteria references. In the case of a jurisdiction that has not adopted an *existing building code*, Appendix A of ACI 562 is applicable and provides criteria for selecting the design-basis code.

The level and extent of the preliminary assessment is subject to the professional judgment of the LDP. In some cases, where the repair project addresses structural damage, the extent of deterioration or deficiency and cause of damage are clearly defined and known. If the structure's historical performance and visual observation of the structural condition of members and systems are acceptable, the level of damage or deterioration is low and modifications for additions, alterations, and changes in occupancy are not planned, then, per ACI 562, 4.6 or A.6, the structure is acceptable and repairs addressing durability and serviceability issues could be performed without performing analysis.

A preliminary assessment is also important to determine if an existing member, portions of a structure, or the entire structure exhibits signs of deterioration, structural deficiency, or behavior that are inconsistent with available design and

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Useful references for evaluating existing concrete structures

The following documents are listed in the commentary of ACI 562 and may provide guidance for evaluating existing concrete structures.

ACI 201.2R—Guide to Durable Concrete
ACI 214.4R—Guide to Obtaining Cores and Interpreting Compressive Strength Results
ACI 228.1R—In-Place Methods to Estimate Concrete Strength
ACI 364.1R—Guide for Evaluation of Concrete Structures before Rehabilitation
AC1 437.1R—Load Tests of Concrete Structures: Methods, Magnitude, Protocols, and Acceptance Criteria

ASCE/SEI 11—Guideline for Structural Condition Assessment of Existing Buildings
ASCE/SEI 31—Seismic Evaluation of Existing Buildings
ASCE/SEI 41—Seismic Rehabilitation of Existing Buildings

ATC 20—Post Earthquake Evaluation of Buildings
ATC 45—Field Manual: Safety Evaluation of Buildings after Wind Storms and Floods
ATC 78—Identification and Mitigation of Nonductile Concrete Buildings

FEMA P-58—Seismic Performance Assessment of Buildings
FEMA P-154—Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA 306 and 307—Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings

The Concrete Society TR 68—Assessment, Design and Repair of Fire-damaged Concrete Structures

International Organization for Standardization (ISO)
Maintenance and Repair of Concrete Structures 16311-3:2014 (ISO/TC 71/SC 71)

construction documents or code requirements in effect at the time of construction (ACI 562, 6.2.1). The LDP of the project may limit the access to the structure, take specific measures to mitigate these conditions, or require the installation of shoring to support the structure or member, if potentially dangerous conditions are present.

As deemed necessary by the LDP, the preliminary assessment may include a review of design and construction documents and verification of existing site conditions by visual inspection and other means. Per ACI 562, 1.7.4, the preliminary assessment should also include a determination of the design strength of the existing structure, including the impact of deficiencies, and a determination if substantial structural damage has occurred. The concept of substantial structural damage is not addressed by ACI 562 if a jurisdiction has adopted the IEBC as an existing code; thus the LDP should use IEBC to determine if substantial structural damage has occurred. The LDP, however, should use ACI 562 Appendix A, A.4, that defines substantial structural damage if a jurisdiction has not adopted an existing building code.

The preliminary assessment should be based on in-place conditions and should use actual material properties and member sizes to calculate the impact of damage on the members and the overall performance of the existing structure. Fire damage or other deterioration mechanisms could affect the material properties of reinforced concrete members; for example, compressive strength and modulus of elasticity of concrete and loss of steel reinforcement area due to corrosion. If a member does not show significant deterioration and construction documents are available, then listed material properties can be used in a preliminary assessment. If construction documents, however, are not available, ACI 562 Chapter 6 provides historical properties based on typical values used at the time of construction.

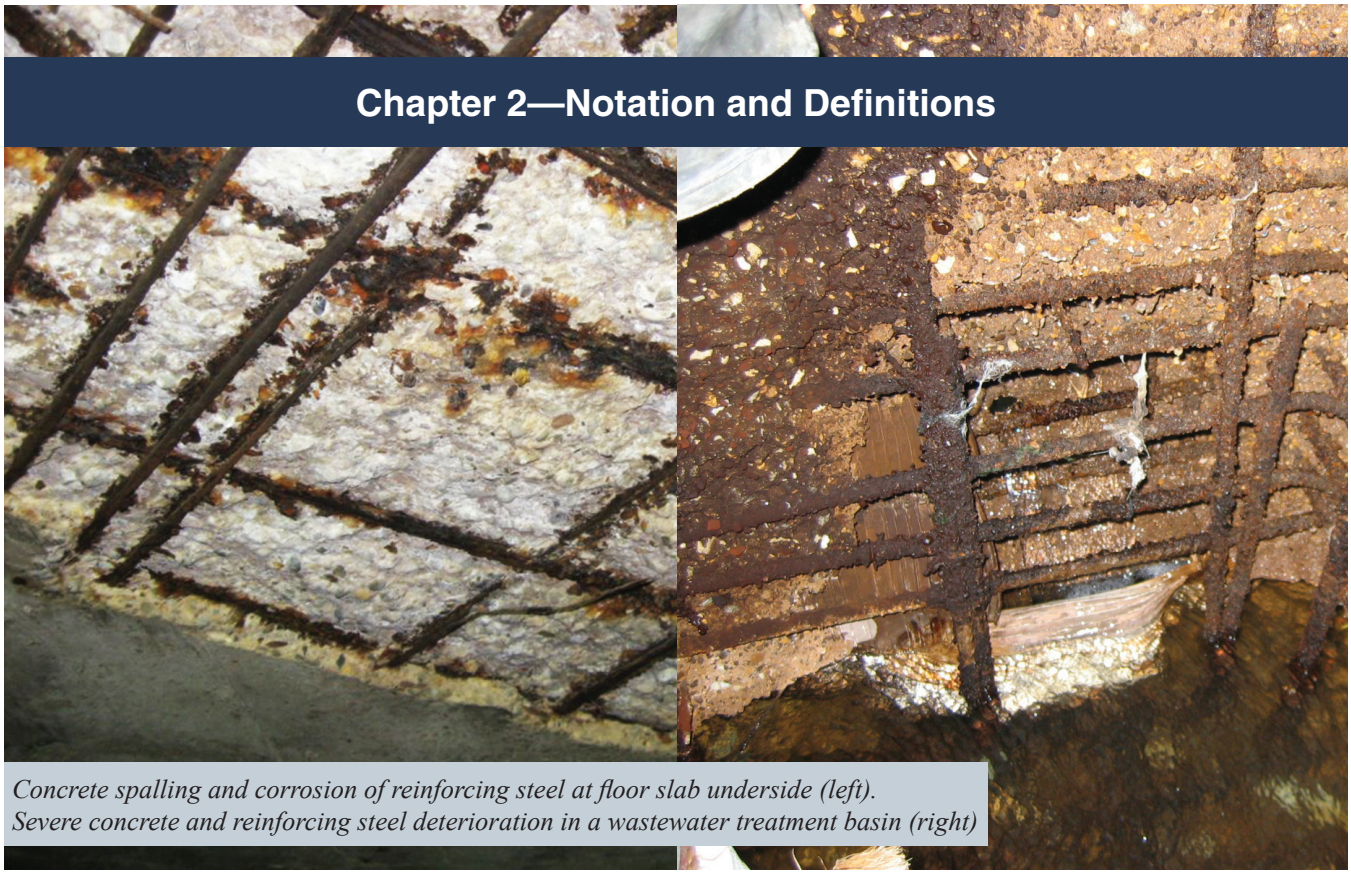
The LDP should document all deficiencies including cracking, spalls, member deflection, cross section dimensions different than specified on the original construction drawings, and construction tolerances exceeding those permitted under the original building code. Deficiencies or unusual behavior identified in the preliminary assessment are evaluated in more detail through a structural assessment, structural analysis, or both, as discussed in Chapter 6 of ACI 562.

The existing conditions, as well as any observed deficiencies or deterioration, should be considered in the course of a preliminary assessment. In other cases, a preliminary assessment may suggest the need for a more detailed assessment, when a member or structure exhibits damage, displacements, deterioration, or structural deficiencies, or behavior that is unexpected or inconsistent with available design and construction documents or code requirements in effect at the time of construction of the structure (Section 1.7.5).

As described in the ACI 562 commentary, numerous published references are available for guidance on performing assessments of existing concrete structures. Several of these are listed in "Useful references for evaluating existing concrete structure." Each of the Project Examples provides a specific example of performing a preliminary assessment, including some of the assumptions and professional judgments that may be considered by the LDP.

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Chapter 2—Notation and Definitions



Concrete spalling and corrosion of reinforcing steel at floor slab underside (left). Severe concrete and reinforcing steel deterioration in a wastewater treatment basin (right)

Overview

Chapter 2 of ACI 562 provides a summary of the notation and terminology used in the ACI 562 Code.

2.1—Notation

Section 2.1 of ACI 562 defines the various symbols and letters used in the formulas and text in the ACI 562 code and commentary. Most often the notation used in a given formula is also defined within the text of the code after the formula is presented. Section 2.1 of ACI 562 is intended to provide the user with an easy single-source reference location.

2.2—Definitions

Section 2.2 of ACI 562 defines unique and specific terminology used in the code and commentary of ACI 562. In some cases, multiple, slightly different definitions are provided for the same term where it is uncertain which definition might be most appropriate for a given scenario or use. For example, "repair process" may have several possible definitions.

The list of definitions provided in Section 2.2 of ACI 562 is not intended to be comprehensive of all terminology used within ACI 562. ACI and the International Concrete Repair Institute (ICRI) provide online resources for terminology:

a. ACI—"ACI CT-16 Concrete Terminology," https://www.concrete.org/store/productdetail.aspx?ItemID=CT18&Format=DOWNLOAD&Language=English&Units=US_Units
b. ICRI—"ICRI Concrete Repair Terminology," https://www.icri.org/page/terminology_H?&hhsearchterms=%22terminology%22

Where indicated in the commentary, some definitions in ACI 562 are repeated verbatim from the 2018 International Existing Building Code (IEBC). Other terms used can differ from the definitions provided within other building codes, specifically the 2018 IEBC. In such cases, the definitions provided in Section 2.2 of ACI

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562 or the definitions provided in ACI CT should be used when interpreting the language of ACI 562. Similarly, the definitions presented in 2018 IEBC should be used when interpreting the language of 2018 IEBC.

To further assist the user, specific terminology that is defined in unique ways to ACI 562 and 2018 IEBC are presented as follows:

Existing structure —

a. *ACI definition*: structure for which a legal certificate of occupancy has been issued. For structures that are not covered by a certificate of occupancy, existing structures are those that are complete and permitted for use or otherwise legally defined as an existing structure or building.

b. *IEBC definition*: a structure erected prior to the date of adoption of the appropriate code, or one for which a legal building permit has been issued.

Rehabilitation—

a. *ACI definition*: repairing or modifying an existing structure to a desired useful condition.

b. *IEBC definition*: any work, as described by the categories of work defined herein, undertaken in an existing building (2018 IEBC).

Repair—

a. *ACI definition*: the reconstruction or renewal of concrete parts of an existing structure for the purpose of its maintenance or to correct deterioration, damage, or faulty construction of members or systems of a structure.

b. *IEBC definition*: the reconstruction, replacement, or renewal of any part of an existing building for the purpose of its maintenance or to correct damage (2018 IEBC).

Repair section—

the combination of the installed repair material(s) and the substrate material(s).

Restoration—

a. *ACI definition*: the process of reestablishing the materials, form, and appearance of a structure to those of a particular era of the structure (ACI CT-16).

b. *IEBC definition*: no specific definition provided in 2018 IEBC.

Structural repair—

a. *ACI definition*: restoring a damaged or deteriorated structure or increasing the capacity of a structure.

b. *IEBC definition*: no specific definition provided in 2018 IEBC.

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Chapter 3—Referenced Standards



Application of an epoxy-based, quartz-reinforced composite overlay on effluent trough of a clarifier basin

Overview

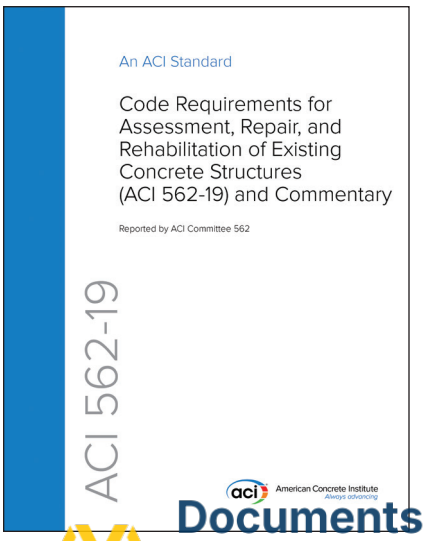
Chapter 3 of ACI 562 provides the full document titles for referenced standards presented in the code portion of ACI 562. These standards include building codes, specifications, and test methods, and are referenced to specify, clarify, or expand upon the code requirements presented within ACI 562. Each of these standards are written with mandatory language and considered part of the code requirements of ACI 562 for the purposes indicated within ACI 562.

The context of the reference within the code language of ACI 562 governs the use and applicability of each of the referenced standards. In some cases, the code requirements of ACI 562 limit the applicability of the referenced standard. The entire standard is not necessarily considered part of the code requirements of ACI 562. For example, Section 5.1.6 of ACI 562 limits the use of ASCE/SEI 7, "Minimum Design Loads for Buildings and Other Structures," by excluding seismic load requirements, but references ASCE/SEI 41, "Seismic Rehabilitation of Existing Buildings," for the treatment of seismic loads.

Current, past, and withdrawn standards are referenced as indicated in Chapter 3 of ACI 562. The dates provided refer to the applicable version of the reference. Those references indicated as being withdrawn refer to the standard at the time it was withdrawn, and not the superseding standard. For example, ASTM A160, "Specifications for Axle-Steel Bars for Concrete Reinforcement (withdrawn 1969)," refers to the version in effect in 1969, and not ASTM A617/A617M, "Standard Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement," which superseded this standard.

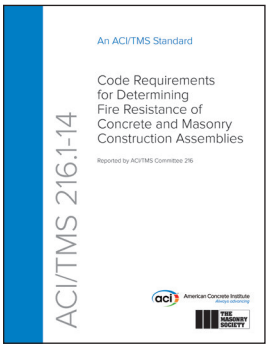
Additional resources that are referenced within the commentary text of ACI 562 are listed in Chapter 11 of ACI 562.

The following ACI codes are referenced in Chapter 3 of ACI 562. A brief description of each document is included.



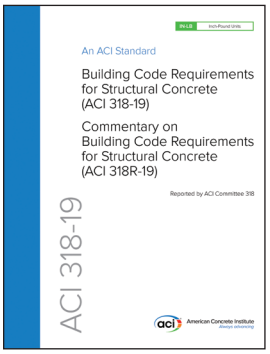
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ACI 216.1-14—Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies

Fire resistance of building elements is an important consideration in building design. While structural design considerations for concrete and masonry at ambient temperature conditions are addressed by ACI 318 and TMS 402/ACI 530/ASCE 5, respectively, these codes do not consider the impact of fire on concrete and masonry construction. This standard contains design and analytical procedures for determining the fire resistance of concrete and masonry members and building assemblies. Where differences occur in specific design requirements between this standard and the aforementioned codes, as in the case of cover protection of steel reinforcement, the more stringent of the requirements shall apply.



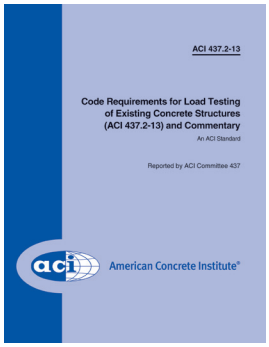
ACI 318-19—Building Code Requirements for Structural Concrete and Commentary

The "Building Code Requirements for Structural Concrete" ("Code") covers the materials, design, and construction of structural concrete used in buildings and where applicable in nonbuilding structures. The Code also covers the strength evaluation of existing concrete structures.

Among the subjects covered are: contract documents; inspection; materials; durability requirements; concrete quality, mixing, and placing; formwork; embedded pipes; reinforcement details; member design of slab systems, beams, columns, diaphragms, walls, structural plain concrete, construction joints; strength and serviceability; development and splices of reinforcement; strength evaluation of existing structures; provisions for seismic design; strut-and-tie modeling; and anchoring to concrete.

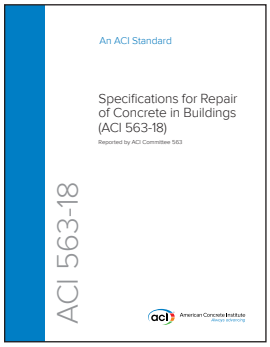
The quality and testing of materials used in construction are covered by reference to the appropriate ASTM standard specifications. Welding of reinforcement is covered by reference to the appropriate American Welding Society (AWS) standard. Uses of the Code include adoption by reference in general building codes, and earlier editions have been widely used in this manner. The Code is written in a format that allows such reference without change to its language. Therefore, background details or suggestions for carrying out the requirements or intent of the Code portion cannot be included.

The Commentary is provided for this purpose. Some of the considerations of the committee in developing the Code portion are discussed within the Commentary, with emphasis given to the explanation of new or revised provisions. Much of the research data referenced in preparing the Code arecited for the user desiring to study individual questions in greater detail. Other documents that provide suggestions for carrying out the requirements of the Code are also cited.



ACI 437.2-13—Code Requirements for Load Testing of Existing Concrete Structures and Commentary

This code provides requirements for test load magnitudes, test protocols, and acceptance criteria for conducting a load test as a means of evaluating the safety and serviceability of concrete structural members and systems for existing buildings as provided for by ACI 562-19. A load test may be conducted as part of a structural assessment to determine whether an existing building requires repair and rehabilitation, or to verify the adequacy of repair and rehabilitation measures applied to an existing building, or both. This code contains provisions for both a cyclic load test and a monotonic load test procedure.



ACI 563-18—Specifications for Repair of Concrete in Buildings

This is a Reference Specification that the Architect/Engineer can apply to any construction repair and rehabilitation project involving structural concrete by citing it in the Project Specifications. Mandatory requirements and Optional requirements checklists are provided to assist the Architect/Engineer in supplementing the provisions of this Specification, as required or needed, by designating or specifying individual project requirements. The first section covers general construction requirements for all repair work. The second section covers shoring and bracing of the structure or member to be repaired, and addresses sequencing of repair work as the structure is unloaded and reloaded. The third section covers concrete removal and preparation of the concrete substrate for repair, and defines common equipment and methods. The next five sections cover materials and proportioning of concrete; proprietary cementitious and polymer repair materials; reinforcement; production, placing, finishing, and curing of repair materials; formwork performance criteria and construction; treatment of joints; embedded items; repair of surface defects; mockups; and finishing of formed and unformed surfaces. Provisions governing testing, evaluation, and acceptance of repair materials as well as acceptance of the repair Work are included. Sections 9 and 10 incorporate by reference two other specifications—ACI 503.7 and ACI 506.2—into this ACI Standard to cover crack repair by epoxy injection and shotcrete, respectively.

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Chapter 4—Basis for Compliance



Step repair project at government building

Overview

Chapter 4 provides the criteria for use of ACI 562 with the IEBC. Section 1.7 specifies a preliminary assessment of deteriorated or damaged existing structures to determine the extent and significance of damage and deterioration and the reduced structural capacity of individual existing members and structures. Based upon the findings of the preliminary assessment, the licensed design professional (LDP) has to make a decision regarding potentially dangerous structural conditions and the required extent of further assessment. The findings from the assessment are used to make a decision regarding the design-basis code for required repairs and IEBC compliance method.

This chapter establishes limits based on demand-capacity ratios for ultimate strength design and allowable stress principles to determine if existing members, systems, or structures are safe or if strengthening, repair, or both, are necessary. The level of strengthening, repair, or both, is influenced by the calculated demand-capacity limits.

The Project Examples illustrate various types of preliminary assessments and methods of determining the design-basis code.

4.1—General

Chapter 4 of ACI 562 applies if a jurisdiction has adopted a code that addresses assessment, repair, and rehabilitation of existing concrete structures such as the International Existing Building Code (IEBC). Per ACI 562, 1.2.4.2, this chapter does not apply to existing structures located in jurisdictions that have not adopted the IEBC. Where Chapter 4 of ACI 562 applies, the LDP has to determine the design-basis code based on the results of the preliminary assessment (ACI 562, 1.7), detailed assessment (ACI 562 Chapter 6), and on the criteria in the existing building code (IEBC) as stated in Section 4.1.2 of ACI 562. The LDP may choose, however,

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to use the current building code referencing ACI 318-19 for concrete structures, TMS 402/602-16 for masonry structures, and AISC-16 for steel structures as the design-basis criteria for all damage states, deterioration, faulty design, or faulty construction instead of the original building code. This may be unnecessarily conservative, however, and may lead to a solution that is cost prohibitive or uneconomical.

The LDP is confronted in the initial stages of a project with the challenge to determine what design-basis code criteria applies. This is more prevalent when a structure was constructed prior to a jurisdiction having adopted a general building code. The structure may have design and construction that do not satisfy current building code requirements. ACI 562, with the IEBC, is used to determine if an existing structure should be rehabilitated or retrofitted to satisfy the requirements of the current building code. The LDP, in the absence of mandatory local ordinances, should determine if a seismic evaluation is necessary for potentially hazardous conditions. Consistent with the IEBC, ASCE/SEI 41 should be used for evaluation of seismic damage to members, systems, or structures that are seismically unsafe. ASCE/SEI 41 may or may not be applicable to nonbuilding structures. The requirements in ASCE/SEI 41 may apply to nonbuilding structures, but the LDP should use judgment as the applicability of these requirements has not been fully verified for every type of structure. This is particularly true for nuclear power plants or other structures designed by nonbuilding standards.

Table 4.1—Design-basis code criteria references for rehabilitation categories

Rehabilitation category	Design-basis code criteria reference
Potentially dangerous structural conditions for gravity and wind loads	4.3.2
Potentially dangerous structural conditions for seismic forces in regions of high seismicity	4.3.3
Substantial structural damage to vertical elements of the lateral-force-resisting system	IEBC Section 405.2.3
Substantial structural damage to vertical elements of the gravity-load-resisting system	IEBC Section 405.2.4
Damage less than substantial structural damage with strengthening	4.5
Damage less than substantial structural damage without strengthening	4.6
Deterioration and faulty construction with strengthening	4.5
Deterioration and faulty construction without strengthening	4.6
Additions	IEBC Sections 502, 606, or Chapter 11
Alterations	IEBC Section 503; Sections 602 and Chapter 7; Sections 603 and Chapter 8; or Sections 604 and Chapter 9
Changes in occupancy	IEBC Sections 506, 605, or Chapter 10

ASCE/SEI 41 states that its provisions do not have to apply to large nonbuilding structures, such as large tanks found in heavy industry or power plants, floating-roof oil storage tanks, and large (greater than 10 ft long) propane tanks at propane manufacturing or distribution plants.

ACI 562 and IEBC should be used to determine the assessment and design-basis criteria for a structure as shown in Table 4.1 (ACI 562 Table 4.1.4) unless the local jurisdiction imposes more restrictive requirements. The IEBC references in Table 4.1 are to sections in the 2018 IEBC.

The LDP is faced with several questions when confronted with deteriorated or weakened structures, which he or she should clarify prior to engaging in the assessment.

ACI 562 4.1.5 and 4.1.6, require that new reinforced concrete members, added to an existing structure, are designed and detailed to satisfy the current design code (ACI 318-19). This also applies to the connections between the new member and the existing structure. When new concrete and reinforcing members are integrated with the repairs, however, the original building code can be used for design. Detailing of the existing structure, however, need not meet the current design code if the following conditions are satisfied:

a. The damage or deterioration to the existing reinforcement is addressed
b. The repaired work area of the structure has capacity equal to or greater than demand per ACI 562, 5.2.2, using the original building code requirements or satisfies the requirements of ACI 562, 4.5.3, when using allowable stress design

The LDP should review the development length of existing reinforcement when cracking is evident near the ends of reinforcement or in regions where reinforcement splices are present. Research has shown that the development length equations from previous versions of ACI 318 may be unconservative for top cast plain reinforcement (Feldman and Cairns 2017). The LDP should also determine if the structure has demonstrated statistically acceptable performance based on historic data, such as acceptable resistance of previous loads that equal or exceed the loads that would be predicted for the remaining life of the structure, the LDP may judge the structure to have demonstrated historic structural reliability. The commentary in ACI 562 lists a few references that provide guidance in judging acceptable performances.

4.2—Compliance method

A compliance method as per the 2018 IEBC is used for assessing the code basis for repair or rehabilitation projects is described in this section. The design-basis code for repair and rehabilitation projects varies based on the extent of alterations, additions, or repairs. In general, the original building code is the design basis for minor alterations without significant changes in load. The current building code serves as the design basis for elements subject to major alterations or significant load changes. It should be noted, however, that ACI 562-19 1.3.8.1, requires the selection of the existing building code for assessment and design for seismic considerations. Similarly, the design of repairs subject to elevated

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Useful references for assessing and evaluating existing concrete structures

The following documents are listed in the commentary of ACI 562, R4.1.6, and may provide guidance in judging acceptable performance.

- ACI 224.1R, "Causes, Evaluation, and Repair of Cracks in Concrete Structures"
- ACI 437R, "Strength Evaluation of Existing Concrete Buildings"
- ACI 437.1R, "Load Tests of Concrete Structures: Methods, Magnitude, Protocols, and Acceptance Criteria"

temperatures and fire needs to satisfy the applicable existing building code.

The LDP should confirm specific requirements of selected compliance method which may vary depending upon IEBC edition. The 2018 IEBC describes three compliance methods: the prescriptive method, the work area method, and the performance method, which are summarized in The Compliance Methods in the 2018 IEBC chapter at the end of this guide.

Assessing structural safety, level of structural damage or conditions with less than substantial structural damage—In the industry, a quantitative measure or scale to determine the level of deterioration or damage exhibited by an existing structure does not exist. There are, however, processes that can be applied to determine the safety level of an existing structure. Nevertheless, the LDP is confronted with several questions that require careful planning and response. Some of the questions may be:

a. When should an existing structure be strengthened or repaired?
b. What is an acceptable demand-capacity ratio limit to consider an existing structure safe?
c. What is the minimum acceptable strengthening or repair level that is considered safe?
d. When should an existing structure's capacity be increased?
e. How should an existing structure be evaluated by the working stress method?
f. When should an existing structure be strengthened or repaired to the original building code, IEBC, or applicable existing building code level?

These and other questions that may arise are addressed in ACI 562-19, 4.3 through 4.5.

4.3—Potentially dangerous structural conditions

The LDP needs to determine if potentially dangerous structural conditions exist by carrying out a thorough assessment of the deterioration or damage to the existing structure, as discussed in Chapter 1 and 6 of this guide. The risk for collapse of each proposed strengthening procedure should be assessed to determine an economical and safe repair strategy. The LDP calculates the strength demand based on the current building code, considering gravity and fluid loads and lateral wind and soil loads but excluding seismic loads. The governing load is determined using

ACI 562 Chapter 2 defines potentially dangerous structural condition as follows:

potentially dangerous structural condition—(1) Structural state of existing concrete within a work area for an individual structural member, structural system, or structure that meets the definition of dangerous or unsafe, is unstable, has potential of collapse of overhead components or pieces (falling hazards), has been determined to have demand/capacity ratio exceeding the limit of Section 4.3.2.2, or has potentially hazardous resistance for seismic events. (2) A limit state of unacceptably low margin of safety against collapse without supplemental resistance.

factored load combinations of ASCE/SEI 7. In this chapter, the term "gravity loads" refers to dead, live, and snow loads. Reduction factors from ACI 562 Section 5.3 or 5.4, are used whether a structure is rehabilitated or assessed. If the demand-capacity ratio, as given in ACI 562 Eq. (4.3.2) is greater than 1.5, then the structure is considered potentially dangerous and must be strengthened or repaired based on the current building code.

$$\frac{U_c}{\phi R_{cn}} > 1.5 \qquad \text{(ACI 562, Eq. 4.3.2)}$$

where U_c is defined as strength design demand by using nominal loads of the current building code and factored load combinations of ASCE/SEI 7 for strength design provisions (LRFD); R_{cn} is the current in-place nominal resistance of the structural member, system, or connection including the effects of damage, deterioration of concrete and reinforcement, and faulty construction; and ϕ is the strength reduction factor obtained from Section 5.3 or 5.4 of ACI 562. A demand-to-capacity ratio greater than 1.5 calculated using Eq. (4.3.2) represents a condition with limited to no margin of safety against failure (Stevens et al. 2019). Potentially dangerous structural conditions requiring immediate attention are reported immediately to the owner per ACI 562, 1.5.2, and to the appropriate authorities when required by the authorities having jurisdiction per ACI 562, 1.5.2.1.

The LDP may also consider the following to satisfy Eq. (4.3.2):

a. Adding structural redundancies, which are desirable to ensure the safety of a structural system
b. Providing alternate load paths, redistributing the load, or limiting the live load such that existing members are not overstressed
c. Adding secondary supporting members to relieve overstressed members

If the demand-capacity ratio, however, is less than 1.5, then less restrictive requirements are implemented as described in Section 4.5 of this guide.

Unless addressed by the authority having jurisdiction, for structures in Seismic Design Categories D, E, and F, the LDP should review the structure for potentially hazardous seismic

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ACI 562-19 Useful references for potentially dangerous structural conditions

The following documents are listed in the commentary of ACI 562 and may provide target reliability indexes, basic probability theory and concepts for an assessment using the specific details of the demand as it relates to the capacity with the strength reduction factors of Chapter 5 for concrete structures.

- ASCE/SEI 7, "Minimum Design Loads for Buildings and Other Structures"
- Galambos, T.V.; Ellingwood, B.R.; MacGregor, J.G.; and Cornell, C.A., 1982, "Probability Based Load Criteria: Assessment of Current Design Practice," *Journal of the Structural Division*, ASCE, V. 108, No. 5, pp. 959-977.
- Ellingwood, B.R., and Ang, A. H.-S., 1972, "A Probabilistic Study of Safety Criteria for Design," Structural Research Series 387, University of Illinois Experiment Station, University of Illinois at Urbana-Champaign, Champaign, IL.

ACI 562-19 Chapter 2 defines substantial structural damage as follows:

Substantial structural damage—Except when using Appendix A, substantial structural damage per the IEBC shall be - A condition where one or both of the following apply:

1. In any story, the vertical elements of the lateral force resisting system have suffered damage such that the lateral load-carrying capacity of the structure in any horizontal direction has been reduced by more than 33 percent from its predamage condition.
2. The capacity of any vertical gravity load carrying component, or any group of such components, that supports more than 30 percent of the total area of the structure's floor(s) and roof(s) has been reduced more than 20 percent from its predamage condition and the remaining capacity of such affected elements, with respect to all dead and live loads, is less than 75 percent of that required by this code for new buildings of similar structure, purpose and location.

When using this code as a stand-alone code, substantial structural damage shall be as defined in A.4.

conditions. The review should be completed to confirm the structure is adequate for either the seismic performance level required by the local authorities, or confirm the structure is compliant with ASCE/SEI 41 for Structural Performance Level – Collapse Prevention using Earthquake Hazard Level, BSE-1. Earthquake Hazard Level BSE-1 has a 20 percent probability of exceedance in 50 years, or a 225-year return period.

When the local authority having jurisdiction does not provide requirements for potentially hazardous seismic structural conditions, then the LDP should refer to ATC-78, the IEBC, and ASCE/SEI 41 appendixes for guidance. The LDP is not required to assess potentially hazardous seismic conditions for concrete structures located in moderate to low seismicity regions.

4.4—Substantial structural damage

A structure with substantial structural damage, as defined in ACI 562 Chapter 2, is assessed and rehabilitated per 2018 IEBC Sections 404.2 through 404.3, or 606.2.2 through 606.2.3 that requires the LDP to submit to the building official the structure's assessment and whether "the damaged building, if repaired to its pre-damaged state, would comply with the provisions of the IBC for wind and earthquake loads." 2018 IEBC has, however, two exceptions; for buildings in SDC A, B, or C, if the substantial damage was not due to an earthquake, and for one-and two-family dwellings. Both do not need to "be evaluated or rehabilitated with load combinations that include earthquake effects."

4.5—Conditions of deterioration, faulty construction, or damage less than substantial structural damage

For structures having less than substantial structural damage but have deterioration or faulty construction and there is reason to question the capacity of the structure, ACI 562 requires that it be assessed by checking one of the criteria in ACI 562, 4.5.1, 4.5.2, or 4.5.3. These sections must not be applied in combination with each other. The demand-capacity ratio of a member, system, or structure is evaluated in accordance with Eq. (4.5.1):

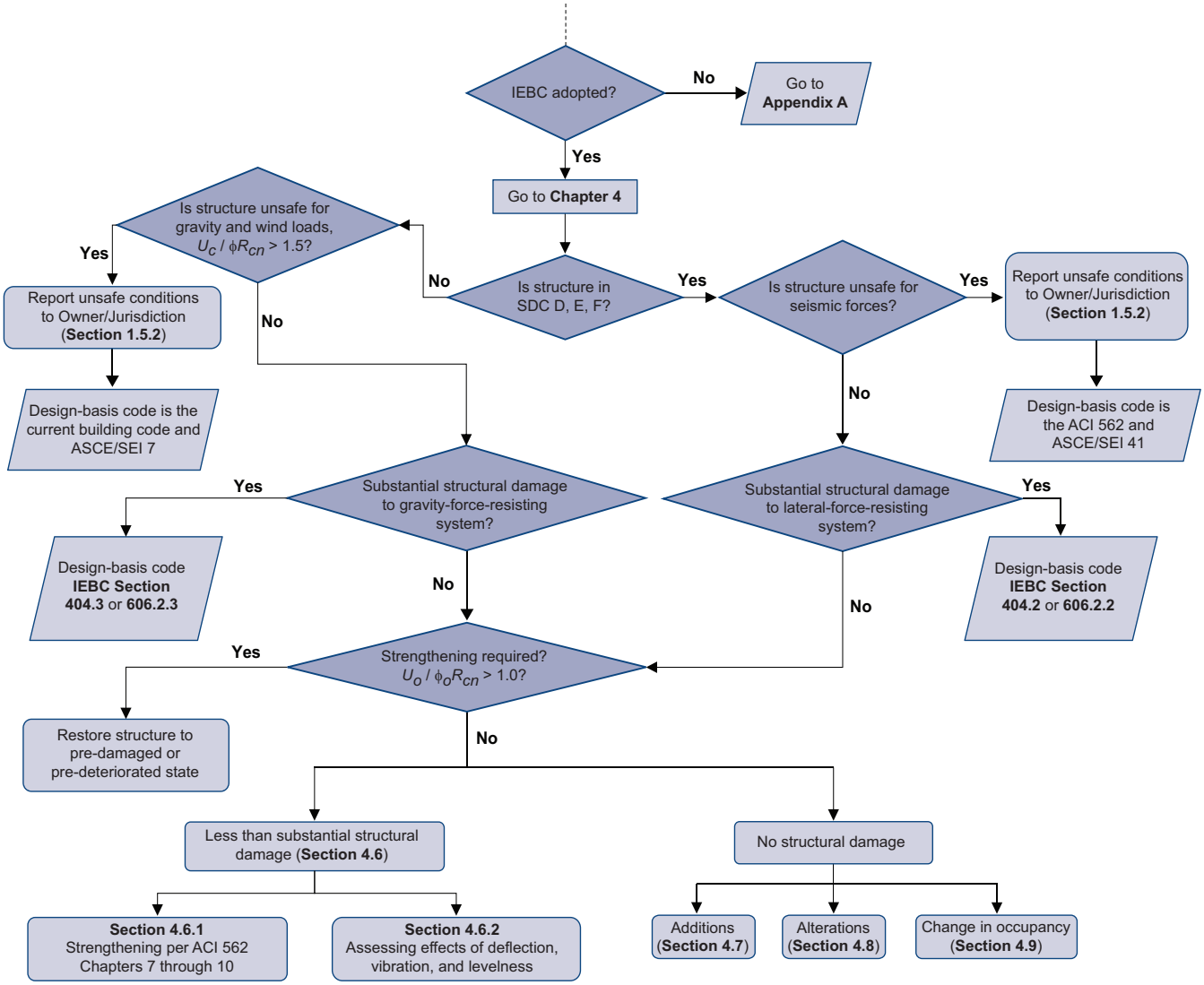
$$\frac{U_o}{\phi_o R_{cn}} > 1.0$$

where U_o is the strength design demand determined by using the nominal loads and factored load combinations of the original building code, excluding seismic loads; $\phi_o R_{cn}$ is the current in-place nominal resistance of the structural member, system, or connection including the effects of damage, deterioration of concrete and reinforcement, and faulty construction adjusted by the strength reduction factor (ϕ_o) of the original building code.

If $U_o/\phi_o R_{cn}$ is greater than 1.0, repairs are required to restore the structure to the pre-damage or pre-deteriorated states based on the original building code. Most existing concrete structures with damage less than substantial structural damage, deterioration, or containing faulty construction, will provide acceptable safety if restored to the strength of the original building code based on the material properties of the original construction. New concrete members and connections to existing construction must comply with ACI 562, 4.5.1.

For structures with a demand-capacity ratio ($U_o/\phi_o R_{cn}$) less than 1.0, strengthening is not required.

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U_c – demand using nominal loads of the current building code and factored load combinations of ASCE/SEI 7 for strength design provisions

U_o – demand using nominal loads and factored load combinations of the original building code for strength design provisions

R_{cn} – current in-place nominal capacity of structural member, system, or connection including the effects of damage, deterioration of concrete and reinforcement, and faulty construction

ϕ – strength reduction factor per ACI 562, Section 5.3 or 5.4

ϕ_o – strength reduction factor of the original building code

Fig. 4.5a—Selecting design-basis code.

For an existing structure that was subjected to known loads equal to or higher than specified in the design documents during its service life that has performed satisfactorily, then it should be taken as an indicator that the existing structure has an adequate safety factor and strengthening is not required. Figure 4.5a provides a road map for selecting the design-basis code.

ACI 562 Section 4.5.2 permits the LDP to use alternative assessment criteria using engineering principles for members, systems, or structures with deterioration, faulty construction, or damage less than substantial structural damage when approved by authority having jurisdiction. The LDP should assess whether the demand or capacity of the original structure is significantly inconsistent with the current standards, which may result in unacceptable structural safety issues. The references listed under Section 4.3 of this guide should be considered in the selection of a relevant assessment criteria. The applicability of the original building code for assessing existing structures should be questioned if there are any of the following:

a. Increased load intensity
b. Added loads
c. Changes in load factors, strength-reduction factors, or load combinations
d. Modifications of analytical procedures
e. Changes in determining capacity between the original and

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current building codes, such as a change from allowable stress design to ultimate strength design

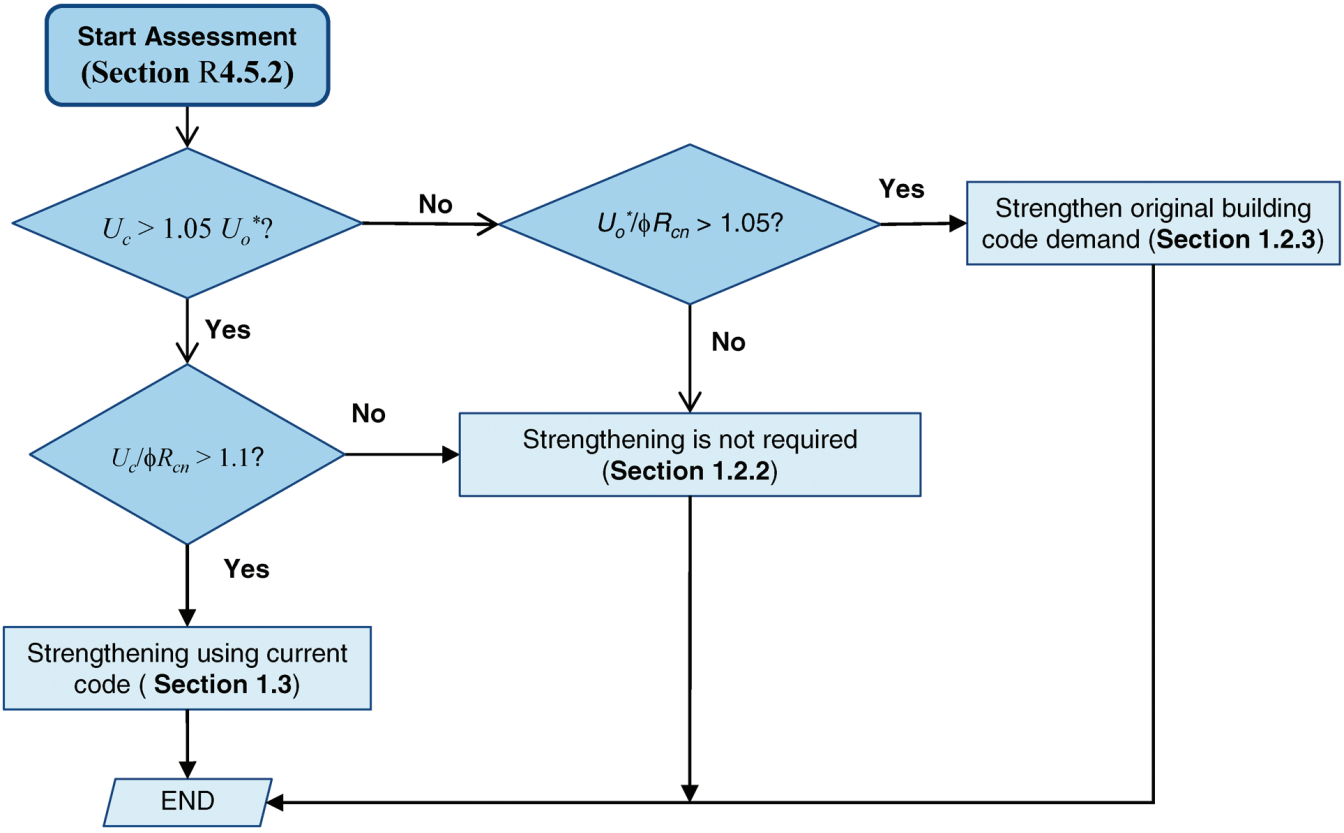
f. The benefits received from strengthening or repair do not justify the incurred cost

ACI 562 defines demand based on the current building code (U_c) as the effect of nominal gravity loads and lateral wind and soil loads, excluding earthquake loads, using ASCE/SEI 7 factored load combinations. ACI 562 defines demand based on the original building code (U_o^*) as the effect of the original building code nominal gravity loads and lateral wind and soil loads, excluding earthquake loading, using the factored load combinations of ASCE/SEI 7. The LDP should compare the demand based on the current building code (U_c) to the demand of the original building code (U_o^*).

If $U_c > 1.05U_o^*$, then the LDP should determine the demand-capacity ratios based on the current building code, $U_c/\phi R_{cn}$. If the ratio exceeds 1.1, ($U_c/\phi R_{cn} > 1.1$), then strengthening of the structure to the current building code is required. Otherwise, strengthening is not required.

If the current building code demand, however, does not exceed the original building code demand by more than 5 percent ($U_c \leq 1.05U_o^*$), then the LDP should check the demand-capacity ratio using the original building code demand and the current building code capacity. If the ratio exceeds 1.05 ($U_o^*/\phi R_{cn} > 1.05$), then the system or member strength should be restored to its original strength using the original building code. Otherwise, strengthening is not required (refer to Fig. 4.5b). For both conditions, the strength reduction factors are obtained from ACI 562 Chapter 5.

The LDP is often confronted with deteriorated or damaged structures designed using the working or allowable stress method that was the only available method for designing structures prior to ACI 318-63. In 1963, the strength design method was introduced into ACI 318 next to the working



U_c – demand using nominal loads of the current building code and factored load combinations of ASCE/SEI 7 for strength design provisions

U_o^* – demand using nominal loads of the original building code and factored load combinations of ASCE/SEI 7 for strength design provisions

R_{cn} – current in-place nominal capacity of structural member, system, or connection including the effects of damage, deterioration of concrete and reinforcement, and faulty construction

ϕ – strength reduction factor per ACI 562, 5.3 or 5.4

Fig. 4.5b—Alternate method for evaluating reinforced concrete structure.

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Table 4.5—Assessment conditions for reinforced concrete buildings

ACI 562 Section	Demand/capacity	Design-basis code
Potentially dangerous structural condition, Section 4.3		
Gravity and wind load (4.3)	$U_c/\phi R_{cn} > 1.5$	Current building code and ASCE/SEI 7 for factored load combinations
Seismic (4.3)		ASCE/SEI 41 and ACI 562
Substantial structural damage, Section 4.4		
Gravity and wind load (4.4)	$1.0 < U_c/\phi R_{cn} < 1.5$	IEBC 404.3 or 606.2.3
Seismic (4.4)		IEBC 404.2 or 606.2.2
Deterioration, faulty construction, or damage less than substantial		
Section 4.5.1	$U_o/\phi_o R_{cn} > 1.0$	Original building code New members use current building code
Alternate assessment criteria for deterioration, faulty construction, or damage less than substantial		
Section 4.5.2C(a)	$U_c > 1.05U_o^*$ and $U_c/\phi R_{cn} > 1.1$	Current building code
	$U_c > 1.05U_o^*$ and $U_c/\phi R_{cn} < 1.1$	Strengthening not required
Section 4.5.2C(b)	$U_c < 1.05U_o^*$ and $U_o^*/\phi R_{cn} > 1.05$	Original building code
	$U_c < 1.05U_o^*$ and $U_o^*/\phi R_{cn} < 1.05$	Strengthening not required
Original building code only used allowable stress design and design service loads		
Section 4.5.3	$U_s/R_a > 1.0$	Original building code
	$U_s/R_a < 1.0$	Strengthening not required



Chloride extraction performed on historic viaduct

stress method. In 1971, ACI 318 dropped the working stress method and retained the strength design method.

ACI 562, 4.5.3, provides provisions to assess such a structure. The demand-capacity ratio is based on service load demand, U_s, and resistance using allowable stresses, R_a. If the demand-capacity ratio is greater than 1.0, $U_s/R_a > 1.0$, then strengthening of a structure is required using the original building code. If the demand-capacity ratio, however, is less than 1.0, $U_s/R_a < 1.0$, then strengthening is not required.

The service load demand includes nominal gravity loads and lateral wind and seismic forces using load combinations of the original building code. The EOR should be aware that

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using the allowable stress design method is inconsistent with the reliability principles of current strength design provisions. Therefore, ACI Committee 562 recommends verifying the structure following ACI 562, 4.5.2, and checking the seismic resistance using ASCE/SEI 41.

Table 4.5 summarizes the different assessment conditions that the LDP has to address when analyzing a structure for repair, rehabilitations, or strengthening.

4.6—Conditions of deterioration, faulty construction, or damage less than substantial structural damage without strengthening

For other structures not strengthened using ACI 562, 4.3 through 4.5, the LDP needs to follow ACI 562, 4.6 through 4.9, to determine the design-basis criteria to implement for strengthening.

For structures with minimal or no damage or faulty construction that do not require strengthening per ACI 562, 4.5, the LDP can use Chapters 7 through 10 of ACI 562 as the design-basis criteria to rectify the shortcomings.

Corroded or damaged reinforcement affects the behavior of the concrete structure. It may result in concrete cracking, possible reduction in section capacity resisting the applied loads, or both. The licensed design professional should evaluate the effectiveness of the reinforcement per Chapter 7 of ACI 562.

ACI 318, as well as other codes, control predicted design deflections by either limiting calculated deflections to some specified allowable limits or specifying a minimum span-to-thickness ratio. These limits, however, are based on past experience with loads (for example, normalweight concrete with loads less than approximately 100 lb/ft^2 [488 kg/m^2] live load for two-way slabs), boundary conditions, and spans, among other factors. Structures with aggressive construction schedules resulting in heavier-than-planned construction loads, premature form removal, and accelerated shoring and re-shoring may result in members or structures with excessive deflections or having vibration issues that should be assessed for safety and comfort of the occupants. Deflections exceeding the code-prescribed design limits may be acceptable to the owner or user provided the member or structure performance is not adversely affected.



Type 1A embedded galvanic anodes on bridge pier

4.7—Additions, 4.8—Alterations, 4.9—Changes in occupancy

In case a structure receives additions, alterations, or has a change in occupancy, ACI 562 requires that the LDP assess and rehabilitate the structure and ensure that any change in loading, addition, or alteration warrants that the existing structure or member with the addition(s), alteration(s), or changes in occupancy conforms to the IEBC (refer to Table 4.1).

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Chapter 5—Loads, Factored Load Combinations, and Strength Reduction Factors



Tensioning new post-tensioning cables on parking deck repair project

Overview

The primary objective of building standards is to limit risk and establish the safety of structures. Chapter 5 of ACI 562 addresses the licensed design professional (LDP)'s responsibilities for determining the load and strength requirements throughout the assessment, repair, rehabilitation, or strengthening process, both relative to the member under investigation and the structure as a whole. The basic requirements for the determination of design strength ϕR_n and required strength U of existing structural members subject to assessment or repair and rehabilitation design are described.

Chapter 5 of ACI 562 also addresses loads and factored load combinations, and specifically the treatment of loading scenarios that may change over the duration of the repair, rehabilitation, or strengthening work. Unlike new construction, this work may take place while the structure remains in service. Additional factored load combinations are provided for repairs with external reinforcing systems to achieve a minimum level of safety during extraordinary events.

The assessment of existing buildings is different from the design of new buildings because the as-built geometries, in-place materials, and material properties can be documented as required. Having knowledge of these attributes greatly reduces the uncertainty associated with the parameters used in the design of reinforced concrete buildings. As such, the strength reduction factors used for design in ACI 318-19 may, in some cases, be unnecessarily conservative. Chapter 5 of ACI 562 addresses this difference for existing buildings and specifies when increased strength reduction factors may be used for assessment and repair design. These alternate strength reduction factors are the same as those in Chapter 27 of ACI 318-19, which applies to strength assessment of existing structures.

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5.1—General

The minimum level of safety regarding load and strength requirements for a given project are stipulated in the design-basis code, which should be determined as described in Chapters 1 and 4 or Chapter 1 and Appendix A of ACI 562, following the general procedure presented in Chapter 1 of this guide. When the design-basis code requires use of ACI 318-19 for the assessment or repair design, the load factors, factored load combinations, and strength reduction factors are obtained from Chapter 5 of ACI 562. When the design-basis code references other standards, such as the original building code, that specify loads, factored load combinations, and strength reduction factors that are different than ACI 318-19, certain sections of ACI 562 Chapter 5 will not apply. The application of Chapter 5 in ACI 562 is dependent on reference to ACI 318-19 in the design-basis code, as shown in Fig. 5.1.

As described in ACI 562 Section 5.1.2, it is not permitted to use load factors and factored load combinations from the original building code with strength reduction factors from ACI 562 Chapter 5, or load factors and factored load combinations from ACI 562 Chapter 5, with strength reduction factors from the original building code. Load factors and strength reduction factors within a given code are calibrated to achieve an appropriate level of reliability in design. Mixing factors from different codes may result in an unsatisfactory level of reliability. The LDP should exercise judgment in applying loads from current editions of ASCE/SEI 7, ASCE/SEI 37, or ASCE/SEI 41 to previous factored load combinations, considering that load magnitudes and combinations may have changed over the years. Wind loads in particular were changed in recent editions of these ASCE/SEI standards. Using current wind loads with factored load combinations, load factors, and strength reduction factors from an earlier code may not yield the desired level of safety that was intended in the development of the current wind loads in these standards. If the loads specified in the current building code have increased significantly from the loads specified in the original building code, then the demand-to-capacity ratio of a member can be evaluated using procedures in ACI 562, R4.5.2 or RA.5.2. Generally, use of current gravity loads with load factors, factored load

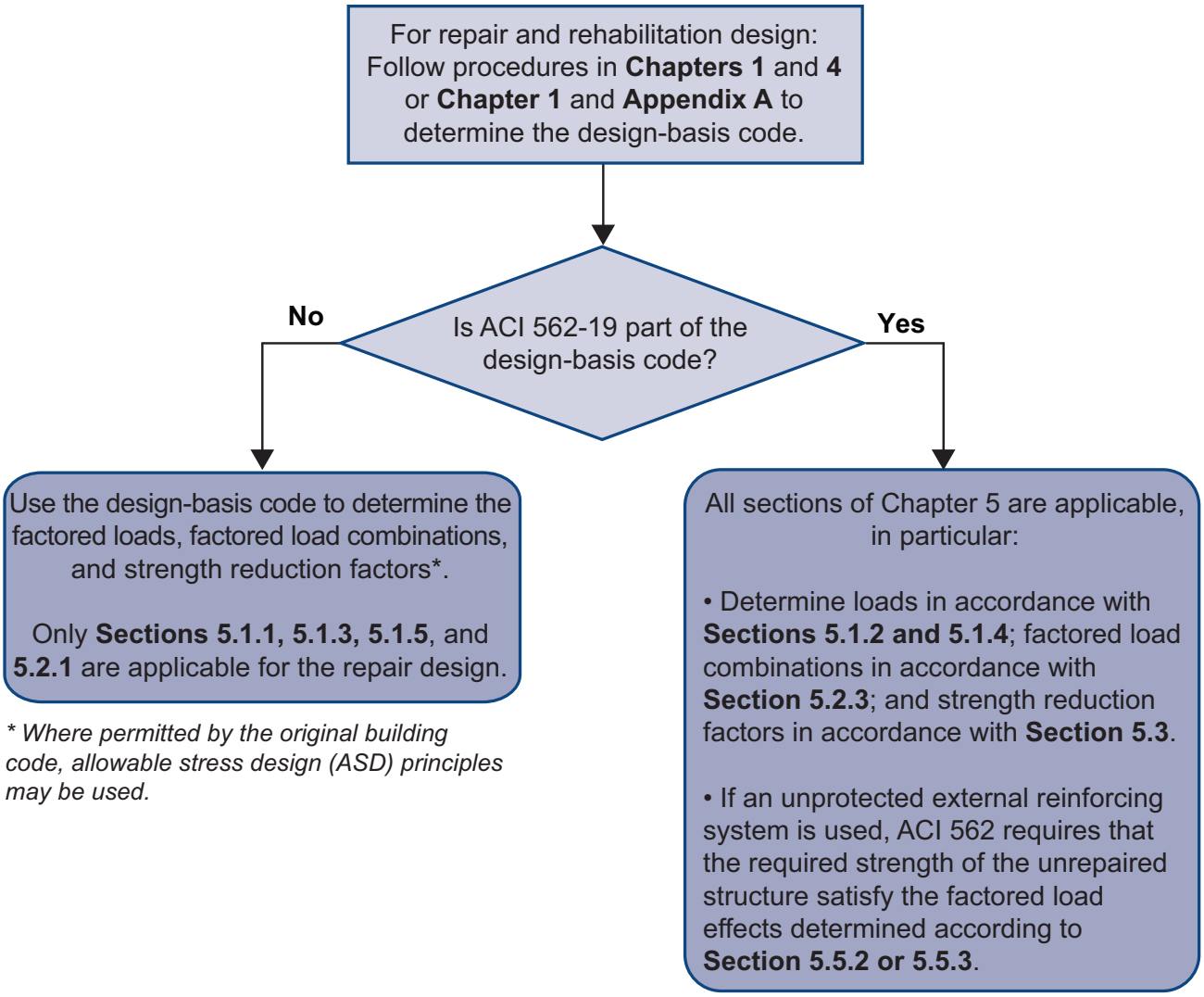


Fig. 5.1—Flowchart for determination of loads, factored load combinations, and strength reduction factors for repair and rehabilitation design.

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combinations, and strength reduction factors from the original building code may be prudent if the design-basis code is the original building code.

The LDP for the project should use the design-basis code loads during construction. ACI 562 Section 5.1.3 requires shoring and temporary construction to be designed to support loadings that may vary throughout the repair process. When shoring and temporary construction is required to support occupied structures and ACI 562 is the design-basis code, the loadings are specified to conform to ASCE/SEI 7. If, however, the structure or portion of the structure where work is performed is unoccupied during the construction period, then less-stringent temporary design loads could be specified based on ASCE/SEI 37. ASCE/SEI 37 provides minimum load requirements during construction, which can often reduce the demand on shoring and temporary construction based on a probabilistic assessment of the factored loads and factored load combinations that could occur during the finite construction period.

Section 5.1.4 of ACI 562 requires the LDP to consider the unique circumstances involved in assessing and designing repairs, rehabilitations, and strengthening of existing structures. Several considerations that may not have been specified or present during the original design and construction may be applicable, including secondary and service load conditions such as those mentioned in Section R5.1.5 of ACI 562. These load consideration requirements are applicable regardless of the design-basis code used for the assessment or repair design.

5.2—Load factors and load combinations

Section 5.2.1 of ACI 562 requires the LDP to consider the existing loads on the structure as well as the effects of the repair process. For example, removal of concrete can cause stresses to be redistributed to other members of the structure or within the member itself. If shoring is provided in this scenario, the ACI 562 Code requires the LDP to consider the effect of shoring loads transmitted to supporting members of the existing structure during each phase of the repair. Additionally, stresses in the member under repair need to be assessed at each stage of the repair process to properly assess the influence of shoring, concrete removal, concrete replacement, and eventual return to service. If shoring is not provided, the ACI 562 Code requires the LDP to consider stresses in the remaining elements of the original member combined with stresses in the repair and original member acting compositely. The LDP should consider the effects and sequencing of the repair process, both on the member being assessed and the structure as a whole. Consideration of the repair process is applicable regardless of the design-basis code used for the repair design.

Section 5.2.3 of ACI 562 stipulates that the required strength U should be at least equal to the effects of the factored load combinations specified in ASCE/SEI 7 for the applicable design loads from the design-basis code. The factored load combinations in ASCE/SEI 7 are consistent with those in ACI 318-19. For example, a load factor of 1.0 and 1.2 for the internal load effects due to reactions induced by prestressing and for the maximum prestressing reinforcement jacking force for the design of post-tensioned anchorage zones, respectively, are specified in Sections 5.2.4 and 5.2.5 of ACI 562; these load factors are also consistent with the design methodology of ACI 318-19.

5.3—Strength reduction factors for repair design

For the repair design, the strength reduction factors, ϕ, in Section 5.3 of ACI 562 are used when the design-basis code references ACI 318-19; these factors are consistent with those provided in ACI 318-19. The strength reduction factors of Section 5.3 of ACI 562 are used in conjunction with the loads specified in Section 5.1.4 of ACI 562 and the factored load combinations specified in ASCE/SEI 7, as referenced through Section 5.2.3 of ACI 562.

When designing a repair of an existing member or structure, the LDP can use the flowchart presented in Fig. 5.1 as a guide to determine the loads, factored load combinations, and strength reduction factors for the repair design. If ACI 562 is part of the design-basis code for assessment and rehabilitation design, then the strength reduction factors of Section 5.3 of ACI 562 apply. The project examples included within this guide illustrate how Fig. 5.1 is used.

5.4—Strength reduction factors for assessment

For assessment of a member, the design strength reduction factors, ϕ, in Section 5.4.1 of ACI 562 are used when the design-basis code references ACI 318-19. The higher strength reduction factors in Section 5.4.1 of ACI 562 may be used when the as-built member dimensions and reinforcement location are determined as part of the structural assessment, as defined in Chapter 6 of ACI 562, and material properties are determined per Section 6.3.5 of ACI 562. These increased strength reduction factors are consistent with those provided in Chapter 27 of ACI 318-19 and are justified by the improved reliability due to the use of accurate field-obtained material properties and actual in-place dimensions. If the increased strength reduction factors of Section 5.4.1 of ACI 562 are used, the assessment should be performed using the factored load combinations specified in ASCE/SEI 7, per Section 5.2.3 of ACI 562. Project Example 3 provides a specific example of using the strength reduction factors of Section 5.4 of ACI 562.

When evaluating a member using material properties based on Tables 6.3.1a through 6.3.1c of ACI 562, the strength reduction factors should not be greater than the factors in Section 5.3 in ACI 562. If the material properties are estimated based on Tables 6.3.1a through 6.3.1c of ACI 562, there is still some uncertainty regarding the actual material properties, which is reflected in the lower strength reduction factors in Section 5.3 of ACI 562.

When performing an assessment of an existing member or structure, the LDP can use the flowchart presented in Fig. 5.4 as a guide to determine the loads, factored load combinations, and strength reduction factors for the assessment. If ACI 562 is part of the design-basis code, then the strength reduction factors of Section 5.4 of ACI 562 apply. Each of the project examples included within this guide illustrate how Fig. 5.4 is used.

For both assessment and rehabilitation design, Sections 5.3.4 and 5.4.3 of ACI 562 specify the same load reduc-

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tion factor of 0.6 for all plain structural concrete members independent of the member's behavior, flexure, compression, shear, or bearing, because plain concrete failures are usually brittle.

5.5—Additional load combinations for structures rehabilitated with external reinforcing systems

Section 5.5.1 of ACI 562 is used to determine the minimum required strength of an existing structure that will be repaired with an external reinforcing system, including, but not limited to, bonded fiber-reinforced polymer (FRP), bonded or anchored steel plates, or external post-tensioning systems. The minimum required strength, expressed in ACI 562 Sections 5.5.2 and 5.5.3 equations, ensures sufficient strength of members with external reinforcing systems when subject to damage by vandalism or fire and elevated temperatures that may limit the performance of the external reinforcing system. The LDP may specify protection to exposed reinforcing systems to resist fire, collision, and vandalism. Repaired members or structures with external reinforcing systems exposed routinely to elevated temperatures are not addressed in this chapter and the LDP is referred to Section 7.9 of ACI 562.

The LDP needs to verify that the strengthened structure or members have at least the capacity to exceed the effects of the factored load combinations specified in ACI 562, Sections 5.5.2 and 5.5.3. The factored load combinations in Section 5.5.2, Eq. (5.5.2a) and (5.5.2b), are intended to minimize the risk of overload or damage to the existing unstrengthened members in the case where, during normal operating conditions, the non-mechanically bonded external reinforcing system is damaged. This would give the owner ample time to be alerted of the damage and allow the structure to remain in service until the damaged external reinforcing system is repaired.

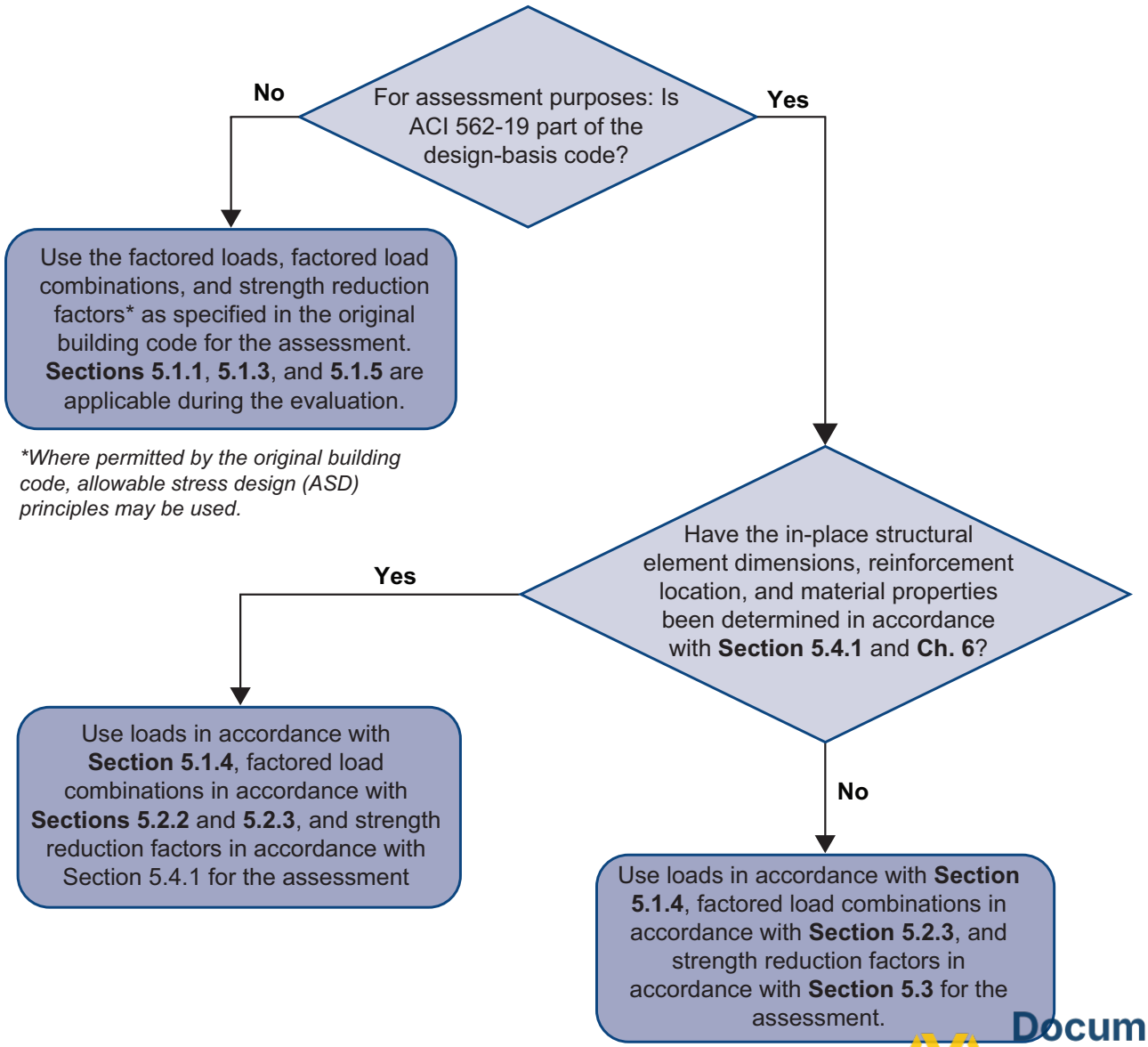


Fig. 5.4—Flowchart for determination of loads, factored load combinations, and strength reduction factors for assessment.

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$$\phi R_n \geq 1.1D + 0.5L + 0.2S \quad (5.5.2a)$$

$$\phi R_n \geq 1.1D + 0.75L \quad (5.5.2b)$$

where D, L, and S are the dead, live, and snow loads, respectively, as defined in Chapter 5 of ACI 562; ϕ is the strength-reduction factor obtained from ACI 562 Section 5.3 or 5.4; and R_n is the nominal strength of the structure without the external reinforcement. These equations also serve as a limit on the amount of strengthening that can be resisted by the external reinforcement.

Repaired structures with external reinforcement need to satisfy Eq. (5.5.3) without considering the added external reinforcement to ensure that the repaired member has sufficient strength during a fire event.

$$\phi_{ex} R \geq (0.9 \text{ or } 1.2)D + 0.5L + 0.2S \quad (5.5.3)$$

where $\phi_{ex} = 1.0$; and R is the nominal resistance of the structure, calculated using the probable material properties during a fire event, determined based on the required fire rating duration. The dead load factor of 0.9 governs when the dead load effect reduces the total factored loads effect. The load effect from fire is a secondary effect caused by restraint to thermally induced expansion, resulting in thrust and moment redistribution. Except for simple span members, the analysis of a member exposed to fire should be based on a design fire scenario and its effect on the behavior of the overall structure. The analysis will require accurate modeling of numerous parameters, including fire characteristics, boundary conditions, connection fixity, heat transfer, and deformations. A broader discussion regarding the effect of fire on buildings can be found in NIST Technical Note 1681 (National Institute of Standards and Technology).

Guidance regarding the reduced strength of concrete under exposure to elevated temperature is provided in ACI 216.1.

The factored load combination given in ACI 562 Section 5.5.3 is based on provisions contained in ASCE/SEI 7. As indicated in the commentary of ASCE/SEI 7, provisions regarding loading from extraordinary events are not intended to replace traditional approaches to ensure fire endurance (that is, fire ratings specified in model building codes based on ASTM E119 using full service loads). However, the provisions of ASCE/SEI 7, and therefore the factored load combination of ACI 562 Section 5.5.3 might be determined by the authority having jurisdiction to be acceptable based on the alternative methods of design and construction provision contained in model building codes. Therefore, the LDP responsible for repair of the structure should consult



New post-tensioning cables installed on parking deck repair project

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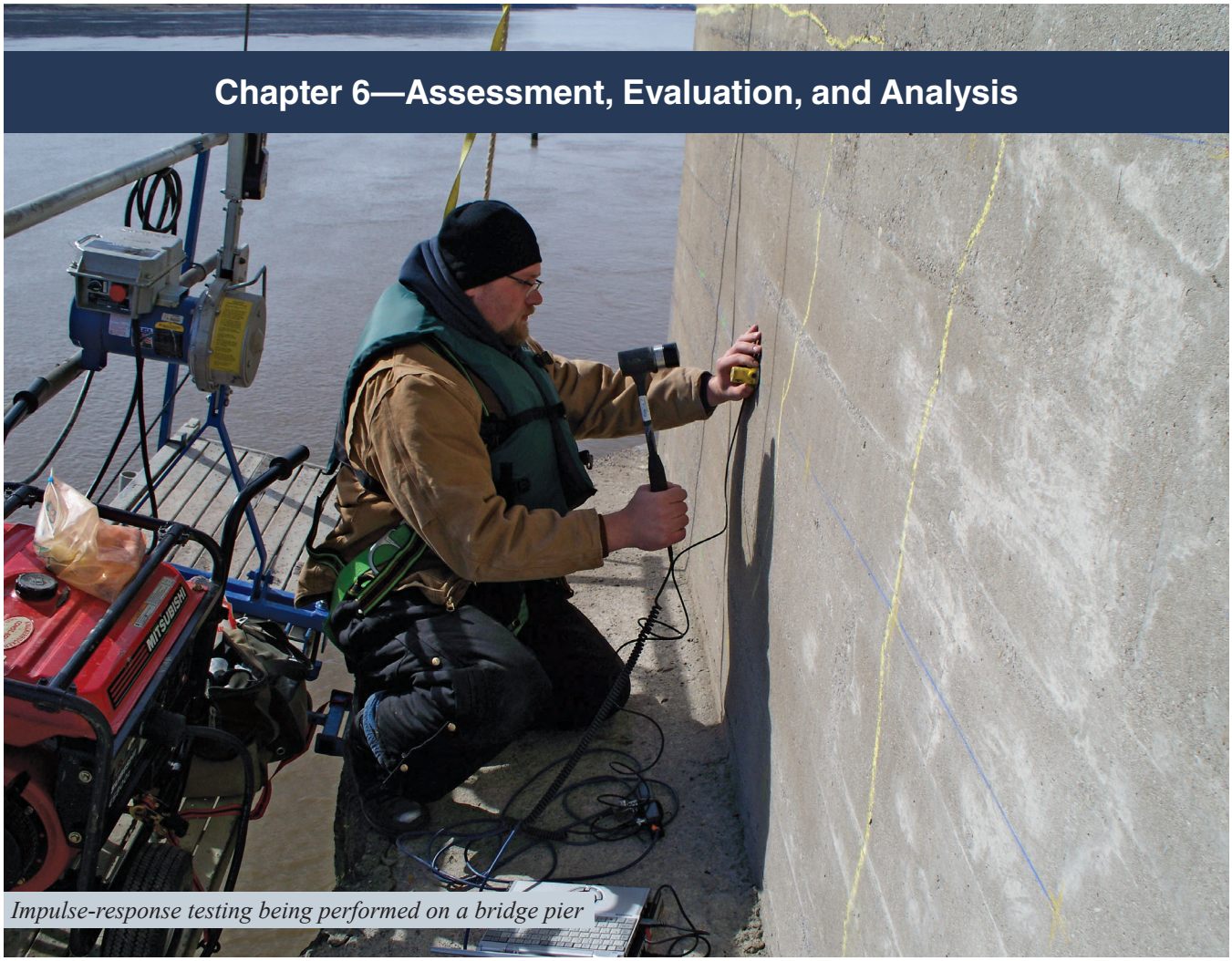
Hydrodemolition concrete removals on waffle floor slab

with involved parties to determine if use of ACI 562 Section 5.5.3 is a viable approach for satisfying the applicable building code as relates to fire resistance. A sustained live load, as in libraries or warehouses, or a live load exceeding 100 lb/ft^2 (488 kg/m^2) will receive an increased live load factor of 1.0 in Eq. (5.5.2a), (5.5.2b), and (5.5.3). When considering the effect of fire on a structure, the loads associated with firefighting operations such as additional water surcharge and wetted materials need to be included in the analysis. The commentary to ACI 562 recommends a live load of 20 lb/ft^2 to account for wetted material during firefighting operations.

The provisions of Sections 5.5.2 and 5.5.3 of ACI 562 are not applicable if ACI 562-19 is not part of the design-basis code. The strength reduction factors in Section 5.3 or 5.4 of ACI 562 should be used with the factored loads provided in Eq. (5.5.2) and (5.5.3) of ACI 562. Project Example 5 illustrates the application of Section 5.5 of ACI 562.

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Chapter 6—Assessment, Evaluation, and Analysis



Impulse-response testing being performed on a bridge pier

Overview

Chapter 6 of ACI 562 provides requirements for conducting a structural assessment of existing concrete members, portions of a structure, or entire structures. The provisions are presented in the order in which a structural assessment would normally be conducted, including provisions for conducting structural evaluation, obtaining and determining material properties, and performing structural analyses. Strength assessment by load testing is also addressed. The assessment method and major tasks that are provided in Chapter 6 and Section 1.7 of ACI 562 are summarized in Fig. 6.

6.1—Structural assessment

A structural assessment consists of documenting the current condition of the structure or member, including the as-built construction and any distress and deterioration. Several assessment tools and approaches are available for use at the judgment of the LDP, including document review, visual survey, material sampling, laboratory evaluation, and destructive and nondestructive testing. A number of publications, including those discussed in ACI 562 Section, R6.1.1, and the related ASTM standards listed in the textbox, are available for guidance and specific aspects of performing assessments of existing concrete structures. Section 6.1 of ACI 562 describes that structural assessment must be performed if required by ACI 562, 1.7.5. It consists of structural evaluation and, if necessary, structural analyses. The goal of a structural assessment is to determine if members or portions of the structure in their current condition have adequate strength and meet serviceability requirements. Structural assessment covers the following three steps:

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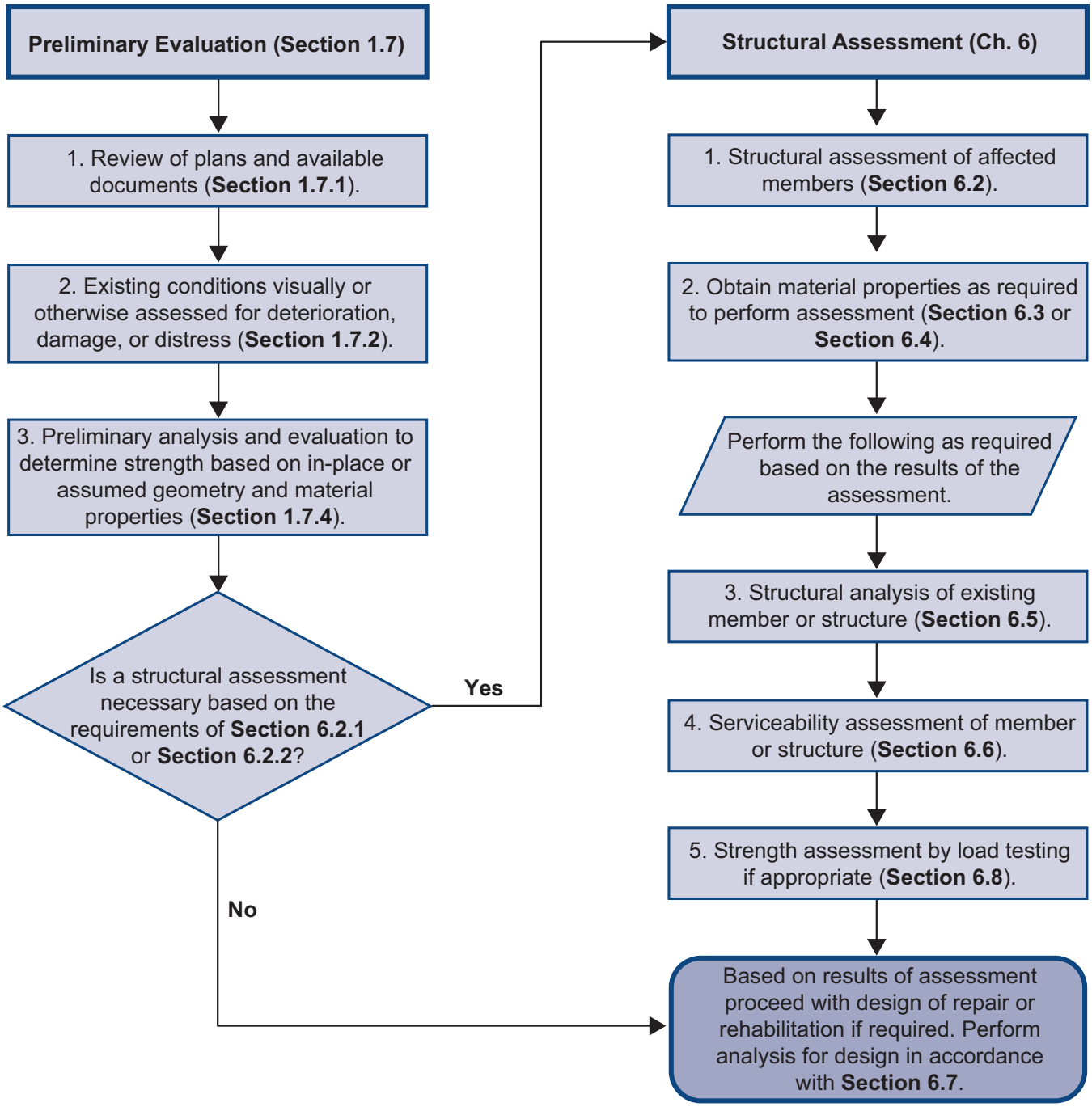


Fig. 6—Summary of assessment methodology of ACI 562.

1. An investigation to establish the in-place condition of the structure in the work area, including environment, geometry, material strengths, reinforcing steel sizes and placement, and signs of distress
2. An evaluation to define the causes of distress, goals of the rehabilitation, and criteria for selection of rehabilitation solution(s)
3. Development of appropriate repair strategies, if required

6.2—Investigation and structural evaluation

If the strength of a structure is not in question or there is no reason to suspect structural issues, a structural assessment is not necessary when making improvements to address strength, serviceability, durability, and fire protection requirements. If a preliminary evaluation (ACI 562, 1.7) determines that there is reason to question the strength or behavior of one or more members of the structure, a structural evaluation

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Is a structural assessment always required?

ACI 562 does not require the LDP to perform a detailed structural assessment in cases where the capacity of the structure is known. Consider the following scenarios when a structural assessment would not be required:

Scenario No. 1: A beam at the lower level of a recently constructed shopping center is impacted by an errant vehicle. The plans and available documents were reviewed by the LDP as part of the preliminary evaluation and indicate the beam was designed to satisfy the required loading. Based on the preliminary evaluation performed by the LDP, the damage is limited to cracking and spalling of the cover at a single beam location. There are no visible signs of damage to the existing reinforcement. Based on the results of the preliminary evaluation, the LDP may proceed with the design of the repair without performing a more detailed structural assessment or structural analysis of the existing beam or structure.

Scenario No. 2: An LDP is retained to review the in-place condition of a parking garage that was opened approximately 5 years ago and provide documents for repairs or maintenance. During the preliminary evaluation, the owner shares that the manager has recently started using de-icing salts after receiving complaints regarding ice on the ramps and parking areas. In addition to replacing failed sealant joints and performing other routine maintenance, the LDP is considering a coating or sealer for durability considerations of the salt-exposed deck. The preliminary evaluation performed by the LDP indicates that the garage is in otherwise good structural condition with no signs of deterioration or structural deficiency. The LDP may proceed with the coating system design and durability repairs without performing a structural assessment or structural analysis of the existing deck or garage. In this instance, additional assessment (for example, material sampling to determine chloride levels in the deck) may be considered by the LDP, but is not required based on ACI 562 Sections 6.1.2 and 6.1.3. A chain drag survey of the deck might also be considered prior to performing any coating repairs.

Use of lower-bound default material properties

While in most cases it is conservative to use the lower-bound values for concrete compressive strength and steel reinforcement yield strength, the LDP should use engineering judgment when selecting historic property values from Tables 6.3.1a through 6.3.1c in ACI 562. In some instances, assuming higher strengths may be more conservative. For example, when evaluating a beam column joint, ACI 318-19, 18.7.3.2, requires the net moment strength of the columns be greater than 6/5 the net moment strength of the beams, which is meant to ensure inelastic deformations occur primarily at the beams instead of the columns during a seismic event. When performing this analysis, it may be more conservative to assume higher yield strengths in the beam reinforcement when evaluating the joint.

should be performed (ACI 562, 6.2.1). The licensed design professional (LDP) may question the capacity of a member or strength of its constituent materials if the member exhibits signs of deterioration, such as spalling, corrosion, or distress, such as wide cracking. As an example, loss of concrete cross section in a compression member or severely corroded tension reinforcement in a beam would likely affect capacity and thus trigger a structural evaluation and analysis of the affected member. The capacity may also be questioned if there is reason to believe the in-place geometry or reinforcement is incorrect. The structural evaluation may be limited to the area identified during the preliminary evaluation; however, if repairs are required on a member, the LDP should determine if an assessment is required on similar members (ACI 562, 6.2.3). If the structural evaluation conducted as part of this assessment determines that the strength of the structure is in fact not in question, a structural analysis is not required (ACI 562, 6.2.1 and 6.2.2). The Project Examples illustrate various scenarios for determining if a structural assessment is necessary.

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Useful references for performing evaluations of existing concrete structures

The following standards from ASTM International may provide guidance for performing evaluations of existing concrete structures.

- ASTM C42/C42M, "Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete"
- ASTM C597, "Standard Test Method for Pulse Velocity Through Concrete"
- ASTM C803/C803M, "Standard Test Method for Penetration Resistance of Hardened Concrete"
- ASTM C805/C805M, "Standard Test Method for Rebound Number of Hardened Concrete"
- ASTM C856, "Standard Practice for Petrographic Examination of Hardened Concrete"
- ASTM C876, "Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete"
- ASTM C1383, "Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Imapct-Echo"
- ASTM C1740, "Standard Practice for Evaluating the Condition of Concrete Plates Using the Impulse-Response Method"
- ASTM D4580/D4580M, "Standard Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding"
- ASTM D6432, "Standard Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation"

The LDP needs to determine the nature of concerns with the as-built construction or the structural implications of distress and deterioration. The structural assessment should then be tailored to obtain information so that these concerns can be evaluated and, if necessary, a structural analysis performed. While there are commonalities between many structural assessments, it is not unusual for unique information to be required to evaluate specific concerns. If an analysis is to be performed, the structural assessment should include, per ACI 562, 6.2.4, documentation of existing conditions including any construction deficiencies or deterioration as required for the analysis which, as a minimum, per ACI 562, 6.2.5, includes the following:

a. As-measured structural section properties and dimensions
b. The presence and effect of any alterations to the structure
c. Load, occupancy, or usage changes that are different from the original design

6.3—Material properties

Determining the material properties of an existing concrete member or structure is critical to performing a structural analysis. ACI 562 Section 6.3 describes the requirements and various methods for obtaining material properties. When required by ACI 562, concrete compressive strength and steel reinforcement yield strength must be determined (ACI 562, 6.3.2). The concrete compressive strength and steel reinforcement yield strength used for analysis can be obtained by one of three methods (ACI 562, 6.3.3):

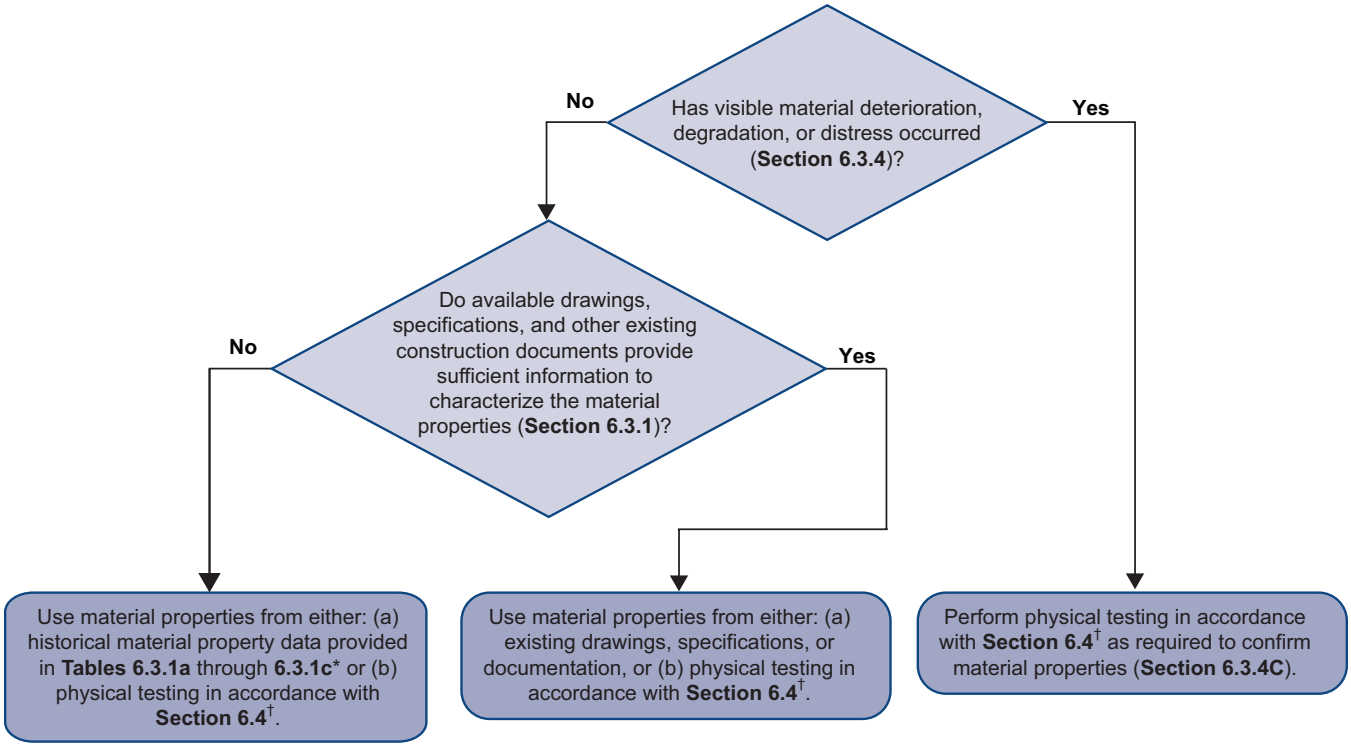
a. Material properties based on historical information (ACI 562, Tables 6.3.1a through 6.3.1c)
b. From available design drawings, specifications, or previous testing documentation (ACI 562, 6.3.4)
c. Physical testing of in-place or sampled materials (ACI 562, Section 6.4)

Figure 6.3 summarizes the process for determining material properties in accordance with ACI 562.



Load test being performed

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* If data is not given in either Table 6.3.1b or 6.3.1c, the historic default value for yield strength should be taken as 27,000 psi (185 MPa) (Section 6.3.6).
† Locations and numbers of material samples should be defined by the LDP (Section 6.3.5).

Fig. 6.3—Summary of process to determine material properties in accordance with ACI 562, 6.3.

When dealing with existing structures, previous drawings, specifications, or test reports are often unavailable. Furthermore, obtaining and testing material samples may not be possible or desirable for a number of reasons. For example, destructive sampling is often undesirable in historic structures. Other times, accessibility or building operations may make sampling difficult or costly to the owner. Accordingly, ACI 562 Tables 6.3.1a through 6.3.1c provide default historical data for use during the structural analysis. These tables include concrete material properties from 1900 to present and steel reinforcement data from 1911 to present. When the steel grade is unknown, the lowest grade of reinforcement for a given historic period is required to be used (ACI 562, 6.4.4). If the historic data for the reinforcement is not included in the tables, a lower-bound yield strength of 27,000 psi (185 MPa) is required to be used (ACI 562, 6.3.6). In some cases, it may be possible to determine the grade of reinforcement based off the bar markings from original fabrication. The Concrete Reinforcing Steel Institute (2010) has information available regarding current reinforcing bar marking sequences, as well as markings used with historical reinforcement. The Wire Reinforcement Institute (2014) has information available regarding historical data on wire, triangular wire fabric mesh and welded wire reinforcement. The material properties in the tables are lower limits and may be conservative for many structures. More accurate material properties can be obtained by sampling and testing the actual concrete and steel.

In general, ACI 562 permits the use of material properties provided in the original construction documents or material test reports, except in cases where visible material deterioration has occurred (ACI 562, 6.3.4). In cases where material degradation may have occurred, such as alkali-silica reaction, sulfate attack, delayed ettringite formation, freezing-and-thawing damage, or reinforcement corrosion, additional material testing may be required to verify the current material properties for the purpose of assessing the effects of material degradation on strength and durability.

The various approaches described in ACI 562 Section 6.3 provide flexibility to the LDP in determining the material properties of existing construction. When material properties are determined by material sampling and testing and the as-built element dimensions and reinforcement location are determined, the LDP can take advantage of higher strength reduction factors shown in ACI 562, 5.4.1. Example 6.1 highlights the various approaches to determining material properties and the potential benefit when higher strength reduction factors can be used.

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Example 6.1—Methods for determining material properties

Background

New mechanical equipment is to be installed within the attic of a historic academic building constructed in 1930. The concrete framing that supports the attic space consists of a concrete slab with integral inverted T-beams. The original construction documents are available and show that the reinforcing for the 6 in. (150 mm) wide by 12 in. (300 mm) tall beams consist of two 5/8 in. (16 mm) deformed diameter bars at top and bottom. No material properties are indicated on the construction documents.

Evaluation

The LDP is retained by the owner to evaluate the capacity of the beams to support the loading from the new mechanical equipment. ACI 562 is applicable, as described in ACI 562, 1.1.2. In accordance with ACI 562, 6.2.5, the LDP measures section dimensions and confirms that the as-built member geometry agrees with the construction documents. The LDP also verifies the quantity and cover depth to the reinforcing bars using a concrete cover meter (pachometer).

The existing documents do not provide sufficient information to characterize the concrete compressive strength or the steel reinforcement yield strength, which are required for the structural analysis.

Historic values

As an initial check, the LDP uses the historical data from Tables 6.1a and 6.1b (Tables 6.3.1a and Table 6.3.1b, respectively, in ACI 562) to perform an analysis of the existing structure with its current loading configuration. Based on the tables, a concrete compressive strength of 2000 psi (14 MPa) is used for the analysis. A default yield strength of 33,000 psi (230 MPa) is used for the steel reinforcement based on the age of construction and the fact that no information is available regarding the grade of steel.

Based on these values and the strength reduction factors of ACI 562, 5.3.2, a demand-capacity ratio of 0.90 was calculated for the existing configuration, indicating the strength of the existing member is adequate for the current loading. When the additional loading for the new mechanical equipment is considered, however, the controlling demand-capacity ratio of the beam increases to 1.27, indicating that the beams require strengthening. For the analysis using historic values, the strength

Table 6.1a—Default compressive strength of structural concrete, psi (MPa)* (after ACI 562 Table 6.3.1a)

Time frame	Footings	Beams	Slabs	Columns	Walls
1900-1919	1000 (7)	2000 (14)	1500 (10)	1500 (10)	1000 (7)
1920-1949	1500 (10)	2000 (14)	2000 (14)	2000 (14)	2000 (14)
1950-1969	2500 (17)	3000 (21)	3000 (21)	3000 (21)	2500 (17)
1970-present	3000 (21)	3000 (21)	3000 (21)	3000 (21)	3000 (21)

*Note: Adopted from ASCE/SEI 41-13.

Table 6.1b—Default tensile and yield strength properties for steel reinforcing bars for various periods, psi (MPa)* (after ACI 562 Table 6.3.1b)

		Structural†	Intermediate†	Hard†				
	Grade	33 (230)	40 (280)	50 (345)	60 (420)	65 (450)	70 (485)	75(520)
	Minimum yield, psi (MPa)	33,000 (230)	40,000 (280)	50,000 (345)	60,000 (420)	65,000 (450)	70,000 (485)	75,000 (520)
Year	Minimum tensile, psi (MPa)	55,000 (380)	70,000 (485)	80,000 (550)	90,000 (620)	75,000 (520)	80,000 (550)	100,000 (690)
1911-1959		X	X	X	—	X	—	—
1959-1966		X	X	X	X	X	X	X
1966-1972		—	X	X	X	X	X	—
1972-1974		—	X	X	X	X	X	—
1974-1987		—	X	X	X	X	X	—
1987-present		—	X	X	X	X	X	—

Note: Adopted from ASCE/SEI 41-13

* An entry of X indicates the grade was available in those years. †The terms "structural," "intermediate," and "hard" became obsolete in 1968.

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reduction factors for flexure and shear were 0.90 and 0.75, respectively.

Material testing

Given the outcome of the analysis using historical properties, the LDP recommends a material sampling program to better determine the actual material properties. Samples were obtained, tested, and the results evaluated in accordance with Section 6.4 of ACI 562. Core sampling and testing are to be performed in accordance with ASTM C42/C42M. The ASTM procedure provides a standard moisture conditioning protocol for the concrete core samples and a correction for core length to diameter ratio. For situations when the core samples do not satisfy ASTM C42 requirements, the procedure in ACI 214.4R can be followed. The equivalent concrete strength (f_{ceq}) was determined per ACI 562 Eq. (6.4.3.1), and the equivalent yield strength as determined per ACI 562 Eq. (6.4.6), using the following material properties:

$\overline{f}_c$ (average) = average core strength

f_{ceq} = equivalent specified concrete strength per ACI 562 Eq. (6.4.3.1)

$$f_{ceq} = 0.9\overline{f}_c\left[1-1.28\sqrt{\frac{(k_cV)^2}{n}+0.0015}\right] \quad (6.4.3.1)$$

f_y (average) = average steel yield strength value from tests

f_{yeq} = equivalent yield strength of steel reinforcement per ACI 562 Eq. (6.4.6)

$$f_{yeq} = (\overline{f}_y - 3500)\exp(-1.3k_sV) \quad (6.4.6, \text{in.-lb})$$

$$f_{yeq} = (\overline{f}_y - 24)^{(-1.3k_sV)} \quad (6.4.6, \text{SI})$$

k_c = concrete coefficient of variation modification factor per ACI 562 Table 6.4.3.1

k_s = steel coefficient of variation modification factor per ACI 562 Table 6.4.6

n = number of sample tests

V = coefficient of variation determined from testing

Results from the use of Eq. (6.4.3) and (6.4.6) in ACI 562 for this scenario are presented in Table 6.1c and 6.1d.

The material property test results yield an equivalent specified strength for the concrete of more than twice the historical value and a comparable equivalent yield strength for the steel to the historical value. Because the material properties were determined in accordance with ACI 562, 6.3.5, the LDP can take advantage of increased strength reduction factors per ACI 562, 5.4. Using the material property test results and increased strength reduction factors results in a demand-capacity ratio of 1.06 for the beam when considering the new mechanical equipment. The strength reduction factors for flexure and shear were 1.0 and 0.80, respectively.

Rather than proceed with a design to strengthen the beams, the LDP elects to collect two more samples for yield strength testing of the reinforcement. The additional samples will improve the coefficient of variation modification factor.The revised steel reinforcement testing results were calculated and are shown in Table 6.1e.

The corresponding demand-capacity ratio of the beam reduces to 0.99 based on the revised testing results for the steel reinforcement. Thus, the beams satsify the strength requirement for the new mechanical equipment.

Table 6.1c—Concrete core results based on ACI 562 Eq. (6.4.3.1)

Variable	Results
n	8
$\overline{f}_c$(average)	6218 psi (42.9 MPa)
V	0.15
k_c	1.10
f_{ceq}	5095 psi (35.1 MPa)

Table 6.1d—Steel reinforcement results based on ACI 562 Eq. (6.4.6)

Variable	Results
n	4
f_y (average)	42,225 psi (291.1 MPa)
V	0.05
k_s	2.34
f_{yeq}	33,261 psi (229.3 MPa)

Table 6.1e—Revised steel reinforcement results based on ACI 562 Eq. (6.4.6)

Variable	Results
n	6
f_y (average)	42,860 psi (295.5 MPa)
V	0.04
k_s	1.69
f_{yeq}	36,049 psi (248.5 MPa)

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6.4—Test methods to determine or confirm material properties

ACI 562 Section 6.4 presents requirements for test methods to obtain in-place mechanical properties of five different types of materials: concrete (ACI 562, 6.4.2 and 6.4.3), steel reinforcement (ACI 562, 6.4.4 through 6.4.6), connector steel (ACI 562, 6.4.7), embedded structural steel (ACI 562, 6.4.8), and prestressing steel reinforcement (ACI 562, 6.4.9). ACI 562 references ASTM C42/C42M and ASTM C823/C823M for concrete sample removal and testing, ASTM A370 for testing yield and tensile strength of steel reinforcement and structural steel, and ASTM A1061/A1061M for testing prestressing reinforcement. Care should be taken in sampling prestressing steel as the steel may still be under some tension and significant energy can be released when the steel is cut. Nondestructive testing may be used to locate existing reinforcement and other embedded material in existing concrete members. This is critical when taking core samples from existing concrete members as the presence of reinforcement or other foreign material such as conduits or wood may adversely affect the strength test results. Core samples should be similar in length-to-diameter ratio as standard strength cylinders, thus the recommended maximum length-to-diameter ratio of 2 to 1. Cores with length-to-diameter ratio of less than 1 are unreliable, yield erroneous test results, and should be rejected. The minimum acceptable core diameter per ASTM C42/C42M is 3.70 in. (94 mm). Smaller-diameter cores are likely to have more variability and a lower strength (Bartlett and MacGregor 1994b).

ACI 562 provides latitude for the LDP to determine the appropriate material sampling and testing program for each particular project, while also providing minimum requirements for sampling, testing, and calculating the equivalent specified strength of the various materials. The equations provided for calculating the equivalent specified strength (Eq. (6.4.3.1), (6.4.6), and (6.4.8) in ACI 562) reflect the uncertainty of sample standard deviation for a small sample size. The coefficient of variation modification factors (k_c and k_s) provide a means to effectively reduce the equivalent specified strength due to the smaller sample sizes. This provides additional flexibility to the LDP to determine an appropriate sampling program. As a minimum, two concrete samples are required to determine k_c and three steel samples are required to determine k_s. The equivalent specified strength obtained from Eq. (6.4.3.1) can be used in strength equations with the strength reduction factors from Chapter 5.

ACI 562, 6.4.3.2, permits the use of nondestructive testing methods for assessment of in-place concrete compressive strength provided that a valid correlation of the nondestructive test method is established between the nondestructive results with data obtained from testing representative core samples.

ACI 228.1R provides information for developing statistical correlations between nondestructive testing and core test results and the following nondestructive testing methods:

a. ASTM C597, "Standard Test Method for Pulse Velocity Through Concrete"
b. ASTM C803/C803M, "Standard Test Method for Penetration Resistance of Hardened Concrete"
c. ASTM C805/C805M, "Standard Test Method for Rebound Number of Hardened Concrete"
d. ASTM C873/C873M, "Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds"
e. ASTM C900, "Standard Test Method for Pullout Strength of Hardened Concrete"
f. ASTM C1074, "Standard Practice for Estimating Concrete Strength by the Maturity Method"

If welding of reinforcement is required as part of repair or rehabilitation, ACI 562 requires that the carbon equivalent of the existing reinforcing steel be calculated prior to welding, as required by AWS D1.4/D1.4M. In general, the lower the carbon equivalent, the more weldable the steel. Steel with higher carbon equivalent is susceptible to cracking in the heat affected zone. Most common reinforcing bars used in construction are ASTM A615/A615M and ASTM A706/A706M. Welding of ASTM A615 reinforcing bars should be approached with caution, as no provisions are included in AWS D1.4 to enhance its weldability; however, ASTM A706 reinforcing bars are manufactured with a chemical



Preparation for beam section enlargement to add shear capacity to the structural member



Local zone reinforcement installed within the post-tensioned anchorage zone

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Unique analysis considerations

Numerous situations are encountered with existing structures that require unique analysis considerations, both for the existing structure and the design of repairs. ACI 562 specifies that the LDP consider the various analysis aspects of each situation. Although not intended to be comprehensive, the following scenarios present unique analysis considerations for various cases:

- Spalling has occurred at the top side of a continuous girder, resulting in loss of bond at some of the top longitudinal reinforcing steel. The damage may have caused loss of development in the reinforcing steel and additional structural demand in other portions of the existing structure as a result of redistribution of the negative moments.
- Full-depth slab repair is required to address top and bottom reinforcing bar corrosion in a parking deck. During repairs, the unbraced length of the adjacent columns could significantly increase and temporary bracing of the column may be required.
- Alterations as a result of change of occupancy will include new openings in a two-way slab. The demolition for the alteration may result in redistribution of existing moments and shear forces in the remaining structure.
- Damage, deterioration, or repairs of prestressed concrete structure that may have resulted or will result in prestressing force release (reference ACI 562, 7.6.4). Repairs that affect the development of prestressing steel reinforcement may reduce member capacity.
- Concrete spalling has occurred on a column. The concrete removal during repair may result in redistribution of internal forces that are locked in. The strength of such columns should be considered in accordance with provision Section 6.5.4 in ACI 562.

composition that is enhanced for welding. ASTM A706 reinforcing bars are typically stamped with a W in the deformation to indicate the bar is weldable. Table 5.2 in AWS D1.4 defines the required carbon equivalent for various size reinforcement. If the carbon equivalent is not less than the value indicated in Table 5.2 of AWS D1.4, then the bars should be preheated as required by AWS D1.4 to preclude the formation of microcracking in the heat affected zone.

6.5—Structural analysis of existing structures

Section 6.5 of ACI 562 specifies the minimum requirements for performing a structural analysis of existing structures. The goal of the analysis is to accurately model the current condition of the structure as a whole and the member under assessment in particular. This includes accounting for the as-built geometry and existing material properties, as discussed in ACI 562, 6.2 and 6.3, respectively. Although the specific method of analysis is left to the judgment of the LDP, ACI 562 requires that the analysis consider material degradation, bond loss, redistribution of forces, modified load paths, and previous repairs or modifications (ACI 562, 6.5.4 through 6.5.6). Material degradation and corrosion of reinforcement often lead to spalling and loss of concrete bond. Any analysis of the existing structure should consider the current state of the structural system, included any associated bond loss. The LDP is cautioned that member deterioration or damage may result in redistribution of internal forces that is different than that assumed in the original design. The redistribution of forces may be determined by analysis or testing.

6.6—Structural serviceability

ACI 562 requires that serviceability concerns such as unusual cracking, excessive deflections, floor levelness, vibrations, water infiltration or leakage, and excessive heat exposure be evaluated when identified (ACI 562, 6.6.1). Serviceability concerns may be related to the design strength of a member. If this occurs, the member should be evaluated as described by ACI 562 Chapter 6. A service-load-level analysis as described in ACI 562, R6.5.1, may also be required to evaluate deflections and expected crack size and distribution.

The LDP should investigate the effect of floor levelness, vibrations, and deflections on the structural performance and to determine if it is acceptable to the owner and users of the structure. These criteria should be established for the structure based upon the intended use of the structure and should consider the existing material properties, existing geometry of the members, and the condition of the existing members.

6.7—Structural analysis for repair design

Section 6.7 of ACI 562 specifies the minimum requirements for the structural analysis used for repair design. As with performing a structural analysis of existing structures, there are several unique considerations that are not typically considered during design of new members or structures. The provisions of ACI 562 are focused on requiring that the LDP consider the actual performance and behavior of the repaired system. These considerations include the sequence of the repair process, the variability of section properties, and the composite action (or lack thereof) in the repair and substrate. These provisions are presented in Sections 6.7.1 through 6.7.3 of ACI 562.

ACI 562, 6.7.4, requires several seismic considerations as part of the analysis for repair design. These provisions are focused on requiring that the seismic response of the repaired structure has been considered by the LDP. The particulars of seismic rehabilitation, including analysis, are not specifically prescribed in ACI 562, as these are addressed through reference to ASCE/SEI 41 and ACI 369R.

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6.8—Strength evaluation by load testing

For some structures, it may be difficult to document the as-built construction and the current conditions in sufficient detail to have confidence that a structural analysis reflects actual structural behavior with a reasonable degree of accuracy. Similarly, the effectiveness of proposed repairs may need to be confirmed. In such cases, load testing might be an option to determine if an existing structure requires repair and rehabilitation or to verify the adequacy or performance of repair and rehabilitation measures. ACI 562, 6.8, permits the use of load testing to supplement structural analysis or to demonstrate the strength of the original or repaired structure. ACI 562, 6.8.1, specifies that load testing needs to be in accordance with ACI 437.2, which establishes the minimum requirements for the test load magnitudes, load test procedures, and acceptance criteria applied to existing concrete structures. ACI 437.2 was developed specifically for use with ACI 562 and contains provisions for both a cyclic load test and a monotonic load test, which provides the LDP with flexibility in determining which procedure is best for a particular application. The load test procedure presented in Chapter 27 of ACI 318-19 presents a similar monotonic test procedure and acceptance criteria. The LDP may waive the deflection limit of $\ell_t/180$ set in ACI 437.2 when the tested member is not damaged by excessive deflections or when the residual deflection criteria is satisfied. If retesting is required because the member or structure failed the cyclic load test, the LDP can waive the deflection limit of $\ell_t/180$.

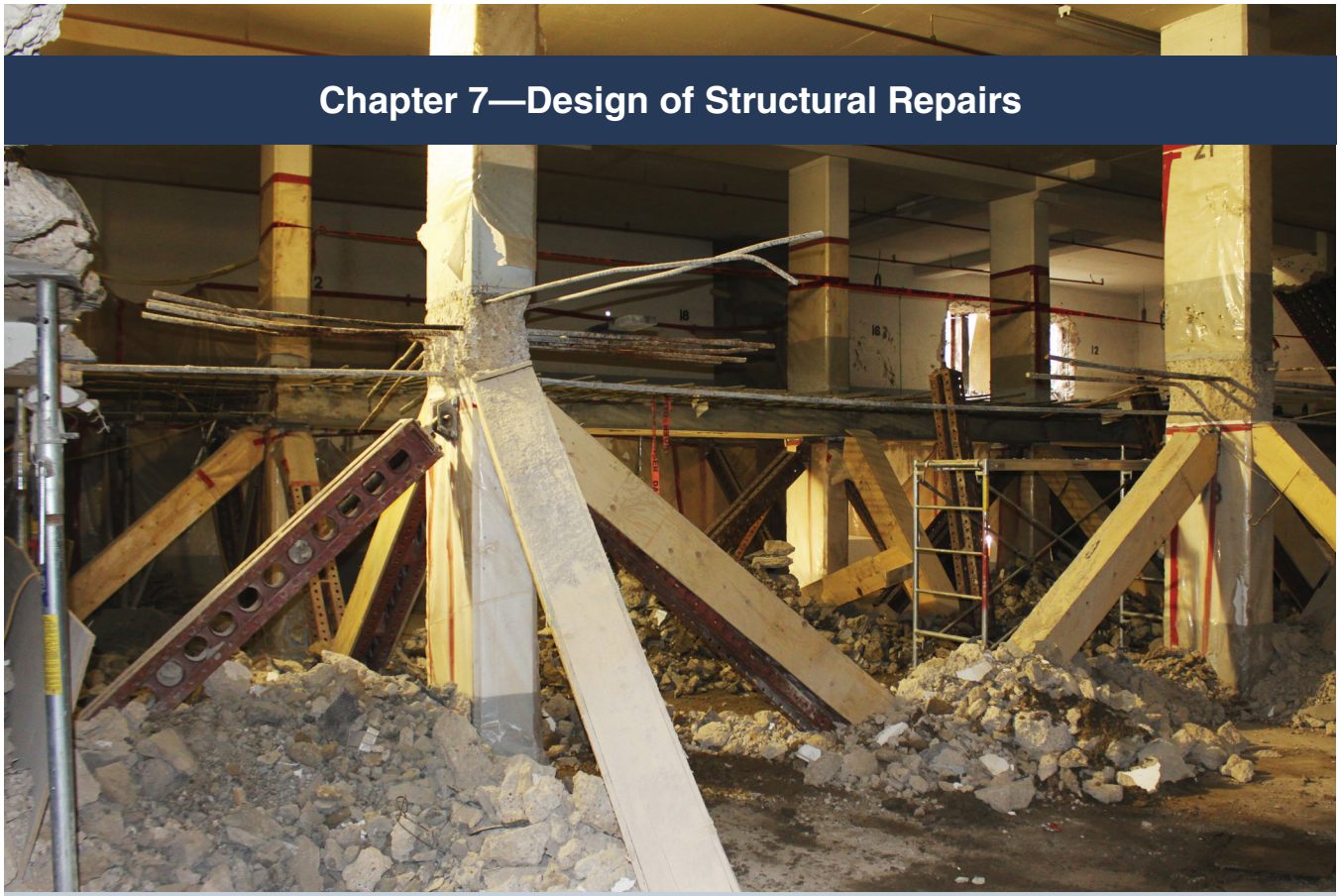
In some cases, in-place load tests in accordance with ACI 437.2 may not be practical or necessary. Accordingly, ACI 562, 6.8.5, permits the use of full or scale models to supplement the structural analysis. The LDP should document experimental model analysis results, interpret the results, and correlate the results with the in-place condition of the structure.

6.9—Recommendations

The structural evaluation performed on a member or structure are the basis for recommending whether the member or structure should be repaired or rehabilitated. If a member or structure needs to be repaired or rehabilitated, then the work should be performed in accordance with ACI 562.

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Chapter 7—Design of Structural Repairs



Steel bracing installed prior to concrete removals at core walls, columns, and perimeter walls (plywood sheeting was installed to protect steel members from damage during the demolition process)

Overview

The need for structural repairs is based upon the results of the preliminary assessment (ACI 562 Chapter 1) or, when required, a more in-depth structural investigation and assessment (ACI 562 Chapter 6). Design-basis code requirements for repair design are determined using ACI 562 Chapter 4 or Appendix A. The design and implementation of structural repairs and the performance of the repaired members and structure vary significantly from the design, construction, and performance of new members and structures. ACI 562 Chapter 7 specifies factors that need to be considered in the design of the structural repairs to achieve the intended performance of the repaired members and structures. The project examples that accompany this guide further illustrate the unique design considerations in the development of a structural repair program in accordance with ACI 562 Chapter 7.

7.1—General

Structural repairs need to be designed so that the repaired structure, including members and connections, have the required strength and serviceability specified by the design-basis code and ACI 562. A repaired section is considered to be the combination of the installed repair material(s) and the substrate material(s). Determination of the design capacity need to consider load factors, load combinations, and strength reduction factors in the design-basis code and ACI 562. Durability considerations are described in ACI 562 Chapter 8.

7.2—Strength and serviceability

The strength and serviceability behavior of existing concrete structures can be evaluated using information from the original design and construction. When deterioration is present, however, the strength and stiffness may no longer be adequately

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predicted using the assumptions from the original design. Deterioration and changes to member stiffness associated with repair work may result in the redistribution of internal forces to other portions of the member or to other members not anticipated by the original design. The deterioration may also cause inelastic behavior, with permanent deformations or cracking. As a result, load redistribution may increase forces and stresses in portions of members less affected by deterioration. This behavior should be carefully considered in the repair and serviceability design process.

While a structural repair is in progress, concrete may be removed from the structure or reinforcing steel bars may be unintentionally damaged or even cut during concrete removal or, in some instances, intentionally cut to achieve a desired outcome (for instance, when creating openings in slabs or walls). The result of concrete removal is a decrease in effective concrete section, which the licensed design professional (LDP) has to consider for the impact it may have on the member integrity both during and after the repair process. Concrete removal may also affect the development or lateral restraint of reinforcing bars, possibly resulting in a decrease in the effectiveness of the reinforcing steel. Damage to reinforcing bars during concrete removal may affect the bar capacities and may result in redistribution of the load effects into adjacent bars; cutting bars may also result in a redistribution of the load effects into adjacent bars. Thus, the repair process could result in further deformations and redistribution of internal forces. Dead load and in-service live loads acting on the structure during repair construction need to be supported by the remaining portions of the members and structure if shoring and bracing is not provided.





Fig. 7.1—Buckled vertical reinforcing bars due to a lack of lateral restraint caused by excessive concrete chipping.

Excessive concrete removal or damage or deterioration of reinforcing, particularly for compression members such as columns, could result in member distress or collapse. The stress in the remaining concrete could exceed the compressive strength of the concrete, resulting in crushing of the concrete. If the unbraced length of reinforcing bars in compression increases due to excessive concrete removal, one or more bars could buckle and lose capacity (Fig. 7.1). Contractors need to be made aware of the importance of concrete removal and reinforcing ties on the stability of compression members. As such, the LDP should determine a safe limit for concrete removal in terms of maximum depth, maximum surface area, maximum unsupported length of reinforcing bar, or some other measure. The LDP should also specify these limits and the monitoring requirements in the repair documents.

Unless measures, such as shoring, are taken before and during the repair process, the deformations and redistributed forces will remain locked into the sound portions of the structure. The LDP should consider the effect of these locked-in internal forces on the safety of the structure during repairs. Internal forces and deformations may be reduced in the sound portions of the members prior to beginning repairs by jacking, shoring, or bracing the members. Initial bracing and shoring may need to be adjusted to accommodate construction dead and live loads that can vary over the course of the repair process. Construction dead and live loads can be later transferred to the repaired members and other portions of the structure. These concepts are further explained in Chapter 9 of this guide.

In many repair programs, the sound portions of the existing members and structure will support most if not all the pre-repair and repair dead loads and, perhaps, some pre-repair and live loads during repairs. After the repair materials have cured and reached design strength, the repair should act compositely with the remaining portions of the existing structure in supporting subsequent superimposed dead and live loads.

Accordingly, ACI 562 Sections 7.2.1 and 7.2.2 require that the LDP develop repair design and construction procedures that consider the stiffness, loading, internal forces, and deformations of both the existing and repaired structure. The repair design needs to consider if the distribution of internal forces and deformations in the members and structure are significantly affected by the repair process and accommodate or alter the repair process accordingly. The effect of the repair process on the stiffness of the structure and member under repair should also be considered. ACI 562, 7.2.2, requires the repair design and construction procedures consider the loadings, the magnitude and redistribution of internal forces, and deformations of the existing and repaired structure.

7.3—Behavior of repaired systems

In some cases, repairs or strengthening of existing members or structures are performed by adding new structural members. ACI 562, 7.3.1, stipulates the minimum

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requirements for such systems. Per ACI 562, 1.3.5, new concrete members are to be designed in accordance with ACI 318-19. ACI 562 requires the repaired structure be designed to act compositely, with repaired and new members designed to share loads with the existing members and structure. ACI 562 also requires the force transfer between the new member and the existing structure to be considered in the repair design. The effect of the new member on the existing structure is to be evaluated and should not compromise the performance of the existing structural system.

In cases where existing members will be repaired or strengthened, ACI 562, 7.3.2, requires the LDP to account for force transfer between the repair section and the existing structure. Composite action between existing and new concrete can be achieved by bond, mechanical means, or a combination thereof. ACI 562 permits the use of ACI 318-19 for the design of force transfer between new and existing concrete. ACI 318-19 addresses bond between existing and new concrete in Section 17.5 and shear friction in Section 16.4. Furthermore, design for composite action between concrete and structural steel members is addressed in ANSI/AISC 360-10, Chapter I, and bond between concrete and fiber-reinforced-polymer systems is addressed in ACI 440.2R.

ACI 562 requires that repairs designed to resist structural loading (that is, structural repairs) must act compositely with the member or structure being repaired under all limit states. For example, repairs to columns should maintain full composite action under service and factored loadings. When repairs are only needed to improve the durability or aesthetics of a member, full composite behavior should be maintained as a minimum under service loads. In situations where a nonstructural repair could pose a life-safety concern, as might occur with an overhead or façade repair, the repair should consider composite behavior under both service and factored loadings or redundancy through supplemental means of restraint for loads in excess of service loadings.

7.4—Interface bond

Bond between the existing concrete substrate and the new repair material or overlay, is an essential component of successful, durable repairs. ICRI 210.3R discusses bond strength in repairs, and ICRI 310.2R focuses on various methods used to prepare concrete surfaces to achieve the desired performance of concrete repairs. ACI 318, 16.4, concentrates on the determination of the nominal shear strength at horizontal interfaces in composite members. ACI 562, 7.4.1 requires the evaluation of the interface stresses, shear, and tension across bonded interfaces between the overlay and the existing substrate.

Bond strength is influenced by the strength of the substrate concrete, the strength of the repair material, the quality of the surface preparation of the substrate concrete, construction procedures, characteristics of the repair materials, and time-dependent factors such as shrinkage of the concrete and variations in repair material properties with time.

7.4.1 *Strength of substrate concrete*—Substrate concrete with low strength may be the limiting factor for bond strength. If the substrate concrete has consistently low strength throughout its depth, removing more of the substrate concrete will have no effect on the achievable bond strength and a lower design bond strength may need to be used.

7.4.2 *Strength of repair material*—The compressive strength of the repair material is typically not a critical factor in determining the interface strength between the concrete substrate and the repair. Repair materials with a higher strength than the substrate concrete may not result in greater interfacial bond strength. The shear strength of a concrete section with a repair or overlay is influenced by the depth of the compression block in the section and the longitudinal tensile reinforcement ratio (ρ_s). In a study by Kim et al. (2016), the shear strength of composite beams made with combinations of a high-strength concrete material on either the tensile or compressive faces was examined. The study indicated the compressive strength of the overlay material did not affect the interface strength.

7.4.3 *Quality of surface preparation of substrate concrete and construction procedures*—The preparation of the substrate concrete is an important factor in the success of repair that affects bond strength and should result in a sound, clean surface with some surface profile and minimal microfracturing (bruising) of the substrate. Increased surface roughness of the substrate improves the shear bond strength between the existing substrate and added overlay. The construction method in which a surface is prepared affects the bond between the two layers. Improperly used concrete removal equipment may result in poor quality bond, delamination, or both. Abrasive, shot, and water blasting methods typically do not result in extensive bruising. The level of bruising damage to existing concrete is directly related to the preparation tools and methods used (Warner et al. 1998). The LDP must specify removal limits that may otherwise compromise the integrity and stability of the concrete member, if not set, and to prevent potential damage to embedded reinforcement or other embedded items. In general, the contractor determines methods and equipment to be used when removing or cutting of concrete is required, unless the LDP limits the weight of equipment that the contractor may use during the repair or strengthening operation. If removal methods produce bruised surfaces or microcracking of the prepared substrate, then the contractor must follow up with secondary removal/surface preparation methods to remove the bruised surface layer.

When considering which surface preparation technique will be best for a job, the LDP must balance the desired outcomes the owner is seeking with practical concerns, including:

a. Avoiding damage to the structure
b. Preventing any deterioration of reinforcements or the bond between bars and existing concrete
c. Ensuring the impact of the chosen method will not compromise the concrete's structural integrity

The advantages of proper surface preparation include:

a. Smoothing out rough spots
b. Addressing surface irregularities
c. Correcting edge curling

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