REMR Technical Note CS-MR-4.5
Spall Repair

Purpose

To provide guidance for repairing concrete spalls.

Overview

A spall in a concrete surface may be the result of localized distress or the symptom of a more widespread distress in the concrete element. In either case, an attempt should be made to determine the cause of the distress prior to selecting a remedy. Causes of spalls include (a) corrosion of reinforcing steel, (b) an inoperative joint resulting from incompressibles in the joint, (c) mis-alignment of joint dowels, (d) impact, (e) freezing and thawing of nonair-entrained concrete in a critically water-saturated condition, (f) freezing and thawing of porous aggregate in a critically water-saturated condition, and (g) alkali-silica reaction.

Repairs of spalls to remedy the symptoms of a more widespread distress are intended to be temporary solutions that extend the service life of a concrete element until a long-term solution can be implemented.

Standard practice for the repair of concrete spalls varies depending on the type of concrete element being repaired, cause and extent of damage, location of the spall, and repair material selected. The repair material selection is typically based on such factors as properties of the repair material, climatic conditions, repair time frame, expected service life, and cost. Properties that influence the selection of repair material include shrinkage, strength, modulus of elasticity, creep, and sag.

The repair process generally includes (a) an inspection to document the extent and details of damage, (b) an evaluation to determine the cause of distress and the as-constructed details for the damaged element, (c) the selection of a repair material, and (d) the application of the repair material in accordance with standard concrete practice for portland cement based concretes or in accordance with the manufacturer's instructions for commercial products.

Concrete Removal

The general procedure for preparing a spalled area for repair is to (a) mark off the area to be repaired using straight lines between corners, (b) make a normal-to-the-surface cut along the marked boundary, (c) remove all concrete from within the cut perimeter to a near uniform depth, (d) sound the remaining concrete within the repair area for weaknesses and perform removal as needed, and (e) clean all surfaces within the repair area. The marked area should have 90-deg corners with the sides parallel or normal to the direction of the reinforcement. The marked boundaries for the repair area should be a minimum of 50 mm (2 in.) outside the perimeter of the spall. For a single spall at a pavement joint, the repair area should be a minimum of 100 mm (4 in.) wide (measured normal to the joint) and 250 mm (10 in.) long (measured along the joint) (Patel, Mojab, and Romine 1993). If a number of spalls are closely located to each other, these spalls should be included in a single area marked for repair.

A normal-to-the-surface cut along the marked boundary should be made with a diamond blade saw. However, when diamond cutting is not practical, the normal edge can be made with an impact hammer. The depth of cut should be a minimum of 25 mm (1 in.), except for spalls at pavement joints, where a minimum 50-mm (2-in.) deep cut is recommended (Patel, Mojab, and Romine 1993). In situations where the diamond saw could cut into the reinforcing steel due to inadequate concrete cover, the boundary edge should be formed by means of impact hammers. A pachometer can be used to estimate the depth of cover.

Concrete should be removed to produce a near uniform depth for the repair area. For spalls at pavement joints, it is recommended that the depth of repair be a minimum of 50 mm (2 in.) (Patel, Mojab, and Romine 1993). A full-depth repair must be used when dowel bars are reached or when the spall depth is greater than one-third of the thickness of pavement.

Full-depth repairs require that a full-depth saw cut be made at the boundaries. For pavements subject to heavy traffic, dowels will be required for load transfer between the existing pavement and repair and back to the pavement in the direction of traffic (American Concrete Pavement Association 1989). Dowel holes should be made with a gang drill to avoid misalignment of the dowels. The American Concrete Pavement Association recommends that a minimum of four 32-mm (1-1/4-in.) to 38-mm (1-1/2-in.) dowels per wheel path be used.

Impact hammers are typically applicable for smaller and moderate areas of removal and for areas of limited access. Removal should begin at the interior of the repair area and progress toward the boundaries. Removal should be performed using 14-kg (30-lb) hammers for the interior and 6.8-kg (15-lb) hammers for around reinforcing and near boundary edges.

Mechanical milling (single drum, rotary cutter head with tungsten-carbide bits) is applicable for large areas where the concrete cover is to be removed. Care must be taken to avoid contact with the reinforcing steel as both the reinforcing and the cutter drum could be damaged. The front and back edges of removal will be rounded and the other two sides possibly feathered.

Rounded and feathered edges should be cut to form normal-to-the-surface boundaries. For spalls at pavement joints, the orientation of boundaries with rounded edges should be parallel to the direction of traffic (Patel, Mojab, and Romine 1993).

Hydrodemolition (water jet blasting) is applicable for large areas of spall repair where the reinforcing steel is to be exposed and reused in the repair. Waterborne fines deposited on newly exposed concrete and reinforcing surfaces during removal should be removed by low-pressure water blasting before deposits dry. Feathered edges along the removal boundary should be cut to form a normal-to-the-surface boundary.

After removal, exposed surfaces should be visually inspected and sounded for weaknesses and delaminations. If found, additional removal will be required.

Additional help in selecting a removal method can be found in REMR Technical Note CS-MR-1.14.

Surface Preparation

Prior to preparation of concrete surfaces, exposed reinforcing should be inspected for proper exposure, clearance, cross-sectional area, and location. Reinforcing bars must be further exposed if the remaining concrete is debonded from the reinforcing steel. Removal must be continued to completely expose the bar if more than half of a reinforcing bar perimeter has been exposed. For completely exposed reinforcing bars, a minimum clearance of 19 mm (3/4 in.) or nominal maximum size aggregate plus 6 mm (1/4 in.), whichever is greater, must be provided between the reinforcing bar and surrounding concrete. A structural engineer should be consulted if the cross-sectional area of a bar has been reduced by 25 percent or more or if two adjacent bars have been reduced by 20 percent or more. Out-of-plane and loose reinforcing should be secured in its design location.

The general procedure in preparing concrete and reinforcing surfaces for optimum bonding is to sandblast the surfaces and then remove dust and debris by air blasting, low-pressure water blasting, or brooming. If the damage was the result of corrosion, an epoxy coating should be considered to protect the exposed reinforcing steel. Final inspection of the prepared area and remedying of deficiencies should be completed just prior to batching the repair material.

Additional help in preparing concrete and steel reinforcing surfaces for bond can be found in REMR Technical Note CS-MR-2.1.

Formwork

If repairs are to be made to vertical or overhead surfaces and a non-sag material is not to be used, formwork will be required. Prior to installing forms, the concrete surface must be inspected for any surface contours that could result in air being trapped during concrete placement or pumping. If found, concrete must be removed to change the contour, or vent tubes must be installed.

Formwork should be designed to withstand a minimum 0.1 MPa (14 psi) hydrostatic pressure (Emmons 1993). Installed form anchors should be tested for slippage via preloading. Formwork should be secured to the concrete with expansion anchors or standard form ties. Preformed foam gaskets or cast-in-place foam may be required to provide a watertight seal between the concrete and form surfaces.

Repair Materials

Restrained contraction of repair materials, the restraint being provided through bond to the existing concrete substrate, is a major factor that significantly increases the complexity of the repair. Drying shrinkage and thermal gradients are the primary causes of contraction, which often results in cracking of the repair material or debonding of the repair. Therefore, repair materials must be dimensionally compatible with the existing concrete substrate to minimize the potential for cracking and debonding as a result of restrained contraction. Those material properties which influence dimensional compatibility include shrinkage, thermal coefficient of expansion, modulus of elasticity, bond, and creep.

Conventional concretes

Conventional concretes are low-cost, general-purpose repair materials that are typically used where the depth of repair is greater than 50 mm (2 in.). The batched mixtures contain a Type I portland cement with admixtures included as needed to shorten the time of setting, to increase strength gain and improve durability of the hardened concrete, and to inhibit the corrosion of reinforcing steel. Most conventional concretes will obtain a minimum compressive strength in the range of 21 MPa (3,000 psi) to 28 MPa (4,000 psi) at 28-day age.

Rapid-hardening cementitious repair materials

Rapid hardening cementitious repair materials are used to minimize out-of-service time for repairing pavements and bridge decks. Repair depth and volume are usually small due to the high cost and rapid heat generation of the rapid-hardening materials. These materials include concretes made with

Type III portland cement, concretes containing regulated-set portland cement, gypsum-based concrete, magnesium phosphate concrete, and concrete containing high alumina cement.

Most of the rapid-hardening products will obtain a minimum compressive strength of 21 MPa (3,000 psi) at 4-hr age. The high alumina concretes require 6 hr to achieve this minimum compressive strength. Concrete mixtures containing Type III portland cement and an accelerator can obtain a minimum compressive strength of 14 MPa (2,000 psi) at 6-hr age. The regulated-set concrete is a very high early-strength concrete that will obtain a minimum compressive strength of 34 MPa (5,000 psi) at 24-hr age.

Concrete containing high alumina cements will have increases in porosity, permeability, and strength losses with time due to the conversion of hydrated aluminate compounds (Zia, Leming, and Ahmad 1991). This will eliminate the high alumina concretes from consideration for many repair applications.

Additional information regarding rapid hardening cementitious repair materials can be found in REMR Technical Note CS-MR-7.3.

High-performance concretes

High-strength concretes are attractive as a potential repair material for structural concrete because of their high durability and strength while requiring minimal out-of-service time in making the repair. These concretes have a maximum water-cement ratio of 0.35; a minimum Durability Factor of 80 percent (American Society for Testing and Materials (ASTM) C 666-92, Method A); and a minimum compressive strength of 21 MPa (3,000 psi) at 4-hr age, 34 MPa (5,000 psi) at 24-hr age, or 69 MPa (10,000 psi) at 28-day age (Zia, Leming, and Ahmad 1991).

High-performance concretes may be obtained with either specialty cements or Type III portland cement (Zia, Leming, and Ahmad 1991). The Type III portland cement will require an accelerator to achieve the required minimum compressive strength at 24-hr age. High-performance concretes frequently require a retarding admixture to control rapid stiffening in even moderate temperatures due to high cement contents.

Mineral admixtures are sometimes included to produce a high-performance concrete via improving the durability or strength characteristics of a mixture (Zia, Leming, and Ahmad 1991). These admixtures include Class C and Class F fly ashes, ground granulated blast-furnace slag, and silica fume.

Drypack mortars

Drypack mortars are typically used to repair small confined areas and cavities in vertical and overhead surfaces. Conventional drypack mortars typically consist of one part cement, three parts of sand passing a No. 16 sieve, and just enough water so that the mortar will stick together when molded into a ball by hand. To reduce shrinkage, the batched mortar should be allowed to stand for 30 min and remixed before placement. For commercial drypack products, follow the manufacturer's recommendations.

Drypack mortars are hand placed in approximately 10-mm (3/8-in.) thick layers followed by tamping or ramming of the mortar into place. A hardwood stick is used to prevent polishing of the surface of the mortar layers during compaction (Emmons 1993). Because of the low water-cement ratio of the drypack materials, there is little shrinkage, and the repair remains tight and is of good quality with respect to durability, strength, and watertightness.

Additional information regarding drypacking can be found in REMR Technical Note CS-MR-3.8.

Pumpable concretes

Pumpable concretes are commonly used to repair large areas at projects where space for construction equipment is limited or access is difficult. Repairs to overhead surfaces are made by the form and pump method, while repairs to vertical surfaces are made by form and pump or form and cast-in-place methods.

For the form and pump method, concrete is pumped into the formed area through a valved entry port. Located at the highest point of repair is a valved exit port, which is opened to allow the air to escape while it is being displaced by the pumped concrete. When the formed area has filled, the exit port valve is closed and pump pressure exerted to consolidate and force the pumped concrete against the existing concrete surface for better bonding.

For the form and cast-in-place repair method, the top of the form has an offset chimney that extends outside the formed face. The concrete mixture is gravity fed through the chimney and into the form until the top of the chimney is filled. The form is vibrated at 30-min intervals until the concrete hardens and no longer responds (EM 1110-2-2002 (Headquarters, Department of the Army 1986)). A form closure plate can be used to separate the repair from the concrete in the chimney during vibration of the concrete. If not, the projection left by the chimney can be removed the next day via saw cutting with a diamond blade having a recessed hub.

It is common to experience a decrease in air content for the concrete mixture during pumping (EM 1110-2-2000 (Headquarters, Department of the

Army 1994)). Therefore, it may be necessary to entrain a higher air content at the pump in order to obtain the specified air content at the point of placement.

The pump selection is dependent on the mixture design, particularly the nominal maximum size aggregate (Emmons 1993).

Preplaced aggregate concrete

Preplaced aggregate concretes are used for repairing large areas where low volume change is required. For repairs to vertical and overhead surfaces, the surface must be formed and aggregate tightly packed within the form. A valved grout entry port is located at the lowest point of the form, and a valved exit port at the highest point of the other end of the formed area.

The preplaced aggregate is gap graded to exclude fines and typically has a 40- to 50-percent void ratio after the aggregate is packed (Emmons 1993). Care must be taken in preplacing coarse aggregate to avoid breakage and segregation of the aggregate (EM 1110-2-2000). This becomes more difficult as the nominal maximum size aggregate increases and when two or more sizes are blended. The nominal maximum size aggregate is typically 38 mm (1-1/2 in.) to 50 mm (2 in.).

Conventional intrusion grout mixtures are proportioned in accordance with ASTM C 938-80 to obtain the specified consistency, air content, and compressive strength. The ratio of cementitious material to fine aggregate is typically in the range of 0.67 for mass concrete mixtures to 1.00 for structural concrete mixtures (EM 1110-2-2000). A grout fluidifier is commonly used to offset bleeding, to reduce the water-cement ratio and still provide a given consistency, and to retard stiffening so that handling times can be extended. If field testing of grout shows an expansion of less than 2 percent or more than 6 percent, adjustments to the fluidifier should be made to bring the expansion within these limits. A pozzolan is typically used to increase flowability of the grout.

For commercial intrusion grouts, follow the manufacturer's recommendations.

Additional information regarding preplaced aggregate concrete can be found in REMR Technical Note CS-MR-9.4.

Polymer concretes

Polymer concretes are typically used for making shallow repairs in pavements and bridge decks where a fast-curing, high-strength, and low-permeability repair material is required. Repair depths are limited to 50 mm (2 in.) or less due to rapid heat generation (Patel, Mojab, and Romine 1993).

For repairs of greater depth, polymer mixtures must be placed in lifts. The cost for the deeper repairs will likely result in another repair material being selected.

Some of the polymers used to make concrete mixtures include epoxy resins, high molecular weight methacrylates, polyesters, vinyl esters, acrylics, styrenes, and polyurethanes. The applications of these mixtures vary greatly. Some applications require a dry surface, some a moist surface, and some are not sensitive to moisture (American Concrete Institute (ACI) 548.1R-92 1993). Non-sag mixtures are available for making vertical and overhead repairs.

The manufacturer's recommended bonding agent must be used and application instructions followed.

Polymer-modified concretes

Polymer-modified concretes are typically used for making shallow repairs up to 50 mm (2 in.) deep in structural concretes where a less permeable, higher tensile strength material than conventional concretes is required. For repairs of greater depth, the concrete mixture must be placed in lifts.

The polymer-modified concretes are generally normal portland cement mixtures to which a water soluble or emulsified polymer has been added during the mixing process (ACI 548.1R-92 1993). The properties and application of these concretes vary widely depending on the type polymer and dosage rate used in the mixture. Some of the concretes have coefficients of thermal expansion and moduli of elasticity near that for structural concretes. The polymer solids content for optimum performance is typically between 15 and 20 percent by weight of the cement.

After placement and finishing, polymer-modified concretes should be covered promptly with a single layer of clean, wet burlap topped with a preferably white sheet of polyethylene film (ACI 548.1R-92 1993). The surface should wet cured for 24 hr and dry cured for 72 hr before vehicular traffic is permitted on the repair surface.

Numerous commercial concretes are available that have the ingredients prepackaged. For these products, the manufacturer's recommendations must be followed.

Shotcrete

Shotcrete mixtures are typically used to repair large spalled areas in vertical and overhead surfaces where the depth of repair is less than 150 mm (6-in.) (EM 1110-2-2002). Conventional shotcretes are the most widely used shotcrete. They are pneumatically applied using a dry- or wet-mix process

(ACI 506R-90 1993). For the dry-mix process, water is mixed at the nozzle with the premixed portland cement and aggregate. For the wet-mix process, the mixture is batched before entering the pneumatic system. Coarse aggregate can be included in the mixture; however, the shotcrete has higher rebound, is more difficult to finish, and cannot be used in thin layers.

The properties for shotcrete are largely dependent on the conditions under which it was placed, equipment selected, and competence and experience of the application crew. Shotcrete typically has a compressive strength in the range of 20 MPa (3,000 psi) to 48 MPa (7,000 psi) (ACI 506R-90 1993). It is recommended in ACI 506R that strengths higher than 35 MPa (5,000 psi) be specified only for carefully engineered and executed shotcrete work. Drying shrinkage generally falls within the range of 0.06 and 0.10 percent. Chemical accelerators should be avoided where not absolutely necessary as they increase drying shrinkage (Emmons 1993). The coefficient of thermal expansion is near that of steel reinforcing.

Special proprietary shotcrete mixtures are available that contain materials, such as sodium and potassium silicates, magnesium phosphates, polymers, silica fume, and steel or plastic fibers. For these special mixtures, the recommendations of the manufacturer must be followed.

Fiber concretes and shotcretes

Steel fiber-reinforced concretes and shotcretes are used to repair concrete where increased tensile strength and toughness are required (ACI 544.1R-82). The more common steel fiber shapes include straight, crimped, surface-deformed, and hooked ends. The straight steel fibers provide the least toughness for the same volume concentration (EM 1110-2-2000). Steel fibers with hooked ends have basically the same properties as straight fibers of the same aspect ratio using fewer fibers per unit volume. Fibers are usually described by their aspect ratio, which is fiber length to diameter.

Steel fiber-reinforced concretes generally have higher cement and fine aggregate contents and smaller nominal maximum size aggregates than conventional concretes (EM 1110-2-2000). Nominal maximum size aggregate for these concretes is usually 19 mm (3/4 in.) or less. The practical upper limit for most steel fibers is generally considered to be 2 percent by volume of the total concrete mixture. Pozzolans are often used to reduce the cement content in the mixture.

Other fibers have been produced from plastic, glass, and natural materials in various shapes and sizes. Glass fibers are subject to chemical attack by alkalinity of the concrete that causes them to become brittle and lose their effectiveness. Plastic fibers made of nylon, polypropylene, or polyethylene are not subject to chemical attack. Incorporation of plastic fibers into a concrete mixture can result in small improvements in flexural and tensile strengths, increase in fracture toughness, and decrease in shrinkage.

Bituminous concretes

Bituminous concretes are used to make temporary patches to extend the service life of spalled concrete pavements and bridge decks. These bituminous concretes are fairly inexpensive, widely available, easy to place, and require little cure time. The most effective of the bituminous concretes are the hot mix asphalts. Many commercial bituminous cold mixtures that perform well are also available. The cold mixtures may become sticky and hard to work when ambient temperatures are near upper product limits.

Batching

The volume of material required for repairing a prepared spall area is often small (0.014 to 0.057 m^3 (0.5 to 2.0 ft^3)) (Patel, Mojab, and Romine 1993). Small drum or paddle-type mixers with capacities of 0.17 to 0.23 m^3 (6 to 8 ft^3) and Jiffy mixers are often used. For large repair jobs, equipment of greater capacities may be required.

For portland cement concretes and mortars, the mixture proportions are usually finalized through trial batches. For big jobs, the materials may be weighed and bagged in advance to make the batching process more efficient. Mixture proportions commonly include air-entraining, water-reducing (conventional and high-range), and accelerating admixtures. For pumpable mixtures, pozzolan and fluidifier admixtures are usually included. To limit chloride ion content in the concrete, calcium-chloride accelerators are being replaced with nonchloride accelerators. Nonchloride accelerators containing calcium nitrite and calcium nitrate have generally proven to be effective replacements (Zia, Leming, and Ahmad 1991).

A corrosion inhibitor should be considered for repairs where corrosion is the cause of the spall. The most common inhibitor is a calcium nitrite based admixture (Zia, Leming, and Ahmad 1991). Calcium nitrite is also an accelerating admixture which may cause mixing and placing problems for some jobs.

For commercial repair products, batching must be performed according to the manufacturer's recommendations. The product binder comes prebagged, and for some polymer concretes, the fine and coarse aggregates are also prebagged.

Bonding Agent

The most common bonding agent for portland cement concretes and mortars is made up of equal volumes of portland cement and fine aggregate mixed with enough water to create a slurry having a consistency of a thick cream. For silica fume, polymer-modified, and other cementitious mixtures, the bonding agent is typically the grout portion of the concrete mixture. These cementitious bonding grouts must be worked into the surfaces with a stiff broom or brush. The grouts should not be allowed to dry more than 10 min before the repair material is placed. If allowed to dry, the grout must be removed and the surfaces prepared. Removal of grout is typically accomplished by low-pressure water blasting followed by sandblasting.

Epoxy and other polymer bonding agents are available for cementitious concretes and mortars. If one of these products is selected, the manufacturer's recommendations must be followed.

For polymer concretes and mortars, the bonding agent recommended by the manufacturer must be used and application instructions followed.

Evaluating Repair Performance

It is important that repairs be inspected periodically to document the field performances of different types of repair materials and techniques. Documentation should include techniques, equipment, and materials employed for removal, surface preparations, batching, placing, and curing; repair date and cost; and assessment date and performance. A summary of repair performances grouped by repair material or technique may show trends that will benefit future repair efforts through technology transfer.

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