


and Repair of Concrete Structures

The repair and preservation of hydraulic cement concrete (HCC) structures is a significant VDOT activity. Annual expenditures typically exceed expenditures for the construction of new bridges and pavements. This chapter describes the repair and preservation practices typically used by VDOT. The chapter covers 8 basic practices as follows:

- Defining the Repair Problem
- Locating Deteriorated Concrete
- Removing Deteriorated Concrete
- Preparing Concrete Surfaces
- Patching
- Crack Repairs
- Hydraulic Cement Concrete Overlays
- Epoxy Overlays, Membranes and Sealers

The first step toward achieving a satisfactory repair or preservation is to correctly define the repair problem. The problem that caused the structure to need to be repaired or have a preservation treatment needs to be identified so that the most appropriate repair or preservation treatment can be specified. The 2nd step is to identify the concrete, reinforcement and or overlay that is deteriorated to the point that it needs to be removed. Replacement of the structure should be considered when more than 50 per cent of the structure must be removed. The 3rd step is removing deteriorated concrete without damaging the concrete and reinforcement that will stay in place. The 4th step is preparing the surface of the concrete left in place so that the new concrete will bond well. Repair activities that are most often used include patching, and crack repair. Typical preservation

treatments include hydraulic cement concrete overlays, epoxy overlays, membranes and sealers.

Defining the Repair Problem

Typical Causes of Deterioration of HCC Concrete include:

- Corrosion of Reinforcement
- Freezing and Thawing Damage
- Alkali-Silica Reaction
- Sulfate Reaction
- Traffic Induced Stress
- Design and Construction Deficiencies

Corrosion of Reinforcement

The most common cause of deterioration in reinforced HCC concrete structures is corrosion of reinforcement. Contributing factors include:

- Chlorides
- Water
- Oxygen
- Thin concrete cover
- Poor quality concrete
- Poor drainage
- Carbonated concrete

Most corrosion is caused by the application of deicing chemicals in the winter and exposure to salt water in marine environments. The quality of the concrete, drainage and concrete cover influence the time it takes for the chlorides to reach the reinforcement.

Chlorides

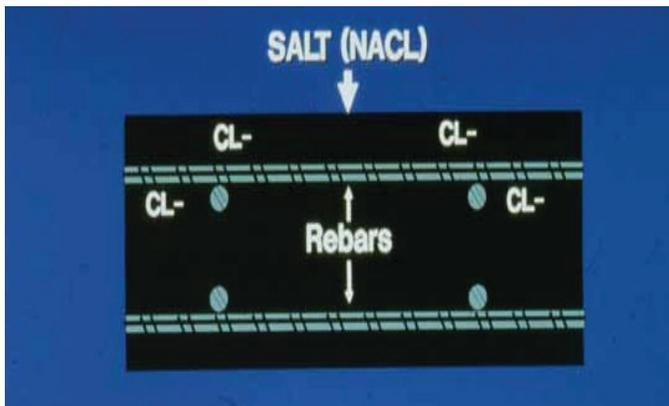


Figure 1 Typical bridge deck section.

Chloride, water and oxygen penetrate concrete and destroy the passive oxide film on the steel. Figure 1 shows a typical bridge deck section with two mats of reinforcement. The time to corrosion is a function of the steel cover depth and the concrete quality. The reinforcement that is closest to the surface that is exposed to chlorides typically corrodes first.

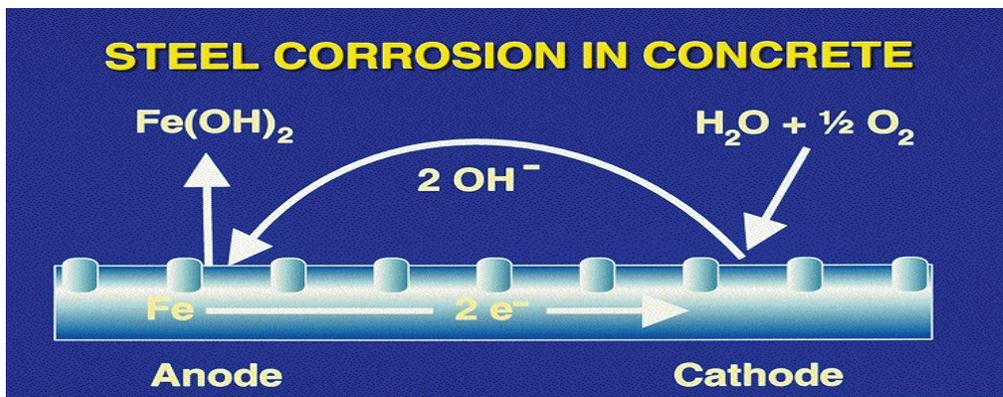


Figure 2 Typical corrosion cell.

Figure 2 shows a typical corrosion cell. Current flows from anode to cathode at a rate that is influenced by the quality and condition of concrete. Corrosion products form at the anode.

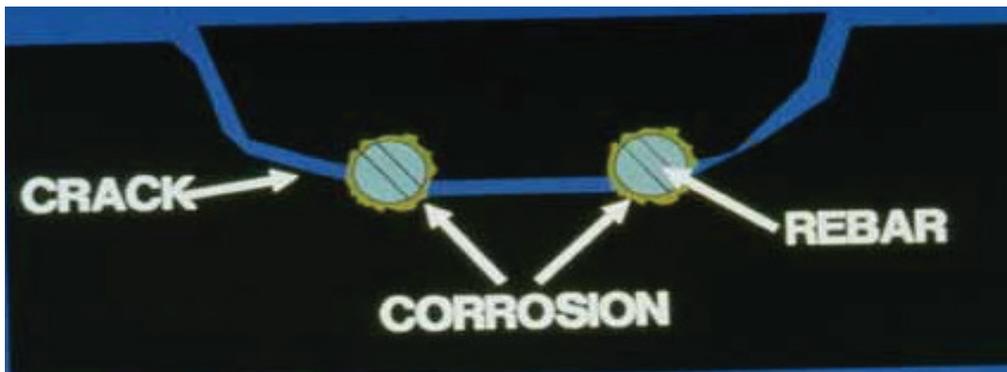


Figure 3 Corrosion of reinforcement causes concrete to crack and spall.

Figure 3 illustrates that corrosion products, oxides and hydroxides, have a larger volume than the steel and cause the concrete to crack, delaminate and spall forming what is typically called a pot hole.



Figure 4 Spall from the bottom of a deck.

Over time chlorides can penetrate to the bottom mat of reinforcement causing a spall from the bottom of a deck. Figure 4 shows a spall from the bottom of a deck. A rust spot on the bottom of an exposed concrete deck is a good indicator of corrosion of the bottom mat of reinforcement. A spall in the vicinity of the rust spot can be anticipated and action should be taken to prevent the spalling concrete from falling on the roadway or waterway below the deck. Steel stay-in-place deck forms can hide the problem.



Figure 5 Failure of epoxy coated reinforcement because of leaking construction joint.

Construction joints and full depth cracks with a width ≥ 0.2 -mm can leak allowing chlorides, water and oxygen to easily reach the reinforcement. Figure 5 shows a section of deck on I81 near Marion that failed leaving a 3-ft square full depth hole in the deck. The deck failed because of corrosion of the reinforcement that crossed the leaking longitudinal construction joints. The epoxy coating absorbed the water and chlorides and lost adhesion to the steel. The reinforcement corroded and lost sufficient steel section to cause failure of the deck 17 years after it was constructed.

Poor Drainage



Figure 6 Drain is not in proper location.

A plugged or improperly located drain can allow water and chlorides to pond on the surface, accelerating the penetration of water and chlorides and increasing the risk of frost damage. Figure 6 shows a section of road with a drain that is not located at the low point along the curb.

Poor drainage reduces the life of the roadway surface and patching or resurfacing must be done much earlier in the life of the structure. The drainage problem should be correct as soon as practical and most certainly when the first patching or resurfacing is done. Otherwise the repairs will have a short life and money will be wasted.



Figure 7 Bottom of a deck with white calcium hydroxide stains.

Over time leaking cracks can also cause freeze thaw deterioration of the concrete in a deck. Figure 7 shows the bottom of a deck with white calcium hydroxide stains that result from water leaking through the deck. The concrete is deteriorated to the point that deck replacement rather than an overlay is the recommended practice.

Carbonated Concrete

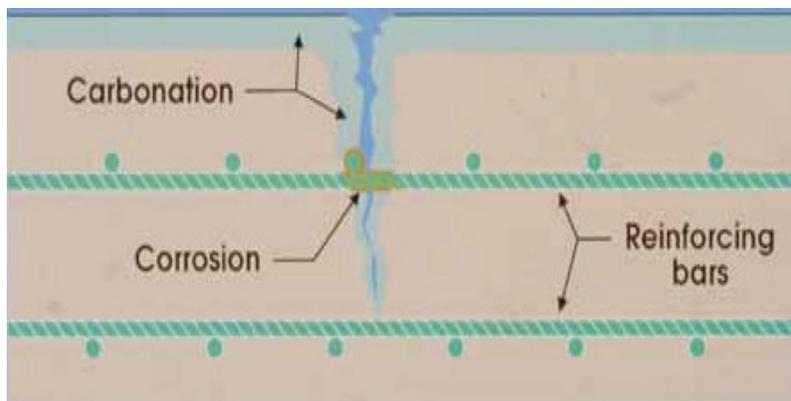


Figure 8 Concrete exposed to air carbonates over time.

New concrete has a high pH which provides corrosion protection for the reinforcement. Concrete exposed to air reacts with carbon dioxide and the pH drops. The depth of carbonation gradually increases over time at a rate that is influenced by the quality of the concrete. Carbonated concrete does not provide the alkaline environment that protects the reinforcement. Reinforcement that is surrounded by carbonated concrete will corrode (Figure 8). Carbonated concrete should be removed when repairs are done. Cracks are sealed to help prevent carbonation of the concrete around the reinforcement.

Freezing and Thawing Deterioration



Figure 9 High strength concrete turning to rubble.

Freezing and thawing damage is another type of concrete deterioration. Water expands 9.1% when it freezes. Air entrained voids provide space for expanding water. Expanding water cracks concrete that is not properly air entrained. Concrete that will be exposed to freezing and thawing in the presence of moisture should not be used if the air content does not meet the minimum requirements. Concrete with insufficient air content should be removed when repairs are done. Figure 9 shows high strength concrete with insufficient air entrainment turning to rubble after 65 and 93 freeze thaw cycles (ASTM C666).

Alkali-Silica Reaction Deterioration

The alkalis in the cement react with silica aggregates forming a gel around the aggregates. The gel absorbs water and swells. The expanding gel cracks the concrete. Alkali-silica reaction products appear as white rings around reacting aggregates. Figure 10 shows a broken cross

section of a core with white rings around some of the aggregates. The white rings can be alkali-silica gel or calcium hydroxide. A petrographer can analyze a core for alkali-silica reaction. Concrete experiencing alkali-silica reaction typically needs to be replaced. However, the reactions stop when the alkalis are all reacted. Therefore, concrete in which the reactions are complete and the concrete is cracked but the concrete has not turned to rubble should be evaluated for strength. If the strength is adequate the concrete can be treated with a sealer or crack filler to preserve the concrete. Sealers and crack fillers can also be used to prevent moisture from reaching the concrete and therefore retard the reactions. Sealing pavement concrete is typically not recommended because moisture can penetrate the concrete from the subgrade and the moisture can be trapped in the concrete accelerating the alkali-silica reaction.

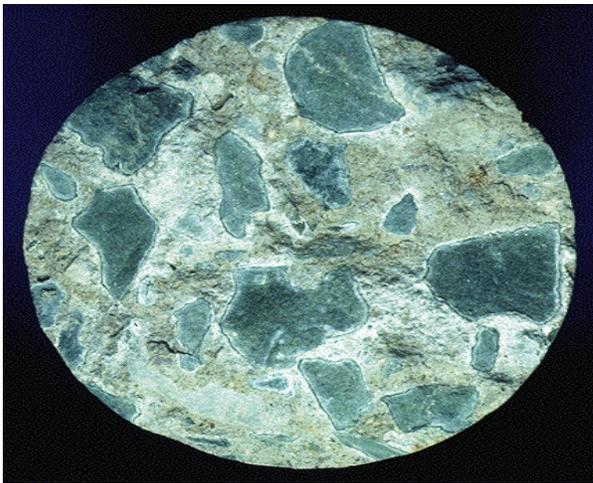


Figure 10 Core with white rings around some of the aggregates.

Sulfate Deterioration

Sulfates in water and soil can react with concrete and the reaction products can crack the concrete. Concrete experiencing sulfate deterioration typically needs to be replaced.

Traffic Induced Stress

The magnitude and frequency of traffic loadings are increasing. Truck traffic is increasing. Concrete can develop fatigue cracks from traffic loads. Concrete that is failing due to fatigue stress typically needs to be replaced. However, overlays can be used to reduce the stress on underlying materials and asphalt and concrete overlays have been placed on concrete pavements in fair condition to extend the life of the pavement.

Design and Construction Deficiencies

Design and construction deficiencies can necessitate repair and preservation treatments at an early age. Deficiencies that may require repair, preservation or replacement of parts of a structure include but are not limited to the following:

- Low strength concrete
- Low air content
- High alkali content
- Poor aggregate
- Shrinkage cracks
- Poor consolidation
- Poor curing
- Premature loading
- Low cover over rebar
- Inadequate reinforcement
- Poor drainage
- Inadequate joints

Poor Consolidation



Figure 11 Bonded concrete overlay that failed due to inadequate consolidation.

Figure 11 shows the sawn vertical face of a failed section of bonded concrete overlay placed with a screed that provided surface vibration. The figure shows that surface vibration during the construction of the overlay was not adequate to properly consolidate the bottom 1 inch of the 3 inch thick overlay. The adhesion of the overlay to the substrate concrete was significantly reduced by the presence of large voids caused by inadequate consolidation. The overlay could not be repaired and had to be replaced. Internal vibrators are required to properly consolidate overlays over 2-in thick.

Shrinkage Cracks

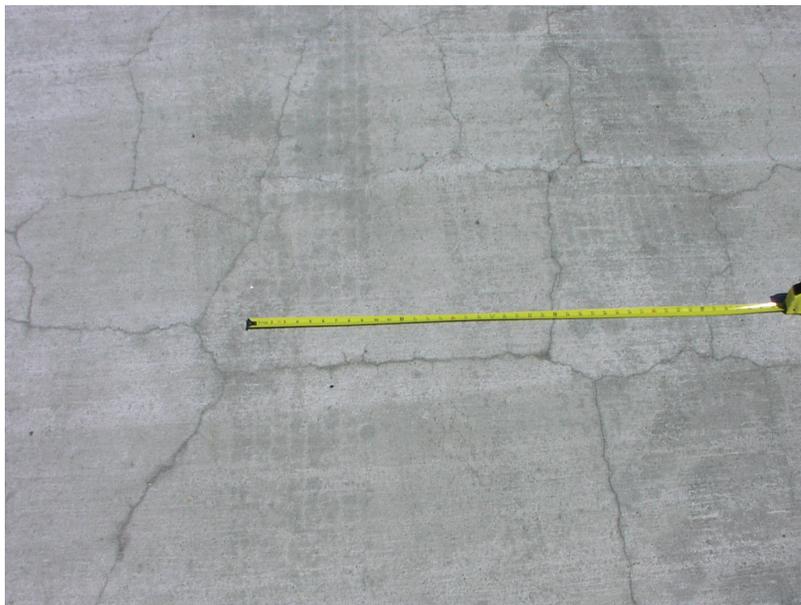


Figure 12 Shrinkage cracks.

Figure 12 shows shrinkage cracks in an overlay. Cracks ≥ 0.2 -mm in width provide an opening water and chlorides to easily penetrate the concrete and reach the reinforcement causing premature corrosion. Shallow cracks in overlays and decks can be filled with gravity fill polymers. Overlays with full depth cracks may need to be replaced as the cracks can increase the risk of delamination of the overlay. Full depth cracks in decks are typically repaired by epoxy injection.

Defining the Repair Problem

The problem causing the deterioration of the concrete structure must be properly defined so that an appropriate repair can be made. Salt contaminated concrete around corroding reinforcement is typically replaced. Concrete suffering from freeze thaw deterioration, alkali-silica reaction or sulfate attack is typically replaced. Concrete pavements suffering from fatigue are sometimes overlaid. Structures with design and construction deficiencies need repair and preservation treatments that are appropriate for the problem.

Locating Deteriorated Concrete

Methods for locating deteriorated concrete are a function of the problem

- Corrosion of Reinforcement: locate areas with corroding reinforcement.
- Freezing and Thawing Damage: locate concrete with insufficient air content.
- Alkali-Silica Reaction: determine the extent of the reactions and deterioration.
- Sulfate Reaction: determine the extent of the reactions and deterioration.
- Traffic Induced Stress: determine the level of deterioration.
- Design and Construction Deficiencies: methods are a function of the deficiency.

Corrosion of Reinforcement

The presence of chlorides around reinforcement typically leads to corrosion of the reinforcement which causes delamination of the concrete and eventual spalling of the concrete. The most common practices for locating deteriorated concrete when reinforcement is corroding are the *Delamination survey* to locate concrete that is delaminated due to corrosion of the reinforcement and the *Half-cell potential survey* to locate reinforcement with a potential more negative than $-0.35 V_{cse}$, which provides a 90 per cent probability that the reinforcement is corroding. Addition information can be obtained by taking samples of concrete at the reinforcement and analyzing them for *Chloride contents*. A *Spall and Patch survey* can be included with the delamination survey as these areas have passed the delamination stage. Since cracks allow chlorides and moisture to more easily reach the reinforcement a *Crack survey* can be done. Since the depth of concrete cover over the reinforcement influences the time to corrosion a *Cover Depth survey* provides useful information. Cover depths < 2.5 -in are a concern and may justify an overlay. A *Carbonation*

survey can be done to identify concrete around the reinforcement that has carbonated and should be removed as it no longer protects the reinforcement from corrosion. Rate of Corrosion measurements can be used to predict the time to lose a cross section of the reinforcement but measurements are time consuming and not very accurate because of the many factors that affect the rate of corrosion.

Delamination, spall and patch survey

A number of techniques can be used for a delamination survey. Fast and low cost methods include the Chain drag for horizontal surfaces and the Hammer for horizontal and inclined surfaces. The Pulse velocity and Impact Echo techniques can be used for Special Investigations. Radar and Infrared thermography surveys are useful for Bridge Management as a number of bridges can be surveyed with minimal traffic control. Results are typically used to prioritize bridges for repair but not to provide bid quantities.

Chain Drag

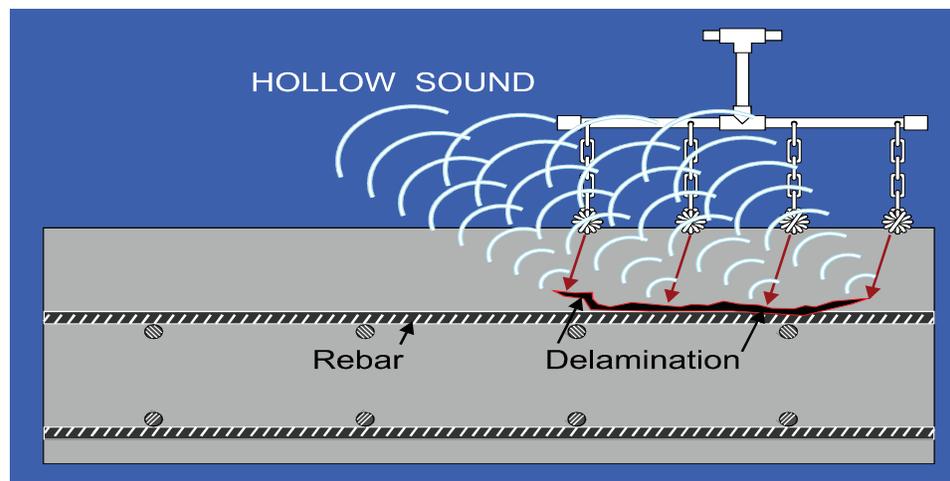


Figure 13 Chain Drag.

Figure 13 shows the Chain Drag technique. A number of chains are dragged over the concrete surface. The chains impacting the surface impart a sound. The sound is thin and hollow over delaminated areas and thick and dense over solid areas. The edges of Delaminated areas can be marked for concrete removal as the sound of the chains changes.

Half-cell potential survey

The Half-cell potential survey can be used to locate reinforcement with a potential more negative than $-0.35 V_{cse}$, which provides a 90 per cent probability that the reinforcement is corroding. The deck is marked into a 4 or 5-ft grid. The lead wire from the potential meter is connected to the top mat of reinforcement. The lead wire can be connected to reinforcement in a spalled area or a hole will have to be drilled to expose the reinforcement. The connection between the lead wire and reinforcement must provide good electrical conductivity. The reinforcement must be clean and the connection good. Areas with a potential more negative than $-0.35 V_{cse}$ can be marked for removal as the survey is done. Figure 14 shows a Half-cell potential survey on a bridge deck.



Figure 14 Half-cell potential survey.

Chloride Content Samples

Information on the potential for chlorides to cause corrosion can be obtained by taking samples of concrete at the depth of the reinforcement and analyzing them for chloride content. While a chloride threshold content of 1.3 pounds per cubic yard has historically been used as a basis for concrete removal, recent research has indicated that depending on the quality of the concrete, corrosion may not be a problem until the chloride content is 2 to 4 pounds per cubic yard. The sampling procedure follows:

- drill to the top level of the reinforcement being careful not to drill into the reinforcement,
- vacuum the cuttings from the hole,

- drill another 0.5-in deep,
- Use a small spoon to collect the powdered sample and place it into a container.

Equipment that is needed includes a reinforcement location meter, drill and bit approximately 1-in in diameter, generator, vacuum, tape measure, spoon, sample container and marking device. Powdered samples can be analyzed at the site or sent to a lab. An alternative procedure is to take 1-in diameter cores and send them to a lab to be cut, pulverized and analyzed.

Summary of Locating Deteriorated Concrete caused by reinforcement corrosion

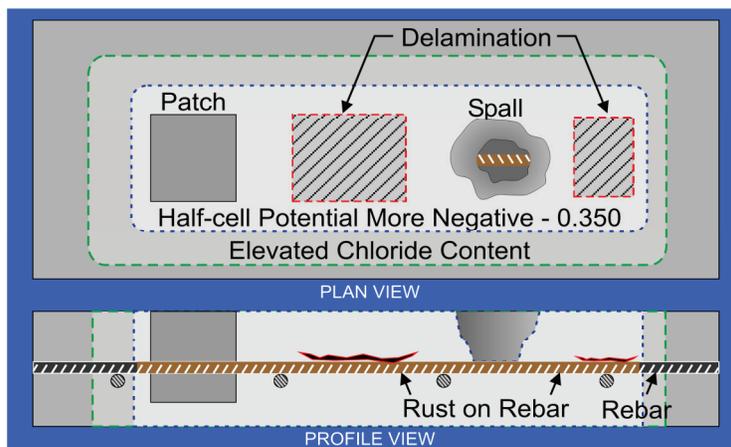


Figure 15 Deck with concrete in various stages of deterioration.

Figure 15 illustrates a typical section of deck with concrete in various stages of deterioration because of chlorides in the concrete and reinforcement corrosion. The area that is patched represents the first area of the deck in which corrosion of the reinforcement caused spalling of the concrete. The spall represents the 2nd area. The delaminated areas will spall in the days ahead. The area with the half-cell potentials more negative than -0.35 Vcse, indicates the location of corroding reinforcement. The largest area is the concrete with chlorides. While all chloride contaminated concrete can be removed it is often not practical. For a long lasting repair, concrete with sufficient chloride to cause corrosion as indicated by the half-cell potentials more negative than -0.35 Vcse, should be marked for removal and removed below the level of the reinforcement.

Concrete Deterioration

Locating deteriorated concrete caused by freezing and thawing damage, alkali-silica reaction, sulfate reaction, traffic induced stress, and or design and construction deficiencies typically requires that cores be taken in the distressed areas. Concrete removal and repair are typically based on recommendations from a petrographer following the evaluation and analysis of the cores.

Removing Deteriorated Concrete

The objective of removing deteriorated concrete is to remove concrete that is chloride contaminated, cracked or deteriorated to a strength that is less than that required for acceptable performance of the structure while not damaging the concrete and reinforcement that is of sufficient quality to stay in place. Concrete is typically removed for patching and for the placement of overlays.

Patching

Concrete removal for patching includes:

- Marking the perimeter of the patch,
- Saw cutting the perimeter of the patch to a depth of 1-in,
- Using pneumatic hammers weighing less than 35 pounds (Figure 16) to fracture the concrete for removal, and
- Sand or grit blasting the concrete surface to remove loose and weak material.

When the reinforcement is within 1-in of the surface the sawcut depth should be reduced to prevent the cutting of the reinforcement. Reinforcement that is cut will have to be spliced with a new bar. The saw cut surface provides a clean vertical face that provides support for the concrete patching material. Pneumatic hammers fracture the concrete and care needs to be used to remove all fractured concrete.



Figure 16 Pneumatic hammers fracture the concrete for removal.

Overlays

Concrete removal for hydraulic cement concrete overlays includes:

- Milling of the surface to a depth of 0.5-in or down to within 0.5-in of the top reinforcement and
- Sand, grit or shot blasting the surface to remove loose and weak material.
- Hydro demolition is sometimes used rather than deep milling and sand, grit or shot blasting.

Milling



Figure 17 Milling machine removes top 0.5-in or more of the concrete surface.



Figure 18 Milling drum with fine milling heads.

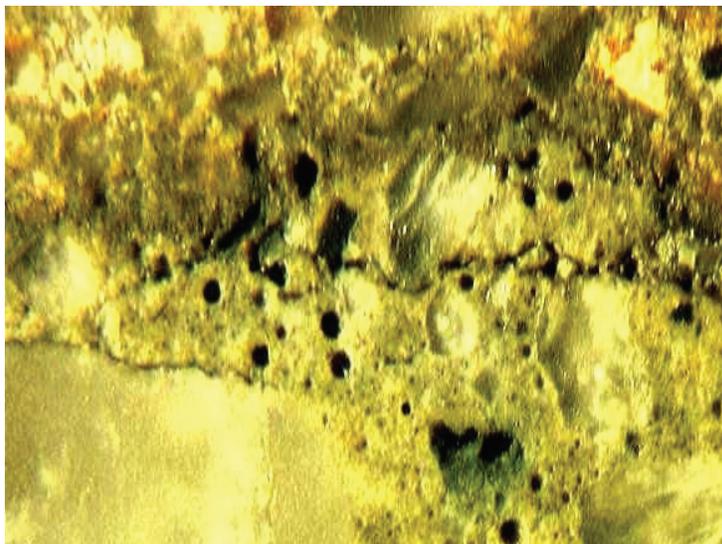


Figure 19 Cracks in the deck caused by milling.

Concrete is milled from the deck surface (Figure 17) to remove the most chloride contaminated concrete, to reduce the dead weight of the deck to help offset the additional weight of the concrete overlay, and to minimize the change in the final profile of the overlaid deck which can impact ride quality. Approach slabs and sometimes the pavement typically have to be resurfaced to achieve good ride quality. The milling machine should be equipped with closely spaced (fine or micro) milling heads (Figure 18) to minimize damage to the milled surface. Large heads and dull heads can leave a surface that is pulverized and cracked. This weak layer must be removed to prevent premature failure of the overlay. Figure 19 shows cracks in the deck from milling. The cracks are just below the overlay.

Hydro demolition



Figure 20 Hydro demolition.



Figure 21 Cuttings being removed by vacuum truck.



Figure 22 Hydro demolition.

Figures 20, 21 and 22 show concrete being removed by hydro demolition. A high pressure water jet inside the housing removes concrete with strength less than the water pressure. Nozzle pressures are in the 20,000 to 30,000 psi range. The equipment is calibrated to achieve the desired depth of removal. The first step in the concrete removal process is to mill the surface using care not to hit reinforcement. Milling is used because it is faster and lower cost than hydro demolition. The milling is followed by hydro demolition to remove chloride contaminated concrete above and often below the reinforcing steel. The cuttings are removed by a vacuum truck. A second pass by a vacuum truck with a water wash is used to further clean the concrete surface. A final pass with high pressure water is used to remove all remaining loose material and to saturate the concrete which provides good surface preparation for the overlay. Hydro demolition can be an economical alternative to removal of concrete with pneumatic hammers and can be better than pneumatic hammers because it does not leave concrete with fractures.

Preparing Concrete Surfaces

Concrete surfaces must be properly prepared to achieve good bond between the new patch or overlay concrete and the old concrete. Surface preparation methods typically include some combination of the following methods:

- Air blasting
- Power washing
- Grit blasting
- Shot blasting
- Hydro blasting and power washing

A specification for preparing concrete surface to receive an overlay or patch follows:

Clean surface by shot blasting and other approved cleaning practices to remove asphaltic material, oils, dirt, rubber, curing compounds, paint, carbonation, laitance, weak surface mortar, and other detrimental materials that may interfere with the bonding or curing of the overlay/patch.



Figure 23 Grit blasting.

Figure 23 shows grit blasting. The quality of the prepared surface depends on the equipment and the operator. Grit blasting is typically used to prepare inclined and horizontal surfaces that will be patched.

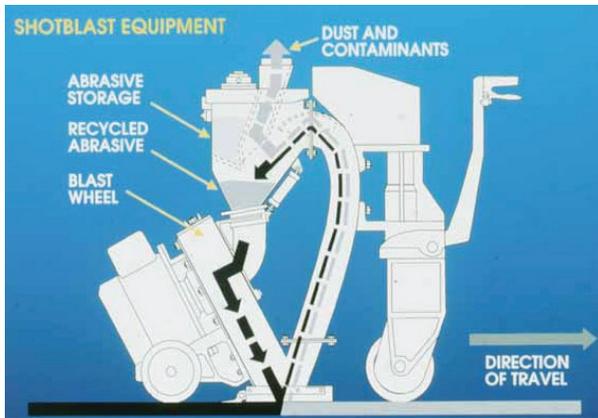


Figure 24 Shot blasting equipment.



Figure 25 Shot blasting equipment.

Shot blasting is typically used to prepare surfaces that will be overlaid. Figures 24 and 25 show shot blasting equipment. The equipment blasts the surface with shot. The shot and cuttings are removed by vacuum. The shot size, speed of the equipment and number of passes control the surface preparation. The equipment is driven over the surface at a speed and number of passes that provide the level of texturing and cleaning that will give acceptable bond strengths between the overlay and old concrete. The texture of the surface increases with each pass of the equipment. When driven at a uniform speed the shot blasting equipment provides uniform surface preparation. The first indication that an aged concrete surface is being cleaned is a change in the color of the surface as shown in Figure 25. The shot blasting equipment is self contained which provides some protection for the workers and the public from dust, blast media and cutting. Safety glasses must to worn to protect the eyes from stray shot.

Patching

Many ingredients are available to use for patching hydraulic cement concrete structures. Patching mixtures may include Portland cement; fine and coarse aggregates; silica fume, fly ash, or slag; and chemical admixtures that provide for air entrainment, setting time, water reduction, fluidity, anti-bleed, self consolidation, and shrinkage reduction. Plastic and steel fibers and inorganic or organic corrosion inhibitors are sometimes used. Use of other hydraulic cements such as magnesium phosphate and calcium sulfoaluminate and dicalcium silicate is increasing because of the need to open patches to traffic in several hours. Polymer and polymer modified concrete are also used for patching. Typically the cost of the mixture increases with the complexity of the mixture. A patching mixture should be selected that has the desired properties at a reasonable cost.

Types of patching concretes

Patching concrete is typically supplied one of three ways as follows:

- Plant batched ready mixed concrete,
- Site batched and mixed with volumetric concrete mixers and
- Site batched and mixed using prepackaged materials.

Ready-mixed concrete (RMC) should be used when a RMC plant is within suitable distance from the project, sufficient volume of concrete is needed to justify RMC and a suitable mix can be obtained. Volumetric concrete mixers should be used when RMC is not practical. Site batched and mixed concrete using prepackaged materials can be acceptable when RMC or trucks that provide volumetric mixed concrete are not practical. Prepackaged materials are typically used when the volume of concrete is too small to justify RMC or volumetric mix trucks. All ingredients must be batched using calibrated containers when prepackaged materials are used.

Types of patching

VDOT typically specifies one or more of the following types of patching for bridge repair:

- Type A (reinforcement not exposed) HCC,
- Type B (reinforcement exposed, < 1/2 deck thickness) HCC,
- Type C (full depth) HCC, and

- Type D (< 19 mm thick), epoxy mortar

Compressive strength of patching mixtures

VDOT has three compressive strength classifications for patching materials as follows:

- Rapid Hardening HCC (≥ 2000 psi in 6 hr)
- Very Rapid Hardening HCC (≥ 2500 psi in 2 hr)
- Bridge Deck Class A4 RMC (≥ 4000 psi in 28 days)

When feasible, patching should be done with Class A4 RMC. In many situations it is not practical or possible to close lanes for 28 days to allow the strength of A4 concrete to be obtained. Patching must be done within an 8 hour lane closure period on an increasing number of projects and consequently use of very rapid hardening HCC is increasing. Figure 26 shows a large Type B patch being constructed with RMC. Internal vibrators must be used to properly consolidate the 4-in thick patch. Figure 27 shows patching being done with prepackaged materials.



Figure 26 Type B patching with RMC.



Figure 27 Patching with prepackaged materials.

Patching



Figure 28 Properly prepared Type B cavity.

Figure 28 shows patching concrete being placed in a properly prepared Type B cavity. The perimeter has been saw cut 1-in deep and the clearance under the reinforcement in ≤ 1.25 -in. The surfaces of the concrete cavity and reinforcement have been grit blasted and the concrete has been wetted to achieve a saturated surface dry condition.



Figure 29 Internal vibrator consolidates the concrete.



Figure 30 Patch being struck off.



Figure 31 Liquid pigmented curing material being applied.

Figure 29 shows an internal vibrator being used to properly consolidate the concrete. Figure 30 shows the patch being struck off and Figure 31 shows a liquid pigmented curing material being applied to the last patch to be done prior to opening the patches to traffic. The curing compound is pigmented white so that it can be seen that it has been applied at the minimum or greater application rate. The curing compound must be applied before the fresh concrete surface loses its sheen and dries. If the surface dries before the application of the curing material the concrete will develop plastic shrinkage cracks because of water evaporating from the concrete. Figure 31 also shows odd shaped patches with many sides and corners. Rectangular patches should be used to reduce the cost of saw cutting and to minimize cracking in the patch caused by corner restraint.

Drying Shrinkage of Patching Concrete

Hydraulic cement concrete shrinks as the cement and water react and the concrete dries because the hardened concrete takes up less space than the un-reacted ingredients. Figure 32 shows length change curves for specimens made with 7 concrete patching mixtures. The curves illustrate the change in length in per cent over a 2 year period. All the concrete specimens get shorter with time with most of the shorting taking place in less than 28 days of age. The mixture with the lowest shrinkage is 0.04 per cent shorter in 24 months and the mixture with the greatest shrinkage is 0.2 per cent shorter in 24 months. A4 concrete shrinks about 0.07 per cent in 24 months. In theory the change in length of restrained concrete should result in crack widths that are equal to the change in length. In reality reinforced concrete strains as it shrinks and crack widths are about 25 per cent of the change in width. Use of mixtures with shrinkage of less than 0.08 per cent is recommended to minimize the cracking caused by drying shrinkage.

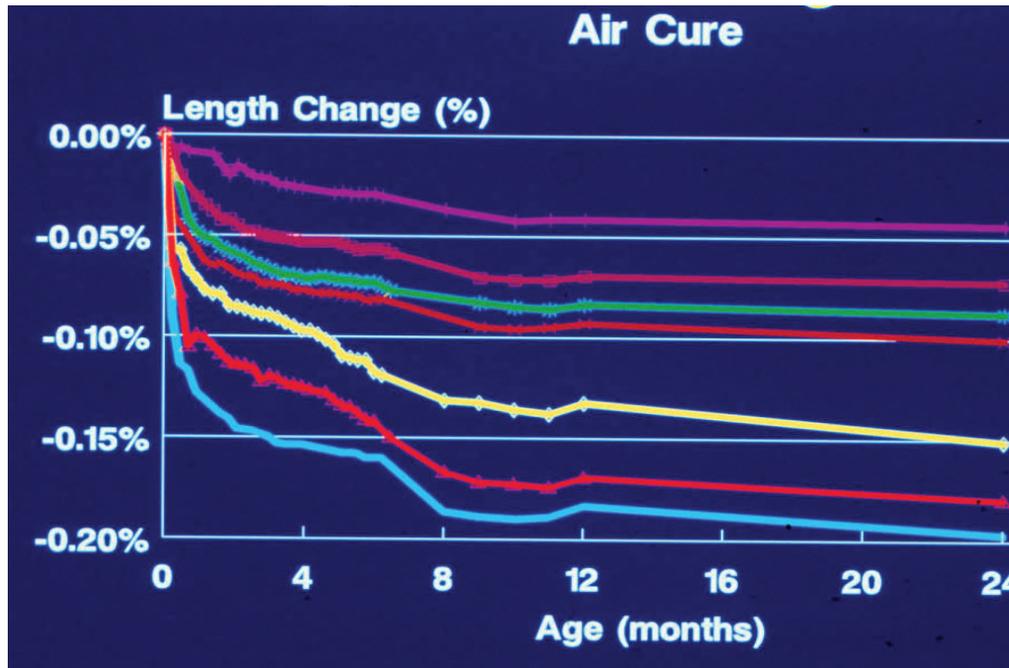


Figure 32 Length change curves for 7 concrete patching mixtures.

Effect of Concrete Temperature on Rate of Strength Development

For the same mixture the concrete develops strength at a rate that depends on the curing temperature of the concrete. The hotter the concrete curing temperature the faster it gains strength and the cooler the concrete temperature the slower it develops strength. Table 1 shows the time required for 3 patching concrete mixtures to achieve 2500 psi compressive strength when cured at 4 temperatures. Mixtures are approved in the lab at a temperature of approximately 72 F. Concretes are used in the field at temperatures that range from 50 to 95 F. The curing temperature of the concrete needs to be considered when planning the curing time required for opening the patches to traffic. More time needs to be allowed in cold weather. The time required to mix and place the mixture needs to be considered when working in hot weather.

Temperature, F°	40	55	72	90
Patch Material 1	5.0	1.7	1.2	0.6
Patch Material 2	3.6	2.2	1.5	0.6
Patch Material 3	6.2	3.4	2.9	2.4

Table 1 Time required to achieve 2500 psi, hours.

Crack Repairs

Typical Methods for Crack Repair

- Gravity Fill Polymer
- Route and Seal
- Pressure Injection of Epoxy

Gravity Fill Polymer



Figure 33 Pattern cracks.

The most economical way to seal pattern cracks is to apply a gravity fill polymer to the cracked surface and work the liquid polymer into the cracks. Materials approved for use by VDOT include high molecular weight methacrylate (HMWM), epoxy and urethane. Applications should be done in accordance with the VDOT Special Provision for FILLING and SEALING RANDOM ORIENTED SHRINKAGE CRACKS IN CONCRETE DECKS and OVERLAYS. Figure 33 shows a deck with pattern cracks. Cracks must be at least 0.2 mm in width for the sealer to penetrate and fill the crack.



Figure 34 HMWM is applied.

Figure 34 shows HMWM being applied to the cracked deck using brooms to spread the polymer and work it into the cracks. The special provision indicates cracks to be filled shall be dry and free of dust, dirt and other debris prior to filling, and shall be air blasted with oil free compressed air prior to application of the sealer. The concrete surface temperature shall not be less than 55°F when the sealer is applied. The sealer shall be applied during the lowest temperature period of the day, usually between 1 a.m. and 9 a.m., when the cracks are open to the greatest extent. The mixed polymer shall be applied directly to the cracks, allowing time for the polymer to seep down into the cracks, making additional applications until cracks are filled. The polymer material may be spread over designated crack areas and worked into the cracks with a broom or squeegee. Excess polymer shall be brushed off the surface prior to the polymer hardening. Mixed polymer shall be applied as soon as practical and polymer that exhibits an increase in viscosity and temperature shall not be placed on the concrete surface. Grade D sand as prescribed in Table II-22 of the Road and Bridge Specifications shall be broadcast over the applied polymer at the minimum rate of 0.5 lb per square yard.



Figure 35 Sand being applied.

Figure 35 shows sand being applied at a heavier rate because the deck has no tined texture or saw cut grooves. The sand shall be broadcast as soon as practical and before the viscosity of the polymer begins to increase. Regardless of the application method used, the polymer shall be applied in sufficient quantity and applications to fill cracks level. An application rate of 1 gallon per 100 linear feet or 100 square feet is usually adequate.



Figure 36 HMWM being applied to a crack.

Figure 36 shows HMWM being applied to individual cracks. The contents of the bottled must be dispensed within approximately 5 minutes because the viscosity of the liquid increases with time after mixing.



Figure 37 HMWM being applied to a crack.

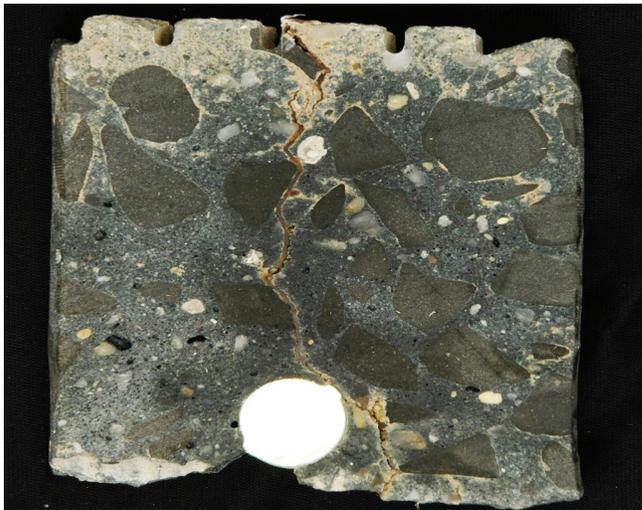


Figure 38 Core showing 0.75-mm wide crack filled with HMWM.

Figure 37 shows HMWM being applied to a crack in a deck with a tined texture. Once the crack is filled, excess HMWM must be spread over the deck surface so as to not fill the valleys of the grooves. The valleys provide for a high skid resistance. Figure 38 shows a crack filled with HMWM.

Route and Seal

In situations in which individual cracks must be sealed and gravity fill polymers won't provide effective results, cracks can be routed with a crack chasing device and the wider space that is created along the top of the crack can be filled with epoxy. Routing and sealing a crack takes longer and is more expensive than using a gravity fill polymer but is faster and lower cost than pressure injection.

Pressure Injection of Epoxy



Figure 39 Pressure injection of epoxy.

The most expensive method for sealing cracks is pressure injection of epoxy as shown in Figure 39. The method includes applying a paste epoxy to seal the top and bottom of the crack, installing injection ports at a spacing equal to the depth of the injection that is desired and injecting a low viscosity epoxy into the crack. The injection is started at the port located at the lowest elevation. The port is injected until epoxy comes out of the adjacent port. The adjacent port is injected until epoxy comes out of the next adjacent port. The process is continued until all ports are injected. After the epoxy has gelled, the ports are removed and the past epoxy is ground off. Epoxy injection is typically used for restoring the strength of cracked concrete sections and for sealing critical cracks.

Minimizing Cracks in Concrete

It is difficult to construct a concrete deck, overlay or pavement that does not have any cracks. Cracks are typically caused by one or more of the following factors.

1. Plastic shrinkage: caused by placing the concrete when the evaporation rate is too high and delayed application of curing materials allowing water to evaporate from the concrete,

2. Autogenous shrinkage: caused by using concrete mixtures with a $w/c < 0.4$ which is not typical ,
3. Drying shrinkage: caused by water reacting with the cement and concrete drying out with age,
4. Thermal contraction cracks: caused by placing concrete with a temperature that is higher than the surfaces it is placed on and or rapid cooling of the concrete surface,
5. Reflection from underlying cracks: caused by placing concrete over cracked concrete, and
6. Live loads: caused by traffic.

Plastic shrinkage cracking can be minimized by using the ACI evaporation rate nomograph (ACI 308.3) and taking steps to reduce the evaporation rate when rates exceed 0.05 lb/ft²/hr. for overlays and 0.1 lb/ft²/hr. for decks and pavements. Fogging as shown in Figure 40 can be used to increase the relative humidity which will reduce the evaporation rate. Figure 41 shows a deck with cracks caused by failure to apply a sufficient quantity of white pigmented liquid membrane curing material. The deck is less white in the center because of the insufficient application of curing material. Drying shrinkage can be minimized by using concrete mixtures with minimal cementitious materials and water and using shrinkage reducing admixtures. Thermal contraction cracks can be minimized by placing concrete that has a temperature that is close to that of the surface it is being placed on and by protecting the concrete from rapid cooling. Cracks that open and shut with traffic loadings and temperature changes will reflect through concrete that is placed over them. Cracks caused by traffic loads are a function of the structural design but can also be caused by premature loading of the concrete.



Figure 40 Fogging can reduce the evaporation rate.



Figure 41 Deck with cracks.

Hydraulic Cement Concrete Overlays

HCC overlays are placed to reduce infiltration of water and chloride ions and improve skid resistance, ride quality, and surface appearance. The most common types of HCC overlays used on bridge decks are:

- Latex modified with Type I/II cement (LMC) ,
- Latex modified with very early strength cement (LMC-VE) ,and
- Silica Fume with Type I/II cement (SF).

HCC overlays with fly ash or slag are typically used on concrete pavements.

Mixture proportions

Typical mixtures for an LMC and silica fume overlays are shown in Table 2. Mixtures typically have the same cement content. LMC has more fine aggregate and silica fume more coarse aggregate. Coarse aggregate typically meet the requirements for No. 7, 78 or 8 gradation. The maximum water to cement ratio is 0.4 for both mixes. The latex additive is 46 to 53 per cent solids in water. A high range water reducing admixture is used to disperse the silica fume. The latex and silica fume provide for low permeability. Bonded HCC overlays are typically 1.25 to 1.75-in thick but it is not uncommon to have thicker overlays. When the overlay exceeds 3-in in thickness larger size coarse aggregate such as No. 68 or 57 gradation should be used to minimize shrinkage. Bonded HCC overlays are rarely thicker than 4-in. unless reinforcement is used to control shrinkage stresses. Thicker overlays are typically unbounded.

Mixture	LMC and LMC-VE	Silica Fume
Cement, lb/yd ³	658	658
Fine Aggregate, lb/yd ³	1552	1269
Coarse Aggregate, lb/yd ³	1187	1516
Water, lb/yd ³	146	282
Air, per cent	5 %	7 %
Other	24.5 gallons latex	46 lb/yd ³ silica fume & hrwr

Table 2 Typical mixtures for an LMC and silica fume overlays

Surface preparation for overlays

The recommended practice for preparing concrete surfaces for hydraulic cement concrete overlays is as follows:

- Clean surface by shot blasting and other approved cleaning practices to remove asphalt, oils, dirt, rubber, curing compounds, paint, carbonation, laitance, weak surface mortar, and other detrimental materials that may interfere with the bonding or curing of the overlay.
- Final cleaning within 24 hours of placing overlay.
- Minimum of 1 hour prior to placing the overlay, water soak the surface and cover with polyethylene.
- Maintain surface in wet and covered condition until overlay is placed.



Figure 42 Volumetric concrete mixer.

Figure 42 shows a volumetric concrete mixer on top of polyethylene sheeting that is being used to protect the prepared concrete surface until the overlay concrete can be placed. The deck has been shot blasted and wetted. The plastic will be removed from the surface at the back of the mixer as the concrete is discharged onto the deck. The volumetric mixer has compartments loaded with the ingredients for a LMC overlay.



Figure 43 Volumetric mixer discharging LMC-VE concrete.

Figure 43 shows a volumetric mixer discharging LMC-VE overlay concrete. A fog spray is used to increase the relative humidity to reduce the risk of plastic shrinkage cracking in the overlay.



Figure 44 Truck discharges ready-mixed silica fume concrete.

As shown in Figure 44 RMC is used for silica fume concrete overlays. Once the concrete is discharged onto the prepared deck surface, both LMC and silica fume concrete overlays are placed the same way. For conventional LMC and silica fume overlays, the mortar portion of the overlay concrete (grout) is brushed into the deck surface ahead of the concrete placement and coarse aggregate that is left behind the brushing operation is shoveled up and discarded. Care must be taken not to brush the grout too far ahead of the concrete placement because the grout can dry and cause lower bond strength. The grout is not applied for LMC-VE overlays and overlays placed on hydro blasted surfaces. LMC-VE stiffens rapidly and grout would likely dry too fast. The texture of hydro blasted surface is too heavy to allow for a uniform application of the grout.



Figure 45 Screed consolidates and strikes off overlay concrete.

Figure 45 shows the overlay concrete is consolidated and struck off with a screed. Areas thicker than 2-in such as areas being patched must be consolidated with internal vibrators.



Figure 46 Vibrating pan on front of screed.

Figure 46 shows the vibrating pan on the front of the screed consolidating the overlay concrete.



Figure 47 Wet burlap is placed as soon as practical.

Figure 47 shows wet burlap being placed on overlay as soon as practical to prevent plastic shrinkage cracking.



Figure 48 Wet burlap is covered with polyethylene as soon as practical.

Figure 48 shows the wet burlap is covered with polyethylene as soon as practical to maintain the moisture in the wet burlap. The burlap must be kept wet for 2 days for LMC overlays, 3 days for silica fume overlays and 3 hours for LMC-VE overlays. White pigmented liquid membrane curing material is applied to the surface of silica fume overlays after the wet burlap is removed. Traffic can be placed on LMC and silica fume overlays when the compressive strength exceeds 3500 lb/in². The required strength for traffic for LMC-VE overlays is 2500 lb/in².

Epoxy Concrete Overlays

Introduction

Epoxy overlays are placed on bridge decks to reduce infiltration of water and chloride ions and improve skid resistance and surface appearance. Epoxy overlays are 2 layers of epoxy and broadcasted aggregate placed on a dry, shot blasted surface. Test patches are done to verify materials, surface preparation, and mixing and placing of materials are acceptable.



Figure 49 Placing the first layer of an epoxy overlay test patch.

The overlay is typically 0.25 in thick. Figure 49 shows a typical epoxy overlay test patch being placed on a shot blasted surface. The first layer of epoxy is spread at the specified application rate and specified aggregate is broad cast into the epoxy. Approximately 1 to 2 hours later the unbounded aggregate is removed and a second layer of epoxy and aggregate is placed. The test patch is typically tested the next day.



Figure 50 Test patch is cored in 3 locations.

Testing (VTM-92) involves drilling through the overlay and into the deck concrete at least 0.25-in at 3 locations (Figure 50), bonding a test cap to the cored disk with a rapid hardening adhesive (Figure 51), loading the cored disks to failure (Figure 52), and computing the failure stress and type of failure (Figure 53). Results are based on the average of 3 tests. An average strength of ≥ 250 psi or failure in the deck concrete at a depth ≥ 0.25 -in over 50 per cent or more of the test area is required for a passing test. A passing result must be obtained for each bridge deck span to be approved to proceed with the overlay placement.



Figure 51 Gluing a test cap to the cored disk. Hook is screwed into cap.



Figure 52 Tensile adhesion test.

**TESTING EPOXY CONCRETE OVERLAYS
FOR SURFACE PREPARATION AND ADHESION**

CALCULATION

TRS = TENSILE RUPTURE STRENGTH
 P = LOAD (DYNAMOMETER)
 A = AREA OF CORED DISC

$$A = \frac{\pi D^2}{4} = \frac{3.14 \times (2.25)^2}{4} = 3.98 \text{ in.}^2$$

$$TRS = \frac{P}{A} = \frac{1150}{3.98} = 289 \text{ psi}$$

Figure 53 Tensile adhesion test result calculation (VTM-92).

Surface Preparation



Figure 54 Shot blast equipment.

Surface preparation is done by shot blasting. Figure 54 shows a large shot blaster being used to prepare the deck and a smaller shot blaster being used to remove paint lines that were left behind by the larger piece of equipment.

Batching and Mixing Epoxy

Epoxy is typically one or two parts A and one part B. The A and B components must be measured out by volume or weight correctly and mixed correctly to achieve an epoxy that cures completely (Figure 55).



Figure 55 Mixing epoxy with drill and paddle.



Figure 56 A 50-ml gel sample.

A batch that is incorrectly measured and mixed will give a gel time that is different from a correctly mixed batch. A 50-ml sample is taken for each batch of epoxy (Figure 56). The batch time and gel time (time it takes for the liquid to gel) is recorded. Gel times that are significantly longer or shorter than the typical gel time for the day are an indication that the batch may have been incorrectly measured and mixed and may have to be removed from the deck.

Placing the Epoxy and Aggregate



Figure 57 Mixed epoxy is poured onto the deck surface

The mixed epoxy is poured on the deck surface (Figure 57). The deck is marked to designate the area over which a batch is to be placed to achieve the specified application rate.



Figure 58 Epoxy is spread with squeegees and aggregate is broad cast over the epoxy.

The epoxy is spread with squeegees (Figure 58). A regular squeegee is used to work the epoxy into the deck surface and a notched squeegee is used to provide the specified application rate. Aggregate is broad cast over the epoxy. The first layer of epoxy is spread at the specified application rate (typically ≥ 2.5 gal per 100-ft²) and specified aggregate is broad cast to excess into the epoxy. Approximately 1 to 2 hours later the unbounded aggregate is removed and a second layer of epoxy (typically ≥ 5.0 gal per 100-ft²) and aggregate are placed. All work must be done in accordance with the plans and specifications. Materials safety data sheets must be posted at the project site and followed. Protect skin from exposure to epoxy by wearing proper clothing. Wash exposed skin immediately with soap and water unless MSDS indicate another procedure. Properly dispose of contaminated material.

Membranes

Asphalt Overlay with Membrane

An asphalt overlay placed over a membrane can be used as a deck protection system. Membranes provide the protection and the asphalt provides the wearing surface. Membranes can be placed as a liquid such as epoxy or as a prefabricated sheet. NCHRP Syntheses 220 and 425 *Waterproofing Membranes for Concrete Bridge Decks* are good references for membranes. The VDOT Road and Bridge Specification has requirements. Figure 59 shows a sheet membrane being placed. The sheets must be properly placed so the membrane does not leak. Figure 60 shows an asphalt overlay being placed over the membrane.



Figure 59 Sheet membrane.



Figure 60 Asphalt overlay being placed over the membrane.

Sealers

Concrete sealers can be used to provide protection for concrete. They are not recommended for surfaces subjected to traffic because the traffic will wear them off in days, weeks or months. They can be applied to parapets and pier caps. They usually have to be applied every 5 years to maintain the protection. NCHRP Synthesis 209 *Sealers for Portland Cement Concrete Highway Facilities* is a good reference. The synthesis identified 232 products in 1994. The synthesis classified the sealers as :

- Water repellent: silane, siloxane, and
- Pore blocker: acrylic, linseed oil, epoxy, polyester, urethane.

Prior to specifying a sealer application, small test applications should be done to provide an indication the sealer will penetrate, cure and provide the desired surface and protection. Pore blockers like linseed oil may not penetrate and may leave a slick surface. Sealers should not be applied by high pressure spray (Figure 61) because the sealer can more easily evaporate and the sealer may contact nearby traffic. Application by low pressure spray bar or by brushing (Figure 62) is recommended.



Figure 61 High pressure spray application of sealer.



Figure 62 Sealer is brushed into the concrete surface.

Criteria for Good Repair and Preservation of HCC Structures

- Proper design (thickness, reinforcement)
- Good surface preparation (high bond strength)
- Quality mixture proportions (low shrinkage)
- Proper placement (adequate consolidation, low evaporation rate)
- Good cure (retain moisture in concrete).

Chapter 2 Study Questions

1. What is the first step in a deck repair? _____
2. What are typical causes of deterioration of concrete? _____
3. What causes corrosion of reinforcement? _____
4. Why is corrosion of reinforcement a problem? _____
5. Why is poor drainage a problem? _____
6. What causes freeze thaw deterioration? _____
7. Why is alkali silica reaction a problem? _____
8. How do you locate deteriorated concrete caused by corrosion of reinforcement? _____

9. How do you remove concrete prior to patching? _____
10. Patching can be done with what materials? _____
11. True or False. Patching should include adequate clearance under the reinforcement, saturated surface dry surface, and the use of an internal vibrator? _____

12. When should white, pigmented liquid membrane curing materials be applied? _____

13. How much does typical bridge deck concrete shrink in one to two years? _____

14. Concrete gains strength the fast as what temperature? _____

15. What information is needed to use the evaporation rate nomograph? _____

16. What materials do we use to fill cracks? _____

17. Hydraulic cement concrete overlays should be placed on what type surface? _____

18. What type hydraulic cement concrete overlays are used in Virginia? _____

19. Epoxy overlays should be placed on what type surface? _____

20. Epoxy test patches are constructed and tested to verify what is acceptable? _____

STUDENT NOTES:

