Guide to Concrete Repair

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This guide presents recommendations for the selection and application of materials and methods for repairing, protecting, and strengthening concrete structures. An overview of materials and methods is presented as a guide for selecting a particular application. References are provided for obtaining in-depth information on the selected materials or methods.

Keywords: anchorage; coating; concrete repair; joint sealant; placement; polymer; protective systems; repair materials; structural strengthening.

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CHAPTER 1—INTRODUCTION

1.1—Guide use

This document provides guidance on removal and preparation, selecting material and application methods for repair, protection, and strengthening of concrete structures. The information is applicable to repairing deteriorated or damaged concrete structures; correcting design or construction deficiencies; and strengthening the structure for new uses or to comply with current, more restrictive building codes.

Current practices in concrete repair are summarized and information provided for the initial planning of repair work and selecting repair materials and methods for various conditions.

1.2—Repair methodology

The methodology for repairing a concrete structure typically includes a condition assessment of the structure, designing repairs, developing construction documents, bidding and negotiation processes, and performing the repair work. Preparing a maintenance plan for the repaired structure is also recommended. A basic understanding of the causes of concrete distress, deterioration, or deficiencies is essential to performing meaningful evaluations and completing successful repairs (ACI 364.1R). Once the cause of deterioration or deficiency is determined, the appropriate repair program can be selected to address these conditions. Depending on the cause and extent of the damage, repair is not always warranted.

Assessment of the structure should determine the cause of the deterioration or deficiency and not focus only on the symptoms. For example, cracking can be a symptom of distress that may have a variety of causes, such as restraint of drying shrinkage, restraint of movement due to thermal cycling, overloading, corrosion of embedded metal, or inadequate design or construction. The cause of distress should be assessed for proper selection and implementation of an appropriate repair program (Fig. 1.2).

1.2.1 *Condition assessment*—The process of repairing a concrete structure starts with the evaluation of existing conditions. The evaluation can be divided into several steps:

a) Reviewing available design and construction documents, previous reports, repair/maintenance records, and test data, if available;

b) Visually examining the existing structure;

c) Performing structural analysis of members in question or the structure in its deteriorated condition;

d) Evaluating corrosion activity;

e) Performing invasive or nondestructive testing, or both;

f) Reviewing physical, chemical, and petrographic analysis results of laboratory-tested concrete samples.

Additional information on conducting condition surveys can be found in ACI 201.1R, 207.3R, 222R, 224.1R, 228.2R, 364.1R, 437R, and 562.

1.2.1.1 *Unsafe conditions*—During the condition assessment, conditions discovered that pose an immediate safety issue should be identified and reported to the owner for mitigation. Local building codes may require that the licensed design professional (LDP) report unsafe conditions to the authorities and typically require that the owner take measures to protect the public safety where hazardous conditions exist. For example, if loose concrete on overhead or vertical surfaces is discovered, access should be limited in the areas adjacent to and below until the hazards are removed or stabilized. If structural members exhibit compromised integrity, these members should be stabilized or the affected areas removed from service.

1.2.1.2 *Global issues*—The performance of a structure depends on maintaining the integrity of the structure and envelope of the building. If the LDP becomes aware of an item of concern outside the assigned scope of work that could compromise the integrity of the structure or jeopardize public safety, the appropriate parties should be notified for implementation of remedial action.

1.2.1.3 *Determination of cause and extent*—During the condition assessment of a structure, the cause of distress, deterioration, or deficiency should be determined. Because many deficiencies are caused by more than one mechanism, a basic understanding of the causes of concrete deterioration is essential to determine what has happened to a particular concrete structure. After completing the assessment, a suitable remedial action plan can be developed, repair applications and materials selected, and contract documents prepared. If a delay occurs between the condition survey and performing the repair work, additional deterioration and distress could occur and consideration should be given to updating the condition survey to minimize variations between estimated and actual quantities of repair work.

1.2.2 *Design considerations*—When designing a concrete repair, strengthening system, or protective system, the LDP should consider the safety and serviceability of the structure

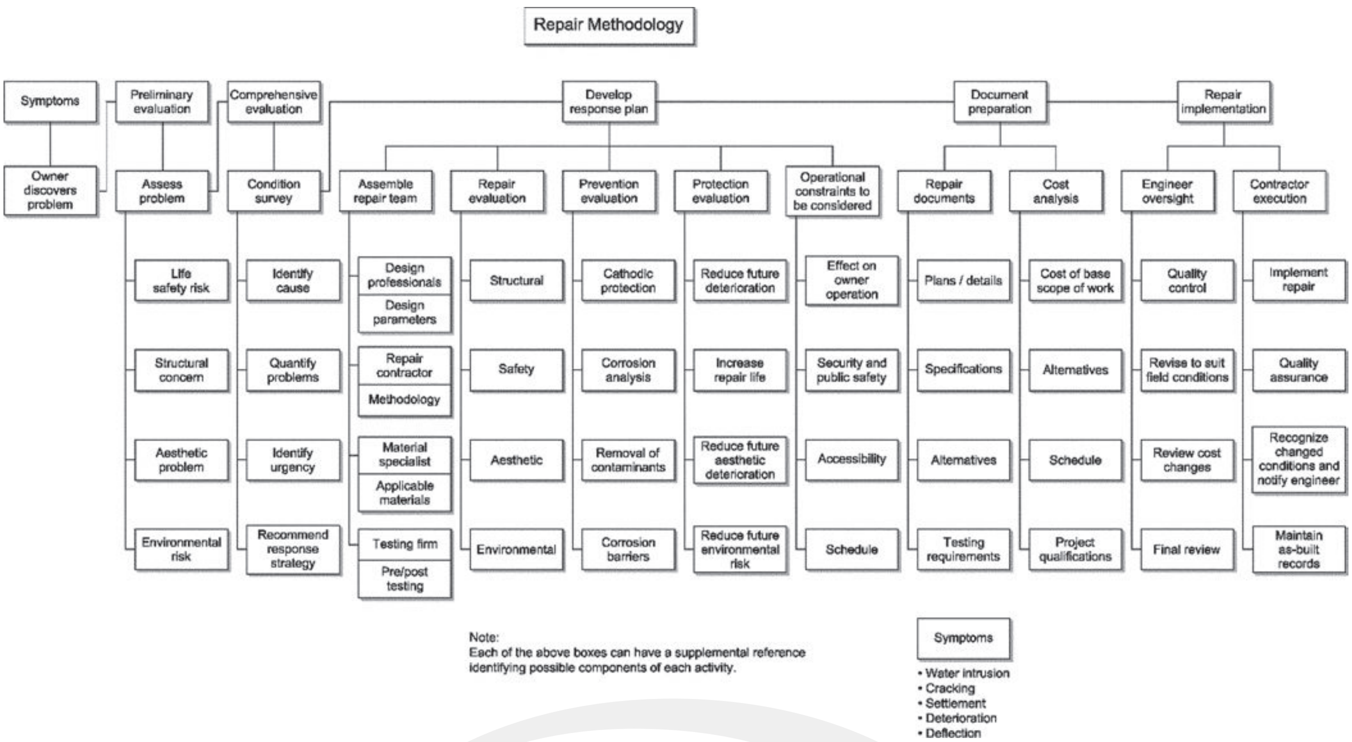

Fig. 1.2—Repair methodology.

during construction and its performance at completion. At a minimum, the repaired structure should satisfy the building code requirements for which it was designed. If required by the governing agency, the repaired structure may have to satisfy current building code requirements and be repaired and strengthened to meet these criteria. In any case, it is the LDP's responsibility to satisfy applicable code requirements for all structural components within the LDP's scope of work. Structural code provisions such as those contained in ACI 318 may not be directly applicable to the current situation. In such cases, ACI 562 requirements should be followed. The LDP should apply basic principles of structural mechanics and have an understanding of material behavior to evaluate and design a structural repair, a strengthening procedure, or a protective system. Several design considerations are discussed 1.2.2.1 through 1.2.2.6.

1.2.2.1 *Current load distribution*—In a deteriorated condition, a structural member or system may distribute dead and live loads differently than when the structure was undamaged. Cracking, deteriorated concrete, and corroded reinforcement can alter the behavior of members, leading to changes in shear, moment, and axial load distribution. As concrete and reinforcement are removed and replaced during the repair operation, these redistributed forces may be further modified. To understand the final behavior of the structural system, the engineer should evaluate the redistribution of the forces. To reestablish the original load distribution, a member can be relieved of the load by jacking or other means before repair implementation. If the structure is not jacked and the dead load is not relieved, the repaired and adjacent members may support loads differently than was assumed in the original design of the structure.

1.2.2.2 *Compatibility of materials*—If a repair and the existing substrate materials have the same stiffness or modulus of elasticity, the behavior of the repaired member may be assumed to be the same as the original member before deterioration or damage. Conversely, if the stiffnesses differ, then the composite nature of the repaired system should be considered. A mismatch of other material characteristics further exacerbates the effects of thermal change, vibration, long-term creep, and shrinkage. If the coefficient of thermal expansion of the repair material differs from that of the original material, stresses will be generated in both the repair and original material by temperature changes.

1.2.2.3 *Creep and shrinkage*—Reduction in length, area, or volume of both the repair and original materials due to creep, shrinkage, or both, affect the structure's serviceability and durability. As an example, compared with the original material, high creep or shrinkage of repair materials results in loss of stiffness of the repair, redistributed forces, and increased deformations. Controlled-shrinkage cementitious repair materials and systems can contribute to the reduction of the volume change effects.

1.2.2.4 *Vibration*—When the installed repair material is in a plastic state or until adequate strength has been developed, vibration of a structure can result in reduced bonding of the repair material. Isolating the repairs or eliminating the vibration may be a design consideration.

1.2.2.5 *Water and vapor migration*—Water or vapor migration through a concrete structure can degrade a repair. Understanding the cause of the migration and controlling it should be a repair design consideration.

1.2.2.6 *Material behavior characteristics*—After a repair is executed, the structural behavior of the repaired section can differ from the behavior of the original section and is dependent on the characteristics of the repair materials. For example, if a beam's steel reinforcement has corroded extensively and has lost part of its tensile load-carrying capacity, the lost portion of the reinforcement may be replaced by external strengthening techniques (Chapter 7), such as fiber-reinforced polymer (FRP) applied externally to the tension face of the beam, following repair or replacement of the deteriorated section caused by steel corrosion. The LDP should consider the behavior and performance of the new repair under the expected service and ultimate loads, and design the repair to provide a level of safety that is at least equivalent to the original design. Such a design is outside the scope of ACI 318 and ACI 562 should be used.

1.2.3 *Selecting repair methods and materials*—Successful concrete repair depends on the selection and proper application of the materials and methods to be used. ACI 546.3R provides specific guidelines for the properties of repair materials and their selection and ACI 546.2R covers underwater repair materials. Repair materials and methods should be selected with the following considerations.

1.2.3.1 *Concrete environment*—Repair work can incorporate adjustments or modifications to remedy the cause of the concrete deterioration, such as reducing exposure to moisture, changing the water drainage pattern, eliminating sources of erosion and water infiltration, providing for differential movements, or eliminating exposure to deleterious substances. However, it is not always possible to correct causes of deterioration. For example, it may not be possible to change the environmental exposure of a concrete structure. In such cases, reasonable efforts should be made to mitigate the problem by providing appropriate protection measures.

1.2.3.2 *Limiting constraints*—Repair work may be affected by constraints such as limited access to the structure or areas of repair. For example, underwater concrete deterioration provides access challenges. Other constraints may include the operating schedule of the structure, weather, and limitations imposed by the owner of the structure, including repair budget.

1.2.3.3 *Inherent problems*—Factors that cannot be corrected, such as continued exposure to chlorides in deicing salts, salt water, or deleterious chemicals, should also be considered. In these cases, repair and protection systems extend the life of the structure but do not eliminate the causes of deterioration.

1.2.3.4 *Environmental and safety requirements*—These items may have a major impact on the selection of materials, methods, or both. Environmental and occupational safety constraints are governed by specific requirements and policies of owners: the Environmental Protection Agency (EPA); the Occupational, Safety, and Health Administration (OSHA); and local regulations. Refer to International Concrete Repair Institute (ICRI) 120.1 for information on further safety aspects relevant to the concrete repair industry.

1.2.3.5 *Service life*—The intended service life of the repaired member and structure should be considered in the selection of repair materials and methods.

1.2.3.6 *Constructibility*—Availability of repair materials, equipment and methods, and the technical feasibility of using them should be evaluated during the material and repair procedure selection process. Manufacturers or suppliers can provide assistance in the selection, availability, and cost of repair materials and for selecting application techniques. When selecting the appropriate repair material, consider that the technical data presented in manufacturer's literature may be incomplete and insufficient because the tests performed may not be representative of the use of the material in a particular application.

1.2.4 *Temporary shoring*—The repair process, including concrete removal and reinforcement repair, may alter the force and load distribution within and between reinforced concrete members. It is essential that the contractor, in conjunction with the engineer, determine the need, extent, and locations of shoring and bracing required as well as the sequence of repair to satisfy structural safety and force distribution considerations.

The need for temporary supports, shoring, bracing, and strengthening to perform the repairs should be determined before performing repair work. Concrete removal often exposes reinforcing steel that may have suffered loss of cross-sectional area; concrete removal around reinforcing steel reduces the bond between the reinforcement and the structural element, thereby reducing the shear, bending, tensile, and compression capacity or stability of the structure. Shoring and bracing may be required to address these temporary conditions.

If structural analysis is performed, the analysis should assess the effects of existing conditions and proposed repairs on the structure, including the evaluation of applicable loads and dimensional changes resulting from thermal differentials. Areas of special concern that may result in conditions that require temporary shoring and bracing include redistribution of negative moments in slabs and beams, joint and connection details, precast spandrel beams and columns, as well as live loads imposed by repair equipment and material storage.

In most cases, unless the dead and live loads are relieved via shoring before the repair work proceeds, the repaired portion of the element may not be effective in supporting loads applied after the repair installation is completed. In cases where restoration of the load-carrying capacity is a primary concern, existing loads may need to be removed and members jacked and shored to support dead loads.

1.2.5 *Contract documents*—The preparation of contract documents includes drawings, details, and specifications. Contract documents should include provisions specific to the project and quality assurance criteria. Because the full extent of concrete deterioration and distress may not be completely known until repair work begins, drawings and specifications for repair projects should be prepared with some flexibility regarding work items such as concrete removal, surface preparation, reinforcement replacement, and quantities of repair materials. Provisions should be included in the documents for addressing hidden conditions and potential changes to the contract estimate of repair quantities.

Where deterioration is particularly severe or where extensive concrete removal is anticipated, provisions for temporary structural support should be included in the project documents. Protection of the repair site and adjacent areas may present unique problems during the execution of a repair project. Structural components and their supports in the immediate area of the repairs should be evaluated to determine if shoring, bracing, or both are required. Redistribution of member internal forces during repair is an important consideration for continuous slabs and beam-and-girder systems, and is critical for unbonded post-tensioned structures. Repair specifications should be clear and concise, delineating the scope of work, repair work items, information on existing concrete conditions if available, material and equipment requirements, surface preparation, installation procedures, quality assurance and testing criteria, and performance testing standards. Supporting documents referencing specific requirements such as tensile strength, surface profiling, compressive strength, bond strength, length change, or shrinkage behavior should be included as appropriate. Details of the concrete repair should be provided, including parameters for concrete removal and, if possible, boundaries of concrete removal and replacement along with any special features of repair system installation necessary, such as protection systems and strengthening techniques. Special attention is required for the details of reinforcement repair or replacement areas and the preparation of existing concrete before surface protection system application.

1.2.5.1 *Contract types*—To perform repairs, the contractor or design/build team typically enters into a contractual agreement with the owner. This contract defines the scope of work, price, and schedule. Payment for contractual requirements can be stated in lump sum or fixed-price terms, unit prices, time and material, or a combination thereof. Refer to ICRI 130.1R for further information on contract types.

1.2.5.1.1 *Lump sum*—This contract type is suitable for a specific, well-defined scope of work in which all repair items, quantities of work, and work conditions are known. The contractor is paid a fixed fee for completed work, regardless of the actual repair items and quantity of work performed.

1.2.5.1.2 *Unit price*—This contract type is suitable for a specific scope of work where all repair items are known but exact quantities are unknown. The final contract sum for the repair items covered by unit prices is based on actual quantities of the repair items properly installed by the contractor. Some individual repair items may be paid on a lump sum or time and material basis.

1.2.5.1.3 *Time and material*—This contract type is suitable for an undefined scope of work where both the repair items and quantities of work are undefined. The contractor is paid at a defined hourly rate for labor and reimbursed for materials and equipment with applicable overhead and profit.

1.2.5.2 *Performance objectives*—Repair documents should define the structural, environmental, aesthetic, and protection objectives to be achieved. Mockups are recommended where appropriate; for example, where the color or texture is specified to match the surrounding concrete (ACI 311.1R, 311.4R, and 311.5).

1.2.6 *Bid or negotiation process*—Selecting a contractor is one of the most important aspects of a repair project. Contractor selection can be determined through a bidding process or negotiated directly with potential contractors. Contractor selection should be based on demonstrated evidence of expertise and successful previous experience with repairs included in the project. Manufacturer-approved installers should be considered for specialized repair products.

1.2.6.1 *Prebid conference*—Before bids are submitted, the engineer, owner or owner's representative, and potential contractors should attend a prebid conference to answer questions regarding the contract documents and to define expectations of the owner. This meeting should include a visit to the repair site.

1.2.6.2 *Addenda*—Clarifications to the contract documents based on questions raised at the prebid conference, during the bid period, or both, can be issued in addenda to the contractors before submission of bids.

1.2.7 *Execution of work*—Repair work should be executed in accordance with the contract documents. The concrete repair process generally consists of removing deteriorated or damaged concrete; surface preparation; repairing, supplementing, or replacing reinforcing steel; implementing specified repair techniques; and installing repair materials. Protecting the executed repairs and strengthening may also be incorporated into the repair process.

1.2.7.1 *Preconstruction conference*—Before starting a project, it is important to have the owner or owner's representative and LDP attend a meeting with the contractor's project manager, superintendent, and foreman to discuss the parameters, means, methods, and materials necessary to achieve the repair objectives. At this meeting, the contractor should present a construction schedule for the owner to review its acceptability and resolve any conflicts with daily operations. The frequency and types of required correspondence should be defined among all parties executing the work to communicate progress, discovered items, and construction problems.

1.2.7.2 *Material submittals and shop drawings*—Prior to use on the project, the contractor should submit technical, installation, and safety data for proposed repair materials in accordance with the contract documents to the LDP for review and acceptance. In addition, shop drawings for items such as shoring and bracing, reinforcing steel, specific repair methods, and repair sequencing should also be submitted by the contractor to the LDP for review and acceptance prior to initiation of the work.

1.2.7.3 *Quality assurance and control*—Quality assurance and control measures should be implemented to provide acceptance criteria, verify conformance to contract documents, and to verify the properties and quality of the installed repair materials. ACI 311.4R provides guidance on setup of quality control, inspection, and testing procedures. ACI 311.1R and ACI 311.5 provide guidance on inspection and testing.

1.2.7.3.1 *Quality assurance*—The LDP should outline quality assurance requirements in the contract documents by establishing standards or criteria for acceptance. The quality assurance program dictates the desired level of quality for repairs.

1.2.7.3.2 *Quality control, inspection, and testing*—Successful completion of the repair program can be verified by implementing quality control measures during the course of the work. Such measures include:

a) Periodic site observations by the LDP to verify general conformance with contract documents;

b) Periodic testing by an independent testing agency to verify that requirements of the contract documents are met;

c) Contractor supervision of the crew's work and weather conditions, including temperature, humidity, and precipitation, which may affect the repair procedure;

d) Recordkeeping by the project team, including documentation of repair locations, repair modifications, quantities installed, documentation reviews by the LDP, weather conditions, changes to the contract documents, and periodic progress reports.

1.2.7.3.3 *Testing and inspection agency qualifications*—The testing agency should meet the requirements of ASTM E329. Inspection or testing personnel should be special inspectors, engineers, the LDP, or ACI-certified, or approved equal, field/laboratory technicians, as applicable.

1.2.7.4 *Project closeout*—If requested by the owner and upon completion of the project, the owner should receive and retain a project manual from the contractor or LDP containing copies of relevant contract correspondence issued during construction. The project manual should include items such as repair drawings and specifications, additional details or clarifications provided by the engineer, field and test reports, photographs, submittals, permits, change orders, requests for information (RFIs) and their responses, insurance certificates, bonds, pay applications, warranties, waivers of lien, and as-built drawings.

1.2.8 *Maintenance after completion of repairs*—Maintenance of the concrete structure and any protection or strengthening system is recommended after completion of a concrete repair project. Lack of adequate maintenance may result in premature failure of the repair or surrounding areas. If requested by the owner, the LDP should develop a maintenance manual for repair work.

1.2.8.1 *Warranty coverage*—Warranty requirements should be followed, including periodic inspections or recoating of membranes and sealers to ensure that warranty coverage is maintained. Warranty items should be reviewed during the warranty period and the contractor contacted to repair failures that occur under warranty.

1.2.8.2 *Periodic inspections*—Continued evaluation of the structure through periodic engineering reviews should be considered to monitor structural integrity and performance of repairs.

1.2.8.3 *Post-repair monitoring systems*—Systems to detect concrete/system failures should be considered, such as corrosion monitoring for detecting corrosion and acoustic monitoring for detecting tendon failures, in post-tensioned structures.

1.3—Sustainability

A green structure is an environmentally sustainable structure designed, constructed, and maintained to minimize its impact on the environment (Schokker 2010). The primary objectives when designing a green structure include reducing energy consumption, conserving water, and recycling waste. Repairing and maintaining concrete structures instead of replacement is a green concept and a sustainable philosophy. Repairing concrete structures meets sustainability objectives by conserving existing materials and thereby reducing energy consumption and material waste.

CHAPTER 2—DEFINITIONS

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology," http://www.concrete.org/Tools/ConcreteTerminology.aspx. Additional concrete repair definitions are found in the International Concrete Repair Institute (ICRI) terminology database, http://www.icri.org/GENERAL/repairterminology.aspx.

CHAPTER 3—CONCRETE REMOVAL AND SURFACE PREPARATION

3.1—Introduction

This chapter covers the removal of deteriorated and sound concrete, and preparation of the concrete surface to receive new repair materials. Exercising care during the removal and preparation phases of a repair project can be the most important factor in ensuring the longevity of the repair, regardless of the material or technique used. Concrete should be removed carefully so as not to damage the existing adjacent concrete or affect bond of the new repair material.

Care should be taken when removing concrete around prestressing steel, both bonded and unbonded strands. When high-energy impact tools such as chipping hammers are used, operators should avoid contacting the strands with the tools, as such contact may cause wires to rupture, possibly leading to strand failure and a reduction in the structure's load capacity. Removing surface concrete may also cause excessive stresses in the concrete to remain and redistribute secondary forces and moments in indeterminate structures. The extent of concrete removal should not be permitted to exceed stress limits in the remaining concrete.

Personal protective equipment should be used in all processes and the containment, handling, and disposal of concrete dust, slurry, and debris considered with the processes employed. Refer to ICRI 120.1 for recommendations on safety in the concrete repair industry to minimize vibrations and noise.

3.2—Concrete removal

A repair project typically involves removing deteriorated, damaged, or defective concrete. In most cases, however, determining the extent of the deteriorated or damaged concrete requiring removal can be difficult. Common techniques to identify distressed concrete are sounding by hammer tapping or by chain drag (ASTM D4580). Deep delaminations and microcracks may not be detected by