Guidelines for Surface Preparation and Repairing before water proofing by ZYCOSIL/ZYCOPRIME & ZYCOFIL

WATER PROOFING APPLICATIONS

- New Buildings
- Existing / Old Buildings
- Coastal Areas
- Cement Roofing Sheets
- Concrete Paved Area
- Cement Articles
- Clay Articles / Tiles / Pots
- Stones
- Exposed Bricks

COMMERCIAL APPLICATION AREA

- Cooling Tower
- Waste Water Treatment Facility
- Cement Concrete Pipes
- Bridges
- Rail Road Sleepers
- Flyovers
- Cement Sheets
- Tunnels
- Marine Piers
- Docks
- Ship Yards

APPLICABLE SURFACE TESTING

Any inorganic surface that can be wet with water can be treated with Zycosil. Simple test can be performed to determined eligibility of the treatable surface. Put a drop of water on the surface, if drop absorbs by the surface in 10 seconds than surface is porous enough to be treated with Zycosil.

SURFACE PREPARATION

Improperly prepared surfaces can result in reduced application integrity and service life. Up to 80% of all failures can be directly attributed to inadequate surface preparation, which affects treatment performance.

Economics and surface contamination (including its effect on the substrate) will also influence the selection of surface preparation methods.

The surface must be dry and in sound condition. Remove mildew, oil, dust, and dirt, loose rust, peeling paint or other contamination to ensure proper treatment.

No exterior application should be done immediately after a rain, during foggy weather, when rain is predicted, or when the temperature is below 10℃.

Concrete

Remove all loose mortar and foreign material from block. Surface must be free of laitance, concrete dust, dirt, form release agents, moisture curing membranes, loose cement, and hardeners. Concrete and mortar must be cured at least 30 days at 20 ^{o}C. On tilt-up and poured-in-place concrete, commercial detergents and abrasive blasting may be necessary to prepare the surface. Fill bug holes, air pockets, and other voids with a cement patching compound.

The following guides will help assure maximum performance of the treatment system and satisfactory treatment absorption to concrete: Cure-Concrete must be cured prior to application. Cured is defined as concrete poured and aged at a material temperature of at least 20℃ for at least 30 days.

1. Concrete must be free of moisture as much as possible.
2. Temperature-Air, surface and material temperature must be at least 10℃ during the application and until the treatment is cured.
3. Contamination-Remove all grease, dirt, loose paint, oil, tar, glaze, laitance, efflorescence, loose mortar, and cement. Imperfection may require filling with a material compatible with Zycosil application

Concrete Treatment-Hardeners, sealers, form release agents, curing compounds, and other concrete treatments must be removed.

Cleaning Procedures

Concrete - Blast Cleaning

Brush Blasting or Sweep Blasting-Includes dry blasting, water blasting, water blasting with abrasives, and vacuum blasting with abrasives.

1. Use 16 - 30 mesh sand and oil-free air.
2. Remove all surface contamination.
3. Stand approximately 2 feet from the surface to be blasted.
4. Move nozzle at a uniform rate.
5. Laitance must be removed and bug holes opened.
6. Surface must be clean and dry and exhibit a texture similar to that of medium grit sandpaper.

Vacuum or blow down and remove dust and loose particles from the surface

Concrete - Acid Etching

This procedure is used only when surface can not be cleaned by other means. This procedure is recommended as last resort and must be done by Professional Cleaning Agency. The following guides will help assure maximum performance of the Zycosil application on concrete surface.

1. Remove all surface contamination
2. Wet surface with clean water.
3. Apply a 10-15% Muriatic Acid or 50% Phosphoric Acid solution at the rate of one gallon per 75 square feet.
4. Scrub with a stiff brush.
5. Allow sufficient time for scrubbing until bubbling stops.
6. If no bubbling occurs, the surface is contaminated with grease, oil, or a concrete treatment which is interfering with proper etching. Remove the contamination with a suitable cleaner and then etch the surface.
7. Rinse the surface two or three times. Remove the acid/water mixture after each rinse.
8. Surface should have a texture similar to medium grit sandpaper.
9. It may be necessary to repeat this step several times if a suitable texture is not achieved with one etching. Bring the pH of the surface to neutral with a 3% solution of trisodium phosphate or similar alkali cleaner and flush with clean water to achieve a sound, clean surface.

Allow surface to dry.

Power Tool Cleaning or Hand Tool Cleaning

1. Use needle guns or power grinders, equipped with a suitable grinding stone of appropriate size and hardness, which will remove concrete, loose mortar, fins, projections, and surface contaminants. Hand tools may also be used.
2. Vacuum or blow down to remove dust and loose particles from surface

Plaster

Plaster must be allowed to cure completely. Damaged areas must be repaired with an appropriate patching material. Bare plaster must be cured and hard. Textured, soft, porous, or powdery plaster should be treated with a solution of 1 pint household vinegar to 1 gallon of water. Repeat until the surface is hard, rinse with clear water and allow drying.

Previously Coated Surfaces

Complete removal of all acrylate or plastic coatings prior to Zycosil application. All surface contamination such as oil, grease, loose paint, mill scale, dirt, foreign matter, rust, mold, mildew, mortar, efflorescence, and sealers must be removed to assure sound bonding to surface.

Glossy surfaces of old paint films must be clean and dull before Zycosil application. Thorough washing with an abrasive cleanser will clean and dull in one operation, or, wash thoroughly and dull by sanding.

The need for proper surface preparation prior to Zycosil application cannot be stressed enough. It has been said many times that INCOMPLETE OR IMPROPER SURFACE PREPARATION IS THE PRIMARY CAUSE OF APPLICATION FAILURES. Thus, the surface should be prepared whatever way is necessary so that it will receive the Zycosil application properly. Indeed, the condition of the surface plays an important role in achieving the degree of penetration required for effective performance. Dirt, grease, mechanical defects of all types and old paint in poor condition are a few of the factors which contribute to poor surfaces and which must be compensated for by proper surface preparation.

Surface preparation differs for each type of surface which you may treat with Zycosil. The surfaces which we address here are as follows:

- Plaster Surfaces
- Drywall Surfaces
- Concrete & Masonry

Plaster

Patching: Cracks and holes in plaster walls require skilful patching to insure a smooth, professional finish. (See detail article about cracks formation and repairs)

Map Cracks: Deep cracks must be cut out and patched before Zycosil is applied. The correct preparation of a deep crack or hole includes cutting away loose or bulging plaster from the edges and then undercutting it so that a cross section looks like an inverted 'V'.

If the bottom of the crack or hole is wider than the top, patching material will be keyed to the surface and will not fall out.

Unless the edges are sealed before patching, the dry plaster will absorb excessive water from the patch and it will ultimately crumble. Patching materials are abundant but vary in composition. Any well known brand of patching plaster or ready mixed acrylic spackling compound is recommended. An even better method than 'V' notching is cutting away loose or bulging plaster, then employ a 2 1/2" wood scraper and scrape along the direction of the crack, the scraper being centered over the crack at all times. The scraped area should have a uniform depth of 1/8" to 1/4". This area is dusted out and primed with Zycosil (1:10). Fiberglass mesh is then applied, followed by coats of drywall cement. Finally, the patch is sanded smooth and is ready for spot priming with Zycosil.

Spot Priming: After the patch dries (a minimum of 24 hours should be allowed for drying), and is sanded smooth, dust completely.

New Plaster: New plaster should always be dry before it is Zycosil is applied. Dry plaster contains less than 15% water; but, there is no simple, reliable test for determining the moisture content. Efflorescence and suction spots may require special attention when Zycosil is applied. Care should be taken in proper cleaning and complete sealing of these potential trouble spots.

Efflorescence can occur on new plaster applied to a masonry surface. It results when moisture in new masonry carries water soluble salts from the masonry to the surface of the plaster. This condition does not harm the plaster; but it may cause aesthetic or stain problems. Efflorescence is best prevented by furring the wall prior to plastering, thus separating the plaster from the masonry.

Efflorescence can be removed by washing concrete with a commercial solution of muriatic (hydrochloric) acid. The normal cleaning strength is achieved by taking 3 or 4 quarts of water and adding a quart of muriatic acid to the water (CAUTION: Always add the acid to the water - NEVER the reverse!!!). Follow the acid wash with a clear water rinse.

Concrete and Concrete Masonry: Unpainted concrete surfaces must be properly prepared in order to prevent poor application. Form oils and releasing agents need to be removed from the surface. Usually, a good washing with a detergent will remove the oils, releasing agents, dust and dirt.

Concrete sets in a short time, but the hardening or curing process continues for up to 96 days. When concrete is completely cured there is no longer active alkali on the surface which will cause crack, peel and generally deteriorate.

Concrete Floors Cleaning: Concrete that is hard and smooth should be etched so that Zycosil application can "grip" the surface. Sandblasting is often the only proper way to prepare the surface for the Zycosil application.

The optimal condition of the concrete surface, however, depends on the type of repair being undertaken and the condition of the substrate. Also, it is not always possible to determine which material must be removed, because the zones of damaged or deteriorated concrete are sometimes not well defined. Thus, the best approach is to remove material until aggregate particles are being broken rather than simply being pried loose from the matrix.

Other Cleaning Methods of Surface Preparation

Chemical Cleaning

Concrete contaminated with oil, grease or dirt can be cleaned with detergent, trisodium phosphate or various proprietary concrete cleaners. The use of these materials should be followed by vigorous scrubbing and thorough rinsing with water to remove all residues. Solvents should not be used to clean concrete since they will dissolve the contaminate and carry it deeper into the concrete. Muriatic acid is relatively ineffective in removing oil and grease.

Waterblasting

This method consists of directing a highvelocity, high-pressure water jet to the concrete surface through a specially designed nozzle that travels transversely along a boom, sweeping back and forth across the concrete surface as the equipment advances incrementally. The equipment can be used in applications ranging from laitance removal to hydrodemolition of concrete to depths of up to 30 mm (12"). The water pressure, the speed of the nozzle as it moves along the boom, and the speed of the machine — all of which can be adjusted — control the depth of removal.

The jet cuts a series of grooves and water pressure breaks up the concrete between the grooves. This method is very effective when used as a final step in surface preparation. Its main limitation is the collection and disposal of wastewater. Waterblasting debris must be removed daily to prevent it from hardening. The advantages of this method are:

- There is no dust, and noise is minimal.
- There are no mechanical vibrations that might cause structural damage.
- The machine selectively removes deteriorated concrete and leaves good concrete intact.
- The reinforcing steel is not damaged as it could be by scarifiers or scabblers.
- The removal of deteriorated concrete is faster than by conventional methods such as jackhammers. Removal rates can range from 0.28 – 0.85 m^3/h (10 – 30 ft^3/h) and 46.45 – 74.32 m^2/h (500 – 800 ft^2/h) when used as a scarifier to remove surface material to a depth of 6 mm (1/4").

Flame Cleaning

Flame cleaning is generally used to clean concrete surfaces that are to receive coatings or resinous overlays. This method is particularly useful for oil-stained floors because it permits the application zycosil to the concrete immediately after. A special multi-flame oxy-acetylene blowpipe is passed over the concrete surface at uniform speed. The thickness of the concrete layer removed depends on the speed at which the blowpipe is moved and the properties of the concrete. The most suitable blowpipe speed lies between 0.02 m/s (0.066 ft/s) and 0.03 m/s (0.099 **ft/s).** Concrete and coating removal involves both the spalling and melting off of the surface. The laitance layer is usually removed to a depth of 1 or 2 mm (0.04" or 0.08") and in a few instances up to 4 mm (0.16"). The moisture content of the concrete has the greatest effect on concrete removal — completely dry slabs do not produce much spalling, while slabs soaked in water prior to flame cleaning produce uniform concrete removal.

European experience indicates that flame cleaning does not promote the migration of deep-seated oil to the surface, does not remove the alkalinity of the matrix — the surface gradually attains alkalinity similar to that of new concrete — and does not promote the development of any visible cracks in the surface.

The method has proven useful for such applications as the recoating of concrete floors or the removal of defective elastomeric waterproofing membranes from parking decks.

Methods for Removal of Stains

There are simple solutions for removing concrete stains. It's the first step in enhancing your home's concrete. From leaky automobiles to rusty patio furniture, you can get rid of those eyesore stains on your driveway, porch, patio, etc. You can also do some easy maintenance to prevent stains from penetrating the surface making cleanup a cinch. Typical stains that give most people problems include:

Removing concrete stains is important if you plan to paint, stain, or seal the surface. They can prevent penetration and leave you with nasty, ugly spots and uneven coloration. Whenever you think you have gotten rid of a stain, always wet it and check for water beading. If water beads, you need to do more cleaning. Keep in mind that some stains are impossible to make disappear completely. This is especially true with motor oil that has been on the concrete for a long time.

Removing Rust Spots in Concrete

Rust spots in concrete can be stubborn and tough to get rid of especially if they have been there for long time. Oxalic acid has been proven successful for eliminating most rust spots. There are some household cleaners that contain oxalic acid. Wet the surface and spray the cleaner on. If it comes in powder form, just sprinkle it on the stain, wet it and brush it around. Let it stand for a few minutes and then scrub it with a brush. Keep repeating this until the stain is gone. For best results, rinse with a pressure washer.

If oxalic doesn't work then try TSP (tri sodium phosphate). This is a powder that can be found at most home improvement stores and paint stores. Mix 1/2 cup of TSP with 1/2 gallon of hot water, pour it on the stain and let it sit 15-20 minutes. Then scrub with a stiff bristled brush and rinse with water. Repeat a few times if necessary.

If rust spots in concrete are so stubborn that this method doesn't work, then you can use an etching solution or diluted muriatic acid (4 parts water:1 part acid) as a last resort. This actually eats away the cementitious material on the surface. So you're not actually cleaning the concrete, but removing the cement that the rust has bonded with. This is a last resort because, by removing some of the cement, the surface is being weakened and becomes more susceptible to chipping and scaling. However, keeping a coat of clear concrete sealer on the surface can eliminate these risks. Use caution with products that contain acid. Wear rubber gloves and safety goggles and keep clean water nearby in case of accidental splashes.

Removing Concrete Oil Stains and Grease Stains

There are a few simple methods to try for removing concrete oil stains and grease stains. Leaky automobiles and dripping grills can leave unsightly spots on your concrete. Getting rid of them is the first step to enhancing your concrete and a must if you plan to paint or stain.

If the stain is fresh and there is still unabsorbed oil on the surface, put down kitty litter or saw dust to soak it up. Clean that up after a few days.

Try household bleach first. Dilute it according to the instructions on the container. Pour it on the stain and let it sit for 10-15 minutes. Then scrub and rinse with water.

If that doesn't work, sprinkle dishwashing detergent on the stain and scrub with hot water. Repeat this a few times and see what happens.

A last resort for concrete oil stains is tri-sodium phosphate (TSP). This is a powder that is sold in most hardware and home improvement stores. Mix one cup with a gallon of hot water, pour it on the stain and let sit for 15-20 minutes. Then scrub with a stiff bristled brush and rinse with water. Repeat if necessary. **Some longstanding oil stains may never come completely clean. If the TSP doesn't totally remove the stain, don't pull your hair out trying to find something that works. Just learn to live with it.**

Removing Concrete Mold and Mildew Stains

Clean mold and mildew off your concrete for a better looking surface. The easy way to do it is to dilute bleach, pour it on the surface, spread it around and let it sit for a few minutes. Then use a pressure washer to clean and rinse the dead fungi. If you don't have a pressure washer, then scrub the bleach in and rinse using a hose with a pressure nozzle.

Removing Tire Marks from Concrete

The easiest way to remove tire marks from concrete is a degreaser combined with a pressure washer. Soak the stain with the degreaser, let it sit for several minutes, and use a pressure washer to rinse. When using a high powered pressure washer, be careful not to leave pressure washer marks on the surface. The stream should be at least 2 inches wide when it strikes the concrete.

Removing Efflorescence from Concrete

If your concrete has a white crystalline or powder-like substance on the surface, this is called efflorescence. When water brings salts to the surface and the water evaporates, the salts are left behind forming those fuzzy white deposits. Getting rid of them is fairly simple and a must if you plan to stain or paint the concrete.

Since the salts are water soluble, brushing with water and rinsing will usually get rid of efflorescence. If you have a severe problem, I recommend using a pressure washer. A solution of muriatic acid will also do the trick but use this as a last resort and follow all safety precautions.

Causes, Evaluation and Repairs of Cracks in Concrete*

Introduction

Cracks in concrete have many causes. They may affect appearance only, or they may indicate significant structural distress or a lack of durability. Cracks may represent the total extent of the damage, or they may point to problems of greater magnitude. Their significance depends on the type of structure, as well as the nature of the cracking. For example, cracks that are acceptable for buildings may not be acceptable in water-retaining structures. Structural cracks should be evaluated by the structural engineer or other professional.

The proper repair of cracks depends on knowing the causes and selecting the repair procedures that take these
causes into account; otherwise, the repair may only be temporary. Successful long-term repair procedures must
Attack the causes of the cracks as well as the cracks themselves.

Causes and Control of Cracking

Cracks are categorized as occurring either in plastic concrete or hardened concrete.

Cracking of plastic concrete

Plastic shrinkage cracking: Plastic shrinkage cracking occurs, when subjected to a very rapid loss of moisture caused by a combination of factors which include air and concrete temperatures, relative humidity, and wind velocity at the surface of the concrete. These factors can combine to cause high rates of surface evaporation in either hot or cold weather." When moisture evaporates from the surface of freshly placed concrete faster than it is replaced by bleed water, the surface concrete shrinks. Due to the restraint provided by the concrete below the drying surface layer, tensile stresses develop in the weak, stiffening plastic concrete, resulting in shallow cracks of varying depth which may form a random, polygonal pattern, or may appear as essentially parallel to one another. These cracks are often fairly wide at the surface. They range from a few inches to many feet in length and are spaced from a few inches to as much as 10 ft (3 m) apart. Plastic shrinkage cracks begin as shallow cracks but can become full-depth cracks.

Steps can be taken to prevent a rapid moisture loss due to hot weather and dry winds. These measures include the use of fog nozzles to saturate the air above the surface and the use of plastic sheeting to cover the surface between finishing operations.

Settlement cracking: After initial placement, vibration, and finishing, concrete has a tendency to continue to consolidate. During this period, the plastic concrete may be locally restrained by reinforcing steel, a prior concrete placement, or formwork. This local restraint may result in voids and/or cracks adjacent to the restraining element. When associated with reinforcing steel, settlement cracking increases with increasing bar size, increasing slump, and decreasing cover.

Cracking of hardened concrete

Drying shrinkage: A common cause of cracking in concrete is restrained drying shrinkage. Drying shrinking is caused by the loss of moisture from the cement paste constituent, which can shrink by as much as 1 percent. Fortunately, aggregate provides internal restraint that reduces the magnitude of this volume change to about 0.06 percent. On wetting, concrete tends to expand.

Thermal stresses: Temperature differences within a concrete structure may be caused by portions of the structure losing heat of hydration at different rates or by the weather conditions cooling or heating one portion of the structure to a different degree or at a different rate than another portion of the structure. These temperatures differences result in differential volume changes. When the tensile stresses due to the differential volume changes
Exceed the tensile stress capacity, concrete will crack.

Chemical reaction: Deleterious chemical reactions may cause cracking of concrete. These reactions may be due to materials used to make the concrete or materials that come into contact with the concrete after it has hardened.

The alkali-silica reaction results in the formation of a swelling gel, which tends to draw water from other portions of the concrete. This causes local expansion and accompanying tensile stresses, and may eventually result in the complete deterioration of the structure. Control measures include proper selection of aggregates, use of low alkali cement, and use of pozzolans, which themselves contain very fine, highly active silicas. The first measure may preclude the problem from occurring, while the later two measures have the effect of decreasing the alkali to reactive silica ratio, resulting in the formation of a nonexpanding calcium alkali silicate.

Certain carbonate rocks participate in reactions with alkalies which, in some instances, produce detrimental expansion and cracking. These detrimental alkali-carbonate reactions are usually associated with argillaceous dolomitic limestones which have a very fine grained (cryptocrystalline) structure. The affected concrete is characterized by a network pattern of cracks. The reaction is distinguished from the alkali-silica reaction by the general absence of silica gel surface deposits at the crack. The problem may be minimized by avoiding reactive aggregates, dilution with nonreactive aggregates, use of a smaller maximum size aggregate, and use of low-alkali cement.

Sulfate-bearing waters are a special durability problem for concrete. When sulfate penetrates hydrated cement paste, it comes in contact with hydrated calcium aluminate. Calcium sulfoaluminate is formed, with a subsequently large increase in volume, resulting in high local tensile stresses that lead to cracking which causes development of closely spaced cracking and deterioration. Portland cement, which are low in ricalcium aluminate, will reduce the severity of the problem. In severe cases, some pozzolans, known to impart additional resistance to sulfate attack, could be used after adequate testing.

The calcium hydroxide in hydrated cement paste will combine with carbon dioxide in the air to form calcium
carbonate. Since calcium carbonate has a smaller volume than the calcium hydroxide, shrinkage will occur (commonly known as carbonation shrinkage). This situation may result in significant surface crazing and may be
especially serious on freshly placed surfaces during the first 24 hours when improperly vented combustion
heaters are used to keep concrete warm during the winter months. With the exception of surface carbonation, very little can be done to protect or repair concrete that has been subjected to the types of chemical attack described above.

Weathering: The weathering processes that can cause cracking include freezing and thawing, wetting and drying, and heating and cooling. Cracking of concrete due to natural weathering is usually conspicuous, and it may give the impression that the concrete is on the verge of disintegration, even though the deterioration may not have progressed much below the surface. Damage from freezing and thawing is the most common weather-related physical deterioration. Concrete may be damaged by freezing of water in the paste, in the aggregate, or in both.

Damage in hardened cement paste from freezing is caused by the movement of water to freezing sites and by
hydraulic pressure generated by the growth of ice crystals. Aggregate particles are surrounded by cement paste which prevents the rapid escape of water. When the aggregate particles are above a critical degree of saturation, the expansion of the absorbed water during freezing may crack the surrounding cement paste or damage the aggregate itself. Concrete is best protected against freezing and thawing through the use of the lowest practical watercement ratio and total water content, durable aggregate, and adequate air entrainment. Adequate curing prior to exposure to freezing conditions is also important. Allowing the structure to dry after curing will enhance its freezing and thawing durability.
Corrosion of reinforcement: Corrosion of a metal is an electrochemical process that requires an oxidizing agent, moisture, and electron flow within the metal; a series of chemical reactions takes place on and adjacent to the surface of the metal. The key to protecting metal from corrosion is to stop or reverse the chemical reactions. This may be done by cutting off the supplies of oxygen or moisture or by supplying excess electrons at the anodes to prevent the formation of the metal ions (cathodic protection). Reinforcing steel usually does not corrode in concrete
because a tightly adhering protective oxide coating forms in the highly alkaline environment. This is known as
passive protection. Reinforcing steel may corrode, however, if the alkalinity of the concrete is reduced through carbonation or if the passivity of this steel is destroyed by aggressive ions (usually chlorides). Corrosion of the steel produces iron oxides and hydroxides, which have a volume much greater than the volume of the original metallic iron. This increase in volume causes high radial bursting stresses around reinforcing bars and results in local radial cracks. These splitting cracks can propagate along the bar, resulting in the formation of longitudinal cracks (*i.e.,*parallel to the bar) or spalling of the concrete. A broad crack may also form at a plane of bars parallel to a concrete surface, resulting in delamination, a well-known problem in bridge decks. Cracks provide easy access for oxygen, moisture, and chlorides, and thus, minor splitting cracks can create a condition in which corrosion and cracking are accelerated. Cracks transverse to

reinforcement usually do not cause continuing corrosion of the reinforcement if the concrete has low permeability. This is due to the fact that the exposed portion of a bar at a crack acts as an anode. At early ages, the wider the crack, the greater the corrosion, simply because a greater portion of the bar has lost its passive protection. However, for continued corrosion to occur oxygen and moisture must be supplied to other portions of the same bar or bars that are electrically connected by direct contract or through hardware such as chair supports. If the combination of density and cover thickness is adequate to restrict the flow of oxygen and moisture, then the corrosion process is self sealing. Corrosion can continue if a longitudinal crack forms parallel to the reinforcement, because passivity is lost at many locations, and oxygen and moisture are readily available along the full length of the crack.

Poor construction practices: A wide variety of poor construction practices can result in cracking in concrete structures. Foremost among these is the common practice of adding water to concrete to improve workability. Added water has the effect of reducing strength, increasing settlement, and increasing drying shrinkage. When accompanied by a higher cement content to help offset the decrease in strength, an increase in water content will also mean an increase in the temperature differential between the interior and exterior portions of the structure, resulting in increased thermal stresses and possible cracking. By adding cement, even if the water-cement ratio remains constant, more shrinkage will occur since the relative paste volume is increased. Lack of curing will increase the degree of cracking within a concrete structure. The early termination of curing will allow for increased shrinkage at a time when the concrete has low strength. The lack of hydration of the cement, due to drying, will result not only in decreased long-term strength, but also in the reduced durability of the structure. Other construction problems that may cause cracking are inadequate formwork supports, inadequate consolidation, and placement of construction joints at points of high stress. Lack of support for forms or inadequate consolidation can result in settlement and cracking of the concrete before it has developed sufficient strength to support its own weight, while the improper location of construction joints can result in the joints opening at these points of high stress. Methods to prevent cracking due to these and other poor construction procedures are well known, but require special attention during construction to insure their proper execution.

Construction overloads: Loads induced during construction can often be far more severe than those experienced in service. Unfortunately, these conditions may occur at early ages when the concrete is most susceptible to damage and they often result in permanent cracks. Precast members, such as beams and panels, are most frequently subject to this abuse, but cast-in-place concrete can also be affected. A common error occurs when precast members are not properly supported during transport and erection. The use of arbitrary or convenient lifting points may cause severe damage. Lifting eyes, pins, and other attachments should be detailed or approved by the designer.

Errors in design and detailing: The effects of improper design and/or detailing range from poor appearance to lack of serviceability to catastrophic failure. These problems can be minimized only by a thorough understanding of structural behavior (meant here in the broadest sense). Errors in design and detailing that may result in unacceptable cracking include use of poorly detailed reentrant comers in walls, precast members and slabs, improper selection and/or detailing of reinforcement, restraint of members subjected to volume changes caused by variations in temperature and moisture, lack of adequate contraction joints, and improper design of foundations, resulting in differential movement within the structure.

EVALUATION OF CRACKING

When anticipating repair of cracks in concrete, it is important to first identify the location and extent of cracking. It should be determined whether the observed cracks are indicative of current or future structural problems, taking into consideration the present and anticipated future loading conditions. The cause of the cracking should be established before repairs are specified. A detailed evaluation of observed cracking can determine which of those causes applies in a particular situation. Cracks need to be repaired if they reduce the strength, stiffness, or durability of the structure to an unacceptable level, or if the function of the structure is seriously impaired. In some cases, such as cracking in water-retaining structures, the function of the structure will dictate the need for repair, even if strength, stiffness, or appearance are not significantly affected. Cracks in pavements and slabs-on-grade may require repair to prevent edge spalls, migration of water to the subgrade, or to transmit loads. In addition, repairs that improve the appearance of the surface of a concrete structure may be desired.

Location and extent of cracking, as well as information on the general condition of concrete in a structure, can
be determined by both direct and indirect observations, nondestructive and destructive testing, and tests of cores
taken from the structure. Information may also be obtained from drawings and construction and maintenance records.

Direct and indirect observation: The locations and widths of cracks should be noted on a sketch of the structure. A grid marked on the surface of the structure can be useful to accurately locate cracks on the sketch. Crack widths can be measured to an accuracy of about 0.001 in. (0.025 mm) using a crack comparator, which is a small, hand-held microscope with a scale on the lens closest to the surface being viewed. Crack widths may also be estimated using a clear comparator card having lines of specified width marked on the card. Observations such as spalling, exposed reinforcement, surface deterioration, and rust staining should be noted on the sketch. Internal conditions at specific crack locations can be observed with the use of flexible shaft fiberscopes or rigid borescopes.

Tests on concrete cores: Significant information can be obtained from cores taken from selected locations within the structure. Cores and core holes afford the opportunity to accurately measure the width and depth of cracks. In addition, an indication of concrete quality can be obtained from compressive strength tests; however, cores that contain cracks should not be used to determine concrete strength.

Review of drawings and construction data: The original structural design and reinforcement placing or other shop drawings should be reviewed to confirm that the concrete thickness and quality, along with installed reinforcing, meets or exceeds strength and serviceability requirements noted in the governing building code(s).

Selection of repair procedures

Based on the careful evaluation of the extent and cause of cracking, procedures can be selected to accomplish
one or more of the following objectives:

1. Restore and increase strength
2. Restore and increase stiffness
3. Improve functional performance
4. Provide watertightness
5. Improve appearance of the concrete surface
6. Improve durability
7. Prevent development of corrosive environment at reinforcement.

Depending on the nature of the damage, one or more repair methods may be selected For example, tensile
strength may be restored across a crack by injecting it with epoxy or other high strength bonding agent. However, it may be necessary to provide additional strength by adding reinforcement or using post-tensioning. Epoxy injection alone can be used to restore flexural stiffness if further cracking is not anticipated. Cracks causing leaks in water-retaining or other storage structures should be repaired unless the leakage is considered minor or there is an indication that the crack is being sealed by autogenous healing. Repairs to stop leaks may be complicated by a need to make the repatrs while the structures are in service. Cosmetic considerations may require the repair of cracks in concrete. However, the crack locations may still be visible and it is likely that some form of coating over the entire surface may be required. To minimize future deterioration due to the corrosion of reinforcement, cracks exposed to a moist or corrosive environment should be sealed. The key methods of crack repair available to accomplish the objectives.

Following the evaluation of the cracked structure, a suitable repair procedure can be selected. Successful repair procedures take into account the cause(s) of the cracking. For example, if the cracking was primarily due to drying shrinkage, then it is likely that after a period of time the cracks will stabilize. On the other hand, if the cracks are due to a continuing foundation settlement, repair will be of no use until the settlement problem is corrected.

Epoxy injection

Cracks as narrow as 0.002 in. (0.05 mm) can be bonded by the injection of epoxy. The technique generally consists of establishing entry and venting ports at close intervals along the cracks, sealing the crack on exposed surfaces, and injecting the epoxy under pressure. Epoxy injection has been successfully used in the repair of cracks in buildings, bridges, dams, and other types of concrete structures. However, unless the cause of the cracking has been corrected, it will probably recur near the original crack. If the cause of the cracks cannot be removed, then two options are available. One is to rout and seal the crack, thus treating it as a joint, or, establish a joint that will accommodate the movement and then inject the crack with epoxy or other suitable material. Epoxy materials used for structural repairs should conform to. The standard procedure describes practices for sealing joints, including joint design, available materials, and methods of application. With the exception of certain moisture tolerant epoxies, this technique is not applicable if the cracks are actively leaking and cannot be dried out.

Wet cracks can be injected using moisture tolerant materials, but contaminants in the cracks (including silt and water) can reduce the effectiveness of the epoxy to structurally repair the cracks. The use of a low-modulus, flexible adhesive in a crack will not allow significant movement of the concrete structure. The effective modulus of elasticity of a flexiile adhesive in a crack is substantially the same as that of a rigid adhesive (Adams et al. 1984) because of the thin layer of material and high lateral restraint imposed by the surrounding concrete. Epoxy injection requires a high degree of skill for satisfactory execution, and application of the technique may be limited by the ambient temperature. The general procedures involved in epoxy injection are as follows: Clean the cracks. The first step is to clean the cracks that have been contaminated, to the extent this is possible and practical. Contaminants such as oil, grease, dirt, or fine particles of concrete prevent epoxy penetration and bonding, and reduce the effectiveness of repairs. Preferably, contamination should be removed by vacuuming or flushing with water or other especially effective cleaning solutions. The solution is then flushed out using compressed air and a neutralizing agent or adequate time is provided for air drying. It is important, however, to recognize the practical limitations of accomplishing complete crack cleaning. A reasonable evaluation should be made of the extent, and necessity, of cleaning. Trial cleaning may be required.

Seal the surfaces. Surface cracks should be sealed to keep the epoxy from leaking out before it has gelled. Where the crack face cannot be reached, but where there is backfill, or where a slab-on-grade is being repaired, the backfill material or sub base material is sometimes an adequate seal; however, such a condition can rarely be determined in advance, and uncontrolled injection can cause damage such as plugging a drainage system. Extreme caution must therefore be exercised when injecting cracks that are not visible on all surfaces. A surface can be sealed by applying an epoxy, polyester, or other appropriate sealing material to the surface of the crack and allowing it to harden. If a permanent glossy appearance along the crack is objectionable and if high injection pressure is not required, a strippable plastic surface sealer may be applied along the face of the crack. When the job is completed, the surface sealer can be stripped away to expose the gloss-free surface. Cementitious seals can also be used where appearance of the completed work is important. If extremely high injection pressures are needed, the crack can be cut out to a depth of 1/2 in. (13 mm) and width of about 3/4 in. (20 mm) in a V-shape, filled with an epoxy, and struck off flush with the surface.

Install the entry and venting ports. Three methods are in general use: a. Fittings inserted into drilled holes. This method was the first to be used, and is often used in conjunction with V-grooving of the cracks. The method entails drilling a hole into the crack, approximately 3/4 in. (20 mm) in diameter and 1/2 to 1 in. (13 to 25 mm) below the apex of the V-grooved section, into which a fitting such as a pipe nipple or tire valve stem is usually bonded with an epoxy adhesive. A vacuum chuck and bit, or a watercooled corebit, is useful in preventing the cracks from being plugged with drilling dust. b. Bonded flush fitting. When the cracks are not V-grooved, a method frequently used to provide an entry port is to bond a fitting flush with the concrete face over the crack. The flush fitting has an opening at the top for the adhesive to enter and a flange at the bottom that is bonded to the concrete. c. Interruption in seal. Another system of providing entry is to omit the seal from a portion of the crack. This method can be used when special gasket devices are available that cover the unsealed portion of the crack and allow injection of the adhesive directly into the crack without leaking.

Mix the epoxy. This is done either by batch or continuous methods. In batch mixing, the adhesive components are premixed according to the manufacturer's instructions, usually with the use of a mechanical stirrer, like a paint mixing paddle. Care must be taken to mix only the amount of adhesive that can be used prior to commencement of gelling of the material. When the adhesive material begins to gel, its flow characteristics begin to change, and pressure injection becomes more and more difficult. In the continuous mixing system, the two liquid adhesive
components pass through metering and driving pumps prior to passing through an automatic mixing head. The continuous mixing system allows the use of fast setting adhesives that have a short working life.

Inject the epoxy. Hydraulic pumps, paint pressure pots, or air-actuated caulking guns may be used. The pressure used for injection must be selected carefully. Increased pressure often does little to accelerate the rate of injection. In fact, the use of excessive pressure can propagate the existing cracks, causing additional damage. If the crack is vertical or inclined, the injection process should begin by pumping epoxy into the entry port at the lowest elevation until the epoxy level reaches the entry port above. The lower injection port is then capped, and the process is repeated until the crack has been completely filled and all ports have been capped. For horizontal cracks, the injection should proceed from one end of the crack to the other in the same manner. The crack is full if the pressure can be maintained. If the pressure can not be maintained, the epoxy is still flowing into unfilled portions or leaking out of the crack.

Remove the surface seal. After the injected epoxy has cured, the surface seal should be removed by
grinding or other means as appropriate.

Alternative procedure. For massive structures, an alternate procedure consists of drilling a series of holes [usually 7/8 to 4-in. (20 to 100-mm) diameter] that intercepts the crack at a number of locations. Typically, holes are spaced at 5-ft (1.5-m) intervals. Another method recently being used is a vacuum or vacuum assist method. There are two techniques: one is to entirely enclose the cracked member with a bag and introduce the liquid adhesive at the bottom and to apply a vacuum at the top. The other technique is to inject the cracks from one side and pull a vacuum from the other. Typically, epoxies are used; however, acrylics and polyesters have proven successful.

The use of epoxy injection as an effective intermediate-term repair procedure for delaminated bridge decks. As reported. This procedure does not arrest ongoing corrosion. The procedure can also be attempted for other applications, and is available as an option, although not accepted universally. Success of the repair depends on the absence of bond-inhibiting contaminants from the crack plane. Epoxy resins and injection procedures should be carefully selected when attempting to inject delaminations. Unless there is sufficient depth or anchorage to surrounding concrete the injection process can be unsuccessful or increase the extent of delamination.

Routing and sealing

Routing and sealing of cracks can be used in conditions requiring remedial repair and where structural repair is not necessary. This method involves enlarging the crack along its exposed face and filling and sealing it with a suitable joint sealant. This is a common technique for crack treatment and is relatively simple in comparison to the procedures and the training required for epoxy injection. The procedure is most applicable to approximately flat horizontal surfaces such as floors and pavements. However, routing and sealing can be accomplished on vertical surfaces (with a non-sag sealant) as well as on curved surfaces (pipes, piles and pole). Routing and sealing is used to treat both fine pattern cracks and larger, isolated cracks. A common and effective use is for waterproofing by sealing cracks on the concrete surface where water stands, or where hydrostatic pressure is applied. This treatment reduces the ability of moisture to reach the reinforcing steel or pass through the concrete, causing surface stains or other problems. The sealants may be any of several materials, including epoxies, urethanes, silicones, polysulfides, asphaltic materials, or polymer mortars. Cement grouts should be avoided due to the likelihood of cracking. For floors, the sealant should be sufficiently rigid to support the anticipated traffic. Satisfactory sealants should be able to withstand cyclic deformations and should not be brittle. The procedure consists of preparing a groove at the surface ranging in depth, typically, from 1/4 to 1 in. (6 to 25 mm). A concrete saw, hand tools or pneumatic tools may be used. The groove is then cleaned by air blasting, sandblasting, or waterblasting, and dried. A sealant is placed into the dry groove and allowed to cure. A bond breaker may be provided at the bottom of the groove to allow the sealant to change shape, without a concentration of stress on the bottom. The bond breaker may be a polyethylene strip or tape which will not bond to the sealant. Careful attention should be applied when etailing the joint so that its width to depth aspect ratio will accommodate anticipated movement.

Stitching

Stitching involves drilling holes on both sides of the crack and grouting in U-shaped metal units with short legs (staples or stitching dogs) that span the crack as shown in. Stitching may be used when tensile strength must be reestablished across major cracks Stitching a crack tends to stiffen the structure, and the stiffening may increase the overall structural restraint, causing the concrete to crack else!- where. Therefore, it may be necessary to strengthen the adjacent section or sections using technically corrected reinforcing methods. Because stresses are often concentrated, using this method in conjunction with other methods may be necessary. The stitching procedure consists of drilling holes on both sides of the crack, cleaning the holes, and anchoring the legs of the staples in the holes, with either a non-shrink grout or an epoxy resin-based bonding system. The staples should be variable in length, orientation, or both, and they should be located so that the tension transmitted across the crack is not applied to a single plane within the section but is spread over an area.

Grouting

Portland cement grouting: Wide cracks, particularly in gravity dams and thick concrete walls, may be repaired by filling with Portland cement grout. This method is effective in stopping water leaks, but it will not structurally bond cracked sections. The procedure consists of cleaning the concrete along the crack; installing built-up seats (grout nipples) at intervals astride the crack (to provide a pressure tight connection with the injection apparatus); sealing the crack between the seats with a cement paint, sealant, or grout; flushing the crack to clean it and test the seal; and then grouting the whole area. Grout mixtures may contain cement and water or cement plus sand and water, depending on the width of the crack. However, the water-cement ratio should be kept as low as practical to maximize the strength and minimize shrinkage. Water reducers or other admixtures may be used to improve the properties of the grout. For small volumes, a manual injection gun may be used; for larger volumes, a pump should be used. After the crack is filled, the pressure should be maintained for several minutes to insure good penetration.

Chemical grouting: Chemical grouts consist of solutions of two or more chemicals (such as urethanes, sodium silicates, and acrylomides) that combine to form a gel, a solid precipitate, or a foam, as opposed to cement grouts that consist of suspensions of solid particles in a fluid. Cracks in concrete as narrow as 0.002 in. (0.05 mm) have been filled with chemical grout. The advantages of chemical grouts include applicability in moist environments (excess moisture available), wide limits of control of gel time, and their ability to be applied in very fine fractures. Disadvantages are the high degree of skill needed for satisfactory use and their lack of strength.

Drypacking

Drypacking is the hand placement of a low water content mortar followed by tamping or ramming of the mortar
into place, producing intimate contact between the mortar and the existing concrete. Because of the low water-cement ratio of the material, there is little shrinkage, and the patch remains tight and can have good quality with respect to durability, strength, and watertightness. Drypack can be used for filling narrow slots cut for the repair of dormant cracks. The use of drypack is not advisable for filling or repairing active cracks. Before a crack is repaired by drypacking, the portion adjacent to the surface should be widened to a slot about 1 in. (25 mm) wide and 1 in. (25 mm) deep. The slot should be undercut so that the base width is slightly greater than the surface width. After the slot is thoroughly cleaned and dried, a bond coat, consisting of cement slurry or equal quantities of cement and fine sand mixed with water to a fluid paste consistency, or an appropriate latex bonding compound, should be applied. Placing of the dry pack mortar should begin immediately. The mortar consists of one part cement, one to three parts sand-passing a No. 16 (1.18 mm) sieve, and just enough water so that the mortar will stick together when molded into a ball by hand. If the patch must match the color of the surrounding concrete, a blend of grey Portland cement and white Portland cement may be used. Normally, about one-third white cement is adequate, but the precise proportions can be determined only by trial. To minimize shrinkage in place, the mortar should stand for 1/2 hour after mixing and then should be remixed prior to use. The mortar should be placed in layers about 3/8 in. (10 mm) thick. Each layer should be thoroughly compacted over the surface using a blunt stick or hammer, and each underlying layer should be scratched to facilitate bonding with the next layer. There need be no time delays between layers. The mortar may be finished by laying the flat side of a hardwood piece against it and striking it several times with a hammer. Surface appearance may be improved by a few light strokes with a rag or sponge float. The repair should be cured by using either water or a curing compound. The simplest method of moist curing is to support a strip of folded wet burlap along the length of the crack.

Crack arrest

During construction of massive concrete structures, cracks due to surface cooling or other causes may develop
and propagate into new concrete as construction progresses. Such cracks may be arrested by blocking the crack and spreading the tensile stress over a larger area. A

piece of bond-breaking membrane or a grid of steel mat may be placed over the crack as concreting continues. A semicircular pipe placed over the crack may also be used. A description of installation procedures for semicircular pipes used during the construction of a massive concrete structure follows: (1) The semicircular pipe is made by splitting an 8-in. (200-mm), 16-gage pipe and bending it to a semicircular section with about a 3-in. (75-mm) flange on each side; (2) the area in the vicinity of the crack is cleaned; (3) the pipe is placed in sections so as to remain centered on the crack; (4) the sections are then welded together; (5) holes are cut in the top of the pipe to receive grout pipes; and (6) after setting the grout pipes, the installation is covered with concrete placed concentrically over the pipe by hand. The installed grout pipes are used for grouting the crack at a later date, thereby restoring all or a portion of the structural continuity.

Polymer impregnation

Monomer systems can be used for effective repair of some cracks. A monomer system is a liquid consisting of monomers which will polymerize into a solid. Suitable monomers have varying degrees of volatility, toxicity and flammability, and they do not mix with water. They are very low in viscosity and will soak into dry concrete, filling the cracks, much as water does. The most common monomer used for this purpose is methyl methacrylate. Monomer systems used for impregnation contain a catalyst or initiator plus the basic monomer (or combination of monomers). They may also contain a cross linking agent. When heated, the monomers join together, or polymerize, creating a tough, strong, durable plastic that greatly enhances a number of concrete properties. If a cracked concrete surface is dried, flooded with the monomer, and polymerized in place, some of the cracks will be filled and structurally repaired. However, if the cracks contain moisture, the monomer will not soak into the concrete at each crack face, and consequently, the repair will be unsatisfactory. If a volatile monomer evaporates before polymerization, it will be ineffective. Polymer impregnation has not been used successfully to repair fine cracks. Polymer impregnation has primarily been used to provide more durable, impermeable surfaces. Badly fractured beams have been repaired using polymer impregnation. The procedure consists of drying the fracture, temporarily encasing it in a watertight (monomer proof) band of sheet metal, soaking the fractures with monomer, and polymerizing the monomer. Large voids or broken areas in compression zones can be filled with fine and coarse aggregate before being flooded with monomer, providing a polymer concrete repair.

Overlay and surface treatments

Fine surface cracks in structural slabs and pavements may be repaired using either a bonded overlay or surface treatment if there will not be further significant movement across the cracks. Unbonded overlays may be used to cover, but not necessarily repair a slab. Overlays and surface treatments can be appropriate for cracks caused by one-time occurrences and which do not completely penetrate the slab. These techniques are not appropriate for repair of progressive cracking, such as that induced by reactive aggregates, and D-cracking. Slabs-on-grade in freezing climates should not be repaired by an overlay or surface treatment that is a vapor barrier. An impervious barrier will cause condensation of moisture passing from the subgrade, leading to critical saturation of the concrete and rapid disintegration during cycles of freezing and thawing.

Overlays: Slabs containing find dormant cracks can be repaired by applying an overlay, such as polymermodified Portland cement mortar or concrete, or by silica fume concrete. Slabs with working cracks can be overlaid if joints are placed in the overlay directly over the working cracks. In highway bridge applications, an overlay thickness as low as 1-1/4 in. (30 mm) has been used successfully. Suitable polymers include styrene butadiene or acrylic latexes. The resin solids should be at least 15 percent by weight of the Portland cement, with 20 percent usually being optimum. The surface to be overlaid should be cleaned to remove laitance, carbonated or otherwise weak material, or contaminants, such as grease or oil. A bond coat consisting of the mortar fraction broom-applied, or an epoxy adhesive should be applied immediately before placing the overlay. Since polymer-modified concretes normally solidify rapidly, continuous batching and mixing equipment should be used. Polymer-modified overlays should be mixed, placed and finished rapidly (within 15 min in warm weather). A 24-hr moist curing is typical for these overlays.

Autogenous healing

A natural process of crack repair known as "autogenous healing" can occur in concrete in the presence of moisture and the absence of tensile stress. It has practical application for closing dormant cracks in a moist environment, such as may be found in mass concrete structures. Healing occurs through the continued cement hydration and the carbonation of calcium hydroxide in the cement paste by carbon dioxide, which is present in the surrounding air and water. Calcium carbonate and calcium hydroxide crystals precipitate, accumulate, and grow within the cracks. The crystals interlace and twine, producing a mechanical bonding effect, which is supplemented by a chemical bonding between adjacent crystals and between the crystals and the surfaces of the paste and the aggregate. As a result, some of the tensile strength of the concrete is restored across the cracked section, and the crack may become sealed. Healing will not occur if the crack is active and is subjected to movement during the healing period. Healing will also not occur if there is a positive flow of water through the crack, which dissolves and washes away the lime deposit, unless the flow of water is so slow that complete evaporation occurs at the exposed face causing re-deposition of the dissolved salts. Saturation of the crack and the adjacent concrete with water during the healing process is essential for developing any substantial strength. Submergence of the cracked section is desirable. Alternatively, water may be ponded on the concrete surface so that the crack is saturated. The saturation must be continuous for the entire period of healing. A single cycle of drying and re-immersion will produce a drastic reduction in the amount of healing strength. Healing should be commenced as soon as possible after the crack appears. Delayed healing results in less restoration of strength.

SUMMARY

This report is intended to serve as a tool in the process of crack evaluation and repair of concrete structures. The causes of cracks in concrete are summarized along with the principal procedures used for crack control. Both plastic and hardened concrete are considered. The importance of design, detailing, construction procedures, concrete proportioning, and material properties are discussed. The techniques and methodology for crack evaluation are described Both analytical and field requirements are discussed.

The need to determine the causes of cracking as a necessary prerequisite to repair is emphasized. The selection of successful repair techniques should consider the causes of cracking, whether the cracks are active or dormant, and the need for repairs. Criteria for the selection of crack repair procedures are based on the desired outcome of the repairs. Twelve methods of crack repair are presented, including the techniques, advantages and disadvantages, and areas of application of each.

*** This information is extracted from the published reports.**