ACI 562 – Development of a Building Code for Repair of Existing Concrete Structures

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Abstract
Evaluation and/or repair of existing concrete structures can be challenging to design professionals, owners, building officials, and contractors. Difficulties arise due to a myriad of questions pertaining to the extent of necessary repairs, responsibilities during the project, and uncertainties regarding the governing code requirements. The concept of a building code for repair of existing concrete structures has been discussed for nearly 30 years. However, a major obstacle to the development of a concrete repair code was the interaction with existing codes, such as ACI 318 [ACI 318-11], general building codes, and the International Building Code [IBC] that were developed primarily for use during new construction. The development of the International Existing Building Code [IEBC-12] provides design professionals a pathway delineating code requirements for repair and alterations of existing structures. However, the IEBC does not provide detailed code requirements that address the unique challenges of how to evaluate damaged concrete structures or provide provisions to extend the service life of both the repair area and the repaired structure.

In 2013, the American Concrete Institute (ACI) published Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings [ACI 562-13] to provide design professionals with a code for the repair of existing concrete structures. ACI 562 represents the first material specific repair code in US practice and is the first code specifically developed to be integrated with the IEBC. ACI 562 contains specific provisions for:

- Evaluation of existing structures;
- Load and resistance factors;
- Design of repairs;
- Durability requirements; and
- Quality assurance.

ACI 562 was developed to be performance-based (in contrast to prescriptive) to provide engineers the maximum amount of flexibility in developing repair solutions. The document’s extensive commentary, including a comprehensive list of references, provides guidance to design professionals using the code. The paper and presentation will describe the development of ACI 562, the relationship of ACI 562 with other building codes, and the impact of the code on typical concrete repair project.

Introduction

The concrete repair industry is estimated to generate between 18 and 25 billion dollars per year in construction spending in the United States. While a significant portion of this sum is spent to repair deteriorated concrete, it has been estimated that 50 percent of repairs are not performing satisfactorily due to errors in design, construction, and/or material selection [REMR and BRE] resulting in "repairs to the repairs." Seeing an area of the industry that could be improved, the ACI Strategic Development Council along with the International Concrete Repair Institute (ICRI) and other organizations developed Vision 2020 in 2006. Vision 2020 [Vision 2020] was a strategic plan for the concrete repair,
protection, and strengthening industry that included the development of a repair/rehabilitation code as one of its specific goals which would:

1) establish evaluation, design, materials, and construction practices;
2) raise the level of repair and durability performance;
3) establish clear responsibilities between owners, designers, and constructors; and
4) provide building officials with means to evaluate rehabilitation design.

ACI took the lead in pursuing the Vision 2020 goal, forming Committee 562, Evaluation, Repair and Rehabilitation of Concrete Buildings, to develop the repair/rehabilitation code. A group of 31 members, comprised of engineers, contractors, and manufacturers from across the United States and Canada spent seven years developing the document *Code Requirements for Evaluation, Repair and Rehabilitation of Concrete Buildings* (ACI 562-13) shown in Figure 1. This paper provides insight into why the code was needed, the development of the code, its relationship with other codes, key provisions, and how it influences a typical concrete repair project.

![Figure 1: Code Requirements for Evaluation, Repair and Rehabilitation of Concrete Buildings (ACI 562-13)](image)

**Need for a Repair Code**

Projects involving repair/rehabilitation of existing buildings can be challenging to engineers for many reasons. For new concrete structures, engineers are typically working with a "blank slate" and can refer to the IBC and ACI 318 *Building Code Requirements for Structural Concrete*, to assist them in specifying material requirements and other design requirements for the structure. For existing structures, the repair engineers must work within the constraints of the existing building, obtain accurate information about the structure’s condition and material properties, address unforeseen conditions, and determine which building code that project should satisfy.

During the development of Vision 2020, it was found that repair and protection practices vary widely between engineers and a current standard practice is hard to define. The variation in practices have allowed for inconsistent levels of reliability of repaired structures and places a burden on building code officials that must approve repair construction documents based on a lack of specific requirements. In absence of any guidance, decisions have often defaulted to requiring a repaired structure to satisfy all criteria of a new building code, like ACI 318, which can result in overly costly repairs and even in decisions to demolish and rebuilding entire buildings.

The goal of the repair/rehabilitation code is to assist in establishing minimum life safety requirements for rehabilitated structures and to provide engineers working with existing structures guidance during their evaluation, while providing a sustainable and economic alternative to demolition and replacement.

**Development**

Once Vision 2020 established the goal of developing a repair/rehabilitation code, the Technical Activities Committee (TAC) of ACI approved the formation of Committee 562, Evaluation, Repair and Rehabilitation of Concrete Buildings in 2006. The committee was formed with a group of 31 members comprised of engineers, contractors, and manufacturers from across the United States and Canada that worked for seven years developing the specific code provisions and commentary that provided additional guidance to the user.

During the initial efforts, the committee realized that developing prescriptive requirements, similar to those found in ACI 318, would be a difficult to impossible task. Unlike new construction where the engineer has a "blank slate" to work with, a repair engineer must work within the constraints of the existing structure and materials. The multitude of
possible scenarios that an engineer may encounter, including type of building, code under which the building was originally constructed, and level of deterioration, is endless. For example, increasing the depth of a beam to accept additional loading may not be feasible due to limited headroom. These constraints typically require the engineer to become creative in their repair designs and to think "outside the box" in developing their repairs. To allow this creativity while maintaining minimum requirements in a repair/rehabilitation code, the only approach through the use of performance based requirements.

The committee also spent considerable effort on the organization of the repair/rehabilitation code. An order that was intuitive and similar to the way a project should be evaluated (Table 1) was desired. Initial chapters provide guidance to the engineer in establishing project requirements/parameters, the design basis code along with other general requirements. Determination of loading requirements, evaluation, and analysis sections can be found within the middle section of ACI 562 which is followed by the design chapter that provides guidance on the repair design. Durability requirements are provided along with quality assurance at the end.

### Table 1 – Summary of ACI 562 Chapters

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1</td>
<td>General</td>
<td>General information regarding design basis code and other general information.</td>
</tr>
<tr>
<td>Chapter 2</td>
<td>Notations and Definitions</td>
<td>Definitions for terminology and notation used within the code.</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Referenced Standards</td>
<td>Listing of standards used as references in the code or commentary.</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Basis for Compliance</td>
<td>Design Basis Code and compliance methods.</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Loads, Load combination and Strength reduction factors</td>
<td>Provides the loads and load factors that are specified to be used in evaluation and analysis.</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Evaluation and Analysis</td>
<td>Guidelines for the evaluation and analysis of existing buildings. Also provides historical material properties.</td>
</tr>
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</table>

Throughout the development process, the committee followed the standardization process of the American National Standards Institute (ANSI) known as "ANSI Essential Requirements: Due Process Requirements for American National Standards." The purpose of the ANSI [ANSI] document is to ensure that a standard is developed in an environment that is equitable, accessible, and responsive to the requirements of various stakeholders.

- Consensus on a proposed standard by a group or "consensus body" that includes representatives from materially affected and interested parties.
- Broad-based public review and comment on draft standards.
- Consideration of and response to comments submitted by voting members of the relevant consensus body and by public review commenters.
- Incorporation of approved changes into a draft standard.
- Right to appeal by any participant that believes that due process principles were not sufficiently respected during the standards development in accordance with ANSI accredited procedures of the standards developer.

### Relationship with Other Codes

In the past, designers have often turned to IBC Chapter 34 (existing structures) or to their local existing building code, if
it exists, when working with existing buildings. In 2006, the ICC published the IEBC to provide additional guidance to designers. During development of the 2015 ICC codes, it was decided that Chapter 34 would be deleted from the IBC leaving the IEBC to govern repairs/rehabilitations to existing buildings. In addition to the I-codes, standards such as ASCE 31 and ASCE 41 are available to the designer when evaluating the seismic performance of existing buildings.

While developing ACI 562, the intention was for the standard to work alongside the IEBC but used as a stand-alone document in areas that have not adopted an existing building code. The committee also included references to ASCE 31 and 41 in the mandatory sections to direct the licensed design professional when considering seismic repairs to a structure.

Key Provisions

To highlight strengths and unique provisions found within ACI 562-13, the authors have selected a few key provisions since providing a detailed description of all provisions of the standard is impractical in a paper.

Design Basis Code

One of the first steps in any evaluation/analysis of an existing building is determining to which code the evaluation/analysis should satisfy, which the committee has termed design basis code. Within ACI 562-13, chapters 1 and 4 provide guidance for the determination of the design basis code, which will typically be the general building code, such as IBC, that was in effect at the time of original construction. In the absence of any data regarding the age of the building or original code information, chapter 4 allows the licensed design professional to evaluate the structure using the provisions given in chapter 6.

An important step in the evaluation is that the licensed design professional must determine whether “substantial structural damage” has occurred within the structure. “Substantial Structural Damage” is defined by the IEBC as a condition where (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 predamaged condition; or (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. IEBC states that if this level of damage is found to exist in a structure, the building and its repairs need to conform to requirements for that of new construction, which will become the design basis code for any repairs.

Load Testing

Figure 2: Load testing of existing structure (Figure courtesy of Chuck Larosche – Wiss Janney Elstner Assoc.).

ACI 562 references the recently developed ACI 437.2-13 Code Requirements for Load Testing of Existing Concrete Structures and Commentary for load testing requirements. This new standard was selected over the procedure contained in Chapter 20 of ACI 318. The ACI 437.2 load testing standard was developed specifically for existing structures and includes acceptance criteria based upon monotonic and cyclic test results and provides for lower load ratings based upon load testing results. Committee members included these provisions, as load testing has been found to be particularly useful to supplement analysis, verify strength of members in lieu of detailed assessments and testing, as well as to verify the effectiveness of repairs.

Historical Properties

It is not uncommon for an engineer performing an evaluation to find that a building's owner has no information, such as drawings or specifications, regarding the building or materials used during original construction. In these situations, the engineer must perform additional field investigations to determine member sizes and spacing. On the material side, the engineer has the option to perform material testing to determine concrete compressive strength of tensile strength of steel reinforcement. As an alternative to the testing, the committee researched and adopted various tables that provide historical material properties for concrete and steel reinforcement from ASCE 41-06. These historical values can be used in the analyses in lieu of potentially costly materials testing. Consistent with the philosophy contained in Chapter 20 of ACI 318, higher strength reduction factors...
can be used when material properties are confirmed by testing. If an analysis using historical values indicates the need for repairs, material testing can be performed to allow the use of higher strength reduction factors, which may be sufficient to eliminate an overstresses.

**Bond**

ACI 562-13 requires a minimum bond strength of 1.5 times greater than the calculated bond force at the repair material to existing concrete interface. While this concept may initially sound new to engineers, the concept was derived from the shear strength requirements found in Chapter 17 of ACI 318. When designing the repairs, these provisions cause the engineer to consider the strength and location of the repair interface and that there is sufficient strength to transfer forces across the interface. Depending on the amount of bond strength needed, the bond strength can be achieved using proper surface preparations that removes deteriorated concrete or providing supplemental reinforcement designed according to the shear friction provisions.

During the development of ACI 562, the committee found that this provision was one of the more controversial and most heavily debated topics within the code. Through continued debate and research, the committee will further refine the code in an effort to closely mirror ACI 318 on this topic. It is also expected that this section will be refined from practitioner feedback, as ACI 562 sees increased usage in repairs projects.

**Fiber Reinforced Polymer (FRP) composites**

FRP is an increasingly popular and cost effective method of providing additional strength to existing elements with minimal impact (Figure 3). Recognizing this trend within the industry, ACI 562 references ACI 440.6 Specifications for Carbon and Glass Fiber-Reinforced Polymer Bar Materials for Concrete Reinforcement in the mandatory language of the document permitting the use of FRP in repair construction. The committee provided extensive commentary with references to the FRP sections to provide sufficient information to the repair engineer to ensure that the FRP is properly integrated into the existing structure.

**Influence on Typical Project**

The ACI 562 code was developed to improve concrete repair practice by providing design professionals performance-based requirements for repair of existing concrete structures. The impact of the code on a typical concrete repair project can be seen through the various phases of a project. The goal in developing the code was to create a document that improved practice without limiting the creativity of the design professional.

During the evaluation phase, a design professional faced with unknown conditions can use historical material properties to perform an initial evaluation or perform a more detailed survey to confirm the properties of the existing structure. Use of the code to perform structural analyses based upon in-place material properties may result in a decrease in the required extent of repairs or eliminate the need for repairs.

In repair design, the overall procedures for repair design are similar to new construction. The design professional has to verify the structure and the repair area have adequate strength and stiffness at all times during the repair process. The code also has additional requirements to address situations of repair including consideration of:

- Corrosion damaged reinforcing steel in repairs.
- Reduced cross-section size during repair.
- The effects of supplemental external post-tensioning.
- The impact of repair sequence.

ACI 562 is the first ACI code to allow the use of FRP materials in concrete repair projects. The code is also unique in requiring consideration of durability in repair design. The
code does not specify a minimum service life for a repair or a repair structure. The goal of the durability requirements is to prevent common errors that limit repair durability.

The final section of ACI 562 is on quality assurance. The code does not require any quality assurance testing beyond that required in the general building code. The code does direct the design professional to include testing and inspection requirements applicable to the project in the contract documents. Consistent with the performance-based framework of the code, the design professional must determine what quality assurance tests are required for a specific project.

Conclusions

A new code for the repair of existing concrete structures has been developed. The code was motivated by a desire of professionals in the concrete repair community to improve the state of practice. The wide range of issues that occur in existing structure repair resulted in the development of a performance-based code in lieu of a prescriptive document.

Concrete repair practice has been found to vary significantly, resulting in variations in reliability of repaired structures and durability of repaired structures, with significant amounts of concrete repairs failing in less than ten years. The goal of the ACI 562 code is to provide minimum requirements that improve the performance of both repairs and repaired structures.

References

1. Code Requirements for Evaluation, Repair and Rehabilitation of Concrete Buildings (ACI 562-13)and Commentary, American Concrete Institute, Farmington Hills, MI, 2013, 59 pp.
2. Building Code Requirements for Structural Concrete (ACI 318-11), American Concrete Institute, Farmington Hills, MI, 2011, 503 pp.
7. http://projects.bre.co.uk/conrepnet/pages/default.htm
8. Code Requirements for Load Testing of Existing Concrete Structures and Commentary (ACI 437.2-13), American Concrete Institute, Farmington Hills, MI, 21 pp.
9. Specification for Carbon and Glass Fiber-Reinforced Polymer Bar Materials for Concrete Reinforcement (ACI 440.6-08), American Concrete Institute, Farmington Hills, MI, 44 pp.