

REPAIR OF CONCRETE BUILDING ENVELOPE COMPONENTS

by
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1. INTRODUCTION

Building facades constructed of exposed concrete framing elements and infill windows are common for many high-rise residential, hotel and institutional buildings. This results in economical construction and allows for free expression of the building structure.

When properly designed and constructed, exposed concrete facade elements can provide a long service life with a reasonable level of maintenance. However, design, construction and material deficiencies can cause premature deterioration of the facade elements, necessitating costly repairs.

The most common facade deterioration mechanisms are associated with cracking due to restrained volume changes in the concrete, corrosion of embedded reinforcing steel or balcony railing posts, and premature peeling of protective/decorative coatings. These factors can contribute to water leakage, air infiltration, poor appearance and safety concerns from falling concrete. If not repaired, severe concrete deterioration can also jeopardize the structural integrity of the building.

This article provides a review of concrete repair methods and materials for building envelope applications.

2. REPAIR CONSIDERATIONS

Prior to designing repairs to a concrete building facade, several factors should be considered. These include the following:

2.1 Cause and Extent of Deterioration

A proper investigation of the deterioration mechanism and its extent should be made. Although under most circumstances, the repair methods for spalled and delaminated concrete will be the same regardless of the cause, the deterioration mechanism and its extent may dictate a different repair approach in some cases. For example, if high levels of chloride ions are present in the concrete, a more aggressive repair approach, such as the use of corrosion

REPAIR OF CONCRETE BUILDING ENVELOPE COMPONENTS

inhibiting materials or cathodic protection measures, may be needed. Also, in most cases, the extent of the deterioration will have a significant impact on the decision to repair or replace a component (e.g., a balcony slab).

The most common type of deterioration encountered in exposed concrete facades is deterioration associated with corrosion of embedded metals. The second most common cause of deterioration in cold climates is the freeze-thaw deterioration of the concrete elements. Coating failures and leakage through concrete cracks are also common problems with such buildings (Reference 1).

2.2 Repair Objectives

Once the cause and extent of deterioration are determined, repair objectives should be defined. Typically, one or more of the following will be the objective of the repairs:

- **Improving the Aesthetics of the Building:** In some cases, the concrete deterioration may not impact the structural integrity, water tightness or the durability of the facade. If so, the only objective would be to improve the aesthetics of the building.
- **Restoring Durability of Building Components:** In most cases, the main objective of the facade repair program will be to restore the durability of the concrete elements and to significantly reduce the rate of deterioration. It should be noted that in most cases where corrosion of embedded metals is the cause of deterioration, completely preventing future deterioration is not practical.
- **Restoring Structural Integrity:** If the extent of deterioration is such that the structural integrity of the building has been compromised, the main objective of the repair program will be to restore the structural integrity of the affected components or the framing system. It should be noted that most conventional concrete patch repairs are cosmetic in nature and will not act compositely with the structural members. If a structural repair of the concrete is needed, special provisions for shoring and temporary removal of all loads from the members should be considered.
- **Leakage Control:** In some cases, deterioration of concrete will result in unacceptable water intrusion through the building envelope components. In such cases, repair objectives will include controlling water leakage. Once again, due to the nature of the building envelopes with exposed concrete framing members, complete prevention of water intrusion is not practical.

REPAIR OF CONCRETE BUILDING ENVELOPE COMPONENTS

2.3 Environmental and Logistical Limitations

Repair design for exposed concrete building envelope components (especially for high-rise buildings) should consider the unique environmental and logistical challenges associated with such work. The following are the most typical environmental and logistical factors that can influence specifications for exposed concrete framing elements:

- **Wind:** High wind on tall buildings can accelerate the drying of concrete patch materials and pose curing problems.
- **Time Limitation:** On tall buildings, lifting of concrete patch materials to the repair location with a swingstage scaffold can take up to 30 minutes. This will reduce the remaining pot life of many materials that have to be mixed on the ground.
- **Lifting of Repair Materials and Lowering Debris:** Deteriorated concrete that is removed will have to be lowered to the ground. Meanwhile, repair materials must be lifted to the repair location, all by scaffolding equipment that has weight and size limitations. These factors can significantly limit repair options and methods. For example, the use of shotcrete for repairs on tall buildings is usually not practical due to these factors.
- **Worker Fatigue:** Working on high-rise facades from a swingstage scaffold while wearing safety equipment is difficult at best. In some circumstances, workers have to remove concrete from soffits of balconies and slab overhangs while standing on a suspended scaffold. These conditions can cause worker fatigue and adversely impact the quality of work. In some cases, repairs that heavily rely on good workmanship are not possible on a consistent basis.
- **Overhead Protection:** Performing repairs on a high-rise building facade will require overhead protection on the ground. Depending on the height and location of the building, the overhead protection may have to extend onto adjacent streets, etc.
- **Temporary Weather Protection:** In most cases, removal patching of concrete is not practical in the same day. Therefore, at areas adjacent to windows and other penetrations, concrete removal and surface preparation will render the building envelope more susceptible to water intrusion. Consideration should be given to temporary waterproofing.

REPAIR OF CONCRETE BUILDING ENVELOPE COMPONENTS

- **Inconvenience to Building Owners:** Concrete repair techniques involve the use of chipping hammers and sandblasting equipment. The use of chipping hammers will typically cause excessive noise and vibration to be transmitted through the building frame. The vibration can result in damage to other building components, such as interior plaster and adjacent windows. Sandblasting can also create dust and can cause considerable damage on the ground if not contained properly. These factors should be considered during the design process and should be communicated to the building owners.

2.4 Temporary Support and Shoring

It is common that the exposed concrete elements being repaired are structural framing members. Therefore, concrete removal around the reinforcing steel will reduce the structural capacity of the member. In high-rise buildings, significant removal of concrete from columns without due consideration to the structural integrity of those columns can have catastrophic results. Also of importance is removing portions of balcony slabs and removing concrete from slab overhangs adjacent to columns where significant shear transfer occurs. Therefore, it is important that the anticipated location and extent of concrete removal be reviewed by a qualified structural engineer prior to specifying repairs. Of course, concrete removal should also be carefully monitored during repairs to avoid the same issues.

2.5 Cost Versus Service Life

As most things in life, longer-lasting repairs can cost more. Features which enhance concrete repairs, such as protective coatings, sealers, corrosion-inhibitors, and cathodic protection, can add significant cost to repairs. However, due to the high access costs for building facades, the additional service life realized will typically offset the initial cost.

2.6 Selection of Repair Materials

Proper selection of repair materials is a critical step toward successful repair of concrete. Past experience has shown that materials that are not compatible with concrete can fail prematurely even if the repair material's characteristics are superior.

One of the most important materials used in the repair of concrete is the patch material itself. Past experiences with epoxy and other resin based materials have not yielded favorable results. Currently, the state of the art in repair materials is more conventional proprietary cementitious repair mortars that contain various additives to improve performance. Among the advantages of the proprietary repair mortars are the exact proportioning provided by the

REPAIR OF CONCRETE BUILDING ENVELOPE COMPONENTS

bagged materials and better quality control. Also, such bagged materials are more suitable for use on high-rise facade repairs where, typically, small quantities of repair mortar are used at one time.

The most common additives found in repair mortars are corrosion-inhibiting admixtures (to reduce the potential for future corrosion of reinforcing steel), shrinkage-compensating materials (to reduce the potential for shrinkage cracking), polymer modifiers (to reduce permeability and increase bond strength to substrate), and accelerators or retarders (to control material set time).

Although sophisticated proprietary repair mortars have been used successfully in the past, conventional concrete materials have also yielded excellent performance for the past several years. Conventional concrete mixes (typically provided by a ready-mix truck, in bags, or mixed at site) offer the advantage of lower cost and better suitability for high-volume applications.

When selecting a repair mortar for a particular application, one should consider the following attributes of the material:

- **Compressive Strength and Modulus of Elasticity:** It is desirable to specify repair materials with compressive strength and modulus of elasticity similar to those of the substrate material. This is more critical when performing structural repairs where the patch material will act compositely with the remaining section of the member.
- **Bond Characteristics:** Durability of concrete repair patches greatly depends on their bond to the substrate material. Therefore, careful consideration should be given to the ability of the repair mortar to bond to the substrate material.
- **Shrinkage:** Another important factor in the durability and performance of a patch is the patch material's shrinkage potential. When placed in the confines of a concrete member that has undergone most of its drying shrinkage, any shrinkage of the repair mortar will result in cracks that can adversely impact its durability.
- **Permeability:** If the repaired areas of concrete are susceptible to air-borne chlorides (such as on buildings along coastal areas), lower permeability repair materials will be desirable to reduce the rate of chloride migration to the reinforcing steel. Lower permeability of the repair materials is also desirable to slow the rate of water penetration into the repaired area and the reinforcing steel.

REPAIR OF CONCRETE BUILDING ENVELOPE COMPONENTS

- **Corrosion Protection:** The selected repair materials should provide adequate protection against future corrosion of the embedded reinforcing steel and adjacent areas. Some of the proprietary repair mortars available on the market today incorporate corrosion-inhibiting admixtures for this purpose.
- **Coefficient of Thermal Expansion:** The repair material's coefficient of thermal expansion should be similar to that of substrate material. Lack of compatibility of the coefficients of thermal expansion can lead to the development of high stresses along the bond line between the patch and the substrate and may ultimately result in failure of the patch.
- **Resistance to Freeze-Thaw Deterioration:** In colder climates, exterior building elements can undergo several freeze-thaw cycles each winter. Exposed balcony slab edges and overhangs are particularly susceptible to such deterioration. Therefore, the selected repair materials should possess good resistance to freeze-thaw deterioration.
- **Aggregate Size:** The aggregate size used in the repair mortar should be compatible with the patch geometry. Most proprietary patch materials are formulated with fine aggregate only (sand). The use of such materials in large patches will result in excessive shrinkage, which in turn can lead to cracking of the patch. For this reason, most repair mortar manufacturers will indicate a maximum recommended application thickness for their products. Conversely, large, coarse aggregate particles are not suitable for small repairs where patch thickness is low or the clearance between the reinforcing steel and the substrate concrete is small.
- **Workability and Set Time:** The workability of the repair mortar should be consistent with the placement methods used. For example, if the dry patching method is used for placement, a stiff material is desired. On the other hand, when the form-and-pour method is used, a more flowable material should be used to facilitate consolidation. Setting time can also be an important consideration, since the repair materials are typically lifted to the patch location via scaffolding after they have been mixed on the ground.
- **Appearance:** Although most patched areas are ultimately covered with a decorative coating, some concrete patches will be left uncoated. In such cases, the texture and color of the patch will have to resemble adjacent materials. Some patch-repair mortar manufacturers offer custom blending of their products with color pigments.

REPAIR OF CONCRETE BUILDING ENVELOPE COMPONENTS

When selecting repair materials, consideration should also be given to the need for bonding agents. In the author's experience, the popularity of bonding agents has diminished over the years. This may be due to the marginal benefits gained by the use of bonding agents, the limited number of failures due to their misuse, and the improvement in bond value between state-of-the-art repair mortars and the substrate concrete.

The purpose of a bonding agent is to improve the bond between the repair mortar and the substrate concrete. Most common types of bonding agents include cement slurry, epoxy resin and polymers. Although all these types of bonding agents can improve bond values between the repair mortar and the substrate, there is no substitute for proper surface preparation and application practices. The misuse of bonding agents can also lead to bond failures. For example, if an epoxy bonding agent is used prior to erection of the form work and sufficient time elapses before the repair mortar is placed, the epoxy bonding agent can harden and become a "bond breaker." For this reason, if a bonding agent is specified, consideration must be given to its application method, set time, etc.

Another repair material that needs to be selected properly is the corrosion-protection coating on the reinforcing steel members. Various protective coatings include zinc-rich coatings, cementitious coatings, and epoxy coatings. All of these coatings have shown various degrees of success. Each has advantages and disadvantages. The selection of the reinforcing-steel coatings should depend on compatibility with other repair materials, ease of application from a swingstage, curing time, and level of corrosion protection.

3. PATCHING TECHNIQUES AND MATERIALS

Over the years, several repair methods have been used by the concrete repair industry. Based on the observed success of such repairs, the following repair techniques and sequence have evolved:

3.1 Identifying Delaminated Areas and Extent of Required Concrete Removal

Delaminated concrete on building facades is typically identified using a hammer tapping method. Although a trained worker can easily identify delaminated or unsound concrete with the hammer tapping method in the great majority of cases, identifying deep delaminations or voids in concrete may require more sophisticated methods, such as those described in Reference 1.

REPAIR OF CONCRETE BUILDING ENVELOPE COMPONENTS

Once the delaminated areas are identified, they should be marked immediately so that they can be verified by an engineer, architect, or qualified inspector.

3.2 Concrete Removal/Rough Demolition

Once the delaminated or unsound areas of concrete are identified, the concrete in the affected areas should be removed. On high-rise facade repair projects, concrete removal is typically performed using pneumatic chipping hammers. The use of chipping hammers in excess of 15 lbs is typically avoided in order to prevent excessive substrate bruising. Substrate bruising can occur when chipping hammers cause microcracking of the existing sound concrete. Excessive substrate microcracking results in a weakened concrete zone along the bond line, where bond strength is crucial.

Concrete removal should always extend into sound concrete without excessive removal of sound areas. In most cases, the extent of concrete removal can be determined only during the rough demolition process. An experienced worker should be able to adjust the patch geometry depending on what is found during concrete removal. In some cases, lightly-corroded reinforcing bars can be encountered several inches past the perimeter of the delaminated area. In such cases, the affected areas should be removed until clean reinforcing steel is encountered. Current industry standard practices dictate that concrete be removed around the entire perimeter of corroded reinforcing steel so that the affected rebars can be completely encapsulated in repair mortar.

Concrete removal should be performed so that large variations in patch depth are avoided. Also, the overall geometry of the patch should be simple (i.e., square, rectangular, etc.) with no re-entry corners. The patch geometry has a significant influence on cracking of the repair mortar and its durability.

3.3 Sawcutting Patch Perimeter and Surface Preparation

After the rough demolition process, the perimeter of the patch should be well-defined by sawcutting around the entire perimeter of the patch. The sawcut will provide a straight edge for the repair mortar to bond to the substrate concrete and will prevent feather-edging the repair mortar. The depth of the sawcut is typically ½ inch; however, the depth of sawcut should be reduced where reinforcing steel is encountered.

On small patch areas where mechanical anchoring of the patch with reinforcing steel is not used, the sawcuts should be made at a slight angle to form a dovetail shape for the patch.

REPAIR OF CONCRETE BUILDING ENVELOPE COMPONENTS

This will mechanically lock the repair mortar in place and prevent spalling if a loss of bond occurs.

Surface preparation of the substrate concrete should include removing all damaged and unsound concrete that is left by the rough demolition process.

3.4 Reinforcing Steel Repairs

Since most concrete repairs on high-rise facades are necessitated by reinforcing steel corrosion, repairs to the reinforcing steel are typically needed. At a minimum, reinforcing-steel repairs should consist of removing all corrosion products around the entire perimeter of the affected bars. This is typically performed using sandblasting or water blasting methods. However, in some areas where sandblasting or water blasting causes containment problems on the ground, wire brushing using power tools may also be used.

Regardless of the method used, cleaning of the reinforcing steel bars should render them completely free of corrosion products.

If reinforcing steel corrosion has resulted in significant loss of bar diameter, a qualified structural engineer should review the patch area and determine if there is a need for supplemental reinforcing. Where supplemental reinforcing is required, it can be coupled to the existing bars using mechanical couplers or simply lapped adjacent to the affected bar.

In some cases where rebar congestion in the patch will prevent proper placement and consolidation of the repair mortar, some bars should be removed. Once again, a qualified structural engineer should determine if such selective removal of reinforcing steel will have an impact on the structural integrity of the member.

Since most concrete repairs do not act compositely with the existing member, supplemental reinforcing steel may be unnecessary in some cases. However, supplemental reinforcement is typically added to provide mechanical anchorage for the patch. This is done so that if a loss of bond between the patch and the substrate concrete occurs, it does not result in spalling of concrete from the facade, a serious safety issue.

Supplemental reinforcing is typically installed in substrate concrete using adhesive anchoring systems. Where supplemental reinforcing is used merely as mechanical anchorage for the patch, it can consist of ¼-inch-diameter stainless steel threaded bars that can be bent and formed easily on a swingstage.

REPAIR OF CONCRETE BUILDING ENVELOPE COMPONENTS

After completion of reinforcing-steel repairs and installation of supplemental reinforcement, a corrosion-inhibiting coating is typically applied over the exposed steel bar surfaces. The most common reinforcing-steel coatings consist of epoxy coatings, zinc-rich coatings, and cementitious coating. Care should be taken to avoid the application of the rebar coating on substrate surfaces, as it can serve as a bond breaker. Care should also be taken to ensure that the entire perimeter of affected bars is coated properly. A routine check of coating application should be made with an examination mirror to inspect areas that are not visible.

Another consideration in performing reinforcing steel repairs is the possibility of galvanic corrosion. For this reason, contact between dissimilar metals should be avoided.

3.5 Final Preparation

The final preparation of the patch cavity should consist of cleaning and roughening the concrete substrate and making final adjustments to the patch cavity geometry. This step is usually performed in conjunction with cleaning of the embedded metals using sandblasting or water blasting methods. Note that sandblasting or water blasting of the patch cavity cannot be performed after application of corrosion-inhibiting coatings on the reinforcing steel.

If additional corrosion protection, such as application of migrating corrosion inhibitors or passive cathodic protection, is planned, it should be performed at this stage.

3.6 Forming

Currently, the majority of concrete patch repairs on high-rise buildings are placed using the form-and-pour method. This includes almost all of the patches placed on horizontal surfaces (such as balcony and overhang top surfaces) and vertical surfaces (such as column and walls). In some cases, repairs made to slab soffits are also placed using the form-and-pour method. This is accomplished by drilling one or more core holes through the entire slab thickness to facilitate placement from the top. In such cases, the patch geometry should be considered carefully to avoid creating trapped air pockets in the patch.

In a few isolated cases, the repair mortar is placed by forming the cavity and pumping the repair mortar from the bottom of the formwork. Although this method is less practical due to its logistical requirements, it does provide certain advantages over conventional placement methods.

Unless the repair mortar is placed using a drypack or shotcrete method, the repair cavity should be formed. Forming of the repair cavity is typically similar to conventional concrete

placement. When forming patches on vertical surfaces for conventional placement (pouring), openings (birds' mouths) should be formed at the top of the patch. When forming for placement with pumping method, openings at the top and bottom of the patch should be made. Depending on the patch geometry, forms should be supported using post shores and other supplemental members.

3.7 Substrate Damping, Patch Placement, and Finishing

In order to achieve optimum bond between the substrate and the repair mortar, the substrate should be saturated surface dry (SSD). Therefore, the patch cavities should be wetted prior to placement of the repair mortar to saturate the substrate. However, sufficient time should elapse before placement of the repair mortar to achieve surface dry conditions.

Repair mortar should then be placed in the cavity or formed areas. If the dry-pack method is used, placement should be followed immediately with finishing of the patch surfaces. In some cases, dry-packed patches can be stamped to match the adjacent surface texture.

3.8 Curing and Form Removal

All cementitious materials require proper curing for optimal strength gain and for reduction of the cracking associated with drying shrinkage. In the case of small concrete patches, such as those on building facades, curing takes on a more important role. This is due to the higher potential for a confined patch to develop shrinkage cracking.

The curing process should prevent evaporation of moisture from the repair mortar surface (thus reducing shrinkage cracking) before the material gains sufficient strength to resist cracking. In some case where materials are placed in colder climates, the curing process should also prevent exposure of the repair materials to low temperatures (typically lower than 40 degrees F).

Typically, properly coated plywood forms can provide adequate protection for patch surfaces that are not exposed to severe climates. After removal of the forms, plastic sheets should be placed over the patch surfaces to prevent rapid drying. If a coating is anticipated to be applied over the patch surfaces, the use of curing compounds should be avoided. In such cases, if curing compounds are used, they should be removed from the surface later by grinding or sandblasting. In all cases, the patch material manufacturer's recommendations for curing duration and methods should be followed.

3.9 Surface Grinding

After curing of the patches, patch surfaces should be inspected for imperfections. Bugholes and voids should be filled with a cementitious mortar. Grinding of the patch surfaces is usually needed around the perimeter of the patch to provide a smooth transition between the patch surface and adjacent concrete.

3.10 Coating Application

Since replicating the color and texture of existing concrete is not practical in most cases, repaired concrete surfaces on high-rise facades typically receive an application of coating to provide for uniform appearance. In addition to aesthetic advantages, some coatings will also provide resistance to carbonation and decrease surface permeability of the concrete (making it less likely to wick water). Coatings alone should not be depended upon to provide waterproofing on concrete surfaces. However, the author acknowledges that there are several coating systems designed for application on concrete facade surfaces that are marketed as “waterproofing coatings.” These materials have exhibited varying degrees of success in imparting a waterproofing characteristic to the concrete surfaces.

Coatings for concrete facade surfaces should be selected carefully, taking into consideration the following factors:

- What is the purpose of the coating – i.e., to provide waterproofing, to improve aesthetics, etc.?
- Are there any existing coating systems that will remain on the surface?
- What is the permeability of the new coating system, and will it allow adequate vapor transmission?
- What are the application limitations of the coating – i.e., temperature limits, required substrate moisture conditions, curing, etc.?

The most popular types of coating systems for concrete facades include rigid acrylic coatings, elastomeric coatings, and cementitious coatings. The use of elastomeric coatings for bridging of cracks should be avoided. In most cases, visible cracks should be routed and sealed with an elastomeric sealant prior to application of the coating, except where cracks have been demonstrated to be non-moving (dead).

4. REPAIRING CRACKS IN CONCRETE

In general, all visible cracks on a barrier-type concrete facade should be routed and sealed. If not sealed, these cracks can lead to water penetration to the building interior or to the reinforcing steel.

Routing of the cracks will create a sealant reservoir that will allow for proper movement of the joint without undue stresses on the sealant. The bottom surface of each sealant reservoir should be treated with a bond breaker to avoid three-sided adhesion. Compatibility of the sealant with the concrete coating system should be checked prior to selecting the sealant.

In some cases, silicone sealant extrusions can be utilized for covering cracks. However, their use will typically make the cracks more visible, even after application of a coating.

Other methods of crack treatment include injection with epoxy or chemical grout and application of a coating system that can bridge the crack. The author recommends that the use of these methods be limited to cracks that have been demonstrated to be non-moving.

More information on repair of cracks in concrete can be found in Reference 2.

5. QUALITY ASSURANCE

Longevity of concrete patch repairs on high-rise facades greatly depends on good workmanship and successful implementation of each of the steps indicated in Section 3 of this article. Therefore, quality assurance at various stages of the work is essential for durable repairs.

Typically, an inspection of each repair area is performed at the following stages of the work:

1. **Initial Sounding and Identification of the Patch Area:** A qualified engineer or inspector should verify that the workers have properly sounded all concrete surfaces and identified delaminated areas.
2. **Rough Demolition:** An inspection is made after completion of the rough demolition to ensure that all unsound materials have been removed, to check the general geometry of the patch, and to ensure that no further deterioration exists beyond the patch perimeter. At this stage, the need for supplemental reinforcing

REPAIR OF CONCRETE BUILDING ENVELOPE COMPONENTS

electrochemical properties between the patch material and the original concrete. These differences in electrochemical properties of the materials cause accelerated corrosion rates outside the perimeter of the patch. Eventually, corrosion can be driven to the interior of the building, making it much more difficult to repair.

Recent advances in reducing or preventing ring anode corrosion (and corrosion of reinforcing steel in general) include the introduction of passive cathodic protection and migrating corrosion-inhibitors. A detailed discussion of these preventive measures is beyond the scope of this article. Several studies are currently underway to evaluate the long-term effectiveness of these measures. It is likely that a definitive conclusion regarding the effectiveness of passive cathodic protection and migrating corrosion-inhibitors will not be reached for a few more years.

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REPAIR OF CONCRETE BUILDING ENVELOPE COMPONENTS

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