codes & standards

The Concrete Repair Guide

A "Roadmap" To Achieve Successful Concrete Repairs

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ACI 546R-04

Deterioration to concrete structures in North America and elsewhere is occurring at an alarming rate. This includes damage to bridges, buildings, parking structures, environmental facilities and other structures.

America's Infrastructure was given an overall grade of D in the 2005 American Society of Civil Engineer's Report Card. The ASCE Report Card indicated that it would take $1.6 trillion spent over the next five years to repair and rehabilitate America's infrastructure. The magnitude of deterioration and damage to structures throughout the world, all requiring repair, is staggering. Delaying repairs usually results in an accelerating rate of deterioration and much more costly repairs in the future. Furthermore, if concrete deterioration or damage is not addressed, eventually some of these structures may cease to be serviceable, or worse yet, failures could occur. The required repair and rehabilitation of the concrete infrastructure, as well as older concrete buildings, parking structures, and other facilities, is an immense challenge to the Structural Engineering profession.

Currently, a concrete repair code does not exist, and as ACI 318 is intended for new construction, it is often not applicable to concrete repair projects. Because many concrete repair issues are not dealt with by code, the judgment of the engineers and contractors who must decide on the proper course of action is vital to achieve safe, reliable, and appropriate solutions. The *Concrete Repair Guide* (ACI 546R-04) provides reliable guidance for concrete practitioners and provides a basis to approach concrete repair projects.

The *Concrete Repair Guide* should be considered a "roadmap" for repair, as it is essentially an overview of the entire process and summarizes the current practices for concrete repair. It provides extensive references to relevant ACI documents, as well as to other sources for more in depth discussions regarding all aspects of concrete repair. The *Guide* was revised in 2004 to include new materials and techniques that were not in previous editions. Moreover, the entire document was improved, and provides additional information on various topics throughout as well as expanded discussions and clarifications. Likewise, obsolete materials and methods were deleted.

The *Guide* includes information regarding:

- Repair methodology
- Concrete removal, preparation, and repair techniques
- Repair materials
- Protection systems
- Strengthening techniques

The Guide provides assistance for repairing deteriorated columns as shown above, as well as for other concrete elements

Repair Methodology

The mindset for engineers working on repair/strengthening projects must be entirely different than it is for new work. On repair projects, the structure already exists, and has performance characteristics that may or may not meet prevailing code requirements. Often drawings for the original construction are not available, or the actual as-built conditions differ from the information on the drawings, making it difficult to determine the design intent. Usually, when structures require repair, there are certain inherent problems with the structure that contributed to the deteriorated state.

The *Concrete Repair Guide* presents in detail the basic steps required for the repair process. The following approach is recommended:

1. Condition Evaluation
2. Determination of the causes of deterioration
3. Selection of repair methods and materials
4. Preparation of drawing and specifications
5. Bid and negotiation process
6. Execution of work
7. Appropriate quality control measures
8. Maintenance after completion of work

Refer to Fig. 1.1,"Repair Process", in the *Guide* which graphically presents the basic steps of the repair process. (See the on-line version of this article for a reproduction of Figure 1.1).

The Guide has been updated to include new technology. For example, delamination of concrete around the perimeter of repair patches due to the "halo effect", as shown above, is a common problem that can occur within years after the repairs are completed. New strategies to delay the onset of the "halo effect" have been added to the Guide.

The repair practitioner must understand the reasons the problems occurred in the first place. To accomplish this, a thorough condition evaluation must be performed as the first step in the repair process. The condition evaluation should include a review of available construction documents and may include a structural analysis in its deteriorated state, a review of test data (including records of any previous repairs and maintenance records), and an inspection of the structure. The visual inspection should be supplemented with any necessary observation openings, appropriate destructive and nondestructive testing, and laboratory testing of material removed from the structure. Upon review of all of the data from the condition evaluation, the repair practitioner should have a thorough understanding of the condition of the concrete structure, along with an understanding into the causes of the observed deterioration or distress.

If possible, the reasons for the existing problems should be corrected as part of the repair process. However, sometimes this is not possible. One example would be the lack of cover over reinforcing bars. This condition is not easily corrected. However, certain strategies could be used to compensate, such as the use of protection systems. Protective systems are discussed in the 546R document.

Safety is emphasized throughout the *Guide*. The engineer should determine the extent of reinforcement deterioration, and if there is a need for shoring. Loose or delaminated concrete should be removed immediately if it is a threat to the public safety. Likewise, during the repair process, redistribution of loading may occur, beams or slabs may be disconnected from their supports, the lateral supports for columns may be removed, and other temporary unstable conditions may result. It is important that the engineers, the contractors and the field personnel understand these conditions, and take proper measures to prevent collapse of the structures or any components from occurring. The methodology for the engineer to approach repair projects focusing on issues such as these are an important part of the *Guide*.

The preparation of drawings and specifications, as well as the bid and negotiation process and aspects unique to repair projects, is discussed in *Chapter 1*. This chapter also includes an overview of the process of executing repairs and the required quality control measures.

Although ACI 318 provides some guidance, the repair engineer has to depend on judgment and experience to develop repair solutions. The engineer should apply principles of structural theory and material behavior to evaluate a structural repair.

The engineer must understand that the stresses in deteriorated portions of the structure have already redistributed to accommodate the loss of certain portions of the structure. It is imperative that the engineer properly evaluate the integrity of the structure for the deteriorated portions as well as for the repaired conditions. This guide provides assistance for the repair practitioner to approach the design and to design repairs to deteriorated structures.

Concrete Removal, Preparation, and Repair Techniques

Corrosion of embedded reinforcing steel is the most common cause of concrete deterioration. When the steel is exposed to water, oxygen, and chlorides, it oxidizes and produces corrosion (rust). The oxidized metal can expand up to 10 times its original volume, causing intense bursting forces in the surrounding concrete, which will eventually crack and delaminate. Likewise, reinforcing steel embedded in carbonated concrete will corrode in the presence of water and oxygen.

The care taken for the removal of concrete and for the follow-up preparation can be the most important factors for successful repairs. This chapter discusses the various concrete removal techniques, and advantages and limitations for each method.

Concrete removal

It's important that all deteriorated or damaged concrete be removed. This is often difficult to determine, but generally it is prudent to continue removal into sound concrete, thereby exposing reinforcing steel beyond the point of corroded steel. It is usually necessary to remove concrete around exposed embedded reinforcing so that the repair material can completely encapsulate the bars. Every precaution should be taken to avoid cutting or damaging the underlying reinforcing steel in the repair areas.

The methods of concrete removal include:

- Blasting methods (usually limited to removal of mass concrete on large structures)
- Cutting methods (includes mechanical sawing, intense heat, or high-pressure water jets)
- Impacting methods (most common methods, usually done with hand-held chipping hammers or boom-mounted breakers)
- Scarifying (removal is done with a concrete cutting tool that employs the rotary action and mass of its cutter bits to rout cuts into concrete surfaces)
- Hydrodemolition (uses high-pressure water jetting to remove concrete and to clean the steel reinforcement)
- Sandblasting (most common method of cleaning concrete and reinforcing steel)
- Shotblasting (cleaning or removal of concrete with use of metal shot on the concrete surface at a high velocity)

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Surface Preparation

Surface preparation consists of the final steps to prepare the concrete surface for the repair material. It is important that the surface of the parent concrete is sound in order for the repair material to properly bond. Impact methods in particular, for example, can result in a weakened plane at the bond-line due to microcracking.

Material placement

There are various techniques used to place repair materials, depending on the constraints and limitations of a project, including:

- Cast-in-place concrete (most frequently used technique)
- Shotcrete (pneumatically placed concrete)
- Preplaced-aggregate concrete (minimizes drying shrinkage because aggregate particles are in point-to-point contact)
- Troweling (hand applied repairs)
- Injection grouting (used to fill cracks, open joints and interior voids)

Repair Materials

The typical properties, advantages, limitations, typical applications, and applicable standards and references of various materials that are available for concrete repair are presented in the 546R *Guide*. The *Guide* also includes data pertaining to bonding materials, coatings for reinforcing, reinforcing options, and guidance regarding the selection of materials.

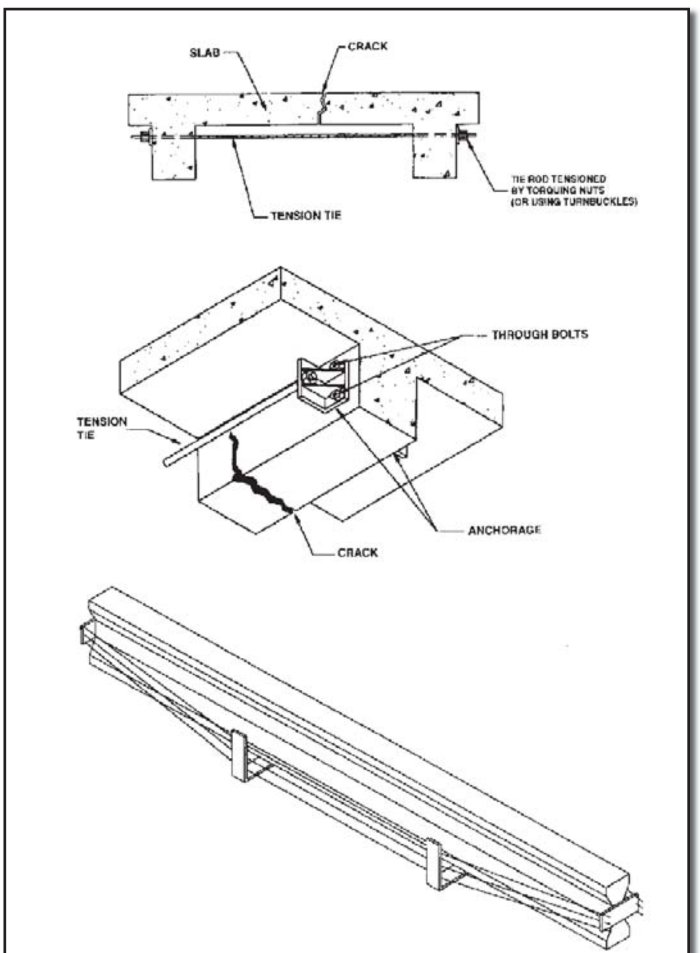

Figure 5.6: External prestressing to close cracks and strengthen section.

The basic categories of materials are cementitious materials (the best choice to match the properties of concrete as closely as possible, which is often an important selection criterion) and polymer materials.

Cementitious materials include: conventional concrete; conventional mortar; dry-pack mortar; proprietary repair mortars; ferrocement; fiber-reinforced concrete; grouts; low-slump dense concrete; magnesium phosphate concrete and mortar; preplaced-aggregate concrete; rapid-setting cements; shotcrete; shrinkage-compensating concrete; and silica-fume concrete.

Polymer materials include: polymer-modified concrete and mortar that use Portland cement as the main binder and polymer concrete where the aggregate is bound together by a polymer binder

Protection Systems

The primary reason for protection is to extend the life of the concrete repairs. Although a protection system is an additional cost, one should be incorporated to extend the life of the repairs as long as possible. Otherwise, the Owner may be repairing the structure again sooner than anticipated.

Selection Factors

The selection of an appropriate protective system weighs several factors, including: economic factors; service record; appearance; environmental considerations; compatibility issues; durability and performance; and safety requirements.

Typical Problems Addressed By Protection Systems

An appropriate protection system should minimize the effects due to: poor quality or inadequate cover over the reinforcing; misplaced reinforcing steel; water penetration; carbonation (reduction of protective alkalinity for corrosion of embedded reinforcing); anodic ring (corrosion around perimeter of repair patches due to the differences of electrical potential at the bond line where reinforcing extends between the repair material and the parent concrete); cracks; chloride/chemical attack; and surface erosion.

Surface Treatments

Surface treatment methods need to be thoroughly evaluated for compatibility, installation requirements, and performance characteristics that will impact the overall functioning of the system.

Surface Treatment Classifications

The 546R *Guide* provides a description for each class of treatment, the products typically included in this group, the uses, and methods of application and limitations.

Surface treatment classifications include:

- Penetrating sealers and surface-applied corrosion inhibitors
- Surface sealers [products up to 0.25 mm (10 mils) or less] that lay on the surface
- High-build coatings [materials with a dry thickness greater than 0.25 mm (10 mils) up to 0.75 mm (30 mils)] applied to the surface
- Membranes [surface treatments with thickness greater than 0.7 mm (30 mils) and less than 6 mm (250 mils)] applied to the surface
- Overlays (products of 6 mm (250 mils) or greater] that can be bonded, partially bonded or unbonded to the concrete surface.

The *Guide* also discusses other protection methods such as the use of joint sealants, cathodic protection, chloride extraction, and realkalization.

Strengthening Techniques

The repair practitioner must determine whether a structural analysis should be performed based on the current condition of the structure. The analysis should take into account the deteriorated condition including the net cross section and effective depths of the embedded reinforcing, the actual properties of the concrete and the loadings on the structure. The results of this analysis may indicate that temporary shoring is required, or that the structure needs to be taken out of service.

The structure also may need to be analyzed for the repaired condition with local code-mandated loadings. The engineer performing this analysis must be aware that load and stress redistribution may have occurred in the structure and possibly within individual members.

The approach for repair projects is much different for this type of work, as opposed to the design of new structures. For example, for columns with heavily corroded reinforcing and delaminated concrete, the stress in the net cross section must be carefully evaluated to determine if the column is safe in its deteriorated condition. The designer should understand that, unless the column is unloaded, a repair patch will not resist the load currently on the column.

The *Guide* provides several acceptable alternatives for strengthening structural members, including examples. The objective is to repair or replace concrete and reinforcement to resist stress caused by flexure, shear, torsion, and axial forces so that the strengthened structure meets the minimum requirements of ACI 318 and other applicable building codes.

Strengthening techniques include: Internal structural repair (crack injection); Interior reinforcement (providing reinforcement across cracks); Exterior reinforcement (such as steel plates or FRP); Exterior post-tensioning (see *Figure 5.6*); Jackets and collars; Supplemental members (such as structural steel); and Repair of columns.

Conclusion

Concrete repair projects are very challenging. It is imperative that the engineer understands the reasons that the damage or deterioration developed, and if possible, develop a strategy to correct the underlying causes. At a minimum, all unsafe conditions must be addressed, and if necessary, temporary shoring or bracing provided, as soon as they are identified.

The *Concrete Repair Guide* is an excellent resource for both those who are not familiar with concrete repair as well with those who have considerable experience with this type of work. It provides an overview of the subject along with references to assist the practitioners to find further information on a wide range of topics.▪

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