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Façade Concrete Repair Using Vacuum Injection Techniques

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Symposium on Building Facade Maintenance, Repair, and Inspection

Facade Concrete Repair Using Vacuum Injection Techniques

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Many building facades have cast-in-place or precast concrete components. Common examples include precast concrete cladding panels, exposed spandrel beams, precast concrete lintels and cast-in-place concrete walls with textured surfaces. Cracks are a common defect in exterior concrete and, while the cracks may not diminish the structural performance of the concrete, they can allow moisture penetration. In climates with freezing weather, cracks can develop into spalls that compromise both the integrity and appearance of the concrete.

Commonly used methods for crack repair in exterior concrete include routing and sealing with caulk, pressure injecting epoxy or polymer fillers, applying surface coatings or overlays, and conventional cementitious patching. All of these techniques change the appearance of the concrete. This can be a serious drawback for many facades. Exposed aggregate finishes, pigmented concrete and textured concrete are common examples of facade treatments where conventional repair techniques can unacceptably alter the facade's appearance.

Vacuum injection or permeation of cracked concrete is an alternative repair technique that can usually be done without altering the appearance of the surface. It can be used on exposed aggregate, textured surfaces, and colored concrete without changing the surface appearance or leaving marks from the repair.

Vacuum methods were originally developed for chloride extraction, re-alkalization and permeability reduction of concrete slabs. These methods have been modified and are now practical for high rise facade work, irregular surfaces, and locations where access is available to only one side of the element to be repaired.

This paper will discuss the development of vacuum techniques, recent innovations, types of filler materials, and equipment. Several repair projects will be briefly discussed .

Key Words: Concrete, Facade, Repair, Rehabilitation, Vacuum Technology, and Masonry

1.0 INTRODUCTION

Current vacuum techniques evolved from methods developed in Europe in the early 1970's. The current proprietary vacuum processes can be used for stone, concrete, and masonry. Some of the advantages of this process are:

- $ Vacuum processes withdraw air from voids prior to the installation of repair materials.
- $ Moisture can be removed so there is no residual water to prevent bonding.
- $ The repairs can be performed without marring exposed surfaces.
- $ Vacuum pressure can hold broken and disbonded pieces together during the repair.
- $ Vacuum pressure does not promote further cracking. Pressure injection can crack some materials.

The basic steps of the vacuum repair process include:

- $ The object or member is enclosed by sealing surface cracks or encasement.
- $ A low pressure zone is created by applying a vacuum source to the enclosure.
- $ A suitable repair resin is introduced into the enclosed system.
- $ The enclosure is removed after the repair resin cures.

2.0 THE VACUUM METHODS

The following are typical repairs that are suitable for vacuum techniques.

- $ Replacing missing, removed, or spalled materials with polymer patching materials.
- $

Vacuum injection/impregnation of individual and discreet cracks to strengthen and increase structural load capacity of the member (c.) Impregnation flushing to impregnate surfaces and completely fill multiple and intimately spaced cracks in a wide area (d.) Vacuum injection/impregnation of member areas, identified as delaminated, which eliminates the requirement of removing the delaminated material and to bring the layered members back into composite, and, (e) Vacuum induction of expansive repair materials to stop leakage. (Ref 1) Using vacuum enables these processes to be applied without detriment to the underlying surface fabric.

Using the vacuum processes and the appropriate repair resins, the processes will fill cracks, including interconnected cracks, voids and networks within the concrete matrix. Upon curing, the repair resin bonds the fractured matrix. Partial vacuum creation, and repair resin introduction, is achieved by adhering vacuum source and introduction porting devices onto the fracture or surface being repaired. By means of tubing, the porting devices are connected to the vacuum source and a partial vacuum is applied to the enclosed system. The repair resins are introduced via injection ports, to fill the cracks and voids. The matrixes of concrete, stone and masonry, are impregnated with the repair resin materials.

Moisture can be evacuated from the material by vacuum. Where excessive moisture is encountered, dry air can be introduced into the enclosed system. The drying process can be monitored by using in-line hydrometers installed in the vacuum tubing. Previous experience has recorded 95% humidity within voids in the concrete matrix. After drying, effluence readings were recorded at 3% humidity.

The vacuum process offered the following advantages over conventional pressure injection methods:
Repairs can be completed in a relatively short period with little disruption to building occupants.Repairs are competitively priced when compared to conventional repair methods. Efficient and complete filling of fractures, interconnected cracks, and voidsEvacuation of moisture from the interior concrete matrix of the fracture.
No possible further damage or delamination due to absence of applied pressures as with pressure injection.Ability to introduce ultra-low viscosity materials into the fracture areas that can pass by and bond to the old repair materials existing in the fractures.
Improved bonding due to the lack of bubbling normally associated with pressure introduction of low viscosity, low specific gravity repair resins.Potential of reinforcement corrosion is significantly diminished because moisture ir removed from and sealed out of the treated concrete matrix.

There are several limitations to the vacuum processes:
While the vacuum process can prevent moisture from entering the concrete, it will not stop corrosion of reinforcing steel that is already active.This process cannot be used with severaly deteriorated and crumbling concrete where removal and replacement is required.

3.0 VACUUM REPAIR MATERIALS
3.1 Methyl Methacrylate (MMA)

This low viscosity, high strength material was particularly developed with special modifiers for the of vacuum injection processes.(Ref 2) It is noted for its ultra low viscosity (5-15 cps), flexibility, and superior wetting and bonding properties. The material is not temperature sensitive and is easily mixed. Unlike epoxies, MMA is favorably forgiving when the components and not properly proportioned and will easily bond to previously cured MMA or epoxy. The vacuum installation of MMA can be used to repair debonded shallow level epoxy repairs.

The basic monomer of the repair material is methyl methacrylate (MMA). MMA is a slightly amber liquid that looks like colored water and is about the same viscosity. An initiator is added to cause polymerization of the monomer. An inhibitor is added for longer storage times.

Inhibitors are additives used in MMA to prevent premature polymerization, that can be caused from excessive temperatures, contaminates, etc.. The two most common inhibitors are methyl ester of hydroquinone (MEHQ) and hydroquinone (HQ). These inhibitors and promoters are normally added to the monomer by the acrylic manufacturer and require no field mixing. Promoters are used in very small quantities to increase the decomposition rate of the initiator or inhibitor, which will result in faster curing of the polymer. The general preferred promoter used is dimethyl-para-toluidine (DPT).

The initiator is added the MMA and initiates the polymerization process, or curing of the repairing resin. The most common initiator is benzoyl peroxide which is a white powder or liquid that readily dissolves in the MMA. The amount of initiator added to the MMA is directly related to the time desired for curing the polymer. Increased amounts of initiator will result in more rapid polymerization of the monomers.

Physical properties of the cured materials generally range in the area of 10,000 psi compressive strength, 7,000 psi tensile strength, 4,000 psi flexural strength and 700,000 psi modulus of elasticity.

The odor and toxicity of the monomers require precautions for handling. It has a sharp odor that can be detected by smell in as little as one part per million. (Ref 4) MMA monomers present an polymerization hazard and is an irritant. MMA requires proper and adequate ventilation of the emitted vapors (Ref 4.). Usual procedures include the use of high volume air moving exhaust equipment to remove vapors from the work area.

3.2 Expanding Vinyl Ester Gel

These low viscosity gels are water-soluble acrylic monomers. They are used for the injection and sealing of joints and cracks against water leaks. These materials have a very low flow resistance due to its ultra low viscosity Therefore, it is able to permeate into the smallest of hairline cracks and capillaries to seal them.

Because the polymerized material will swell to double its volume, dimensional changes of cracks or pores will not affect the ability of the material to seal. The resins are solvent free and during the curing (polymerization) stage, the monomers link together to form long chain molecules. These chains are themselves cross-linked to form a three dimensional network.

There are small side-chains on the monomers which have a water-soluble character. When these side-chain comes into contact with water, the side chains become weakly bonded to the water molecules. The material will take up the water and swell while retain its external shape. The process is reversible and when the water is removed, the material returns to its original size. Because of this unique property, the material will retain its self-healing properties even when in a dry condition.

4.0 APPLICATIONS AND EXAMPLES

This section deals with the actual applications of the methods described above to demonstrate the successful uses. The projects are selected to cover types of applications. The examples are:

4.1 Somerset House Condominiums

Thomas Downey, LTD, Consulting Engineers
Bethesda, MD

The Somerset House Condominium Building is a sixteen story condominium complex with concrete frame construction and decorative precast concrete panel facade. The panels were cast with exposed aggregate and sandblasted finish on the same panel. When fine cracks, some less than 0.005 inches in width, developed in some of the panels, the surfaces presented a challenge in how to repair the panel without changing their appearance. Conventional pressure methods of repair were unsuitable. It was suspected that the fineness of the cracks would prevent adequate filling. Conventional pressure injection of the cracks would require sealing the fine cracks with rigid epoxy paste. It would be necessary for the paste material to tenaciously bond to the surface of the panel being repaired in order to contain the pressure required to introduce the forthcoming repair resin. At the conclusion of the repair, it would be impossible to remove the paste without changing the existing surface finish.

It was decided to try repairing the cracks using vacuum injection of acrylic resin. This method, called CleanSet[tm] had been successfully employed to seal cracks in historic structures with exposed aggregate concrete facades. This method was selected to repair and seal the cracks in the precast panels at Somerset House.

After the cracks were examined and limits of repair determined, technicians installed surface mounted ports along the crack line using a thermally activated, gun applied adhesive. No drilling was necessary to mount the ports with the method. Where the crack was wider, the ports were spaced further apart as the repair material could flow more easily. With the ports in place, the fracture line was sealed using a similar thermally activated material. Since the sealing material was thermally activated, no "cure time" was necessary so vacuum was immediately applied, followed by the introduction of the repair resin.

Since the repair resin reaches complete cure in less than one hour, the material used to seal the crack line can be removed quickly. By the time the equipment was demobilized, technicians began stripping the sealer and ports from the crack line. Close examination of the fine crack line revealed complete fill of the fracture. The sealer material was removed from the surface with no damage or change in appearance.

4.2 Hirshhorn Museum of Art Building
Smithsonian Institute
Washington, DC

The Hirshhorn Museum of Art Building is a concrete structure located within eyesight of the U.S. Capitol. Because of its close proximity to the Capitol, the relatively young building is desingated as a historic structure. This designation caused considerable concern when, in 1993, in cracks in the building and wall structures began to enlarge. These cracks were believed to provide the source of water leaking into the building.

It was later concluded the cracks, located in structural beams were allowing water to enter into the building and the cracks were enlarging. As the concrete surrounding these cracks were believed to be saturated, they posed a threat of spalling during the freeze thaw cycles typical to the region. Superficial patching of the defects had been performed on a number of occasions, however, these surface applied patches were more concerned with aesthetics than the ongoing leakage and deterioration of the concrete and reinforcing materials. Sandblasting, water blasting or any other form of abrasive, chemical or pressure cleaning was prohibited because of the requirement to preserve the exposed aggregate surface finishes. This restricted most repairs methods and totally eliminated any form of pressure injection repairs that would damage or change the appearance of the surface. Pressure injection methods require aggressive methods cleaning in preparation of the repairs. Moreover, pressure injection requires a tenaciously bonding sealer material that confines the pressurized repair resin (usually epoxy) and requires high heat or grinding to remove the material upon the completion of the repairs. In either instance, residue of the material and/or marring of the surface cannot be avoided. Removal is conspicuously evident on the adjacent surfaces upon completion of the repairs.

Other attempts to seal surface cracks with a concoction of latex, fine sand and coloring to match the surfaces had been mildly, but only temporarily successful.

A test to vacuum injection of repair materials into the cracks without the kindred marring of the surface was suggested. By creating a partial vacuum in the concrete, repair resins could be introduced into the fracture resulting in a more complete and permanent repair.

An obscured portion of a garden wall was selected for testing but certain ground rules were established. These rules included that no abrasives or power washing would be allowed for the preparation and most importantly, no residual materials of any kind would be left on the surface when the repair was concluded.

Impact-Echo testing was performed and revealed the block of concrete selected for the test (3'x3'x6'), to be riddled with cracks and voids. As the cracks were mapped prior to repair, the effectivness of the repairs would be readily measurable.

A specially formulated thermally activated adhesive was used as the sealing material and wasapplied across the cracks. Plastic injection ports were mounted along the surface of the cracks with the same heated adhesive. Vacuum was applied to the enclosed system and the repair resin was introduced. This induction continued until the crack was full as evidenced by refusal. However, during the injection process, the surface sealant debonded in a number of areas that required immediate remedial actions. Upon conclusion of the repairs, the sealant removed easily with no residue.

While Impact-Echo testing later confirmed that the cracks had been completely filled, in a number of areas, the repair material slightly stained the surface concrete. Although the leaks of the repair resin had been quickly stopped, the light amber color of the resin was evident on the surfaces in the areas where leaks occurred.

After testing, technicians determined that the sealing material used earlier to contain the resin and vacuum lacked the bond strength necessary to contain the repair resin. Sealants of a different formulation were applied at slightly higher temperatures. The surfaces were left un-cleaned, cleaned with a mild detergent and water and, lightly cleaned with plain water and a soft bristled brush. With the change in sealant formulation, higher application temperature of sealant and of light cleaning with plain water proved to provide sufficient adhesion for induction of resin and the sealant was easily removed with no leaks, residual staining or residue.

The Smithsonian awarded a contract to repair the defective waterproofing and repair cracks in the Museum of Art Building. The process was repeated on the total of the cracks, exceeding 240 lineal feet, with no evidence of the repairs visible.

This method can be used in any instance where the repair of individual structural cracks requires maintenance of sensitive aesthetics and/or complex surface contours.

4.3 Leak Repairs

Ronald Reagan International Airport
Washington, DC

Within a pedestrian tunnel linking a parking structure with the main terminal facility at Ronald Reagan Washington National Airport several hundred lineal feet of cracks developed in the 30" thick concrete floor of the tunnel constructed 25-30 feet below grade. The cracks began to leak prior to completion of construction. Vacuum injection of

Wall cracks also developed, but the major source of intrusion was generated from the floor. For some time after each rainfall, these cracks allowed the natural high water table to flow up through the floor and into the areaway. Now nearing completion linking, the floors are to receive a terrazzo finish and the leaks were required to be repaired by the general contractor.

The general contractor performing the completion work, and the overseeing engineer sought a long term solution and a five year guarantee. After several weeks of soliciting contractors to perform the repairs, the general contractor located a company willing to perform the repairs and provide the guarantee required by the contract.

Unlike the conventional method of pressure injecting expanding polyurethane into drilled holes, the company employs the TecSeal™ Process of leak repair. This process utilizes vacuum technology that sets up a negative pressure zone within the fracture. Then, a thin expanding acrylic resin was introduced through surface mounted porting devices.

Examination of the cracks within the tunnel posed two problems: (1) the cracks were very fine and ranged form 0.005in to 0.010in in width and, (2) the thickness of the slab, some 30", was complicated with grade beams and expansion joints. The fractures were notably fouled with efflorescence deposits resulting from the long period of leaking.

The efflorescence was removed by abrasive blasting and the mouths of the fractures were opened in the process. Surface mounted ports were installed along the crack line and the entire length and offshoots of the singular fracture was sealed. The ability of the fracture to accept resin was then tested by applying negative demand on the enclosed fissure. Each port along the length was tested for evidence of the demand and identified. While maintaining the negative demand, water-thin vinyl ester repair resin was introduced into the tightly sealed system.

Only minimal lengths of the wall cracks required drilling access holes. Because of flow and configuration, holes were drilled at 45° angles to intersect the fracture at 5"-6" depth. Ports were installed into the drilled holes and spaced along the length the crack. The entire length of the crack was then sealed. By applying negative demand to the enclosed system the repair resin was introduced deep into the fissure and the flow was arrested.

Upon completion of the tunnel, the pumps used to facilitate the construction were disconnected and removed. The cracks treated with the TecSeal™ Process are completely dry and there is no evidence of water intrusion.

The TecSeal™ Permeation Leak Repair Process has been successfully applied to the leaking cracks in the floors and walls of the Pedestrian Tunnel at Ronald Reagan Washington National Airport. With the exception of a few lineal feet, the entire task was completed without the necessity of drilling. By applying negative demand, the TecSeal™ Process intakes repair resin deep into fracture zones and can eliminate unsightly member destruction by drilling.

This proprietary method of delivering repair materials into leaking cracks has a number of advantages over conventional pressure methods. Conventional pressure injection of resins are poorly suited to deliver materials into fine cracks. Attempts to do so by increasing delivery pressure often damages the member and exacerbates the problem. Interconnected fractures are pressure locked and receive little resin and internal shears can separate large areas of delamination with dangerous consequences. Rather than fight the flow, TecSeal™ entices the resin along and into the finest of hairline cracks and interconnecting cracks.

The vinyl ester repair resin used for the TecSeal™ Process contributes substantially to the success of the repair and has a number of advantages over polyurethanes which are typically used for this sort of work. Low viscosity (1cps) and low flow resistance, vinyl ester penetrates into the narrowest cracks and capillaries to seal reliably and permanently. Because the resin does not chemically react with water, there is no foam layer or resulting reduction of adhesion that accompanies polyurethane. Most importantly is the ability of the vinyl ester to self-heal after dry periods. Unlike polyurethane, the cured gel will re-swell when contacted with water and reestablish equilibrium.

The TecSeal™ Permeation Leak Repair Process can be used in any instance where it is required to stop leaking or seeping water flow. The process can be performed at temperatures as low a -20°F and will maintain a strong resistance against constant hydrostatic pressure.