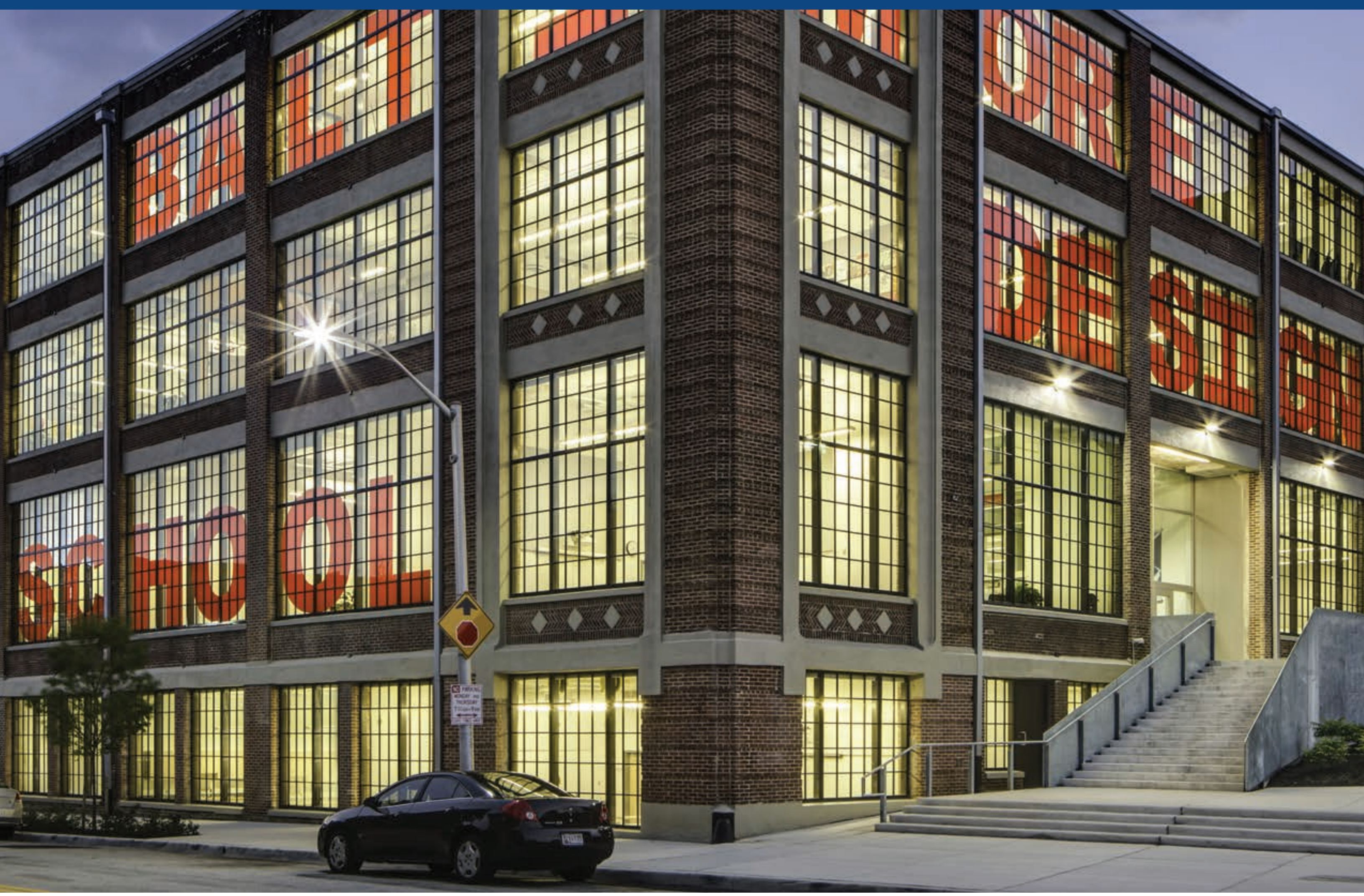
An ACI / ICRI Manual

Guide to the Code for Evaluation, Repair, and Rehabilitation of Concrete Buildings

A Companion to *ACI 562-13*



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Strategic Development Council
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Guide to the Code for Evaluation, Repair, and Rehabilitation of Concrete Buildings

First Edition

Prepared by the team from Wiss, Janney, Elstner Associates, Inc., of Project Manager Richard A. Walther, Stephen W. Foster, Gary J. Klein, and Richard C. Reed under the review and approval of an ACI/ICRI review group consisting of Chair Jay H. Paul and members Eric L. Edelson, Fred R. Goodwin, Keith E. Kesner, and Antonio Nanni with comment by ACI Committee 562, Evaluation, Repair, and Rehabilitation of Concrete Buildings, and ICRI Committee 150, ICRI Notes on ACI 562 Code Requirements.

Guide to the Code for Evaluation, Repair, and Rehabilitation of Concrete Buildings

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On the Cover

Baltimore Design School

Historic Category 2014 ICRI Project of the Year

The following summary is taken from the November/December 2014 issue of Concrete Repair Bulletin.

The Baltimore Design School is a first-of-its-kind, combined public middle and high school dedicated to students interested in architecture, graphic design, and fashion. It is located in the North Central Historic District of Baltimore, MD, and is the first arts and entertainment district in the city listed on the National Park Service's National Register of Historic Places. The school was founded a few years ago but now proudly resides in its new 110,000 ft^2 (10,210 m^2) home.

Workers in the original factory

The History of this Structure

The four-story structure, constructed in 1914, was the machine shop for a global supplier of bottle caps before housing a clothing manufacturer. The Crown Cork and Seal Company machine shop was designed by Baltimore Architect Otto G. Simonson and built by the West Construction Company. Constructed of reinforced concrete, the building was the first in Baltimore to use a "beamless floor system," also known as flat-slab construction, that did not require structural beams to span between columns.

Inside the factory before restoration

Condition Assessment

A design and construction team was assembled to perform a condition assessment. Unoccupied and lacking maintenance for over a quarter of a century, the building was in extreme disrepair (see back cover). Due to the lack of concrete cover, lower-quality concrete, and advanced carbonation, corrosion had spread throughout the exterior reinforced elements and interior columns. Ceilings and spandrel beams were especially heavily damaged from accelerated corrosion. Testing revealed that the concrete compressive strength was 2000 psi (13.8 MPa), consistent with building codes of that era. The steel reinforcement was smooth and uncommonly placed diagonally to column alignment. The severe corrosion diminished the capacity of the reinforcement, making it necessary to use structural strengthening in addition to the repair and protection work.

Repair Strategy

Upon completion of the assessment, it was clear that an extensive and multi-faceted approach would be required to meet the complex challenges induced by decades of neglect. The following was the agreed and employed strategy of the design and construction team.

Structural and Nonstructural Crack Repair

Cracks that were not corrected as a result of the extensive spall repair techniques were individually classified into two categories: structural and nonstructural. The structural cracks were welded by means of low pressure injection with high-modulus, low-viscosity epoxy resin. Nonstructural cracks that were primarily a concern for worsening through freezing-and-thawing cycles were addressed by rout and seal with low-modulus polyurethane sealant for adhesion, flexibility, and overcoating benefits.

Concrete Repairs

All major methods of concrete repair techniques were incorporated into the overall strategy. This included hand-applied, machine-applied, form-and-pour, and form-and-pump applications. The method of installation was selected based on the orientation, the size of the repair, and the predicted productivity of the technique. Materials were selected based on the ability to bond to the original concrete, resist corrosion with minimum cover, and provide the workability benefits associated with the application method.

1. Any surviving smooth reinforcing steel in the repairs was thoroughly cleaned and coated with a corrosion-resistant primer that also increased adhesion with the repair material. However, much of the reinforcement throughout the structure was terminally corroded and had to be replaced with new reinforcing steel or complimented with additional strengthening. New reinforcement was required for all the spandrel beam repairs.
2. The hand-applied method was chosen for both the smaller, more isolated repairs on columns and ceilings, and for the more complicated architectural features, such as with the exterior arches.
3. Machine-applied repair mortar was used to repair some large ceiling sections. This method was selected to greatly improve production while providing a very dense material.
4. Flowable repair mortars and concretes were predominately used in larger surface area repairs to the columns varying from shallower to deeper thicknesses.
5. Prepackaged self-consolidating concrete was used to repair the vast volume of spandrel beams at all the windows. The limited width and depth of the repair, combined with the quantity and size of the required reinforcement, plus the expansive length of spandrel beams, dictated special consideration to the application and material. Working time, flow, segregation concern, and consolidation in addition to adhesion, durability, and shrinkage properties all had to converge for a successful installation. This required the expertise in pumping supplied by the installing subcontractor and a material specifically designed to meet the stringent characteristics.

Spalling ceiling

Carbon-fiber plates

Structural Strengthening

Roof slabs of the building had extreme section loss requiring new reinforcement. Supplemental reinforcement was also used to bring slabs back to their safe load-bearing capacity. Carbon-fiber plates were installed for strengthening these areas along with strengthening locations of new cutouts for conduits, pipes, ducts, and vents and for the new HVAC system.

Corrosion Mitigation

As the destructive nature of the carbonation-induced corrosion was on display to great extent all throughout the interior and exterior of the structure, strategic effort had to be employed to avoid overlooking the future challenge from the covert corrosion that had yet to reveal itself. Therefore, a penetrating surface-applied corrosion inhibitor was sprayed to the underside of the roof slab, all exterior surfaces, and all interior areas within 4 ft (1.2 m) of the exterior.

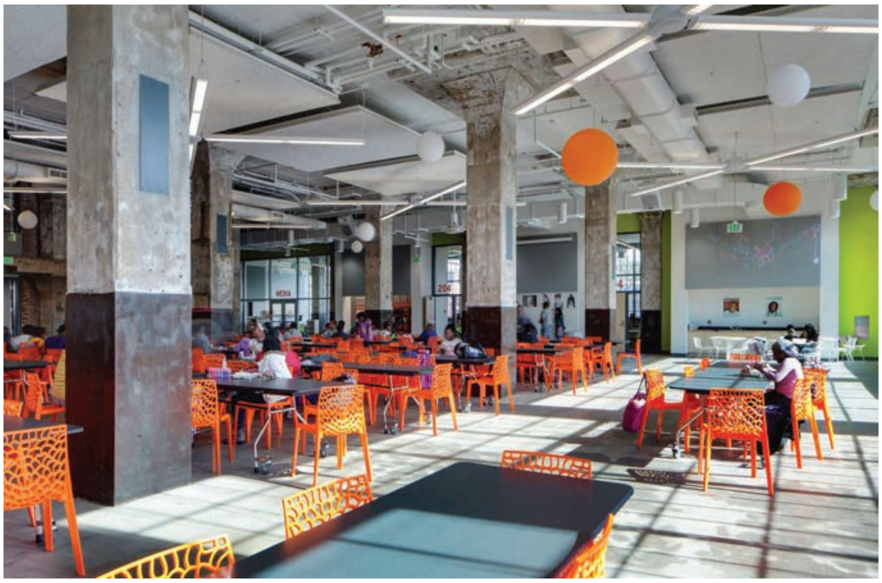
Protective and Architectural Coatings

Careful deliberation was given to the selection of an interior coating. Historic consideration and the impact of maintaining the original feel of the building were factors suggesting not coating the concrete and brick. Conversely, the effects of continued dusting and the awareness of the results of unhindered carbonation demanded a coating. Research and site-applied samples forged consensus to use a clear, breathable, anti-carbonation coating that would halt the carbonation process, bind up and seal in the dust, and preserve the historic appearance.

This acrylic coating also blocks wind-driven rain and has outstanding ultraviolet light resistance, so the project architect had several special color samples produced and installed for the protection of all the exterior concrete.

Architectural Achievement

The transformation of the building from blight to a state-of-the-art teaching facility within the confines of the budget demonstrates the power of design with the help of advanced methods of concrete repair, protection, and structural strengthening. The exterior of the building's historic fabric was successfully integrated with modern features. The interior slabs, columns, and walls remain exposed to view and are complimented with current decor. The vast, open environment supports the creative, design-focused curriculum of the school.



Completed cafeteria

Acknowledgments

The Lebow Clothing Factory. Description by Seawall Development.

Baltimore Design School

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Acknowledgments

The development of "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings (ACI 562-13) and Commentary" is a major milestone in the concrete repair industry. Prior to the document's publication 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 requirements in ACI 562-13 take 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 is significant room for interpretation when deciding whether a particular code requirement has 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 is a new code that engineers would be using for the first time and with which they would have no prior experience. Recognizing the difficulty of producing a first version of a guide document through normal committee processes in a timely manner, ACI and ICRI agreed to pursue proposals for an outside author whose work would be reviewed and approved by a small review group consisting of both ACI and ICRI members. After approval for the project was granted by the ACI and ICRI Boards of Direction, qualification statements and proposals from several candidates were reviewed, and the proposal to author the document by Wiss, Janney, Elstner Associates, Inc., was accepted.

ACI and ICRI wish to acknowledge the efforts of several groups involved in the development of this document.

Wiss, Janney, Elstner Associates, Inc., authored the text and examples that make up this document. The Project Examples are based on work performed by the company and modified to illustrate the requirements of ACI 562-13. Their experience in repair and rehabilitation projects provided excellent background knowledge regarding the questions and issues that repair engineers would have and that the guide should attempt to address. ACI and ICRI would like to thank Wiss, Janney, Elstner Associates, Inc., for agreeing to develop this guide.

"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 this guide.

Members of ACI Committee 562, Evaluation, Repair, and Rehabilitation of Concrete Buildings, and ICRI Committee 150, ICRI Notes on ACI 562 Code Requirements, provided comments on the initial drafts of the chapters and project examples in this guide. ACI and ICRI would like to thank the members that volunteered their time to provide constructive comments to ensure that the guide addressed the major components of the repair code and would meet the expectations of the repair industry.

Finally, ACI and ICRI would like to thank the review group for this guide consisting of Chair Jay H. Paul and members Eric L. Edelson, Fred R. Goodwin, Keith E. Kesner, and Antonio Nanni. The review group was responsible for consolidating comments from the initial committee reviews, providing review comments for subsequent versions, and final approval of the document. Their careful review and dedication to the project on top of all their other volunteer time for both institutes made it possible to develop this guide in a timely manner while maintaining the quality expected by the industry.

Preface

Introduction to ACI 562-13

The explosive growth in the need for concrete evaluation, repair, rehabilitation, and strengthening in the past 50 years has created an industry that supports engineers, architects, manufacturers, suppliers, researchers, educators, contractors, and lawyers. The annual cost to owners for repair, protection, and strengthening of existing concrete structures is estimated between $18 billion and $21 billion in the United States alone.[1] Simply put, even good 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 inter-industry 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 entitled "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings and Commentary" is the end result of that initiative.

As stated in its introduction, the purpose of ACI 562 is to provide minimum material and design requirements for the evaluation, repair, and rehabilitation of structural concrete members. Like other ACI standards, ACI 562 is organized in a dual column format, with mandatory code provisions on the left of each page, and nonmandatory commentary on the right to provide additional guidance and information on the material 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 will serve to unify and strengthen concrete evaluation, repair, and rehabilitation projects while accommodating the diverse and unique strategies and materials used throughout 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 318-14, "Building Code Requirements for Structural Concrete," with new concrete construction. As with ACI 318 and the 2015 International Building Code (2015 IBC), plans are underway for ACI 562 to be adopted into the 2018 version of the International Existing Building Code (2018 IEBC) as a supplement to matters pertaining to evaluation, repair, rehabilitation, and strengthening of concrete members within existing buildings. Local jurisdictions and building authorities can also adopt ACI 562 directly. Accordingly, while ACI 562 currently defines the standard for the concrete evaluation, repair, and rehabilitation industry, the code provisions of ACI 562 will likely soon become mandatory requirements as part of the governing building codes that regulate work in existing buildings.

Overview of Guide Content

The primary purpose of this Guide is to help licensed design professionals gain more knowledge, skill, and judgment to interpret and properly use ACI 562. Although specifically developed for licensed design professionals, the Guide will also serve to provide insight into the use and benefits of ACI 562 for contractors, material manufacturers, building owners, and building officials. To achieve this goal, the Guide is separated into two main components: Chapter Guides and Project Examples.

The Chapter Guides and Project Examples work together to explain and illustrate the proper use of ACI 562. The Project Examples illustrate the process of carrying out a concrete building evaluation, repair, rehabilitation, or strengthening project from inception through completion. The Guide, and the Project Examples in particular, is not intended to serve as a "how-to" manual for performing concrete evaluation, repair, rehabilitation, or strengthening. Several other documents are available and referenced throughout ACI 562 and this Guide to assist the reader in evaluating the various options and approaches to performing successful concrete evaluation, 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 the various sections of ACI 562 are applied together to execute the project. For convenience, related provision numbers from ACI 562 are given to the right of the project example text. Five Project Examples are included in Chapters 12 to 16 of the Guide, and include:

1. Typical Parking Garage Repairs;
2. Typical Façade Repairs;
3. Repair of Historic Structure for Adaptive Reuse;
4. Strengthening of Two-Way Flat Slab; and
5. Strengthening of Double-Tee Stems for Shear.

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 11 of this Guide correspond to the provision numbers in ACI 562. The Chapter Guides include background and explanation of the various ACI 562 provisions with particular insight into how the particular chapter and section of the code fit within the whole of 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.

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

Lastly, a summary of the various provisions of ACI 562 and the corresponding location where each provision is covered within the Guide is provided in Appendix D. The reader may use this as a tool when additional information for a specific provision of ACI 562 is desired.

Contents

About This Book

The Chapter Guides in Chapters 1 to 11 of this guide correspond to the identically numbered sections of ACI 562-13, "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings." Related ACI provision numbers are included to the right of the Project Example text in Chapters 12 to 15.

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 judgement must be applied to the unique requirements of individual projects.

Chapter 1: General

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; the various building codes that might affect the design of the repairs and the selection of the building code for the repair design; and the responsibilities of the licensed design professional, including submittals to building officials and the owner and the development of maintenance recommendations.

1.1 Scope

Determination of Applicable Building Codes

Prior to performing an evaluation, repair, rehabilitation, or strengthening of an existing concrete building or structural element, the licensed design professional (LDP) should first determine the building codes applicable to the project and understand their relevance to evaluation and repair, rehabilitation, and strengthening design decisions. Per ACI 562, the LDP should identify the following codes:

- *Current Building Code* per ACI 562, Section 1.1.3;
- *Original Building Code* per ACI 562, Section 1.1.3;
- *Existing Building Code* per ACI 562, Section 1.1.2; and
- *Design Basis Code* per ACI 562, Section 1.1.4.

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