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Repairs to Restore Serviceability in Concrete Structures

by Noel P. Mailvaganam and Lyndon Mitchell

Lasting repairs of deteriorated concrete structures depend on careful selection of materials and methods suitable for the service and application conditions. This Update describes the factors that facility managers and designers need to consider to ensure durable repairs. The factors discussed address the restoration of serviceability and the correction of cosmetic defects and are not applicable to failures resulting from overloading.

Many concrete structures fail prematurely and require repair. The repair, if not properly planned and executed, can also fail early and can even be detrimental to adjoining sound concrete.

Figure 1. *Deterioration of bridge pier due to de-icing salts from wheel spray*

There are many causes of concrete failure, and many methods available for the repair of failures. Effective repair requires a rational, analytical process that begins with diagnosing the reason for the failure, and using this information to select materials and methods that best meet the requirements for the repair.

Failure Diagnosis

The first step in the selection of effective concrete repair is diagnosing the cause of failure. If the repaired area is not resistant to the original cause of failure, the repair will fail, or, the damage will be extended to adjoining parts of the structure. Generally, the cause of failure is one or more of the following:[1]

- *Faulty concrete mix, placement or curing:* Poor concrete will be more prone to failures resulting from all the following failure modes. In cases where poor concrete is extensive, the economics of repairs versus reconstruction will need to be considered.
- *Chemical attack:* Oil, chemicals and especially de-icing salts can severely damage concrete (Figure 1) or the reinforcing steel, eventually leading to structural damage. Repairs should include a combination of concrete or mortar, membranes, sealants, and drainage improvements to eliminate or reduce the contact time between the chemical agents and the concrete.
- *Damage from movement:* Damage from shrinkage, creep, settlement and thermal contraction may require only minor repairs to keep the damage from progressing. However, if the movement is still progressing, repairs will not last.
- *Freeze/thaw damage:* Freeze/thaw action on concrete not capable of accommodating these stresses will cause damage. If the problem is localized, conventional patch repair methods capable of resisting the stresses may be successful. If the damage is widespread, reconstruction using concrete overlays must be considered.

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Figure 2. Deterioration of concrete deck

- *Mechanical damage:* Damage from abrasion (traffic or equipment) and erosion will require the selection of repair methods that have a higher resistance to mechanical damage than the original concrete. Consideration should be given to extending the repair to adjacent areas that are less affected but subject to the same traffic (Figure 2).
- *Failure of auxiliary materials:* The failure of sealants and membranes may expose the concrete to water and chemical damage. Repairs should address both the concrete and the sealant or membrane.[2,3] The reason for the failure of the sealant or membrane needs to be determined to avoid repeat failure.

Only when the reason for failure has been determined should the process of repair selection commence.

Repair Procedure

Concrete surfaces subjected to aggressive environments that include freeze/thaw cycling, chemical spillage, abrasion and diurnal thermal cycling degrade and are often rendered unserviceable. A successful repair must be capable of resisting the stresses or agents that caused the original damage. This Update discusses repair procedures that correct existing deterioration of serviceability and damage of an aesthetic nature. Serviceability repairs restore surfaces to a satisfactory operational standard while cosmetic patching restores the concrete surface to a more pleasing appearance.

When the principal cause of deterioration has been diagnosed, the removal of defective concrete, selection of appropriate repair materials and methods should be based on the (a) properties of the repair materials (b) compatibility of such materials with the substrate concrete and (c) stability under service conditions. These are discussed below.

Repair Material Properties

There are three main categories of surface repair material: polymer resinous mortar, polymer-modified cementitious mortar and plain cementitious mortar. Each category has specific physical properties (Table 1). It is important to understand their properties, as this will allow the selection of a repair system that matches, as closely as possible, the properties of the concrete to be repaired. This is done by examining the original mix design records (where possible) and taking core samples to determine compressive strength, porosity and chloride content to gauge electrochemical compatibility with prospective repair systems.[3]

Polymer resin mortars are two-part epoxy, polyester, acrylic and polyurethane. Polymer-modified cementitious mortars are one-part water-soluble polymers. While these polymer repair products are versatile and are being used more and more, premature failure of repairs will occur with incorrect use. Polymers may differ significantly from the concrete to be repaired in terms of permeability, strength, coefficient of expansion, porosity or electrochemical properties, and if so, their use will violate the principles of good concrete repair. In addition, the successful application of polymer systems is highly sensitive to workmanship. Therefore, careful attention to detail is required when selecting polymer repair systems.

There are two main categories of factors that need to be considered in selecting the best repair method. The first is the compatibility of the patch

Table 1. Properties of typical concrete repair materials[4]

Repair system **Property**	**Polymer resin mortar**	**Polymer-modified cementitious mortar**	**Plain cementitious mortar**
Compressive strength (MPa)	50-100	30-60	20-50
Tensile strength (MPa)	10-15	5-10	2-5
Modulus of elasticity (GPa)	10-20	15-25	20-30
Coefficient of thermal expansion (per °C)	$25\text{-}30 \times 10^{-6}$	$10\text{-}20 \times 10^{-6}$	10×10^{-6}
Maximum service temperature (°C)	40-80	100-300	> 300

with the adjoining concrete and the second is service and application conditions.

Compatibility with the Concrete Substrate

It is crucial that the selected repair material be compatible with the adjoining, sound concrete. Large discrepancies in properties (for example, stiffness or coefficient of expansion) may result in shortened repair life and promote damage to adjoining, sound concrete. The following are important guidelines for selecting the most appropriate repair method.[5]

Performance record. It is essential to check that the repair methods under consideration have a proven performance record for similar failure modes and service conditions.

Bonding. Good bonding between the repair material and the concrete substrate is essential. Therefore, there should be no shrinkage of the material during curing, or, if shrinkage does occur, it must not cause failure of the bond between the material and the adjoining sound material. Bond failure will inevitably result in failure of the repair and possible damage to areas that were sound before the repair was made. There are four key requirements for ensuring bond integrity:[1]

1. Proper surface preparation of the concrete substrate — including the application of bonding agents — in readiness for application of the repair material.[6,7]
2. The use of concrete or mortar that can be placed with a very low water content.
3. The use of construction procedures that minimize the potential for shrinkage (such as dry pack, dry mix shotcrete and preplaced aggregate).
4. The use of repair products that provide shrinkage compensation once they are mixed and placed.

To maintain bond, the coefficient of thermal expansion (dimensional change caused by temperature change) of the repair material must match that of the adjoining concrete, especially for structures exposed to large service temperature ranges, and for large (long or thick) repairs. Proper surface preparation provides a dry, even and level surface free of dirt, dust, oil and grease. Removal of surface contaminants allows primers, bonding agents and repair materials to have direct contact with a substrate of increased roughness and surface area.

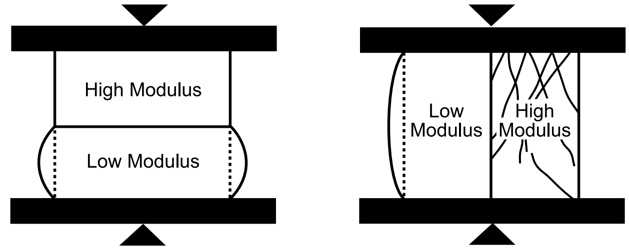

Figure 3. Effects of dissimilar moduli of elasticity

Bonding agents (natural or synthetic materials) increase the strength and integrity of the old surface, thereby increasing the anchorage of the repair material.

Modulus of elasticity. The modulus of elasticity of a material is a measure of its stiffness. It is important that the repair material have stiffness similar to that of the adjoining concrete. When materials with widely different moduli are in contact with each other, differences in deformability will cause problems under certain loading conditions (Figure 3).

Permeability. Permeability is the capability of a material to transmit liquids or vapours. The materials used for surface repair should have permeability that allows moisture vapour transmission closely matching that of the adjoining sound concrete. Large impermeable patches, overlays or coatings can impair the escape of moisture from the base concrete, leading to blistering at the bond line or within the weaker of the two materials.

Chemical compatibility. The repair material must be compatible with steel reinforcing, other embedded metals, the surrounding concrete, and protective coatings or sealers.[2] If there is a large permeability or chloride content differential between the patched area and the rest of the concrete, anodic regions are produced on either side of the patch, accelerating the rate of corrosion and causing premature failure of the patch or adjoining concrete.

Service and Application Conditions

The choice of the appropriate concrete repair material also depends on the service conditions (for example, high traffic or impact loads, temperature) and the working conditions at the time of repair. Factors to consider include:

- Material properties determine the time required for repair before loading can resume, the pot life, coverage, application methods, and economics. For example, if traffic closure time is limited, a fast-setting material will be required.

- High moisture content in the adjoining concrete will restrict repair choices. For example, moisture may cause curing problems like delamination or blistering for some polymer repair materials.[6]
- The temperature at the time of the repair affects the curing rate of cementitious and polymer repair materials, which in turn dictates how soon the repair will be strong enough to accept traffic.
- The orientation of the area to be repaired (vertical or horizontal surface) affects the optimum consistency (flowing or non-sag) of the repair materials and the method of placement or application.
- Access and worker safety affect the types of materials that can be used. For example, if the repair materials must be pumped into place, the repair material must be suitable for pumping.
- Many coatings, membranes and adhesives have special application requirements that determine the kind of surface preparation needed for the concrete to be repaired. For example, for thin coatings, the surface to be repaired must be fairly smooth.[7]

The assessment of repair options will include a comparison of repair cost to expected service life and ideally the selection of the most cost-effective method.

After the repair is completed, it is important to monitor it on a regular basis to ensure that it is durable and that no damage to the adjacent concrete is occurring.

Summary

Concrete structures often face severe climatic challenges and the design of long-lasting repairs is essential for economical operation. Effective concrete repair should return the structure to a good condition rating, with many more years of service without the need for major intervention.

There are many factors that must be taken in account for making good concrete repair decisions. The first step in concrete repair is the diagnosis of the reason for the failure so that repaired sections will not be subject to the same failing.

The second step is the selection of a repair method that is compatible with the physical and chemical properties of the concrete to be repaired. In addition, the constraints of service and application conditions must be considered.

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