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Concrete Repair—Guide

Reported by ACI Committee 546

ACI PRC-546-23



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Concrete Repair—Guide

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38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

Concrete Repair—Guide

Reported by ACI Committee 546

Peter Barlow, Chair

Chris White, Secretary

Michael M. Chehab
Kevin Conroy
Marwan A. Daye
John D. Fauth
Michael J. Garlich

Paul E. Gaudette
Timothy R. W. Gillespie
Matthew R. Hansen
Susan Isble
Lawrence F. Kahn

Brian F. Keane
Kenneth M. Lozen
John S. Lund
Johan L. Silfwerbrand
Michael M. Sprinkel

Peter Tarara
Joseph E. Tomes
David A. VanOcker
Kurt Wagner
David W. Whitmore

Consulting Members

Peter Emmons
Etien Frett
Fred R. Goodwin
Harald G. Greve

Noel P. Mailvaganam
James E. McDonald
Kevin A. Michols

Richard Montani
Jay H. Paul
Don T. Pyle

Aamer H. Syed
Nicholas R. Triandafilou
Patrick M. Watson

*Special acknowledgments to Matthew Hansen (subcommittee Chair), Kaveh Afshinnia, Peter Barlow, John Fauth, Etien Frett, Tim Gillespie, Ann Harrer, Ashlee Hossack, Sue Isble, Adrienne Larson, John Lund, Terry McGovern, Mark Nelson, Peter Tarara, and Chris White for their contributions to this guide.

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—Summary

The successful repair of concrete structures depends on many factors, including proper design, material selection, and application methods. The information provided in this guide is intended to assist the reader with repairing deteriorated and damaged concrete structures (Fig. 1.1), correcting design and construction deficiencies, and strengthening existing structures for new uses and to comply with current building codes. Current practices in concrete repair and

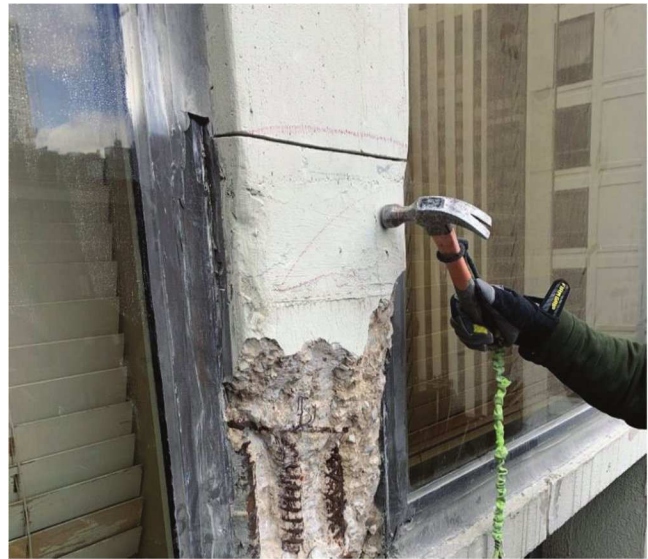


Fig. 1.1—Deteriorated concrete column on building façade.

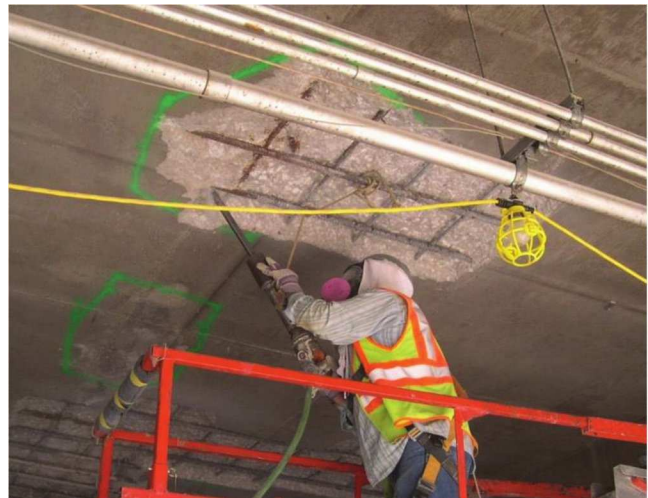


Fig. 1.2—Concrete removal at underside slab repair in progress.

strengthening are summarized and information is provided for the planning, design, and execution of repair and strengthening work for various conditions.

1.2—Scope

This document provides guidance on concrete removal, substrate and reinforcement preparation, material selection, material application methods, and protective systems for concrete structures (Fig. 1.2). An overview of concrete repair methodology is included with references to [ACI 562](#) and [ACI 563](#).

In addition to concrete repair, this document provides guidance for the strengthening of concrete structures. Many of the same techniques are used to both repair and strengthen concrete members and structures, including demolition,

bonding new material to existing substrate, and installation of new reinforcing steel.

CHAPTER 2—DEFINITIONS

ACI provides a comprehensive list of definitions through an online resource, “ACI Concrete Terminology.” Additional concrete repair definitions are found in the International Concrete Repair Institute (ICRI) terminology database, https://www.icri.org/page/terminology_A.

CHAPTER 3—REPAIR METHODOLOGY

3.1—Introduction

The methodology for repairing a concrete structure typically includes:

- Condition assessment (Section 3.2)
- Design considerations (Section 3.3)
- Selection of repair methods and materials (Section 3.4)
- Temporary shoring (Section 3.5)
- Construction documents (Section 3.6)
- Bid or contract negotiation process (Section 3.7)
- Execution of work (Section 3.8)
- Maintenance after completion of repairs (Section 3.9)
- Sustainability considerations (Section 3.10)

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 and the residual structural capacity is assessed, the appropriate repair program can be selected to effectively address these conditions. Figure 3.1 presents a detailed overview of the process for effecting successful concrete repairs.

3.2—Condition assessment

The process of repairing a concrete structure starts with the assessment of existing conditions. The assessment can include the following steps:

- Reviewing available design and construction documents, previous reports, repair/maintenance records, and test data, if available
- Performing a visual condition survey of the existing structure and surrounding environment and documenting deterioration and distress
- Evaluating corrosion activity
- Performing invasive or nondestructive testing, or both
- Reviewing physical, chemical, and petrographic analysis results of laboratory-tested concrete samples
- Performing structural analysis of members in question, or the structure overall, in its deteriorated condition

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

3.2.1 Potentially dangerous conditions—During the assessment, conditions may be discovered that pose an immediate safety issue; these should be reported to the owner for mitigation upon discovery. Local building codes may require that the licensed design professional (LDP) report unsafe conditions to the authorities and may require that the owner take measures to protect the public safety. 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 signs of behavior suggesting an inability to support required loads, these members should be stabilized, shored, or the affected areas removed from service.

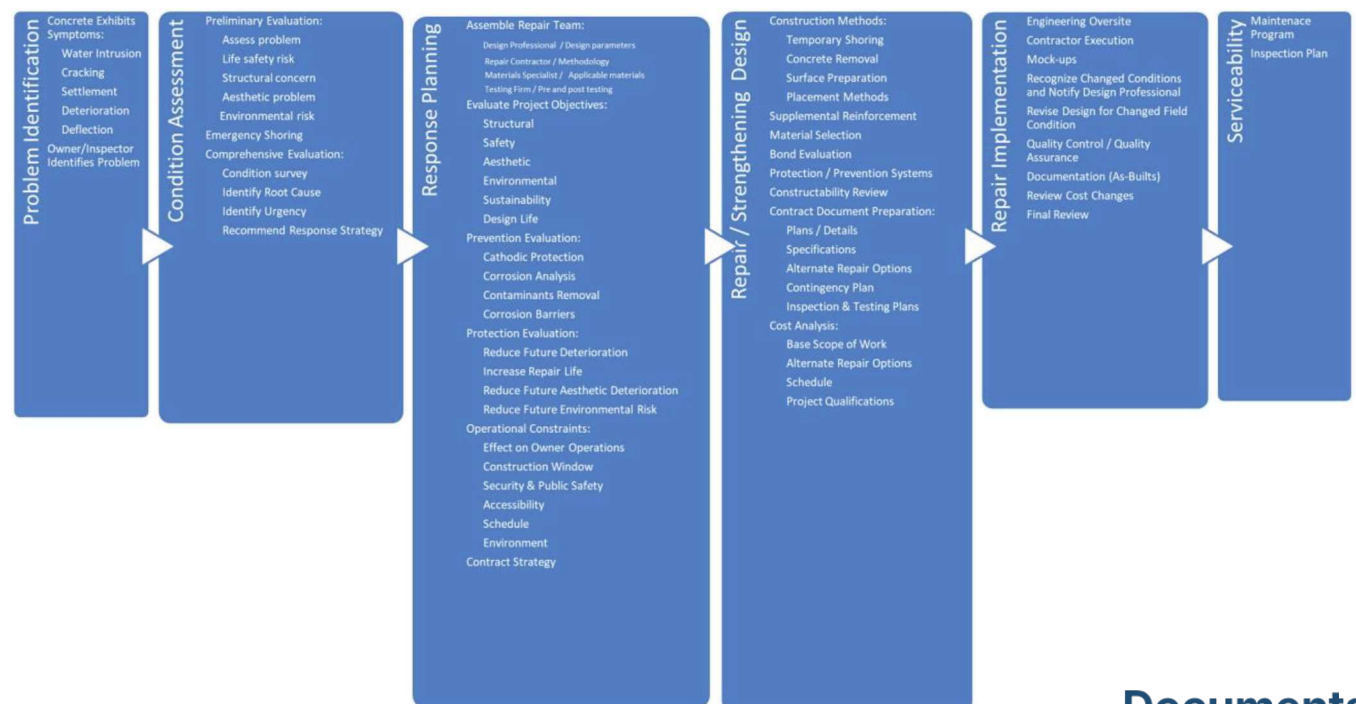


Fig. 3.1—Concrete repair/strengthening process.

3.2.2 Global issues—The satisfactory performance of a structure depends on maintaining the integrity of the structure, including the exterior envelope of the building. In situations where an LDP is performing an assessment of a limited portion of a structure and 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 LDP should inform the owner of such conditions and advise that an expanded evaluation be conducted to confirm whether implementation of remedial action is warranted ([ACI 132R](#)).

3.2.3 Determination of cause, severity, and extent—During the condition assessment of a structure, the cause of distress, deterioration, or deficiency should be determined. For example, cracking is a symptom of distress that results from one of several possible causes, such as drying shrinkage, thermal cycling, overloading, corrosion of embedded metal, or inadequate design or construction. As deficiencies may be caused by more than one mechanism, a basic understanding of the causes of concrete distress and deterioration is essential to determine an appropriate repair option. After completing the assessment, a suitable remedial action plan can be developed, repair methods and materials selected, and construction documents prepared. If a considerable 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 variation between estimated and actual quantities of repair work.

3.3—Design considerations

In designing a concrete repair, strengthening system, or protective system, the LDP should consider the safety and serviceability of the structure during construction and its performance after 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 of the existing structure, as the [ACI 562](#) code requirements were developed specifically for existing concrete structures and may prove more applicable to assessment, repair, and strengthening conditions. The LDP should apply basic principles of structural mechanics and understand material behavior to evaluate and design a structural repair, a strengthening procedure, or a protective system. Several design considerations are discussed in 3.3.1 through 3.3.6.

3.3.1 Current load distribution—In a deteriorated condition, a structural member or system may distribute dead and live loads differently than it did in its undamaged condition. Cracks, deteriorated concrete, and corroded reinforcement can alter the behavior of members, leading to redistribution of shear and moment forces, and changes in axial load. As

concrete and reinforcement are removed as part of the repair process, these redistributed forces may be further altered. To understand the final behavior of the structural system, the LDP 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 alter the load path differently than was assumed in the original design of the structure. Furthermore, the LDP should consider the loss of structural capacity due to the reduced concrete section and effectiveness of reinforcement during demolition in determining shoring and repair phasing requirements.

3.3.2 Compatibility of materials—If a repair material 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 material characteristics further exacerbates the effects of thermal change, vibration, long-term creep, and shrinkage. Concrete coring and petrographic analysis may be performed to determine properties of existing concrete. Refer to [ACI 546.3R](#) and [ACI 364.5T](#) for additional information on material selection and compatibility.

3.3.3 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. Creep and shrinkage of concrete tends to diminish over time, so newly placed cementitious repair materials may exhibit a higher rate of creep and shrinkage than the older underlying original concrete, resulting in differential movements between the two materials. This differential movement can cause cracks to occur between the repair and the surrounding original concrete, and to even cause the repairs to delaminate, resulting in a loss of stiffness of the repaired structure creating a redistribution of forces in, and increased deformations of, the structure. Controlled-shrinkage cementitious repair materials and systems can contribute to the reduction of the volume change effects.

3.3.4 Vibration—When the installed repair material is in a plastic state or prior to the development of adequate strength, vibration of a structure can damage the bond between the repair material and surrounding concrete. Isolating the repairs or eliminating the vibration may be a design consideration. Examples of potential vibration sources include live traffic on bridge decks adjacent to repair areas, rotating equipment in process units, and concrete demolition and surface preparation in adjacent areas.

3.3.5 Water and vapor migration—Water or vapor migration through a concrete structure can degrade the bond strength and durability of a repair. Understanding repair material properties and their susceptibility to moisture damage and controlling the cause and degree of moisture migration should be a repair design consideration.

3.3.6 Material behavior characteristics—The structural behavior of a repaired section is dependent on the characteristics of the repair materials. Therefore, after a repair is executed, the structural behavior can differ from that of the original section. 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 8), such as fiber-reinforced polymer (FRP) applied to the tension face of the beam. The LDP should consider the behavior and performance of the new repair under the expected service and ultimate loads and should design the repair to provide a level of safety that is at least equivalent to the original design. Such design considerations are included in ACI 562 but are outside the scope of ACI 318.

3.4—Selection of repair methods and materials

Successful concrete repair depends on the proper selection and application of the materials and methods to be used. ACI 546.3R provides specific guidelines for the properties of repair materials and their selection, while ACI 546.2R covers repair materials for underwater applications. ACI 546.4R provides specific guidelines for jobsite quality control and quality assurance of cementitious packaged materials. Repair materials and methods should be selected with the following considerations.

3.4.1 Concrete environment—Repair work can incorporate adjustments or modifications to mitigate the cause of future concrete deterioration, such as reducing exposure to moisture, changing the water drainage pattern, eliminating sources of erosion and water infiltration, accommodating differential movements, or eliminating exposure to deleterious substances. However, it is not always possible to remove the causes of deterioration.

3.4.2 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 impact on facility operations within a structure, weather, aesthetic concerns, and historical building restrictions (U.S. Department of the Interior 2017). Owner-imposed budget and schedule constraints are common challenges to repair programs.

3.4.3 Inherent challenges—Factors that cannot be corrected, such as continued exposure to chlorides from deicing salts, saltwater, or deleterious chemicals, should be considered. In such cases, repair and protective systems extend the life of the structure rather than eliminating the causes of deterioration.

3.4.4 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 ICRI 120.1 for information on further safety aspects relevant to the concrete repair industry.

3.4.5 Service life—The intended service life of the repaired member and structure should be considered in the selection of repair materials and methods. The owner should be consulted to establish an estimated service life consistent with their long-term plans for their facility, taking into consideration anticipated routine inspection and maintenance programs.

3.4.6 Constructability—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 aid in the selection, availability, and cost of repair materials, and in the selection of 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. ACI 364.3R provides a uniform testing protocol for repair materials to permit direct comparison of important properties. Further testing and/or mockups may be required (refer to ACI 546.4R).

3.5—Temporary shoring

As presented earlier in this guide, the repair process, including concrete removal and reinforcement repair, may weaken a deteriorated structure further or otherwise alter the force and load distribution within and between reinforced concrete members. It is essential that the contractor, in conjunction with the LDP, 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. Shoring considerations, including aspects of delegated design and the contractor's specialty engineer, are covered in ACI 563 and ACI 132R.

Refer to Section 4.2.2 of this document, Section 2 of ACI 563-18, and Section 9.2 of ACI 562-16 for temporary shoring considerations.

3.6—Construction documents

The preparation of construction documents includes drawings, details, and specifications. Construction 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 ideally include allowances for adjustments in work items such as concrete removal, surface preparation, reinforcement replacement, and quantities of repair materials. Provisions should be included in the documents for addressing unforeseen conditions and potential changes to the contract estimate of repair quantities. Contingency plans may be developed in the likelihood that the extents of unsound concrete and/or reinforcing steel corrosion are greater than anticipated. Contingency materials, such as varying lengths and sizes of reinforcing steel bars, may be procured and stored on-site during the demolition phase to minimize project delays.

Where deterioration is particularly severe or where extensive concrete removal is anticipated, provisions for temporary structural support should be included in the construction 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, concise, and current delineating:

- (a) Scope of work
- (b) Repair work items
- (c) Information on existing concrete conditions, if available
- (d) Material and equipment requirements
- (e) Surface preparation, installation procedures
- (f) Shoring requirements
- (g) Qualification/certification requirements for contractor and quality/testing agency
- (h) Quality assurance and testing criteria
- (i) Performance testing standards

Supporting documents referencing specific repair or material requirements should be included as appropriate. These may include:

- (a) Tensile strength
- (b) Surface profiling
- (c) Compressive strength
- (d) Bond strength
- (e) Length change
- (f) Shrinkage behavior
- (g) Density
- (h) Creep ratio
- (i) Thermal expansion coefficient
- (j) Fire resistance characteristics

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 protective 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 protective system application.

3.6.1 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 and **ACI 132R** for responsibility in concrete construction.

3.6.1.1 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. Note that lump sum contracts are not often used for repair projects because exact quantities are difficult to define prior to demolition.

3.6.1.2 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.

3.6.1.3 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.

3.6.2 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 311.4R**, **ACI 311.5**, and **ACI MNL-2**).

3.7—Bid or contract 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. Other regulations may apply to public projects.

3.7.1 Prebid conference—Before bids are submitted, the LDP, owner or owner's representative, and potential contractors should attend a prebid conference to answer questions regarding the construction documents and to define expectations of the owner. This meeting should include a visit to the repair site and mockup requirements/objectives (if required) should be discussed.

3.7.2 Addenda—Clarifications to the construction 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.

3.8—Execution of work

Repair work should be executed in accordance with the construction 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.

3.8.1 Preconstruction conference—Before starting a project, it is important to have the owner, LDP, contractor, subcontractors (if required), quality inspectors, and testing agency attend a meeting to discuss the parameters, repair methods, and materials necessary to achieve the repair

objectives. The frequency and types of required correspondence should be defined among all parties executing the work to communicate progress, discovered items, and construction problems.

3.8.2 Material submittals and shop drawings—Prior to use on the project, the contractor should submit technical, installation, mockup testing, and safety data for proposed repair materials in accordance with the construction 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.

3.8.3 Quality assurance and control—Quality assurance and control measures should be implemented to provide acceptance criteria, verify conformance to construction 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 MNL-2** and **ACI 311.5** provide guidance on inspection and testing. All inspectors should be qualified in accordance with **ACI 562**. **ACI 546.4R** provides guidance on jobsite quality assurance and control for packaged materials.

3.8.3.1 Quality assurance—The LDP should outline quality assurance requirements in the construction documents by establishing standards or criteria for acceptance. The quality assurance program dictates the required actions for providing and documenting assurance that what is being done and what is being provided are in accordance with the contract documents and standards of good practice for the work.

3.8.3.2 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 construction documents and when unexpected items are discovered during demolition
- (b) Periodic testing by an independent testing agency to verify that requirements of the construction documents are met
- (c) Contractor supervision of the crew's work and monitoring of 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 construction documents, and periodic progress reports

3.8.3.3 Testing and inspection agency qualifications—The testing agency should meet the requirements of **ASTM E329**. Inspection or testing personnel should be qualified per **ACI 562** and can include special inspectors, engineers, the LDP, ICRI Concrete Surface Repair Technicians (CSRT), and ACI-certified or approved equal field/laboratory technicians, as applicable.

3.8.4 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 as-built repair drawings and specifications, additional details or clarifications provided by the LDP, 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.

3.9—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. The LDP should develop a maintenance manual for repair work and the types and frequency of future maintenance should be documented in the basis of design.

3.9.1 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.

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

3.9.3 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.

3.10—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 minimizing use of new materials, thereby reducing energy consumption and material waste.

CHAPTER 4—CONCRETE REMOVAL AND SURFACE PREPARATION

4.1—Introduction

This chapter covers the removal of deteriorated and sound concrete, and preparation of the concrete and reinforcing steel surfaces to receive new repair materials. Exercising care during the removal and preparation phases of a repair project can be the most important factor in achieving a long-

lasting repair, regardless of the repair material or application technique used. Concrete should be removed carefully to minimize damage of the existing adjacent concrete and reinforcing steel to remain, as this damage will affect bond of the repair material.

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. The dust created by certain concrete removal and surface preparations techniques may be considered hazardous material and require specialized methods and precautions to mitigate exposure to workers and the general public. Refer to **ICRI 120.1** for recommendations on safety in the concrete repair industry.

4.2—Concrete removal

A repair project typically involves removing concrete, whether deteriorated, contaminated, or otherwise unsound, as well as sound concrete to effectuate a durable long-term repair. Removing all damaged or delaminated concrete at the interface between the substrate concrete and the repair material is important to achieve a durable bond.

Determining the extent of removal in advance of beginning a concrete repair project is challenging. A common technique to identify areas requiring removal is mechanical sounding (**ASTM D4580/D4580M**). Deep delaminations and microcracks may not be detected by hammer sounding or chain dragging. Other nondestructive techniques to identify deteriorated and damaged concrete include impact-echo testing (**ASTM C1383**), ground-penetrating radar (GPR) (**ASTM D6087**), and infrared thermography (**ASTM D4788**). Concrete core sampling and petrographic analysis can also be used to determine depth of carbonation and distress mechanisms. Refer to **ACI 228.2R** and **ICRI 210.4R** for additional information and other test methods used to identify deteriorated and damaged concrete.

4.2.1 General considerations—Concrete removal techniques should be effective in removing deteriorated and sound concrete, be safe for the structure and the construction workers, and minimize damage to the concrete left in place. The chosen removal technique may have a significant effect on the repair project duration. Some techniques may allow a portion of the repair work to be accomplished without removing the structure from service. In some instances, a combination of removal techniques may be more appropriate to speed removal and limit damage to the existing concrete. Field testing mockups of selected removal techniques can help determine the best procedures to use for the repair program.

In general, the construction documents specify the concrete repair requirements. The repair contractor selects the removal method considering effectiveness and other factors. In some instances, the LDP may specify removal techniques for the repair or prohibit techniques due to constraints and logistics of the structure. Weight limitations, vibration levels, and avoiding introduction of water into the structure are considerations that may limit removal techniques.

The following information is important to consider in determining the effective methods and cost of concrete removal:

- (a) Size, quantity, and location of reinforcing steel
- (b) Size and type of aggregates
- (c) Concrete compressive strength and modulus of elasticity
- (d) Existing coatings, toppings, overlays
- (e) Other existing or as-built conditions

4.2.2 Temporary shoring—It is essential to evaluate how concrete removal operations impact the structure's integrity throughout the repair process. Construction documents may delineate the general extent of shoring as determined by the licensed design professional (LDP) but commonly delegates a more detailed analysis and shoring design to the contractor. **ACI 563** requires the contractor to evaluate shoring requirements in consideration of his planned removal techniques and sequences, and retaining the services of a specialty engineer. Structural elements to be repaired may require temporary shoring, removal of applied loads, or both, to prevent structural deformations, buckling or movement of reinforcement, or possible collapse as well as to ensure that the repaired member behaves as intended (Fig. 4.2.2).



Fig. 4.2.2—Temporary shoring partitioning of garage floor (top) and balcony slabs (bottom).

4.2.3 Quantity of concrete to be removed—The anticipated quantity of concrete removal is directly related to the extent of the distress and the repair or removal technique. When a delay occurs between the time a condition assessment is performed and when the project is finally undertaken, potential quantity overruns are likely between preparation of the quantity estimates and actual removal. Estimating inaccuracies can be minimized by a thorough condition survey performed as close as practical to the time the repair work is executed. If delays occur, estimated removal quantities should be increased or a contingency should be provided to account for continued deterioration. Because most concrete repair projects are based on unit prices, repair areas should be accurately measured upon completion of the work. This is typically done jointly by the LDP and the contractor. It is not uncommon for final measured quantities to exceed the initial estimated quantities. Refer to [ICRI 130.1R](#) for guidelines for methods of measurement for concrete repair work.

4.2.3.1 Removal of concrete surrounding reinforcing steel—Existing reinforcement should not be cut or damaged except where directed by the LDP. Removal of deteriorated and damaged concrete is commonly performed before saw cutting to confirm the location and depth of reinforcement. Care should be used during removal of concrete to avoid cutting and damaging existing reinforcing steel (Fig. 4.2.3.1a).

Concrete removal should include the removal of deteriorated and damaged concrete surrounding existing reinforcing steel. Care should be used to prevent further damage to the reinforcing or prestressing steel. For this reason, prior to removal operations, the depth, size, quantity, and approximate location of existing reinforcement within the repair area should be determined. This can often be accomplished using nondestructive methods, a cover meter or reinforcing bar locator, and structural drawings if available.

Once the selected concrete has been removed within the repair area, a less invasive removal method, such as smaller handheld concrete breaker (nominal 15 lb [67 N]) should be used to remove concrete around exposed reinforcement

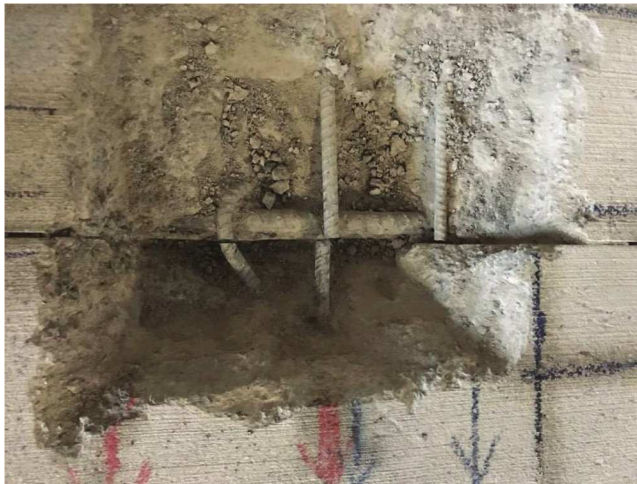


Fig. 4.2.3.1a—Reinforcing bars cut by saw cutting of repair area.

(Fig. 4.2.3.1b). Care should be taken to not damage reinforcement or otherwise cause loss of bond to the existing remaining concrete. If the existing reinforcing steel is only partially exposed after concrete removal, it may not be necessary to remove additional concrete to expose the full circumference of the reinforcement, provided the reinforcement is uncorroded and has not lost bond to the existing concrete, and the reinforcement has not been exposed more than 50% of the bar's circumference. Even in cases where the bar is exposed less than 50%, full undercutting of the reinforcement is often preferred for structural performance or other reasons ([Silfwerbrand 1989, 2017](#)).

When the exposed reinforcing steel has loose rust, corrosion products, is not well bonded to the surrounding concrete, or if the concrete surrounding the reinforcing steel is unsound or chloride-contaminated ([AASHTO T 260](#), [ASTM C1152/C1152M](#), and [ASTM C1218/C1218M](#)), or pH ([ASTM F710](#)) has been affected by carbonation ([7.2.4](#)) or acid attack, concrete removal should continue around the reinforcing steel to create a minimum of 0.75 in. (19 mm) clearance to the surrounding concrete or 0.25 in. (6 mm) larger than the maximum nominal size of the coarse aggregate in the repair material. Undercutting the exposed reinforcing steel provides clearance around the reinforcing steel for cleaning, complete bonding of the repair material to the existing concrete, and structurally secures the repair ([ICRI 310.1R](#)). In cases where concrete removal around the steel is not required, providing alternate means of achieving mechanical bond of the repair material should be considered.

Special attention is necessary when removing concrete around bonded and unbonded prestressed steel strands, as excessive concrete removal can lead to changes in strand profile, reduce forces in the strand, and compromise the integrity of the structure. When impact tools such as concrete breakers are used, operators should avoid contacting the



Fig. 4.2.3.1b—Handheld concrete breaker used to remove concrete around exposed reinforcement.

strands or tendon conduits with the tools, as such contact may cause wires to rupture, possibly leading to strand failure and a reduction in the structure's 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 strength limits in the remaining concrete.

4.2.3.2 Preparation of repair perimeter—The perimeter of the repair area should be saw cut to create a simple symmetrical configuration, preferably square or rectangular with square corners. Reentrant corners in the perimeter of removal areas should be avoided. Saw cut to a depth of 0.50 to 0.75 in. (13 to 19 mm) into the existing concrete at the repair perimeter to provide a vertical edge, to avoid feather edges and to provide a minimum thickness of repair material at the edge. Refer to contract documents for the overall spec-

ified depth and the manufacturer's recommendations for the selected repair material. Saw cutting to a lesser depth may be necessary at locations where the reinforcing and prestressing steel have reduced concrete cover. A perimeter saw cut is often unnecessary with concrete removal methods such as ultra-high-pressure water-jetting water jets (hydrodemolition) that can provide a uniform cut along edges. Following saw cutting, some removal of sound concrete may be required to achieve the repair geometry and avoid abrupt changes of depth within the repair.

4.2.4 Concrete removal methods—Removing concrete using aggressive methods, such as heavy-impact equipment or blunt-tipped tools, can damage the substrate or adjacent concrete. Impact tools may also result in microcracking or bruising (Hindo 1990) to the substrate. Unless this damaged, bruised layer is removed, the substrate concrete will be weakened, possibly resulting in reduced bond strength (refer to ACI PRC-364.7 for more information on bruising).

In most cases where impact methods are the primary means of concrete removal, the remaining concrete surfaces should be prepared by a secondary method, such as abrasive blasting or ultra-high-pressure water jetting, to remove any remaining damaged and microcracked surface material. The suitability of the substrate to receive the repair material can be verified by tensile pulloff testing of trial repairs (ICRI 210.3R; ASTM C1583/C1583M).

For shotcrete repairs, the edges of the removal areas should taper toward the center of the removal area to avoid acute angles that can make shotcrete placement more difficult and to allow air to escape during placement (ACI 506R). Large variations in the depth of removal within short distances should also be avoided, as they may result in cracking due to varying behavior of the repair materials with different thicknesses.

Concrete removal and excavation methods can be categorized by the way in which the process acts on the concrete. Common processes are cutting, impacting, and ultra-high-pressure water jetting (hydrodemolition), as shown in Fig. 4.2.4a. Other less-common methods of concrete removal are also available, such as blasting and presplitting methods, but these are typically only used for large-scale concrete removal. Table 4.2.4 provides a general description of these processes, lists the specific removal techniques within each category, and provides a summary of information on each technique. Refer to ICRI 310.1R and 310.2R and NACE No. 6/SSPC-SP 13 for additional information on concrete removal.

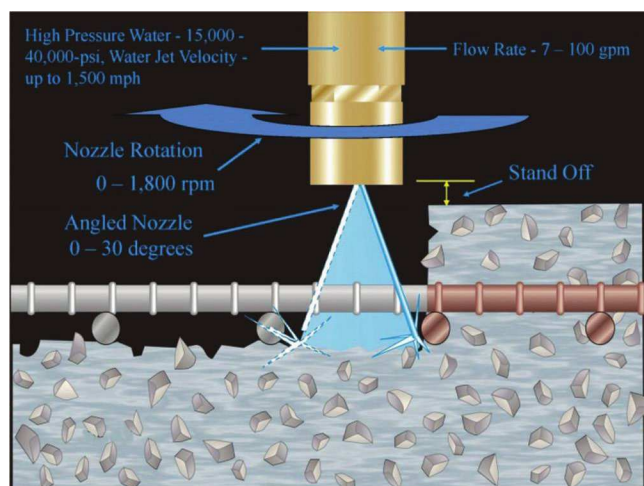


Fig. 4.2.4a—Hydrodemolition process (top); and hydrodemolition using a handheld lance (bottom).

Table 4.2.4—Summary of features, considerations, and limitations for concrete removal methods

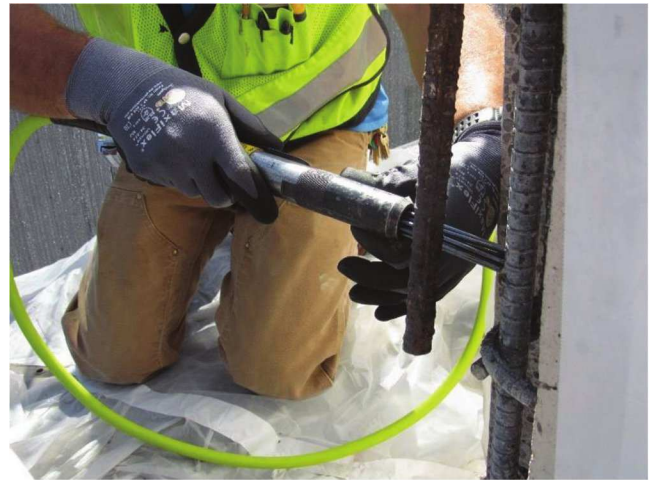
Category	Description	Features	Considerations/limitations
Saw cutting (applicable for making cutouts through slabs, decks, and other thin concrete members)	Diamond or carbide saws are available in sizes ranging from small to large, providing the ability to cut depths of approximately 5 ft (1.5 m).	(a) Makes precision cuts (b) No vibration is produced (c) Handling of debris is efficient because bulk of concrete is removed in large pieces	(a) Performance is affected by type of diamonds and the diamond-to-metal bond in blade segments (segment selection is based on aggregate hardness) (b) The higher the percentage of steel reinforcement in cuts, the slower and more costly the cutting (c) The harder the aggregate, the slower and more costly the cutting (d) Controlling flow of wastewater, if used, will be required
Impacting (uses repeated striking of the surface with a mass to fracture and spall the concrete)	Impact methods are the most commonly used concrete removal techniques. Impact methods involve striking a concrete surface repeatedly with a high-energy tool with hardened points or large mass to fracture and spall the concrete.	(a) Applicable for limited volumes of concrete removal (b) Applicable where blow energy must be limited (c) Widely available commercially (d) Can be used in areas of limited workspace (e) Produces relatively small and easily handled debris	(a) Performance is a function of concrete soundness and aggregate toughness (b) Significant loss of productivity occurs when breaking action is other than downward (c) Removal boundaries will likely require saw cutting to avoid feathered edges (d) Concrete that remains may be damaged (microcracking) (e) Produces high levels of noise, dust, and vibration (f) Impact methods are the most commonly used concrete removal techniques
Handheld breakers (Fig. 4.2.3.1b)	The handheld breaker or chipping hammer is probably the most common and best known of all concrete removal devices. Handheld breakers are available in various sizes with different levels of energy and efficiency. These tools are generally defined by weight and vary in size from 8 to 90 lb (3.5 to 41 kg).	(a) Smaller handheld breakers are commonly used in partial-depth removal of sound and unsound concrete and concrete removal around reinforcing steel because they minimize damage to the existing concrete and reinforcing steel (b) Sharp-pointed tools and light-weight breakers used at a shallow angle also tend to reduce the potential for microcracking of the surface concrete left in place	(a) Larger hammers have greater potential to cause microcracking and growth of repair areas (b) Hammer tips should be replaced as they become blunt throughout the demolition process, as blunt tips produce greater amounts of bruising
Boom-mounted breakers applicable for full-depth removal of slabs, decks, and other thin concrete members and for vertical and overhead surface removal from more massive concrete structures (Fig. 4.2.4b)	The boom-mounted breaker is similar to the handheld breaker except that it is mechanically operated and considerably larger than a handheld breaker. Boom-mounted breakers differ from handheld breakers, as they function on the principle of high energy and low frequency rather than low energy and high frequency and are driven by compressed air or hydraulic pressure. The reach of the hydraulic arm enables the breaker to be used on vertical or overhead surfaces at a considerable distance above and below the machine level. The boom-mounted breaker is a highly productive means of removing concrete; however, the high-cycle impact energy delivered to a structure by the breaker generates forces that may damage the existing concrete and reinforcing steel and adversely affect the integrity of the structure.	(a) Can be used for vertical and overhead surfaces (b) Widely available commercially (c) Produces easily handled debris	(a) Blow energy delivered to the concrete may have to be limited to protect the structure being repaired and the surrounding structures from damage (b) Performance is a function of concrete soundness and aggregate toughness (c) Damages remaining concrete (d) Damages reinforcing steel (e) Produces feathered edges (f) Produces high level of noise and dust

Table 4.2.4, cont.—Summary of features, considerations, and limitations for concrete removal methods

Category	Description	Features	Considerations/limitations
Scabblers	Scabblers are best known for their ability to remove shallow depths and delaminations of concrete from a surface. Scabblers impact the concrete with cutting heads to create a chipping and pulverizing action. Scabbler heads are available in various sizes and geometrical shapes, and varying numbers of heads may be mounted on the cylinders. Equipment size depends on the number of cylinders. The equipment is normally driven by compressed air.	(a) Low initial cost (b) Can be operated by unskilled labor (c) Can be used in areas of limited workspace (d) Removes deteriorated concrete from wall or floor surfaces efficiently (e) Readily available commercially (f) Designed to remove deteriorated or sound concrete from horizontal, vertical, and overhead surfaces to relatively shallow depths (1/8 to 3/4 in. [3 to 19 mm]) (g) Can remove brittle coatings and provide deep profiling	(a) High cyclic energy applied to a structure will produce fractures in the surface of the remaining concrete (b) Produces high level of noise and dust (c) Limited depth removal (d) Produces a very irregular surface with a fractured coarse aggregate profile and typically causes microcracking of the concrete surface
Needle scaler applicable for surface preparation of steel and concrete and limited volumes of concrete removal (Fig 4.2.4c)	Needle scaling uses the pointed tips of a bundle of steel rods contained by a steel tube to impact and remove concrete.	(a) Can be used in areas of limited workspace (b) Can be used for vertical and overhead surfaces (c) Produces relatively small and easily handled debris (d) Used for removing existing coatings	(a) Limited concrete removal depth (b) Concrete that remains can be damaged (microcracking) (c) Produces feathered edges
Scarifier/milling (applicable for removing deteriorated concrete surfaces from slabs, decks, and mass concrete)	A scarifier is a concrete removal device that uses rotary action and several cutter bits mounted on a drum to fracture and pulverize the concrete from a surface. Concrete removal depths typically range from 1/8 to 3/4 in. (3 to 19 mm) and may require multiple passes with the equipment. Scarifying can remove deteriorated and sound concrete in which some of the concrete contains form ties and wire mesh. Scarifiers are available in a range of sizes for removing deteriorated concrete on horizontal, vertical, and overhead surfaces.	(a) Boom-mounted cutters are applicable for removal from wall and ceiling surfaces (b) Removal profile can be controlled (c) Method produces relatively small and easily handled debris (d) Used for the removal of brittle coatings and adhesives, and profiling of concrete surfaces	(a) Removal is limited to concrete without steel reinforcement (b) Sound concrete reduces the rate of removal (c) Can damage concrete that remains (microcracking) (d) Noise, vibration, and dust are produced
Ultra-high-pressure water jetting (uses perimeter cuts to remove large pieces of concrete)	A narrow high-pressure water jet driven at high velocities, commonly producing pressures of 10,000 to 40,000 psi (69 to 276 MPa) to cut and remove concrete and prepare concrete surfaces. Ultra-high-pressure water jetting without abrasives will remove concrete but will not cut or damage the reinforcing steel. The addition of abrasives to the water jet can result in cutting of the concrete and the reinforcing steel.	(a) Ultra-high-pressure water jetting without abrasives (b) Applicable for making cutouts through slabs, decks, and other thin concrete members (c) Cuts irregular and curved shapes (d) Makes cutouts without overcutting corners (e) Cuts flush with intersecting surfaces (f) No heat, vibration, or dust is produced (g) Handling of debris is efficient because bulk of concrete is removed in large pieces	(a) Cutouts for removal limited to thin sections (b) Cutting is typically slower and more costly than diamond blade sawing (c) Moderate levels of noise may be produced (d) Controlling flow of wastewater will be required (e) Additional safety precautions are required due to the high water pressure produced by the system (f) Does not cut reinforcing steel unless abrasives are added

Table 4.2.4, cont.—Summary of features, considerations, and limitations for concrete removal methods

Category	Description	Features	Considerations/limitations
Hydrodemolition applicable for removal of deteriorated concrete from surfaces of bridges and parking decks and other deteriorated surfaces where removal depth is 6 in. (150 mm) or less (Fig. 4.2.4a)	Hydrodemolition uses high-pressure pumps capable of generating pressures from 10,000 to 40,000 psi (69 to 276 MPa) with water flow rates between 6 and 100 gpm (25 and 380 lpm) (ICRI 310.3R) to remove deteriorated concrete and clean existing reinforcement. Hydrodemolition should not be used in post-tensioned structures with unbonded tendons, except under the direct supervision of a structural engineer.	(a) Minimizes damage to the concrete that remains (b) Steel reinforcement is left clean and undamaged for reuse (c) Method produces easily handled aggregate-sized debris (d) Leaves a saturated, rough, irregular surface profile (e) Efficient at removing unsound concrete over large areas of the concrete surface cleaning the reinforcing steel while leaving sound concrete intact (f) Can remove coatings and waterproofing membrane systems	(a) Productivity is reduced when sound concrete is being removed (b) Removal profile will vary with changes in depth of deterioration (c) Method requires large source of potable water to meet water demand (d) Surface requires additional cleaning of surface after hydrodemolition; wastewater will have to be controlled (e) A permit may be required if wastewater is to enter a waterway (f) Flying debris is produced (g) Additional safety requirements are required due to the high pressures produced by these systems

*Fig. 4.2.4b—Boom-mounted concrete breaker used for underside repair.**Fig. 4.2.4c—Needle scaler.*

4.3—Surface preparation

Following concrete removal, the next step is surface preparation to ensure cleanliness and adequate surface profile of the repair area. Regardless of the type of the repair material, proper preparation of the reinforcing steel and concrete surface is essential to develop a good bond with the repair material. This section discusses the surface preparation of concrete and reinforcing steel for a repair. **ACI 515.3R** provides information on the methods of surface preparation related to membranes and surface coatings.

4.3.1 General considerations—Surface preparation consists of the steps necessary to prepare the concrete surface to receive repair materials. The appropriate preparation of the concrete surface depends on the procedures used to remove the concrete and on the type of repair to be undertaken.

Some of the concrete removal methods described in Section 4.2 can be used for surface preparation, but the final repair profile may exclude certain concrete removal methods that provide an irregular surface in situations where a membrane coating is to be installed. Some concrete removal methods damage or weaken the remaining concrete surface, such as removal with a concrete breaker.

(67 N) size. For example, microcracking of the concrete surface occurs when using certain removal methods. Left in place, microcracking often produces a weakened plane in the underlying concrete substrate, below the bond line of the repair material. In this case, a less invasive and aggressive method of final surface preparation, such as abrasive or high-pressure water jetting, may be necessary to remove the damaged surface layer. **ICRI 310.2R** provides a concrete

surface profile (CSP) system for identifying and specifying the surface profile necessary for various repair applications (Fig. 4.3.1) or assessing actual prepared substrate profile in the field.

In many repair situations, the proposed repair requires only surface profiling, exposure of coarse or fine aggregate, removal of a thin layer of damaged concrete, or cleaning of the concrete surface. Within the limits described in the previous paragraph, several of the concrete removal methods described in Section 4.2 can be used for this type of surface preparation. The referenced methods offer a wide range of surface characteristics and results. For example, the required surface preparation may vary from a light abrasive cleaning suitable for the application of a coating, to a deeper roughening and surface profiling necessary for good bond and reliable performance of the repair material. Selecting a suitable method of surface preparation is extremely important, as it influences the cost and performance of the repair.

4.3.2 Surface preparation methods—Common surface preparation techniques include abrasive blasting, shot-blasting, waterblasting, and cleaning methods. Table 4.3.2 provides a general description of surface preparation techniques. Refer to ICRI 310.2R for additional information on these methods.

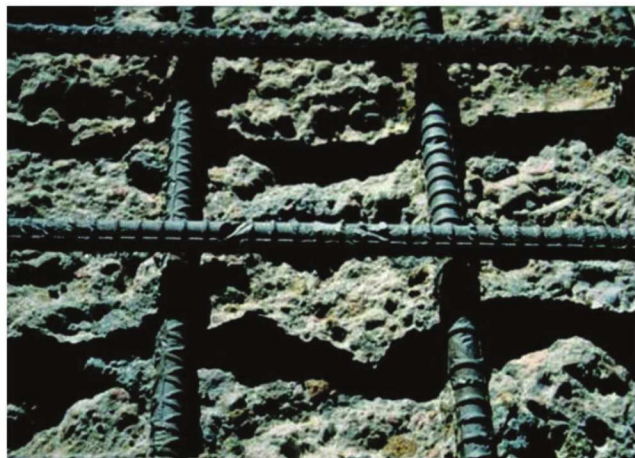


Fig. 4.3.1—Profiled concrete surface.

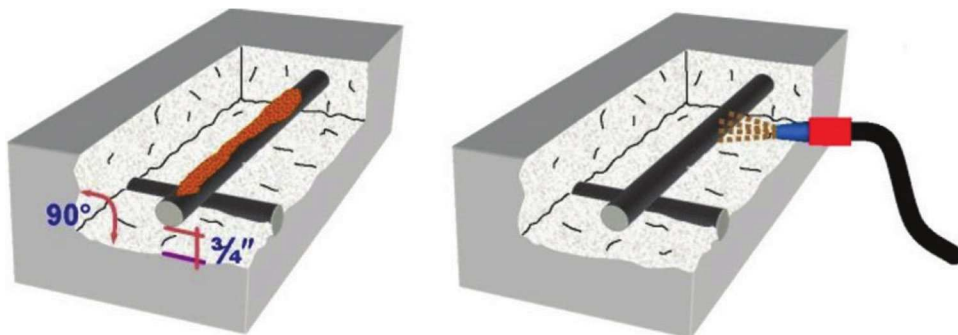


Fig. 4.3.2a—Sandblasting: (left) concrete preparation condition prior to sandblasting corroded reinforcing bar; and (right) condition after sandblasting.

Table 4.3.2—Summary of features and considerations/limitations for surface preparation methods

Category	Description	Features	Considerations/limitations
Abrasive blasting—Sandblasting (dry) (Fig. 4.3.2a).	Abrasive blasting removes and cleans concrete by propelling an abrasive medium in compressed air at high velocity against the concrete surface to abrade and pulverize it. Abrasive blasting is commonly used to clean reinforcing steel and clean and profile concrete surfaces in preparation for sealers, coatings, and overlays. The process uses common sands, silica sands, metallic sands, granular slags, or other media for the abrasive medium. Abrasive particles are propelled at concrete and steel surfaces in a stream of compressed air at a minimum pressure of 100 psi (0.7 MPa). The compressor size will vary depending on the size of the equipment. The abrasive particles are typically angular and may range in size from passing a No. 70 to a No. 4 (212 to 4.75 mm) sieve.	(a) Efficient method for roughening the surface and exposing aggregate (b) Cleans reinforcing steel (c) Removes surface contamination (d) Larger particles produce rougher surfaces, finer particles are used for removing contaminants, laitance and loose scale from reinforcing steel	(a) Abrasive blasting procedure produces large volumes of dust (b) Not practical for removal exceeding 0.25 in. (6 mm)
Abrasive blasting—Sandblasting (wet) (Uses equipment that propels an abrasive medium at high velocity)	Free particulate rebound that results from the sand being projected at the concrete surface is confined within a circle of water.	(a) Efficient method for roughening the surface and exposing aggregate (b) Cleans reinforcing steel (c) Removes surface contamination	(a) Wet abrasive blasting is slow (b) May leave a residue on the surface that may require further cleaning
Low-pressure water cleaning (with abrasives)	Low-pressure water cleaning with abrasives is a cleaning system using a stream of water at low pressure (1500 to 5000 psi [10 to 35 MPa]) with an abrasive such as sand, aluminum oxide, or garnet, introduced into the stream. This equipment can remove dirt or other foreign particles and concrete laitance, thereby exposing the fine aggregate and leaving the concrete surface clean and free of dust.	(a) Selectively removes defective concrete (b) Precise control of preparation process (c) Cleans reinforcing steel while removing concrete (d) Produces minimal damage to remaining concrete (e) Produces no heat or dust (f) Abrasives enable jet to cut steel reinforcement and hard aggregates	(a) High initial investment (b) Additional protection and safety procedures may be required due to water pressure (c) Controlling flow of contaminated wastewater will be required
Abrasive blasting—Shotblasting (Fig. 4.3.2b).	Shotblasting equipment cleans and prepares concrete by projecting steel shot at the concrete surface at high velocity within an enclosed blast chamber that recovers and separates most of the dust and reusable shot. The shot erodes and pulverizes the concrete at the surface.	(a) Efficient method for roughening the surface and exposing aggregate (b) Low dust emissions (c) Removes surface contaminants by using smaller (0.017 to 0.028 in. [0.43 to 0.71 mm] diameter) shot and setting the machine for maximum travel speed (d) Controlled depth of concrete removal (e) Readily available commercially (f) Surface profile determines size of shot and speed of machine travel (g) Shotblasting can provide CSP ranging from CSP2 to CSP9 (ICRI 310.2R), making this method suitable for roughening horizontal surfaces in preparation for receiving sealers, coatings, and overlays	(a) Large units may produce high noise levels (b) High-voltage power requirements

Table 4.3.2, cont.—Summary of features and considerations/limitations for surface preparation methods

Category	Description	Features	Considerations/limitations
Chemical cleaning	In many cases, chemical cleaning methods of surface preparation are not appropriate for use with the concrete repair materials and methods presented in this guide. With certain sealers and coatings under certain conditions, however, it may be possible to use detergents, trisodium phosphate, and various proprietary concrete cleaners to remove dirt, oil, grease, buildup, and oxidation deposits from concrete surfaces (ASTM D4258).	(a) Application of chemicals to remove dirt and contaminants from surface (b) Additional surface preparation may be necessary to remove cleaning chemical residue (c) Follow cleaning chemical manufacturer's recommendations (d) Follow coating manufacturer's instructions	(a) Additional surface preparation may be necessary (b) May not be effective in removing all contaminants (c) May have strong chemical odor (d) Protection of adjacent area necessary
Acid etching	Acid etching of concrete surfaces has long been used to remove laitance and surface concrete. The acid removes cement paste and provides a slight surface profile by exposing fine aggregate. This lightly profiled surface promotes penetration and adhesion of sealers and coatings, especially thin-film coatings.	(a) Effective in removing cement-based materials (b) Increases porosity of concrete surface	(a) Protective clothing is necessary (b) Large amounts of water necessary (c) May permanently stain concrete (d) Protection of adjacent area necessary (e) May contaminate and damage remaining concrete surface (f) Acids may penetrate the concrete surface through cracks and promote corrosion of underlying reinforcing steel in structural concrete (g) Surfaces must be thoroughly cleaned after acid etching to remove the weakened surface
Low-pressure water cleaning (without abrasives)	Water is sprayed to remove dirt and loose, friable material. Using pressures less than 5000 psi (35 MPa), this method does not remove any significant amount of concrete.	(a) Effectively removes surface contaminants without chemical residue (b) Minimal protection of adjacent areas necessary (c) Can be used where mist and water are tolerated	(a) Control of large amounts of water (b) Removal of small amounts of concrete may be noticeable, but does not produce any significant increase in texture, profile, or pattern in the concrete and therefore should be a supplement to other methods in most surface preparation applications (ICRI 310.2R)

*Fig. 4.3.2b—Shotblasting.*

4.3.3 Cleaning reinforcing steel—All exposed surfaces of the reinforcement should be thoroughly cleaned of all loose concrete, rust, oil, and other contaminants. Abrasive

blasting is a commonly used method. The degree of cleaning depends on the repair procedure and material selected. For localized areas, wire brushing or other hand methods of cleaning may be acceptable. An oil-free compressor should be used when cleaning the steel and removing loose particles from the repair area after cleaning to ensure that neither the reinforcing steel nor the concrete substrate become contaminated with oil. High-pressure water jetting is also effective in cleaning the surface and reinforcing steel. Refer to [Sections 6.4](#) for reinforcement repair and [7.7.4](#) for installation of embedded galvanic anodes and cathodic protective systems to reinforcing steel.

4.3.4 Final cleaning of repair area—Upon completion of surface preparation and cleaning of the reinforcing steel, the surface should be clean, dry, and free of microcracking. All loose concrete, aggregate, rust, oil, and other contaminants should be removed from the concrete surface and reinforcing steel. This may require further sand, water, or air blasting; vacuuming; or other techniques.