Concrete Repair Basics

By Gerard C. Feldmann, P.E.

During the past holiday season, there was an annoying television commercial that seemingly hawked, every 15 minutes, an amazing repair material that claimed it could fix anything. Next holiday season: "Instant Concrete Fix. Just add water and pour. No prep, no mess! Can support an elephant in only 5 minutes!!" I am only joking here, but the use of great repair materials will not guarantee a successful repair without knowing the nature and cause of the failure.

Figure 1: Deterioration of concrete due to rebar corrosion.

Reinforced and unreinforced concrete is used for the construction of a variety of structures that include buildings, dams, bridges, garages, water tanks, etc, because of its strength and its ability to form shapes of any configuration. Concrete structures are generally designed to give a certain service life ranging from 25 to 100 years. Structures being designed today have the advantage of many years of hard-learned lessons of what not-to-do, and can utilize building materials not available to engineers 20 years ago. A previous article in the January 2007 issue of STRUCTURE® magazine gave a quick primer on the most common non-destructive testing methods to determine the mode of concrete deterioration. This article will concentrate on the proper repair methods for existing concrete structures by outlining approaches that are based upon the cause of deterioration.

Deterioration Mechanisms

Consider the scenario where concrete deterioration is found on a structure. Why did it happen? The cause of deterioration needs to be defined, which would allow the engineer to properly design the repairs. Blindly repairing concrete without knowing the existing conditions may set up an equally quick failure of the repair. This article does not include all known concrete deterioration mechanisms, just the most common ones.

The most prevalent forms of concrete deterioration are all-too-familiar: spalling and delamination due to corrosion of embedded steel reinforcement from chloride contamination or carbonation (*Figure 1*). Freshly placed concrete has a high internal pH that protects embedded uncoated steel from corrosion by forming a protective layer on the surface of the steel. Contaminates such as chlorides and carbon dioxide break down this protection and create conditions conducive to corrosion. Corrosion of the steel will occur under these conditions if water and free oxygen are present. Corrosion by-products, which form rust, expand the outer surface of the steel, creating large internal bursting stresses that crack the concrete. Spalled concrete, with visibly corroding reinforcement, is the end result of this process.

Less common forms of deterioration can also occur. The concrete matrix itself can be broken down by a variety of mechanisms. The surface can be physically eroded by water (such as found in tunnels), by equipment, or by chemical attack. The concrete can be broken down from within by alkali-silica reactions (ASR) and by freeze-thaw damage. ASR occurs when the aggregate reacts with the highly alkaline cement in the presence of water. A gel forms around the aggregate creating bursting forces that crack the concrete matrix. Freeze-thaw deterioration typically is the result of concrete that does not contain proper air-entrainment. Deterioration occurs if the concrete becomes saturated, followed by freezing temperatures, causing complete breakdown of the mortar fraction of the concrete. The concrete matrix literally breaks down into sand and aggregate. See *Figure 2* for an example of this damage. In this instance, asphalt topping that was removed from a bridge deck revealed 4 inches of sand.

Figure 2: Breakdown of concrete due to freeze thaw deterioration.

Repair Design

Once the deterioration mechanism is determined, then a repair strategy can be outlined. Too many times, clients have stated that they are repairing concrete patches every few years. Proper patching designs will extend the service life considerably. The repair material should match, as closely as possible, the properties and chemistry of the existing concrete. For example, one does not necessarily need a 10,000 psi compressive strength patch material applied to a 3,000 psi base material. Conversely, if the existing concrete contains excessive chloride ion contamination, repair materials that contain chlorides should certainly not be used. So, a balance needs to be struck between the mechanical and chemical properties of the repair material and the mechanical and chemical properties of the material that needs repair.

What kind of repair material? There is not enough space here to explain all the choices. A broad grouping includes prepackaged and ready-mix products. Prepackaged materials contain the gamut

Figure 3: Ring corrosion.

of additives, but there are many additives for ready mix concrete as well. The key properties for patch materials are low shrinkage (to prevent cracking), good bond, protection for new/existing embedded steel from new contaminates, integral corrosion inhibitor (to reduce the chance of ring corrosion – see below), and a lifetime replacement warranty (wishful thinking). In our experience, the realistic service life for a well designed and executed patch, with a concrete sealer added after repairs, is over 5 years, and sometimes, over 10 years.

While the patched concrete may be durable, the possibility of ring corrosion should be addressed. Ring corrosion is the result of electrochemical differences between the existing concrete and the repair material (*Figure 3*). The area directly adjacent to the repair will develop delamination, forming a halo or ring around the patch. In this instance, the cracked, dark gray patch was completed first, followed by the adjacent patches in subsequent rounds of repair. One way to minimize the potential for this is to: a) electrically isolate the patch by coating any continuous steel and the patch interface, or, b) use corrosion inhibitors or passive cathodic protection in the form of small electrodes cast into the repair that are attached to the reinforcement (*Figure 4, page 16*).

The key aspects of a successful concrete repair are preparing the surface properly, specifying the proper repair material, properly mixing and placing the repair material, and properly curing the repair material. All of these steps are important. Neglecting any of these, most likely will create premature failure of the repair.

Repair Procedures

Step one: Remove loose and contaminated concrete. This sounds simple. Typically, this is part of a repair specification. However, discussion of this needs to be expanded depending upon the field conditions encountered after the start of the repairs. How much concrete needs to be removed? Below is a list of some of the possible conditions:

1) Concrete that is highly contaminated with chlorides can be dealt with in two ways. The straightforward approach is for the removal of all concrete above the recommended threshold, which could involve the full removal of the structure in some cases. Chloride extraction techniques can be utilized in some cases, but this can be expensive and should be evaluated for cost. Partial depth repairs are typically performed and, if properly designed and implemented, can add years. of serviceability to a structure.
2) Repair of ASR damaged concrete is dependent upon the state of the ASR. Testing may indicate ASR by-product, but the reaction may have stopped. This can be repaired conventionally. If ASR is still actively occurring, then removal of the loose material and protection from further moisture may suffice, but that is an engineering judgment beyond the scope of this article.
3) Repair of freeze-thaw damaged concrete needs to address the lack of proper air-entrainment throughout the existing structure. All the damaged concrete needs to be removed and the finished repairs need to be waterproofed to prevent a reoccurrence of the problem. Erosion-type or chemical attack surface damage can be repaired similarly, by over-laying the existing concrete with a repair material containing more durable aggregates, such as iron for equipment wear applications, or with a repair material able to tolerate the offending chemical.

Partial depth concrete removal should utilize the least destructive tools that can meet cost and schedule requirements. The best tools utilize small pneumatic and electric chipping

Figure 4: Passive cathodic protection. Courtesy of Vector Construction Group.

hammers followed by hydro demolition, which cleans the steel and the concrete at the same time. Using removal equipment that is too large creates collateral damage, unnecessarily enlargement of the repair area, and microcracks in the substrate that can weaken the patch.

Step Two: Prepare the surfaces. Concrete and steel surfaces should be free of dust, rust, loose material or any foreign contamination. This is accomplished by utilizing hydro demolition during the concrete removal process, and by utilizing water/abrasive blasting, rotary wire wheels, wire brushes, etc. as required to achieve the specified surface roughness. Also, it is good practice to add some mechanical anchors at the outer perimeters of large patches – especially if no existing steel is present – to help bond the new patch material to the existing concrete in case chemical bond failure occurs.

Step Three: Patching. Mix and place, right? Not so fast. Critical first step: A saturated, surface dry (SSD) bond surface must be provided prior to placing the patch. What is SSD? The bonding surface needs to be saturated, but with no standing water. Why? The freshly mixed material contains only enough water (if mixed properly) to develop the designed properties (strength, bond strength, density, etc.) of the patch. If the bonding surface is dry, water will be drawn out of the patch, creating different (not for the better) concrete patch properties. The most prevalent result of premature drying at the bond line is excessive shrinkage, which then debonds the patch at the perimeter. If the patch is completed in multiple layers, as is typically the case for vertical or overhead work, each layer would need a SSD surface prior to patching. For horizontal repairs, the use of vibration during placement achieves the best results if a free-flowing material is not specified. Vibration gives full consolidation of the patching material creating full mating of the bonding surface and encapsulation of any exposed reinforcement. Is a bonding compound useful? Sometimes, but placing the repair material alone, unless the manufacturer recommends otherwise, is usually sufficient.

Figure 5: Shrinkage cracking of patch due to lack of proper curing.

Step Four: Curing, curing, curing! One of the most important ingredients in a successful repair that cannot be stressed enough is curing. The proper curing of the repair material will reduce the potential for plastic shrinkage cracking, allow the maximum strength gain, reduce the permeability from future contaminates, and create the strongest bond. Seven days of wet curing is optimal, but a minimum of three days is generally specified due to time constraints. The repair needs to be kept wet continuously during the curing period and the use of polyethylene sheeting is recommended. The manufacturer's curing recommendations for prepackaged repair materials generally calls for following ACI guidelines for wet curing, and discourages the use of curing compounds on intermediate layers of multi-layered repairs. The use of curing compounds can be substituted, and are strongly recommended for vertical and overhead repairs where the use of water curing is difficult or not possible. Hot weather repairs are especially susceptible to plastic shrinkage cracking if not cured properly. Too often the curing step, though specified, is not taken seriously by the contractor, resulting in cracked patches before they are even off the job. *Figure 5* shows a failed patch from a one-level parking deck that was repaired in the hottest time of the year. In this instance, an overhead patch experienced heavy cracking and curling, indicating that extreme premature drying took place.

Step Five: Water protection. For the most part, the above steps will yield a high quality repair. However, if large areas of original concrete that did not require repair are still present, application of a surface treatment is recommended to prevent a reoccurrence of the problem and an outbreak of new deteriorated areas. Certain conditions, however, need to be evaluated further.

As an example, consider the repair of a parking garage with the typical slab deterioration due to chloride ion exposure. Topside concrete patching repair was specified followed by the installation of a waterproof membrane to prevent further water and contaminates from reaching the steel. However, this slab was also deteriorated on the underside. Some of the deterioration was caused by through cracks that brought contaminates to the bottom reinforcement mat. However, it appeared that much of the deterioration was caused by carbonation that reached the level of the steel. Topside waterproofing will stop the leakage, but corrosion will still occur, albeit at a slower pace, just due to moisture in the air penetrating the concrete. Waterproofing both sides of a slab is generally prohibited as any water leakage that is still present in the concrete slab will be trapped, creating an environment for accelerated corrosion and deterioration. In this instance, a penetrating migrating corrosion inhibitor was specified to stabilize the corrosion of the bottom reinforcement.

Conclusions

Concrete is a unique building material that allows structures to be built with greater flexibility and aesthetic expression than others. Problems unique to concrete structures result from the fact that these load carrying elements are exposed. Long term serviceability of concrete structures is sometimes marred by deterioration. Proper analysis of the cause of concrete deterioration is essential in designing a proper repair for durability and compatibility. With the current state of knowledge increasing in the intervening years, we hope to extend the time before repairs are needed again.▪

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