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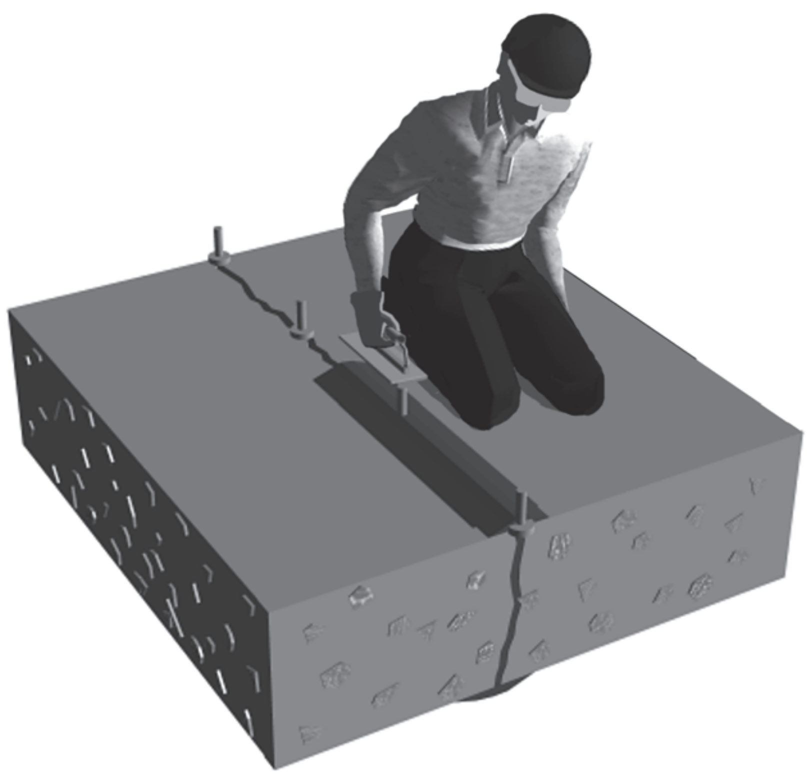
ACI RAP Bulletin 1

FIELD GUIDE TO
CONCRETE REPAIR
APPLICATION PROCEDURES

Structural Crack Repair by Epoxy Injection



Field Guide to Concrete Repair Application Procedures

Structural Crack Repair by Epoxy Injection

Reported by ACI Committee E706

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ACI Repair Application Procedure 1.

Introduction

Certain things in life are inevitable. Some are said to include death, taxes, and concrete cracks! The latter is subject to volumes of literature on causes and cures. Some of the more typical causes for concrete cracking include:

- Drying shrinkage;
- Thermal contraction or expansion;
- Settlement;
- Lack of appropriate control joints;
- Overload conditions that produce flexural, tensile, or shear cracks in concrete; and
- Restraint of movement

One of the potentially effective repair procedures is to inject epoxy under pressure into the cracks. The injection procedure will vary, subject to the application and location of the crack(s), with horizontal, vertical, and overhead cracks requiring somewhat different approaches. The approach used must also consider accessibility to the cracked surface and the size of the crack.

Cracks can be injected from one or both sides of a concrete member. If access is limited to only one side, installation procedures may include variations in epoxy viscosities, injection equipment, injection pressure, and port spacing to ensure full penetration of epoxy into the crack.

Depending on the specific requirements of the job, crack repair by epoxy injection can restore structural integrity and reduce moisture penetration through concrete cracks 0.002 in. (0.05 mm) in width and greater. However, before any concrete repair is carried out, the cause of the damage must be assessed and corrected and the objective of the repair understood. If the crack is subject to subsequent movement, an epoxy repair may not be applicable.

Note: Horizontal cracks of sufficient width can be filled by gravity-fed epoxies where suitable for the repair (See Crack Repair by Gravity Feed with Resin, RAP-2).

What is the purpose of this repair?

The primary objective for this type of repair is to restore the structural integrity and the resistance to moisture penetration of the concrete element.

When do I use this method?

Injection is typically used on horizontal, vertical, and overhead cracks where conventional repair methods cannot penetrate and deliver the specific repair product into the crack.

Prior to proceeding with a crack repair by epoxy injection, the cause of the crack and the need for a structural repair must be determined. If the crack does not compromise the structural integrity of the structure, injection with polyurethane grouts or other nonstructural materials may be a more suitable choice to fill the crack. When a structural repair is required, conditions that cause the crack must be corrected prior to proceeding with the epoxy injection. If the crack is damp and cannot be dried out, an epoxy tolerant to moisture should be considered. Cracks caused by corroding reinforcing steel should not be repaired by epoxy injection because continuing corrosion will cause new cracks to appear.

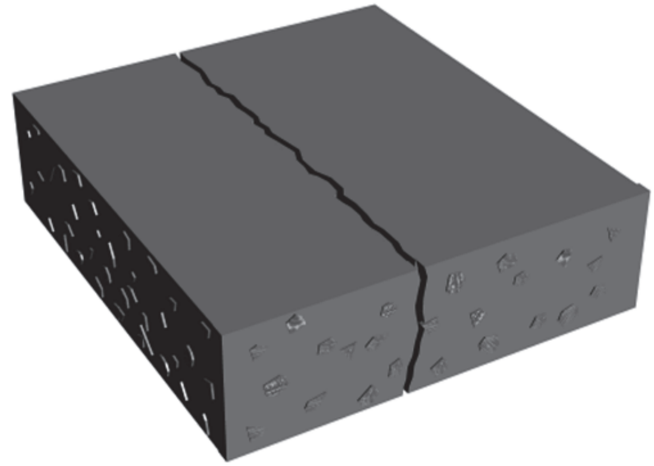

Fig. 1—Cracks must be clean and free of debris.

How do I prepare the surface? (see Fig. 1)

Clean the surface area about 1/2 in. (13 mm) wide on each side of the crack. This is done to ensure that materials used to seal the top of the crack (the cap seal) will bond properly to the concrete. Wire brushing is recommended because mechanical grinders may fill the cracks with unwanted dust. Contaminants can also be removed by high-pressure water, "oil-free" compressed air, or power vacuums. When using water to clean out the crack, blow out the crack with oil-free, compressed or heated air to accelerate drying. Otherwise, allow enough time for natural drying to occur before injecting moisture-sensitive epoxies.

Where concrete surfaces adjacent to the crack are deteriorated, "V"-groove the crack until sound concrete is reached. "V" grooves can also be used when high injection pressures require a stronger cap seal.

How do I select the right material?

The appropriate viscosity of the epoxy will depend on the crack size, thickness of the concrete section, and injection access. For crack widths 0.010 in. (0.3 mm) or smaller, use a low-viscosity epoxy (500 cps or less). For wider cracks, or where injection access is limited to one side, a medium to gel viscosity material may be more suitable.

ASTM C 881, "Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete," identifies the basic criteria for selecting the grade and class of epoxies (see Table 1).

For concrete sections greater than 12 in. (305 mm), the working time may need to be increased, and the viscosity decreased, as the crack gets smaller.

In addition to the criteria used in Table 1 for epoxy selection, the following product characteristics may also have to be considered:

- Modulus of elasticity (rigidity);
- Working life;
- Moisture tolerance;
- Color; and
- Compressive, flexural, and tensile strengths.

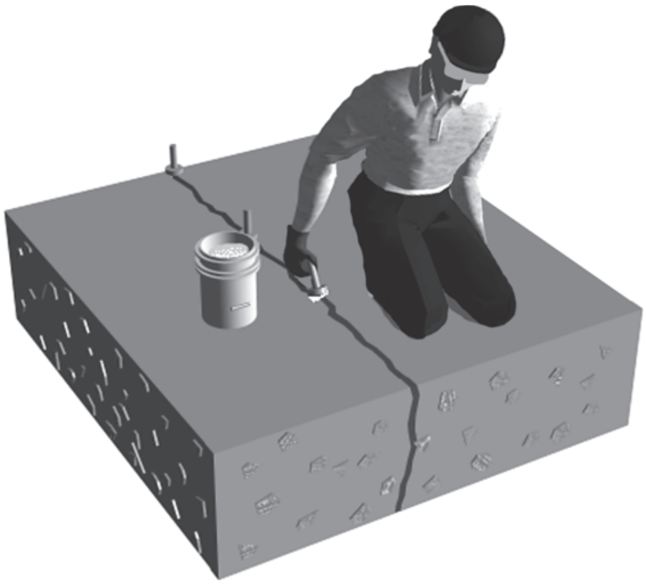

Fig. 2—Installation of entry ports.

What equipment do I need?

Equipment for epoxy injection by high-pressure or low-pressure systems includes:

- Air guns;
- Hand-actuated delivery systems;
- Spring-actuated capsules; and
- Balloon-actuated capsules.

Determine the delivery method that will best suit the repair requirements by considering the size and complexity of the injection repair and the economic limitations of the project.

What are the safety considerations?

Epoxy resins are hazardous materials and must be treated as such. Job-site safety practices should include, but not necessarily be limited to, the following:

- Having Material Safety Data Sheets (MSDS) available on site;
- Wearing protective clothing and protective eyewear where required;
- Wearing rubber gloves or barrier creams for hand protection;
- Having eye wash facilities available;
- Wearing respirators where needed;
- Providing ventilation of closed spaces;
- Secured storage of hazardous materials;
- Having necessary cleaning materials on hand; and
- Notifying occupants of pending repair procedures.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Table 1—ASTM C 881 requirements for epoxy resins that are used to bond hardened concrete to hardened concrete

	Type I*	Type IV†
Viscosity, centipoise		
Grade 1 (low-viscosity), maximum	2000	2000
Grade 2 (medium-viscosity), minimum	2000	2000
Maximum	10,000	10,000
Consistency, in.		
Grade 3 (non-sagging), maximum	1/4	1/4
Gel time, min.	30	30
Bond strength, minimum, psi		
2 days, moist cure‡	1000	1000
14 days, moist cure	1500	1500
Absorption, 24 h maximum, %	1	1
Heat deflection temperature		
7 days minimum, °F	—	120
Linear coefficient of shrinkage		
On cure, maximum	0.005	0.005
Compressive yield strength		
7 days minimum, psi	8000	10,000
Compression modulus, minimum, psi	150,000	200,000
Tensile strength, 7 days minimum, psi	5000	7000
Elongation at break, minimum, %	1	1

*Type I: for use in non-load-bearing applications.
†Type IV: for use in load-bearing applications.
Source: ASTM C 881, Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete.
‡Moist-cured systems should be tested by assembling the sections to be bonded before immersing in water.

Preconstruction meeting

Prior to proceeding with the repair, a preconstruction meeting is recommended. The meeting should include representatives from all participating parties (owner, engineer, contractor, materials manufacturer, etc.) and specifically address the parameters, means, methods, final appearance, and materials necessary to achieve the repair objectives.

Repair procedure

1. Port installation (see Fig. 2).

Install the entry ports only after proper surface preparation. Two types of entry ports are available for the injection process:

- Surface-mounted; or
- Socket-mounted.

Entry ports (also called port adapters) can be any tubelike device that provides for the successful transfer of the epoxy resin under pressure into the crack. Proprietary injection guns with special gasketed nozzles are also available for use without port adaptors. Port spacing is typically 8 in. (40 mm) on center, with increased spacing at wider cracks. Port spacing may also be a function of the thickness of the concrete element. Surface-mounted entry ports are normally adequate for most cracks, but socket-mounted ports are used when cracks are blocked, such as when calcified concrete is encountered. Entry ports can also be connected by a manifold system when simultaneous injection of multiple port locations is advantageous.

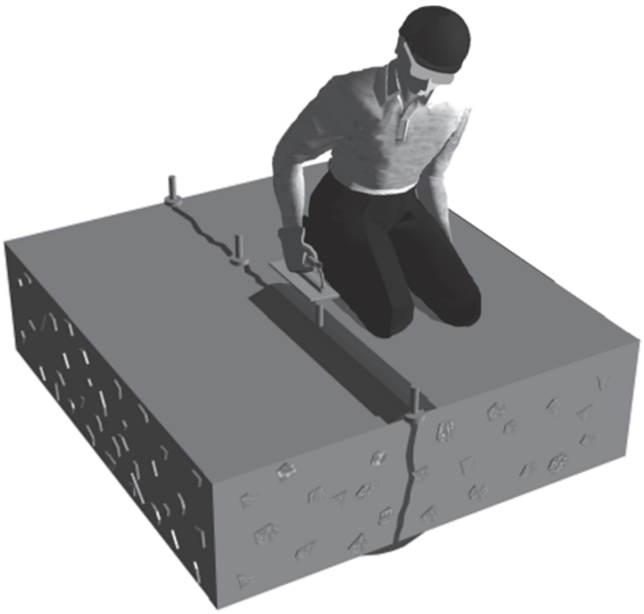

Fig. 3—Installation of seal cap.

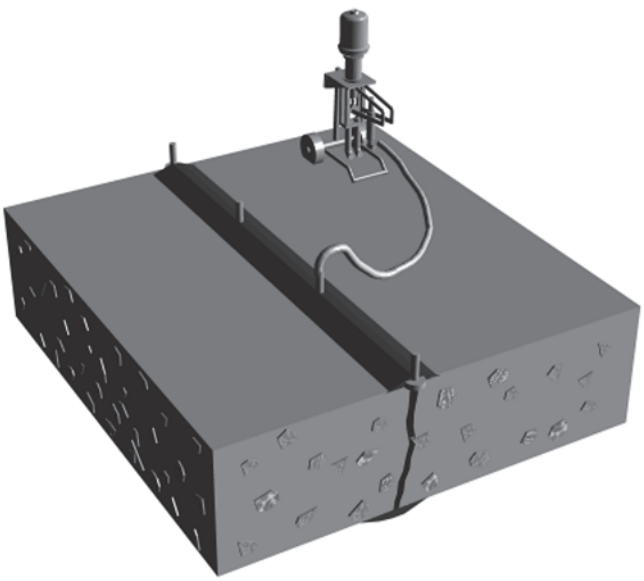

Fig. 4—Start injection at widest segment of the crack.

2. Install the cap seal (see Fig. 3).

Properly installed, the cap seal contains the epoxy as it is injected under pressure into the crack. When cracks penetrate completely through a section, cap seals perform best when installed on both sides of the cracked element, ensuring containment of the epoxy. Cap seals have been successfully installed using epoxies, polyesters, paraffin wax, and silicone caulk. The selection of the cap seal material should consider the following criteria, subject to the type of crack to be repaired:

- Non-sag consistency (for vertical or overhead);
- Moisture-tolerance;
- Working life; and
- Rigidity (modulus of elasticity).

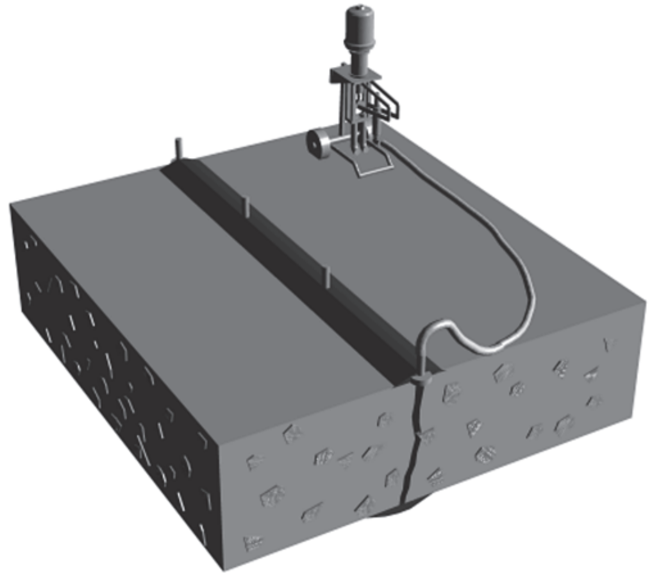

Fig. 5—Continue injection until refusal.

Concrete temperature changes after installation of the cap seal but prior to injection may cause the cap seal to crack. If this occurs, the cap seal must be repaired prior to resin injection.

Prior to proceeding with installation of the cap seal, mark the location of the widest portion of the crack and pay close attention to the following:

- Use only materials that haven't exceeded their shelf life;
- Accurate batching of components;
- Small batches to keep material fresh, and dissipate heat;
- Port spacing; and
- Consistent application of the material (1 in. wide x 3/16 in. thick [25 x 5 mm]) over the length of the crack.

3. Inject the epoxy (see Fig. 4 and 5).

For a successful epoxy injection, start with the proper batching and mixing of the epoxy components in strict accordance with the manufacturer's requirements. Prior to starting the actual injection, be sure that the cap seal and port adapter adhesive have properly cured so they can sustain the injection pressures.

Start the injection at the widest section of a horizontal crack. (Be sure to locate and mark these areas before installing the cap seal.) Vertical cracks are typically injected from the bottom up.

Continue the injection until refusal. If an adjacent port starts bleeding, cap the port being injected and continue injection at the furthest bleeding port. Hairline cracks are sometimes not well suited to "pumping to refusal." In those cases, try injecting the epoxy at increased pressure (approximately 200 psi [1.3 MPa]) for 5 min. Closer port spacing can also be considered. When injection into a port is complete, cap it immediately. Higher pressure can be used for injecting very narrow cracks or increasing the rate of injection. However, the use of higher pressure should be managed with care to prevent a blowout of the cap seal or ports.

4. Remove ports and cap seal (see Fig. 6).

Upon completion of the injection process, remove the ports and cap seal by heat, chipping, or grinding. If the appearance is not objectionable to the client, the cap seal can

Fig. 6—Remove seal cap.

be left in place. If complete removal is required for a subsequent application of a cosmetic coating, prepare the concrete surface by grinding.

How do I check the repair?

To ensure that the injection has been successful, quality assurance measures may include test cores or nondestructive evaluation (NDE).

1. Test cores:

- Core locations should be chosen to avoid cutting reinforcing steel, drilling cores in areas of high stress, or creating core holes below the waterline. The engineer should determine core locations when these types of conditions exist;
- Be sure the epoxy has set before extracting a core;
- Take cores (normally 2 in. [50 mm] diameter) to check that the penetration of the epoxy is adequate;
- Inspect the core visually to determine the penetration of the epoxy into the crack;
- Cores can be further tested for compressive and split tensile strength per ASTM C 42; and
- Subsequently, patch the removed-core area (after proper surface preparation) with an expansive cementitious or epoxy grout compatible with the existing substrate concrete and the surrounding environment.

2. Methods for nondestructive evaluation:

- Impact echo (IE);
- Ultrasonic pulse velocity (UPV); and
- Spectral analysis of surface waves (SASW).

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ACI RAP Bulletin 2

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FIELD GUIDE TO
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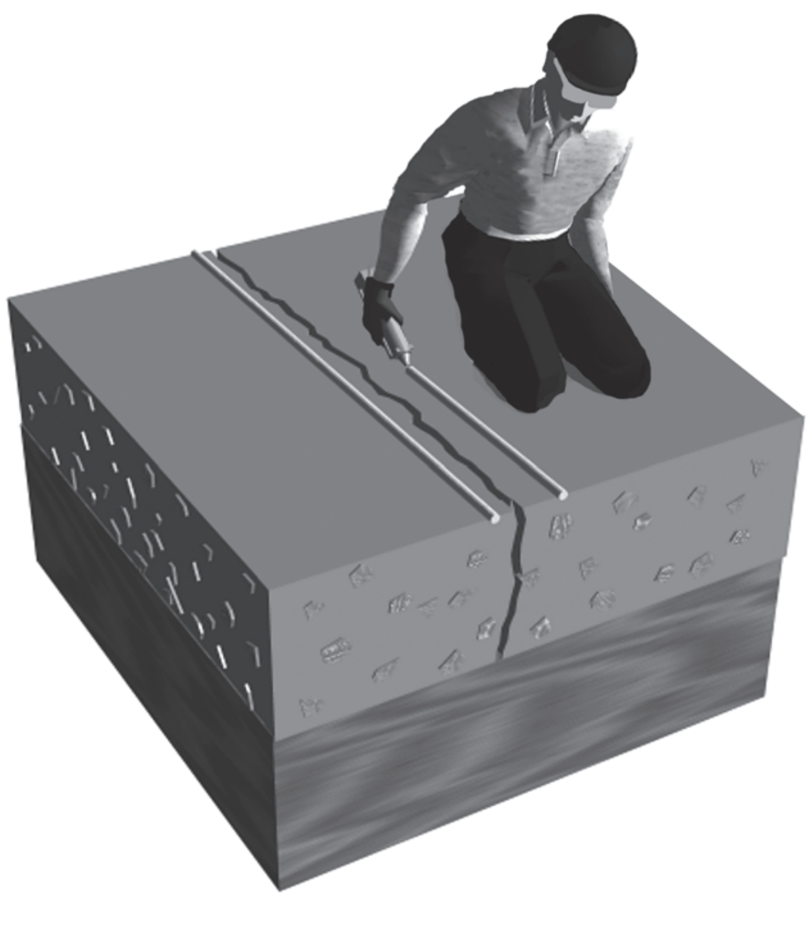
APPLICATION PROCEDURES

Crack Repair by Gravity Feed with Resin



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Introduction

This topical application for crack repair uses a thin polymer resin to fill the crack. Penetrating by gravity alone, the resin fills the crack and forms a polymer plug that seals out water, salts, and other aggressive elements. In some cases, a structural repair of the crack can be achieved.

Before any concrete is repaired, the cause of the damage must be assessed and the objective of the repair must be understood.

Typical causes of concrete cracking include steel corrosion, freezing and thawing, sulfate attack, and alkali-aggregate reaction (AAR). Poor practices during the original construction can cause excessive shrinkage or settlement in the structure. Improper joint spacing and load imbalances also contribute to cracking.

What is the purpose of this repair?

The primary objective of this repair is to fill the crack and structurally bond the concrete on both sides of the crack. This repair is to seal cracks that are not moving—for example, shrinkage cracks, and settlement cracks that have stabilized. By penetrating and filling the cracks, the resin is able to form a polymer plug that seals the crack, keeping out water, chlorides, carbon dioxide, sulfates, and other aggressive liquids and gases.

This repair method is, therefore, a way to reduce possible future deterioration caused by freeze-thaw cycles, steel corrosion, and chemical attack of the concrete.

A common secondary objective of this repair is the protection of the entire deck or floor with a penetrating sealer. Instead of gravity feeding individual cracks, a flood coat on the entire deck or floor is often done to seal the concrete surface, in addition to "healing" the cracks. This is why the term sealer/healer is often associated with this application and material.

Finally, it is occasionally an objective to achieve a structural repair of the cracks using this method. Consult a qualified structural engineer if it is determined that a structural repair is needed. While many of these resin materials exceed the strength of the concrete, ensuring a structural repair with full depth penetration by gravity is difficult. Special care must be taken in these instances to ensure the cracks are open, clean, and not contaminated with any bond-inhibiting materials such as oil and grease, which can often be the case on horizontal decks and floors exposed to traffic. If a structural repair of the crack is critical, pressure injection may be a preferred option (see RAP 1).

When do I use this method?

This repair can only be applied to horizontal concrete elements such as bridge and parking decks, floor slabs, plaza decks, and similar surfaces.

Gravity feed of resin is not effective for repairing moving cracks. This is because the materials are unable to act as a flexible joint material. In these cases it is most often necessary to rout and seal the crack to create a joint capable of movement.

Likewise, gravity feed of resin should not be viewed as a long-term solution to cracking caused by corrosion, sulfate attack, or AAR. At best, this repair will keep out water, chlorides, and sulfates, which may slow the progress of future damage around the crack, but it certainly will not stop it indefinitely. In these situations, a complete repair and protection approach is required to address the entire area affected, not just the cracks.

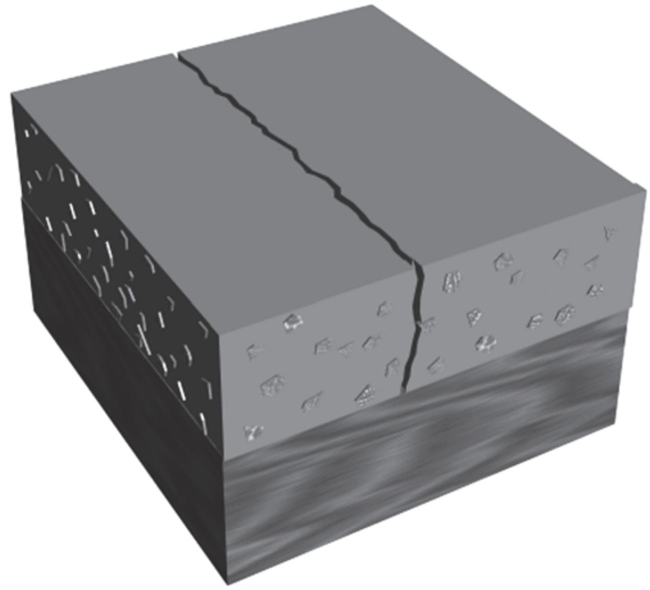

Fig. 1—Cracks must be clean and free of debris.

How do I prepare the surface?

Proper preparation of the cracks for gravity feed of resin is essential to a successful repair. All potential barriers to penetration must be removed. Clean away all dirt, oil, grease, paints, striping, curing compounds, and sealers. To prepare large areas for flood treatments, consider dry sand- or shot-blasting.

For cleaning individual cracks, begin with wire brushes and wheels, followed by high pressure, oil-free compressed air to remove dust from the surface of the crack.

If the crack surface is packed solid with dirt and/or debris, remove it prior to applying the resin. In this case, remove the debris by routing the crack surface with crack-chasers or grinders and follow up with compressed air to remove fines. This routing of the crack has the advantage of producing a wider surface opening. Vacuum cleaning of cracks can prevent dust from getting packed into the crack, which can hamper resin penetration.

Allow the repair area to dry for at least 24 hours before applying the resin. Moisture within the cracks and the concrete pores can prevent penetration because the resin materials are very thin and are not able to easily displace water.

How do I select the right material?

The two most common polymer materials used for gravity feed crack repairs are epoxies and high molecular weight methacrylates (HMWM). Both must be formulated to have a very thin consistency (low viscosity) and low surface tension to enable them to easily penetrate fine cracks by gravity alone. Viscosities below 200 centipoise (cps) should be a minimum requirement. Many epoxies are available with viscosities below 100 cps. Most HMWMs have viscosities below 50 cps.

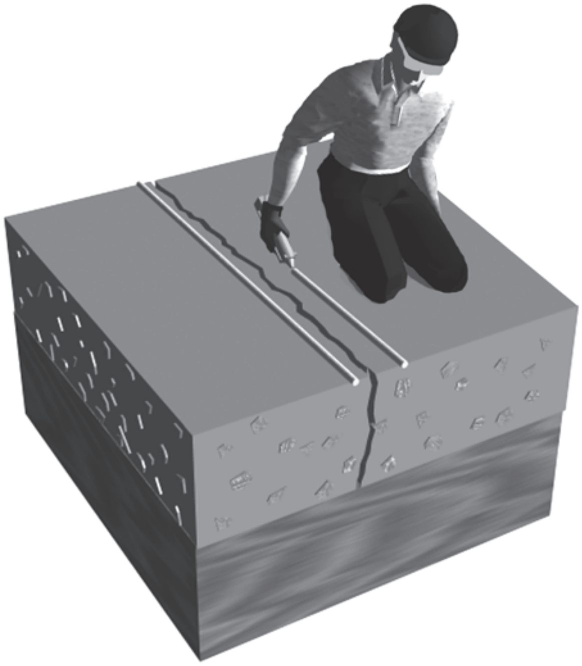

Fig. 2—On individual cracks, a sealant can be used to create a reservoir.

While both resin types are able to form the desirable polymer plug within the crack, they do have their differences. The epoxies tend to bond better when moisture is present within the concrete pores and they are easier and can be safer to mix and apply. HMWMs are generally lower in viscosity and surface tension and have less critical mixture ratios than epoxies. They can also be formulated to set faster. Successful applications of both polymer types have been documented in concrete cracks less than 0.006 in. (0.15 mm) wide.

What equipment do I need?

For small to midsize projects (up to 10,000 ft^2 [930 m^2]):

- Mixing buckets, drills, mixing paddles;
- Flat rubber squeegees, brooms, or rollers;
- Small cans or squeeze bottles for pouring into individual cracks; and
- Grinder and air compressor.

For large projects (over 10,000 ft^2 [930 m^2]):

- Mixing buckets, drills, mixing paddles;
- Mixing tanks with spray bar (low pressure pumps, no atomization);
- Flat rubber squeegees, brooms, or rollers;
- Sand spreaders or blowers; and
- Grinder and air compressor.

What are the safety considerations?

Epoxies and HMWMs are hazardous materials and should be treated as such. Job-site safety practices should include, but are not limited to, the following where applicable:

- Material Safety Data Sheets (MSDS). Adhere to all manufacturer recommendations for special safety equipment and requirements;
- Protective clothing. Cover the body fully and use adequate footwear;

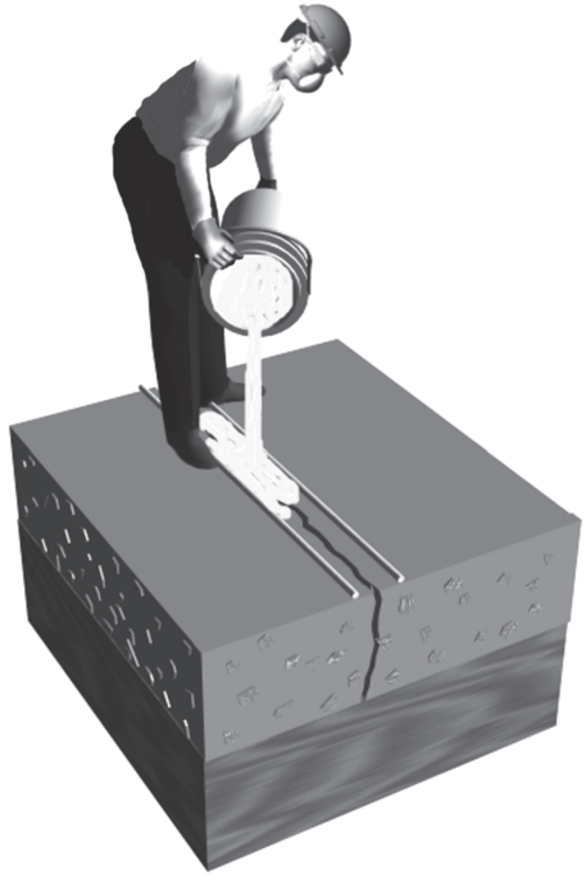

Fig. 3—Continue to gravity-feed the resin and "top off" until crack is completely filled.

- Protective eyewear. Face shields are recommended as a minimum;
- Wear rubber gloves for hand protection;
- Have eye wash facilities available;
- Take special precautions with flammable or combustible materials;
- Ventilate closed spaces. Wear appropriate masks to protect against fumes;
- Store hazardous materials in a secured area;
- Have necessary cleaning materials on hand; and
- Notify occupants within the structure being repaired prior to beginning work.

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Special note regarding HMWM mixing: These polymers utilize a two-part catalyst usually consisting of an initiator (such as a peroxide) and a promoter (such as cobalt napthanate). These two materials must never come into direct contact with one another or a violent reaction may occur. It is important that the promoter first be added to the

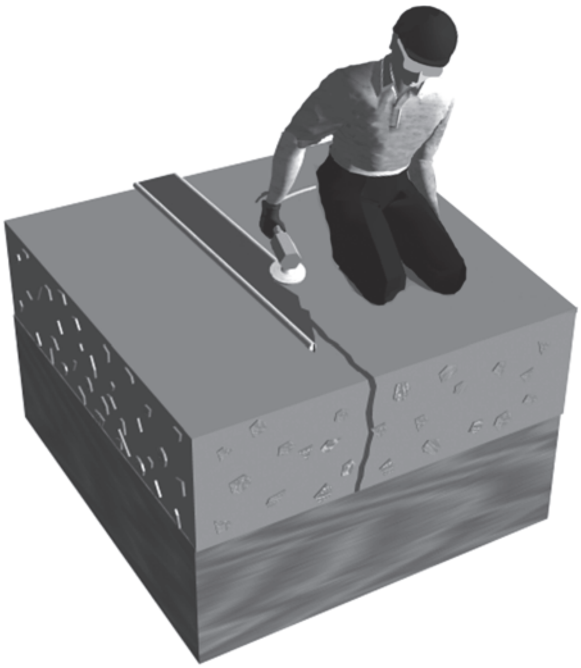

Fig. 4—Removal of sealant and grinding of excess resin.

HMWM monomer and mixed uniformly throughout before adding the initiator. Some formulations are available as a two-component system (pre-promoted) to avoid this potentially dangerous situation. Always refer to the material manufacturer's instructions.

Preconstruction meeting

Prior to proceeding with the repair, a preconstruction meeting is recommended. The meeting should include representatives from all participating parties (owner, engineer, contractor, materials manufacturer, etc.) and specifically address the parameters, means, methods, and materials necessary to achieve the repair objectives.

Repair procedure

1. Mix the resin.

After preparing the surface, mix the resin according to the manufacturer's instructions. If cracks run all the way through and the underside of the deck or slab is accessible, seal the underside of cracks at least temporarily to prevent resin loss (see RAP 1).

2. Pour the resin.

Pour the mixed material (within the pot life of the resin) over the top of the cracks and allow it to penetrate. Keep filling the cracks until they will no longer accept resin.

For flood coat applications, distribute the resin evenly over the deck initially and then puddle the resin over the cracks. On smooth surfaces, use flat rubber squeegees; on tined or irregular surfaces, use brooms or rollers.

3. Inspect the filling.

Look for signs of penetration such as air bubbles escaping from the cracks as the resin displaces the air.

ALLOW TIME FOR PENETRATION. Twenty to 30 minutes should be a minimum. Also, be aware that several minutes may pass before resin has fully penetrated tight cracks and more resin may still be required.

4. Remove excess resin.

Once all cracks have been filled to refusal, remove the excess surface resin with a flat rubber squeegee.

5. Apply sand.

For safety purposes, lightly broadcast sand into the remaining resin to produce a skid-resistant surface. Apply about 1 to 2 lb/yd^2 (0.5 to 1.0 kg/m^2) of an ordinary 8/20 blasting sand (or similar) within 20 to 30 minutes after the last application.

6. Finish smooth (if desirable).

After the polymer has fully cured, remove sealant and grind smooth. Be careful not to inhale vapors during the grinding of the polymers.

How do I check the repair?

Quality control tests should be taken on site to verify:

- Resin properties—taken in the form of cured prisms (ASTM D 495 type) to be checked for compressive strength as an indicator of proper mixture ratio and cure;
- Penetration depths—verified by cores taken at regular intervals. For very fine cracks, the cores may be analyzed under "black light" to highlight resin penetration depth within the cracks; and
- For structural repair checks, take cores and follow ASTM C 496, "Splitting Tensile Test."

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RAP-3

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Spall Repair by Low-Pressure Spraying

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This document is intended as a voluntary field guide for the Owner, design professional, and concrete repair contractor. It is not intended to relieve the user of this guide of responsibility for a proper condition assessment and structural evaluation of existing conditions, and for the specification of concrete repair methods, materials, or practices by an experienced engineer/designer.

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ACI RAP Bulletin 3

FIELD GUIDE TO
CONCRETE REPAIR
APPLICATION PROCEDURES

Spall Repair by Low-Pressure Spraying

by Patrick "Doc" Watson

Introduction

Similar to wet-mix shotcrete but sprayed at a much lower velocity, low-pressure spall repair spray comes in the form of prepackaged mortar. The spray is applied using small concrete pumps or heavy-duty grout pumps to force the low-slump mortar through a hose. Air is added at the nozzle to impel the mortar. Bond with the prepared substrate is achieved through a combination of proper surface preparation, low-velocity impact, and the material properties of the prepackaged mortar.

Compared with either wet- or dry-mix shotcreting, this method allows the spray nozzle to be much closer to the repair surface. This means it can be used in tight spaces. Due to the viscous, sticky nature of the mixture and the low pressures involved, there is considerably less rebound than with high-velocity shotcreting.

Before any concrete repair is carried out, the cause of the damage must be assessed and the objective of the repair must be understood.

Typical causes of concrete deterioration include steel corrosion, sulfate attack, alkali-aggregate reactions (AARs), excessive deflection, and freeze-thaw damage. Poor practices during the original construction can lead to premature deterioration. Improper joint spacing and load imbalances also contribute to cracking and spalling.

What is the purpose of this repair?

Depending on the mortar mixture selected, low-pressure spray is used for surface repairs, structural repairs, or cosmetic renovation. The spray can be formulated for freeze-thaw durability, sulfate resistance, low permeability, and other desired or specified characteristics.

When do I use this method?

Low-pressure spray is typically used for vertical and overhead repairs. Successful applications have included structural repairs to bridges, bridge and building piers, structural slab undersides, tank walls (interior and exterior), stadiums, tunnels, and retaining walls. Structural repairs utilizing low-pressure spray are best done under the guidance of a qualified engineer.

The placement thickness can be 1/2 to 4 in. (13 to 100 mm) in a single lift. Thicknesses greater than 6 in. (150 mm) are possible in multiple lifts. If the repair application requires more than a 4 in. (100 mm) thickness, other methods may be more economical (see ICRI Guideline No. 03731, "Guide for Selecting Application Methods for the Repair of Concrete Surfaces").

The ingredients that make up the mortar vary widely, and the ingredients selected will depend on the specific repair situation. Formulas may contain ingredients such as corrosion inhibitors, air-entraining agents, and bonding additives.

The initial material costs are generally higher with this method than for a typical shotcrete application, but in-place costs are often lower or comparable because this method produces less rebound and requires less cleanup. Certified nozzle operators are not required.

How do I prepare the surface?

Consult the recommendations of ICRI Guideline No. 03732, "Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays," or ICRI Guideline No. 3730, "Surface Preparation for Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion."

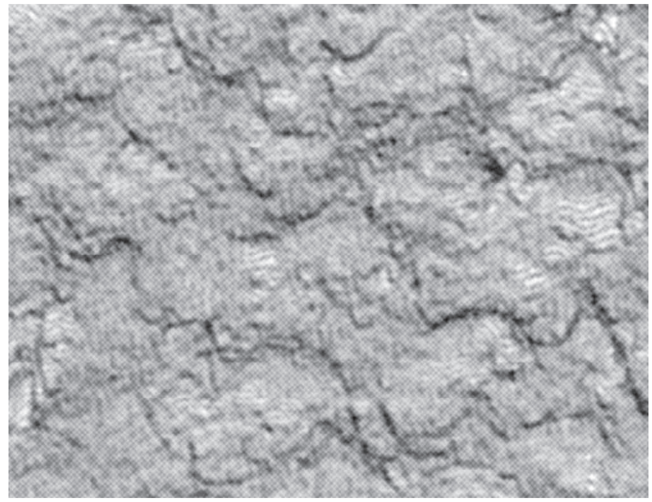


Fig. 1—Typical plus or minus 1/4 in. profile. (From ICRI Guide No. 03732 Profile No. 7). This is the standard recommended surface profile for low-pressure spray-applied mortars.

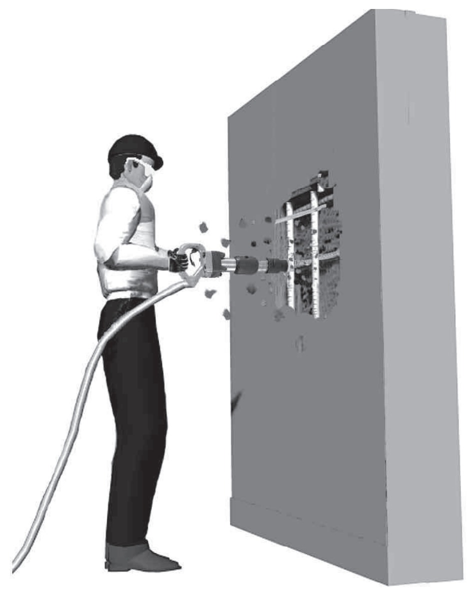


Fig. 2—Chipping surface.

Because many of the materials applied using low-pressure spray are prepackaged, the manufacturer's recommendations should also be consulted.

A typical roughness or profile recommendation for this repair method is ICRI Concrete Surface Profile (CSP) No. 7 or higher, as per ICRI Guideline No. 03730. A CSP No. 7 is equivalent to an amplitude of approximately 1/4 in. (7 mm) (see Fig. 1).

Factors that will influence the specific surface preparation include, but are not limited to:

- Desired roughness profile of the prepared surface (CSP);
- Method of preparation. These may include, but are not limited to, hydrodemolition, sandblasting, and use of pneumatic hammers (see Fig. 2);

Fig. 3—Presaturate prepared surface with water.

- Possible contamination of the surface by chemicals, oils, soaps, or carbonation. Test for carbonation with a pH indicator. The pH should be 11.5 or higher;
- Methods of treatment for contaminated surfaces.
- Required substrate saturation (see Fig. 3);
- Reinforcing requirements from the mortar manufacturer, the engineer, or the owner; and
- Treatment of existing cracks and joints: Repair the cracks? How? Fill the joints? If so, how and with what?

How do I select the right material?

Low-pressure spray-applied repair materials are proprietary, prepackaged cementitious products. Specifiers, applicators, and owners should consult ICRI Guideline No. 03733, "A Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces." Consult the American Concrete Institute publications on concrete repair by ACI Committee 546, Repair of Concrete. Refer to manufacturers' data sheets for material properties.

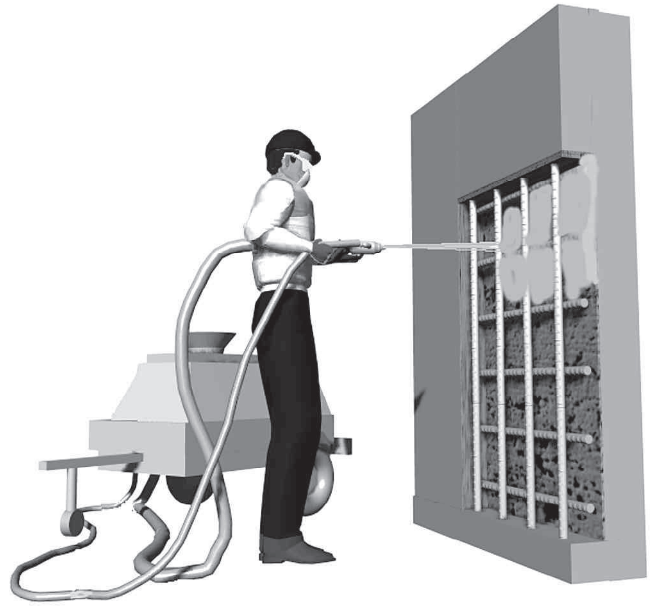
Physical property requirements such as bond strength, freeze-thaw durability, permeability, and flexural strength will vary from project to project.

When low-pressure spray-applied materials are used, some repair applications may require that the material be coated with a protective barrier system. When this is the case, confirm the required curing and drying time before installing the coating.

What equipment do I need?

Be sure that all necessary equipment and tools are on site and in proper working order. Have backup equipment or alternate methods planned and available. Typical equipment needed for low-pressure spray application of repair mortars includes, but is not limited to:

- Concrete or grout pumps suitable for low-pressure spray. Field experience has shown that ball valve pumps are not suitable. Short stroke, swing-type piston pumps or heavy-duty rotor-stator pumps perform well;
- If using a rotor-stator or "moyno" type pump, have a backup rotor on hand at the job site;



(a)

(b)

Fig. 4(a) and (b)—Application of mortar with pressure equipment and nozzle.

- Air compressor with pressure gages and controls. (Some pumps come equipped with built-in air compressors and controls.);
- A suitable mixer for mixing the mortar is needed. A backup mixer is recommended in case of breakdown. (Some repair type pumps come equipped with mortar mixers.); and
- A water measuring device, preferably a meter. (Many repair-type pumps equipped with mixers include built-in water meters.).
- A means of communication between the pump and mixer operators and the nozzleman.

Fig. 5—Skilled worker applying final finish to surface.

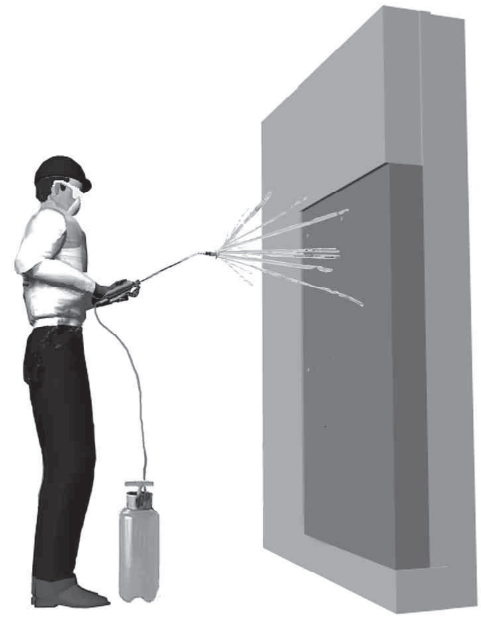


Fig. 6—Application of curing compound.

- All finishing, handling, and testing tools required by specification or good concreting practices.

What are the safety considerations?

Prepackaged mortars are hazardous materials and should be treated as such. Job-site safety practices should include, but are not limited to, the following where applicable:

- Material Safety Data Sheets (MSDS) should be on hand;
- Safety equipment: all machinery and equipment being used must have the correct safety equipment, guards, and warnings in place;
- Protective clothing: protective gloves for workers in contact with wet, cementitious material;
- Protective eyewear: safety glasses or face shields will be needed for all workers;
- Eyewash facilities should be provided;
- Respirators: dust masks will be needed for workers operating the material mixer;
- Ventilation of closed spaces: confirm that adequate ventilation is available before operating equipment that emits dangerous exhaust;
- Secured storage should be available for all hazardous materials;
- Fuel for equipment operation needs a safe storage area, well marked and visible; and
- A safety meeting with all involved should be held and led by the prime contractor's safety manager prior to beginning repair operations.

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Preconstruction meeting

Prior to proceeding with the repair, a preconstruction meeting is recommended. The meeting should include representatives from all participating parties (owner, engineer, contractor, materials manufacturer, etc.), and specifically address the parameters, means, methods, and materials necessary to achieve the repair objectives.

Repair procedure

1. The prejob (preconstruction) meeting agenda might include:

- On-site availability of power;
- On-site availability of water;
- Site accessibility;
- Debris removal and disposal;
- Dust, odor, and emissions control;
- Confirmation that all materials documentation is on hand—for example, MSDS sheets;
- Methods of curing and time required for curing;
- Possible emergencies and breakdowns—what to do if they occur;
- Finish requirements;
- Testing required; and
- All other concerns that could affect the progress of the repair.

2. Apply the repair.

- Inspect and approve the surface preparation. (See ICRI and ACI references);
- Presaturate the prepared substrate. Twenty-four hours is standard. Prepared saturated surface should be saturated surface-dry when the repair mortar is sprayed;

- Install the specified reinforcement;
- Install/apply bonding agents, corrosion inhibitor sacrificial anodes, if called for;
- Mix the repair mortar and load it into pump hopper.
- Begin spray operations with pump, compressor, and suitable spray nozzle; and
- Apply the mortar at the thickness recommended by the material manufacturer. Most low-pressure spray materials require application in lifts when the thickness of the total application layer exceeds 3 in. (76 mm).

3. Finish the repair.

Confirm the final finished appearance of the repair with the owner. This may vary from rough as-sprayed to smooth troweled. If smooth troweling is specified, production may be reduced and additional labor may be required. One nozzle operator may require multiple finishers to keep pace. This will be influenced by such factors as:

- The installed thickness of the material being applied;
- The drying conditions caused by ambient and substrate temperatures;
- The setting characteristics of the repair mortar; and
- Whether the repair is vertical or overhead.

Because of the non-bleeding, sticky nature of these materials, use of an evaporation control film when finishing is recommended.

Proper curing is important and should be conducted in accordance with ACI 308.1-98, "Standard Specification for Curing Concrete." Additional curing information is available from ACI 308R-01, "Guide to Curing Concrete."

For most cementitious low-pressure spray-applied mortars, application of a curing compound that complies with the moisture retention requirements ASTM C 309 is satisfactory. As an alternate, moist cure for 7 days.

Always refer to the mortar manufacturer's instructions for specific curing methods and materials recommenced for the product selected.

How do I check the repair?

Requirements may include:

- Before and after photos;
- Confirmation of acceptable surface preparation. This can include the prepared surface profile and the pH of the prepared surface. A pH of 11.5 or greater is recommended;
- Confirm repair depth;
- Material property tests performed by a qualified testing agency. This is usually done to confirm the material manufacturers' published material properties;
- In-situ direct tensile strength tests of the prepared surface;
- In-situ bond direct tensile tests of the hardened, cured repair; and
- Confirmation that all materials used were as specified, cross checking material purchase orders with quantities estimated and with actual quantities billed.

Sources for additional information

ACI Committee 308, 1998, "Standard Specification for Curing Concrete (ACI 308.1-98)," American Concrete Institute, Farmington Hills, Mich., 1998, 9 pp.

ACI Committee 308, 2001, "Guide to Curing Concrete (ACI 308R-01)," American Concrete Institute, Farmington Hills, Mich., 2001, 31 pp.

ACI Committee 503, 1993, "Use of Epoxy Compounds with Concrete (ACI 503R-93)," Appendix A, Farmington Hills, Mich., 28 pp.

ACI Committee 506, 1995, "Guide to Shotcrete (506R-90 (Reapproved 1995))," American Concrete Institute, Farmington Hills, Mich., 41 pp.

ACI Committee 546, 1996, "Concrete Repair Guide (ACI 546R-96)," American Concrete Institute, Farmington Hills, Mich., 1996, 41 pp.

"Guide for Selecting Application Methods for the Repair of Concrete Surfaces," *ICRI Guideline* No. 03731, 1996.

"Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces," *ICRI Guideline* No. 03733, 1997.

"Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Membranes," *ICRI Guideline* No. 03732, 1997.

"Surface Preparation for Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion," *ICRI Guideline* No. 03730, 1995.

RAP-4

Surface Repair Using Form-and-Pour Techniques

Reported by ACI Committee E 706

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The committee would like to thank Brandon Emmons for his illustrations in these bulletins.

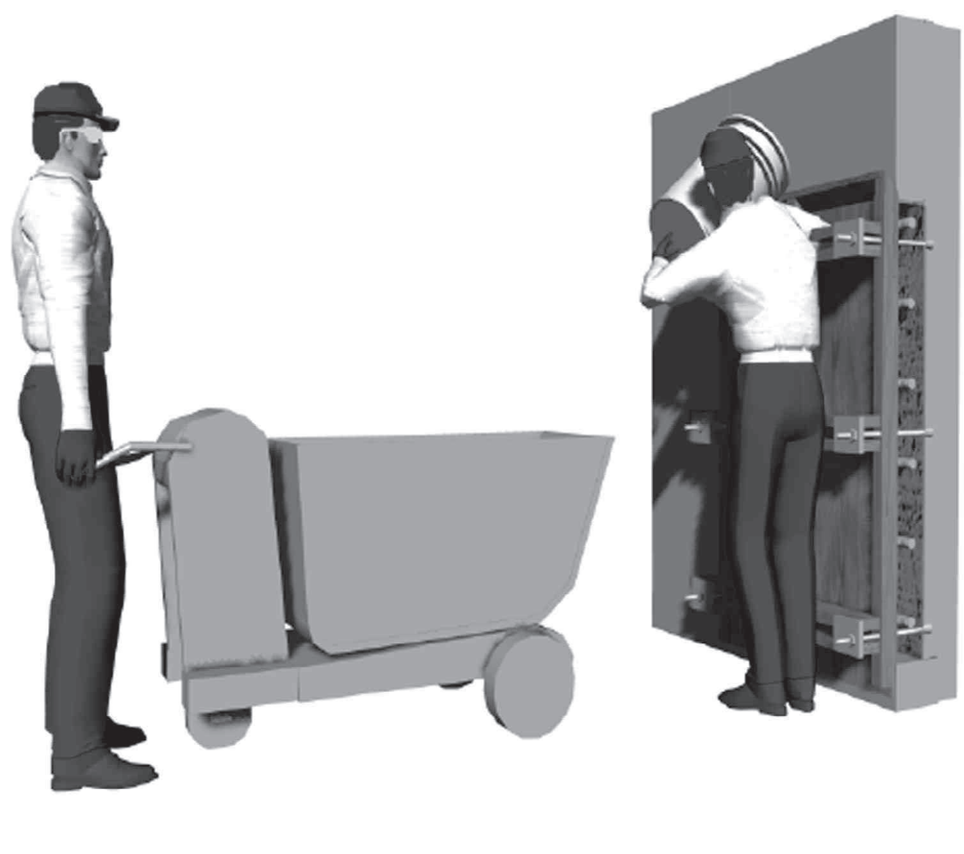
ACI Repair Application Procedure 4.

ACI RAP Bulletin 4

FIELD GUIDE TO
CONCRETE REPAIR
APPLICATION PROCEDURES

Surface Repair Using Form-and-Pour Techniques

by Peter Emmons



Introduction

The form-and-pour placement technique is a multistep process of preparation, formwork construction, and placement of repair materials. Repair materials are placed in the cavity between the formwork and the prepared substrate with buckets, pumps, chutes, or buggies. The form-and-pour technique allows the use of many different castable repair materials. Placeability is the primary consideration material selection. Depending on the consistency of the repair material, consolidation is accomplished by vibration, rodding, or when the material has extremely high slump (self consolidating), no additional steps may be required.

What is the purpose of this repair?

The primary purpose of this type of repair is to restore the structural integrity, or concrete cover requirements, or both, for the damaged element.

When do I use this technique?

This technique is commonly used on vertical surfaces such as walls, columns, and other combinations such as beam sides and bottoms. When used to repair slab soffits, the repair material is typically placed through holes or openings cut through the slab. Adhesive bonding agents or grouts are not commonly used with this technique. A trial installation is highly recommended for each project, to verify the preparation, material, and placement technique using quality-control procedures outlined at the end of this document.

The form-and-pour technique offers many advantages:

- Many different types of repair materials can be used;
- Repair material can be placed around reinforcing steel; and
- Formwork protects against early-age drying that promotes cracking.

The primary limitation of the form-and-pour technique is that formwork installation makes it more labor-intensive than alternative placement methods such as shotcrete or hand application (see Fig. 1).

How do I prepare the surface? (Fig. 2)

Regardless of the repair method, surface preparation is essentially the same. Concrete is removed until sound concrete is located. Exposed bars are undercut, and surfaces are cleaned with high-pressure water, or are abrasively blasted. With form-and-pour techniques, it is important to understand how the existing surfaces will permit the repair material to penetrate and flow. On partial-depth vertical repairs, the upper edges of vertical surfaces should be trimmed to eliminate potential pockets of entrapped air and promote complete filling from the location of the chute. Refer to page 3 for step-by-step preparation procedures.

Step 1—Sound the concrete to locate areas of delamination.

Step 2—Remove unsound concrete with a 15-lb chipping hammer. Hammers larger than a 15-lb class may cause damage to the substrate and reinforcement.

Step 3—Mark the perimeter of the repair area. Layout should be simple square or rectangular shapes.

Step 4—Sawcut the perimeter of the repair. Note: sawcut should not be deeper than the cover over reinforcement.

Step 5— Repair reinforcement as necessary. When reinforcing

Prepared concrete surfaces with formwork ready for erection.

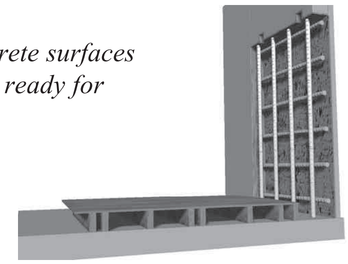
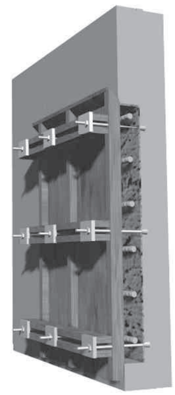


Fig. 1(a).



Section view through repair showing formwork and chute at top for placement of repair material.

Fig. 1(b).

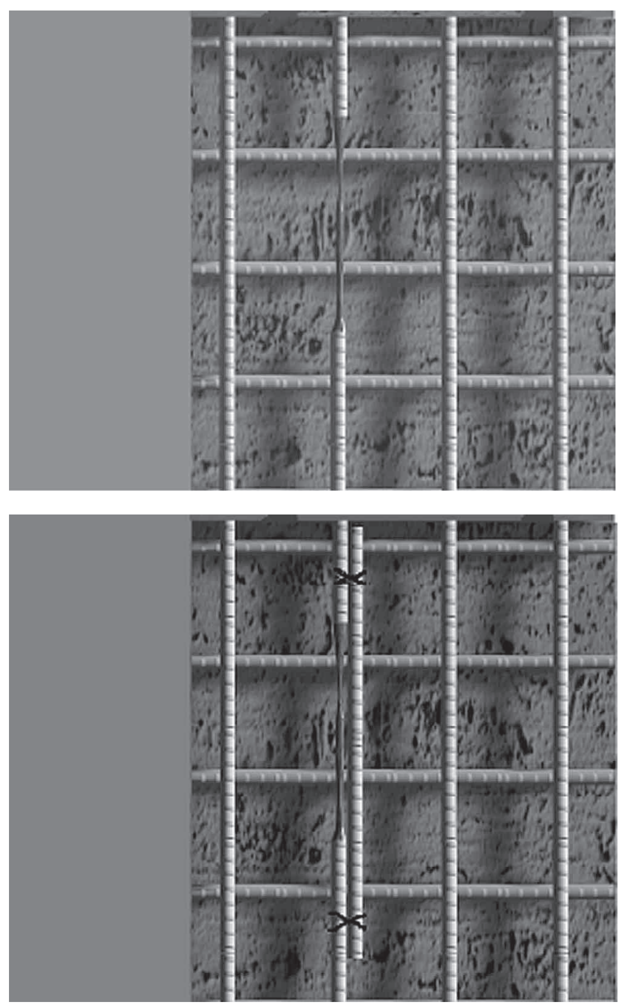


Fig. 2—Lapping of supplemental reinforcing.

steel is heavily corroded and the diameter is reduced, consult a structural engineer for repair procedures. For many applications, supplemental reinforcement can be lapped to adjacent damaged bars, as shown (see Fig. 2)

Step 6—Clean reinforcing steel and concrete with abrasive blasting.

How do I select the proper repair material?

Constructibility requirements for repair materials used with the form-and-pour technique are limited only by their ability to be transported to the formwork cavity. Maximum aggregate size should not exceed 25% of the space between the formwork and the substrate, or 50% of the distance between the reinforcing steel and the substrate—whichever is smaller. In general, the largest practical maximum size aggregate should be used to minimize drying-shrinkage and reduce the potential for cracking of the repair. Mixtures with high flowability (high slump) will make the placement easier; however, do not sacrifice a low water-cement ratio (< 0.40) for high slump. Use high-range water-reducing admixtures as necessary. Prepackaged repair materials, which are designed for high-flow placement, include shrinkage-compensating additives, and are appropriate for many applications. All mixture proportions should be optimized to minimize drying shrinkage. Shrinkage testing in accordance with ASTM C 157 measured over a 120-day period is recommended.

What equipment do I need?

Placement equipment may include either concrete buggies, buckets, or concrete pumps. Concrete pumps should be sized for the type of repair material being placed. If the repair is mixed on site, a portable mixer is required. Check with the manufacturer of the product to determine the recommended type of mixer.

What are the safety considerations?

Job site safety practices include, but are not limited to, the following where applicable:

- Material Safety Data Sheets (MSDS) available;

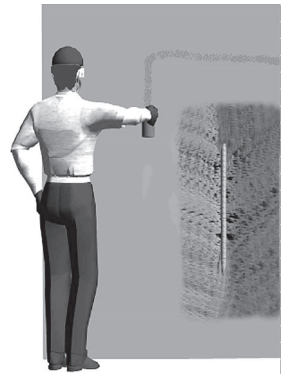
STEP 1

Sounding of concrete to locate areas of delamination.

STEP 2

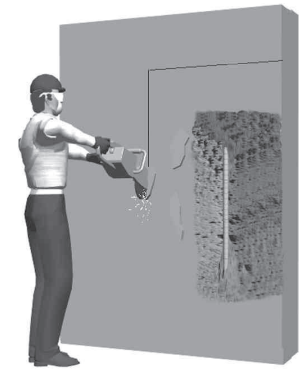
Unsound concrete removed with 15-lb chipping hammer. Hammers larger than a 15-lb class may cause damage to substrate and reinforcement.

STEP 3



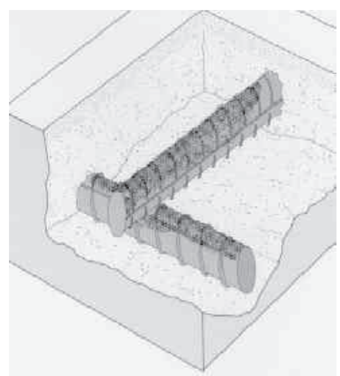
Mark perimeter of repair area. Layout should be simple geometric shapes.

STEP 4



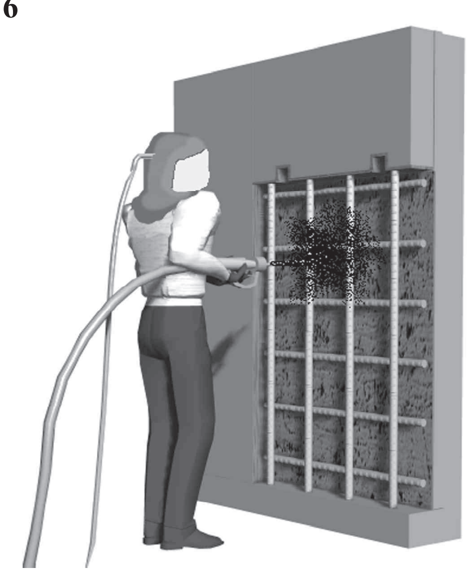
Sawcutting perimeter of repair. Note: sawcut should not be deeper than cover over reinforcement. Remove sound concrete within sawcut area.

STEP 5: *Reinforcement repair. When reinforcing steel is heavily corroded and the diameter is reduced, consult a structural engineer for repair procedures. For many applications supplemental reinforcement can be lapped to adjacent damaged bars, as shown.*



***Important Note**: If corroded reinforcing bars are encountered in the preparation process, then concrete surrounding the bars must be removed to fully expose the full circumference. Clearance under the bar should not be less than 3/4 in. (19 mm), or 1/4 in. (6 mm) greater than the largest aggregate size of the repair mixture, whichever is greater.*

STEP 6



Cleaning of reinforcing steel and concrete with abrasive blast.

- Protective clothing worn by workers handling or exposed to hazardous materials;
- Use of protective eyewear during pumping and placement of repair materials;
- Availability of eye wash facilities; and
- Use of respirators and ear protection during demolition.

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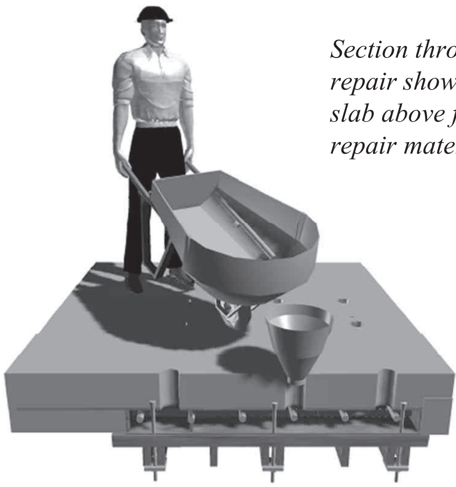
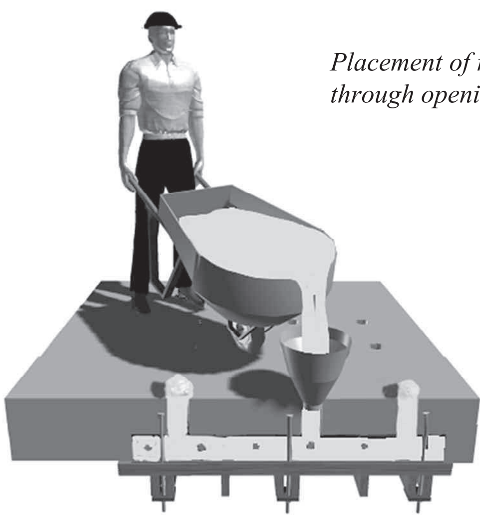
Preconstruction meeting

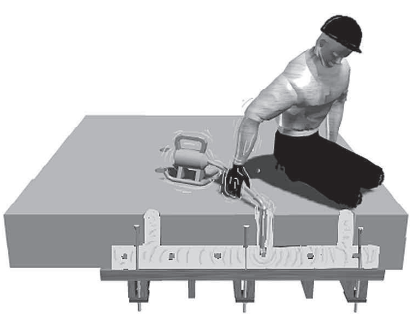
Prior to proceeding with the repair, a preconstruction meeting is recommended. The meeting should include representatives



Section through overhead repair showing opening in slab above for placement of repair material.



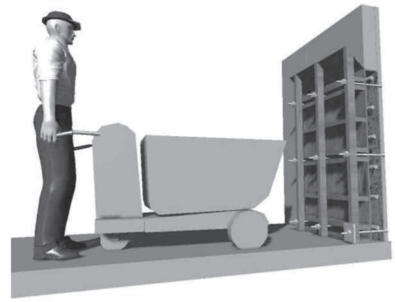
Placement of repair material through opening in slab



Pencil vibrator is used to consolidate repair material in cavity.

Fig. 3—Material placement: horizontal application.

Repair material is brought to the repair site via concrete buggy or other suitable means. Five-gallon buckets make useful tools to deposit repair material into form.



After the repair material is placed into cavity, vibrators are inserted into placement and consolidated. It is recommended that consolidation be done in lifts of no more than 2 to 3 ft (0.7 to 1 m).

Curing compound is immediately rolled or sprayed onto repaired surfaces after formwork is removed. Proper curing will help ensure repair material does not have premature drying and cracking, and the material develops its full strength.

Fig. 4—Material placement: vertical application.

from all participating parties (owner, engineer, contractor, materials manufacturer, etc.), and specifically address the parameters, means, methods, and materials necessary to achieve the repair objectives.

Repair procedure

Formwork construction—Formwork must accommodate the mass and pressure of the repair material. Design of the forms should follow standard practice for cast-in-place concrete construction. Formwork is best attached directly to the concrete surface with expansion anchors or rock anchors designed for coil rod. In cases of repair of slab soffits (underside), scaffold frames or shoring posts can be used to support the formwork tight against the concrete surfaces. When expansion/rock anchors are used, ensure anchors are firmly set in place to prevent slippage under load. Preloading of rock anchors with coil rod can be accomplished with a center-hole jack applying loads to the coil rod with a stand-off. Forms should be constructed to fit tightly against existing surfaces. Preformed gaskets or cast-in-place foam work well on difficult-to-match surfaces. Placement openings or chutes are required to place the repair material behind vertical forms. Chutes should be constructed to permit development of a hydraulic head above the prepared upper edges of the concrete surface. This will provide for repair material supply into these upper horizontal zones after concrete is consolidated. For large, vertical surfaces exceeding 10 ft (3 m) in height, multiple lifts should be considered to reduce free-fall segregation and excessive formwork pressures. Formwork for overhead surfaces does not require openings for placement of repair materials. Generally, placement occurs through openings in the slab from above.

Material placement—Prior to placement of the repair material, moisture conditioning of the prepared surface should provide for saturated-surface dry conditions. It is important not to overwet the surface. Saturated surfaces will prevent proper bonding because the surface pores are clogged with water, unable to absorb the repair material. Mixed repair material is brought to the formed area via whatever transport technique is appropriate for the situation. This may include buckets, pumpline, buggies, or wheelbarrows. For vertical surfaces, material is placed into the chute or opening. External or internal vibration is a must for almost all mixture consistencies. Some self-leveling repair materials, also known as self-consolidating, can be placed without vibration. When the cavity is filled, extra care should be taken to ensure that the uppermost surfaces are filled adjacent to the chute or opening where placement occurs. Rodding or tamping can ensure proper filling. Formwork should be left in place for the prescribed curing period. After stripping of formwork, any spaces not filled should be trimmed, cleaned, and dry-packed. Placement of a membrane curing compound is recommended immediately after removal of formwork.

How do I check the repairs?

After stripping of forms, various tests can be performed to confirm that the repair material was thoroughly consolidated and that adequate bond to the substrate was achieved. A

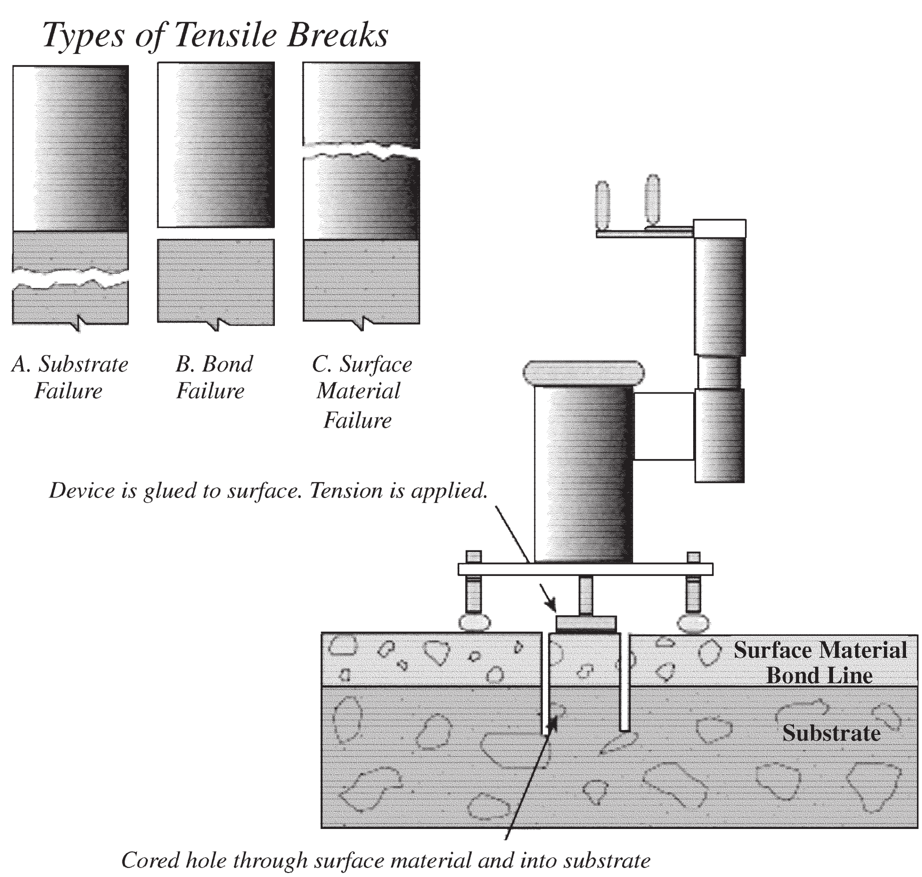


Fig. 5—Test procedure.

uniaxial bond test can be performed by drilling through the repair into the substrate. A bonded plate attached to the core is pulled until rupture occurs. The location of the failure should be reviewed. Bond values typically exceed 100 psi (0.7 MPa) and, in most cases, exceed 150 psi (1 MPa). These tests are performed in accordance with ACI 503R Appendix (see Fig. 5).

The complete repair area should also be hammer-sounded to locate voids and delaminations within the top 6 in. (150 mm). Any hollow sounds may indicate poor bond or voids.

Sources for additional information

1. "Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion," No. 03730, International Concrete Repair Institute, 1995, 5 pp.

2. "Guide for Selecting and Specifying Concrete Repair Materials," No. 03733, International Concrete Repair Institute, 1996, 34 pp.

3. ACI Committee 347, "Guide to Formwork for Concrete (ACI 347-01)," American Concrete Institute, Farmington Hills, Mich., 2001, 32 pp.

4. ACI Committee 546, "Concrete Repair Guide (ACI 546R-96 (Reapproved 2001))," American Concrete Institute, Farmington Hills, Mich., 1996, 41 pp.

5. ACI Committee 503, "Use of Epoxy Compounds with Concrete (503R-93 (Reapproved 1998))," American Concrete Institute, Farmington Hills, Mich., 1998, 28 pp.