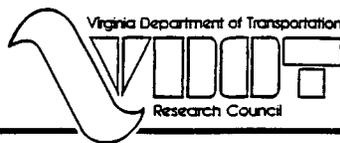


# A MANUAL FOR THE REPAIR AND PROTECTION OF HYDRAULIC CEMENT CONCRETE BRIDGE DECKS



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VIRGINIA TRANSPORTATION RESEARCH COUNCIL



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BRIDGE DECKS

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(Prepared for Distribution at Hydraulic Cement Concrete Construction  
Certification School(s))

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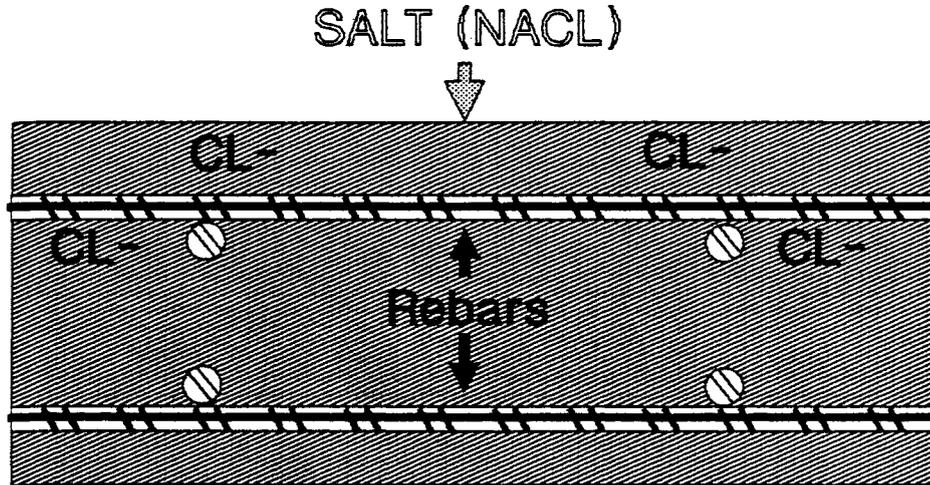


Figure 1. Chloride ions destroy the passive oxide film on portions of the reinforcing steel.

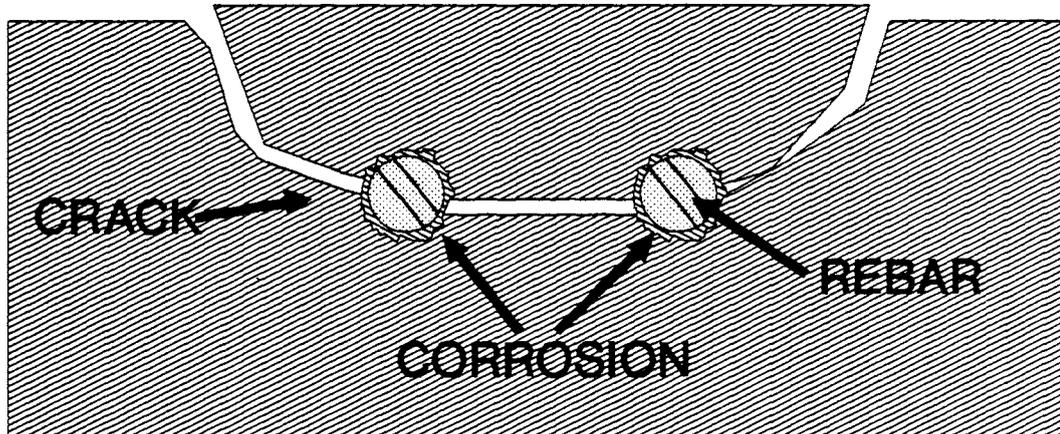


Figure 2. At the anode, the steel (Fe) reverts back to its ionic state (Fe<sup>++</sup>), eventually forming oxides and hydroxides, which occupy a much larger volume than the original steel. The resulting bursting forces soon crack the concrete.

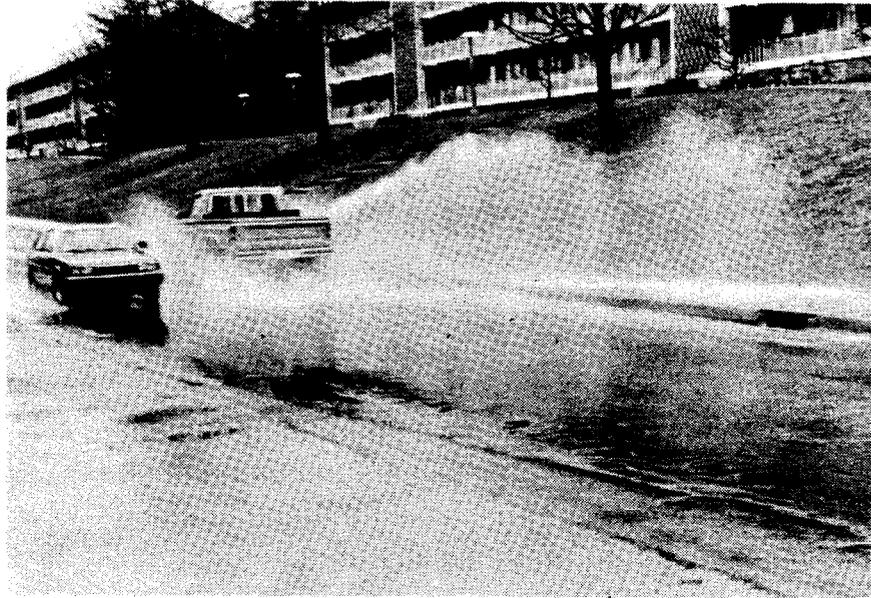


Figure 3. A plugged or improperly located drain (shown above) does not provide for proper drainage. Poor drainage allows water and salt to pond on the surface and to saturate the concrete, which causes freeze and thaw damage in the concrete and creates high salt concentrations at the reinforcing steel.



Figure 4. Several chains hanging from a pipe (chain drag) can be dragged over the deck surface to locate delaminated and very unsound concrete. The chain produces a hollow sound when it passes over delaminated concrete.



Figure 5. A delamect can be rolled over the deck surface to produce a strip chart that can be examined to identify delaminated areas.

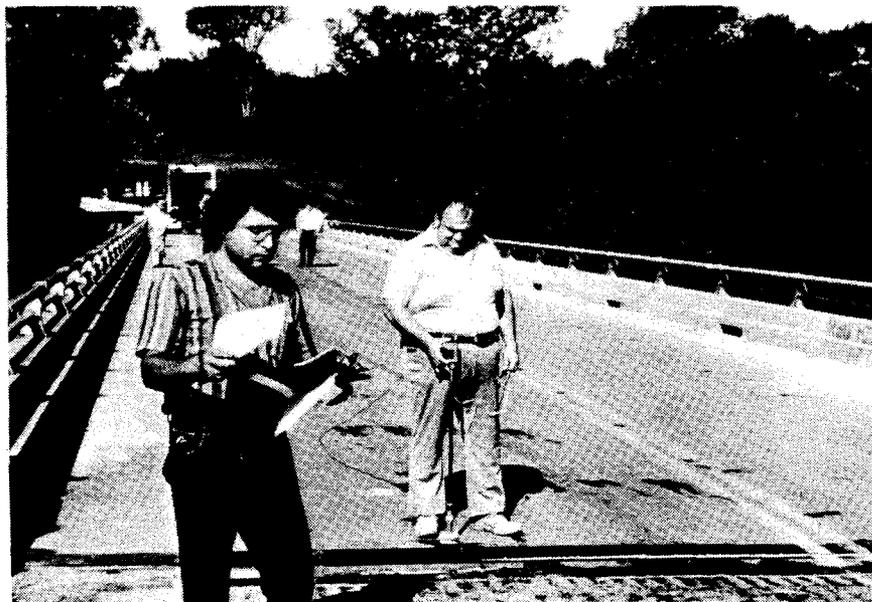


Figure 6. A deck can be marked off into 4- or 5-ft grids, and copper sulfate half-cell potential measurements can be taken at the grid points to identify areas that have a high potential for corrosion (those with measurements more negative than  $-0.35$  volts).



Figure 7. Chloride content measurements can be made on samples of pulverized concrete taken in the vicinity of the reinforcement. A pacometer can be used to locate and to provide an indication of the depth of cover over the reinforcement. A drill should be used to remove the concrete above the sample down to within approximately 1/2 in. of the reinforcement. A vacuum can be used to remove concrete from the drill hole.



Figure 8. The drill should be returned to the hole, and the sample in the vicinity of the reinforcement should be pulverized. A spoon can be used to collect the sample. A chloride content  $\geq 2$  lb/yd<sup>3</sup> can cause corrosion.



Figure 9. The area over which the concrete is to be removed should be "squared up" and marked with paint.

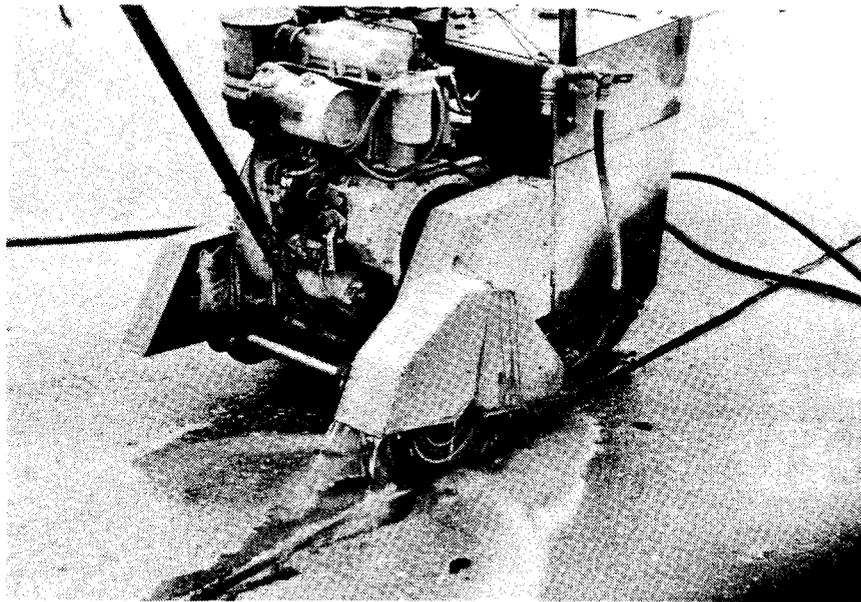


Figure 10. A saw should be used to cut the concrete to a depth of 1 in (or to a depth that will clear the rebar) along the perimeter of the area to be removed.

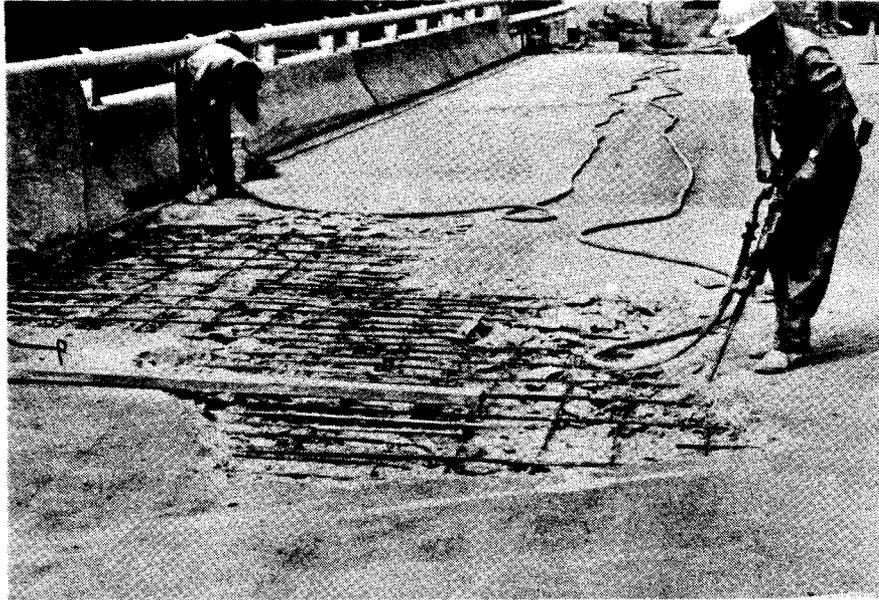


Figure 11. Pneumatic hammers weighing  $\leq 30$  lbs should be used at an angle of 45 to 60° to dislodge the deteriorated concrete in areas to be patched. When rebar is exposed, the concrete shall be removed to a depth of  $\geq 1$  in below the rebar.

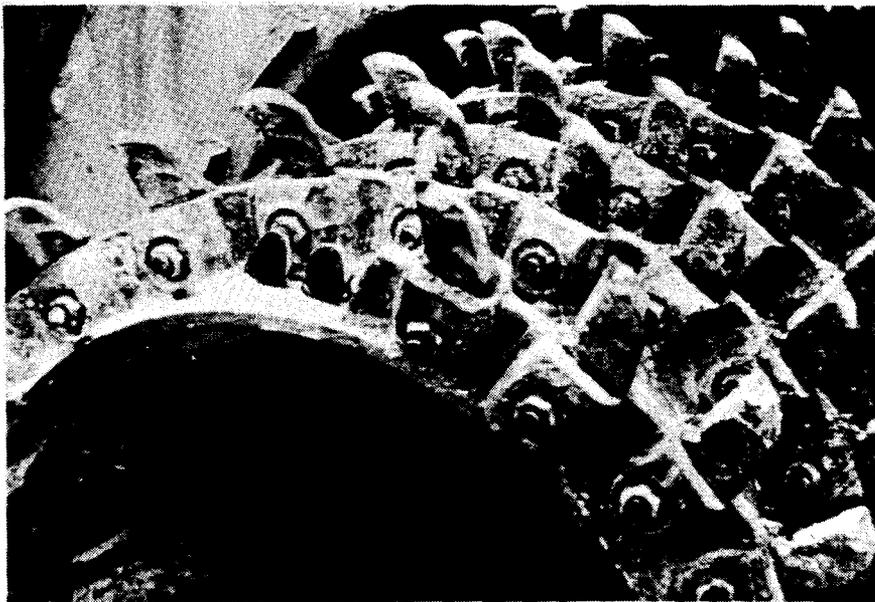


Figure 12. A cold milling machine can be used to remove concrete above the reinforcement. The impact heads of the scarifier shown above can fracture the concrete that is left in place. Care should be taken to remove the fractured concrete. Hand-held pick hammers and heavy grit blasting can be used to remove some of the fractured concrete.



Figure 13. Sandblasting (typically with slag rather than sand) can be used to remove carbonation, laitance, weak surface mortar, and other materials that may be detrimental to the bonding of the overlay or to the repair material.

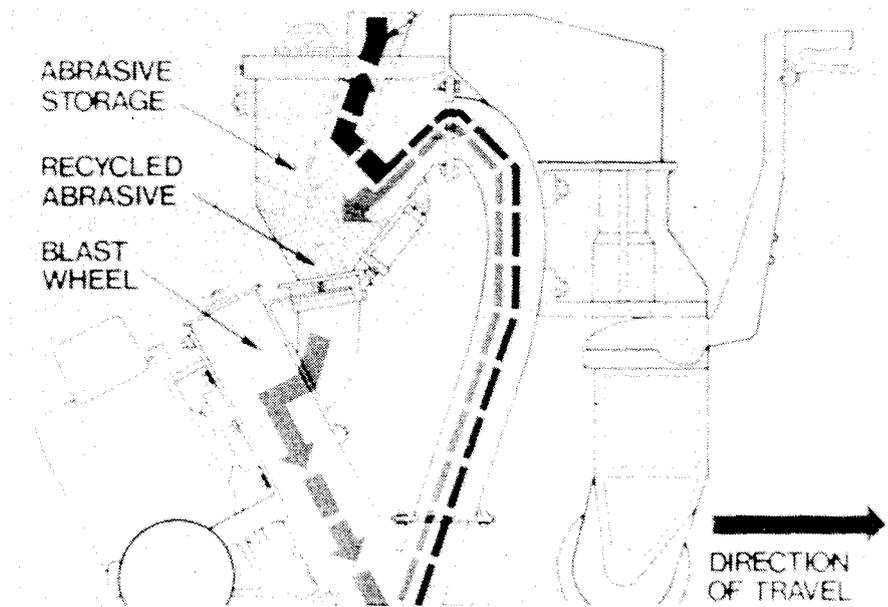


Figure 14. A schematic of a shotblasting unit that can be used to blast the surface with steel shot and to recover the shot and cuttings from the surface.



Figure 15. Shotblast equipment is available in a range of sizes. Units that blast a 9-in-wide strip and a 6-ft-wide strip are shown above.

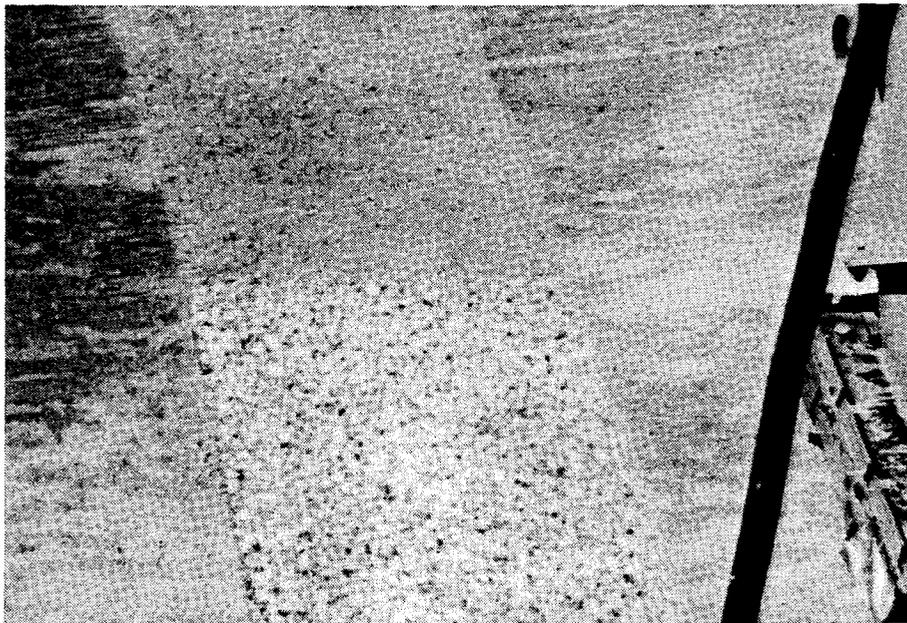


Figure 16. The degree of cleaning obtained with shotblast equipment is a function of the forward speed, the number of passes, the size of the shot, and the gate opening. Once the proper setting is identified, the entire surface should be cleaned at that setting. A slow speed or multiple passes are required to obtain the exposed aggregate surface shown above. The lighter cleaning (top of figure) was obtained by increasing the forward speed of the blaster. It is usually necessary to expose the coarse aggregate to obtain adequate bond strength.

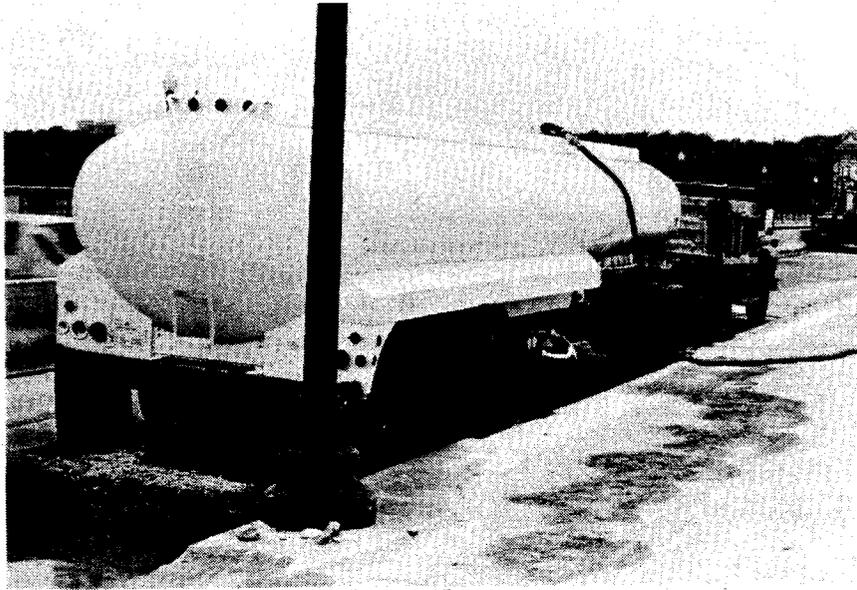


Figure 17. A tank truck can be used to supply water required for hydro demolition.

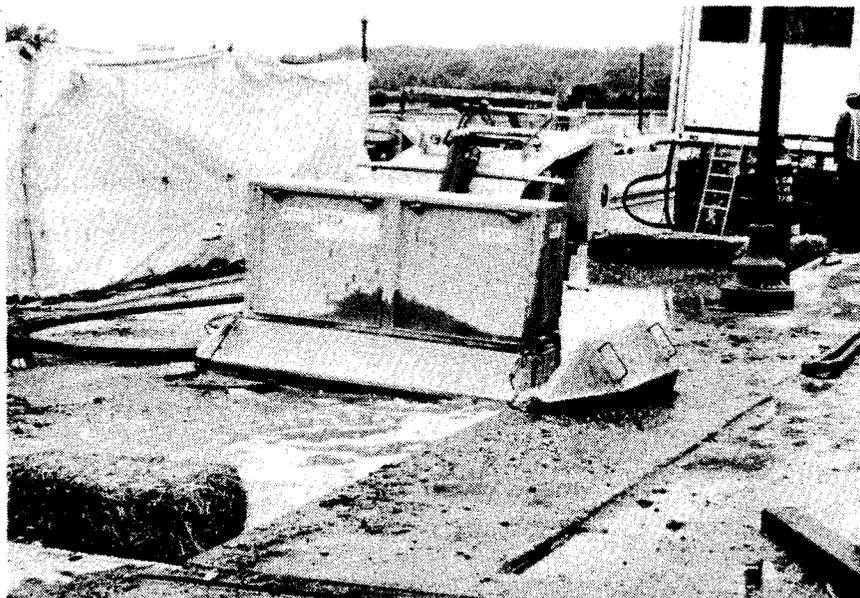


Figure 18. A high pressure water jet moves from left to right inside the blasting unit, thereby removing concrete with a strength that is lower than the pressure setting of the jet.



Figure 19. Concrete can be dislodged and reinforcement can be cleaned by hydro demolition. The dislodged concrete and water must be removed from the surface prior to placing the overlay or repair material. Vacuums, shovels, and air blasting have been used to remove contaminants. Proper containment and disposal of blast water and concrete rubble is necessary.

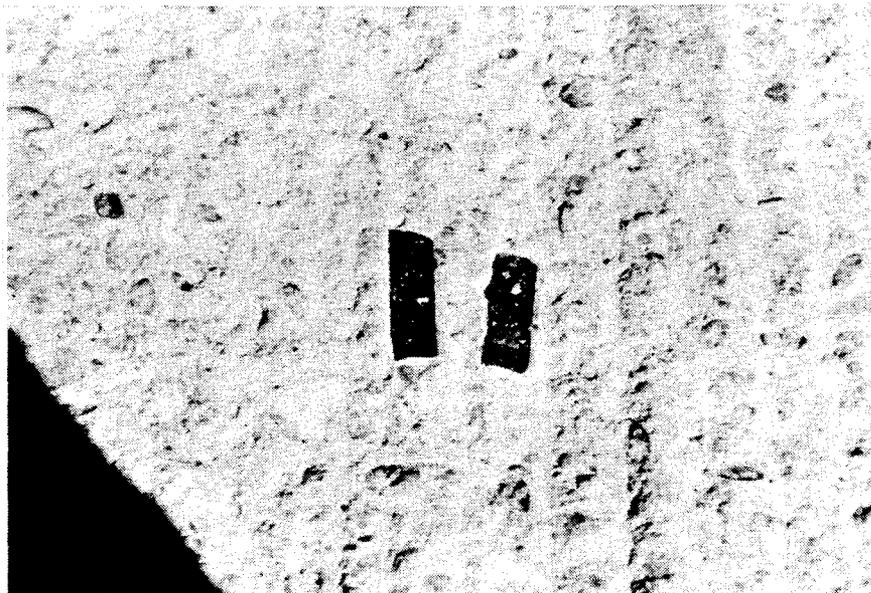


Figure 20. Black electrical tape can be applied to the blasted surface and removed and examined to identify dust that could interfere with the bonding of an overlay or repair material. An acceptable surface will only leave traces of dust on the sticky side of the tape (see tape on left above). The surface should be airblasted with oil-free compressed air to remove dust.

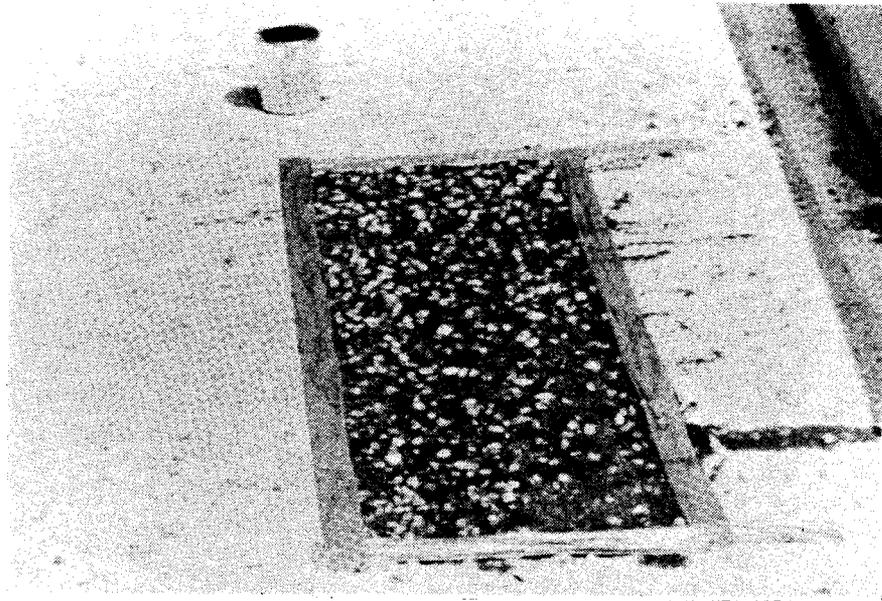


Figure 21. Resin should be applied for first layer of 1 ft x 3 ft test patch for ACI 503R tensile adhesion test.



Figure 22. Aggregate should be broadcast onto resin.

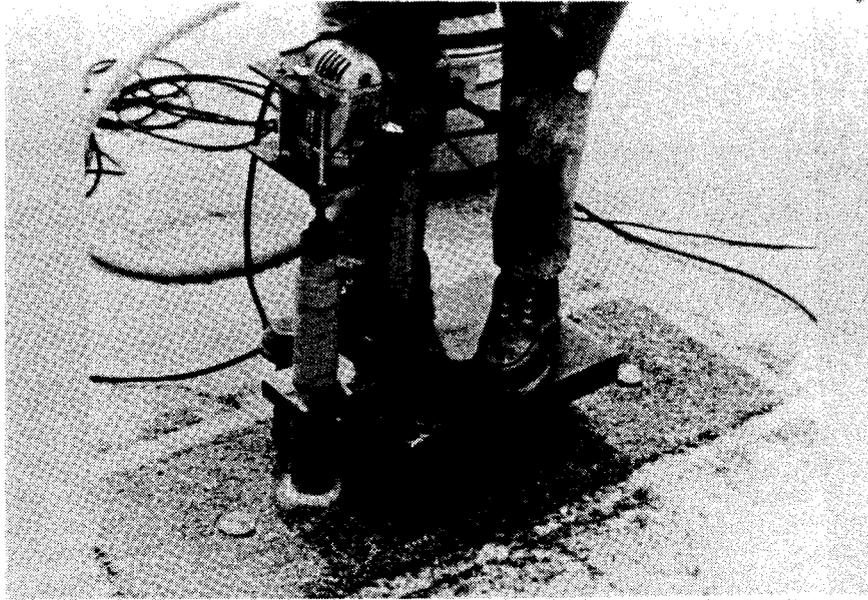


Figure 23. Once the layers required for the overlay are placed and cured for at least 24 hours a 2 1/5-in diameter circular portion to test should be separated by drilling through the overlay to a depth of at least 1/4 in into the base concrete. The area of the test portion should be measured and recorded in square inches.



Figure 24. A pipe cap should be bonded to the surface using a rapid-setting adhesive.

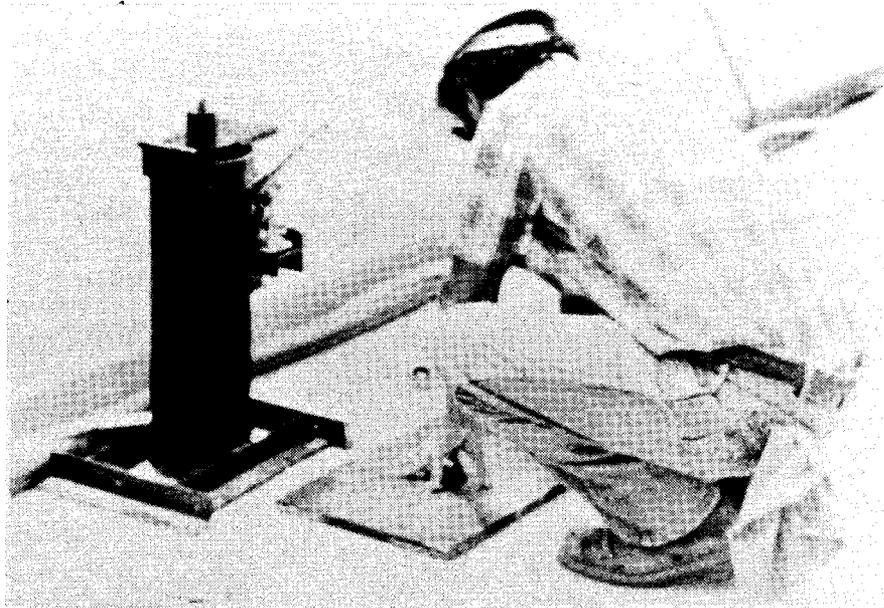


Figure 25. A template should be used to center ACI 503R pull-off device over pipe cap. A dynamometer with a capacity of at least 2,000 lbs should be hooked to the pipe cap and the loading hook and the load applied at the rate of 100 lbs every 5 sec. The dynamometer reading at rupture and the type failure, as percent concrete, bond, and overlay should be recorded.

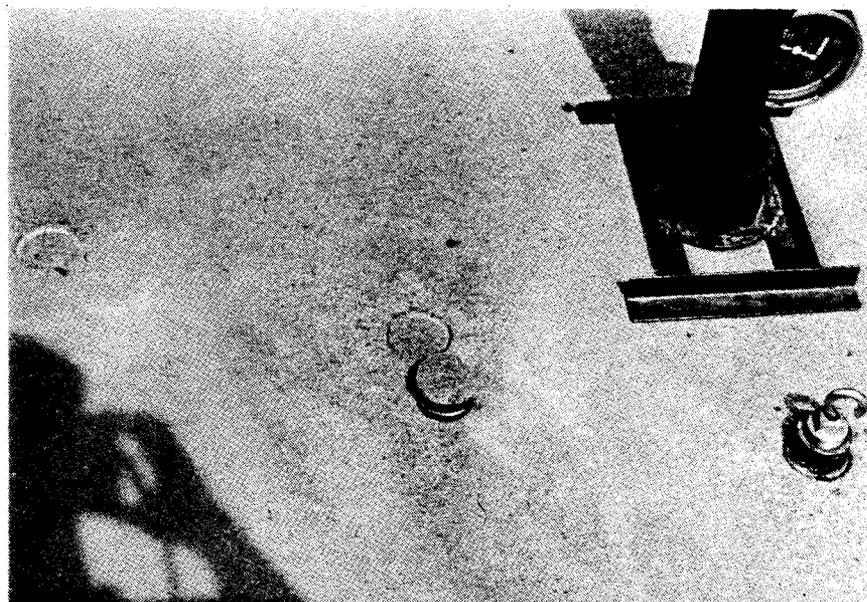


Figure 26. The failure stress should be computed by dividing the dynamometer reading in pounds at rupture by the test area. The average of three tests performed on each test patch should equal or exceed 250 psi. A failure in the base concrete at a depth greater than 1/4 in and at a rupture strength less than 250 psi is indicative of a low strength substrate and not of inadequate surface preparation.

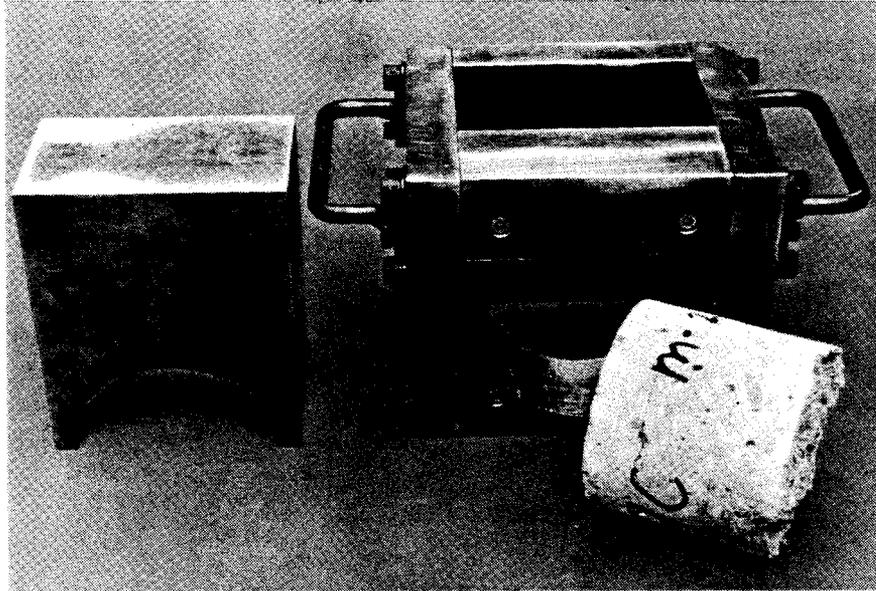


Figure 27. A guillotine shear apparatus can be used to measure the shear bond strength of 4-in diameter cores removed from a deck or overlay specimens prepared in the laboratory.

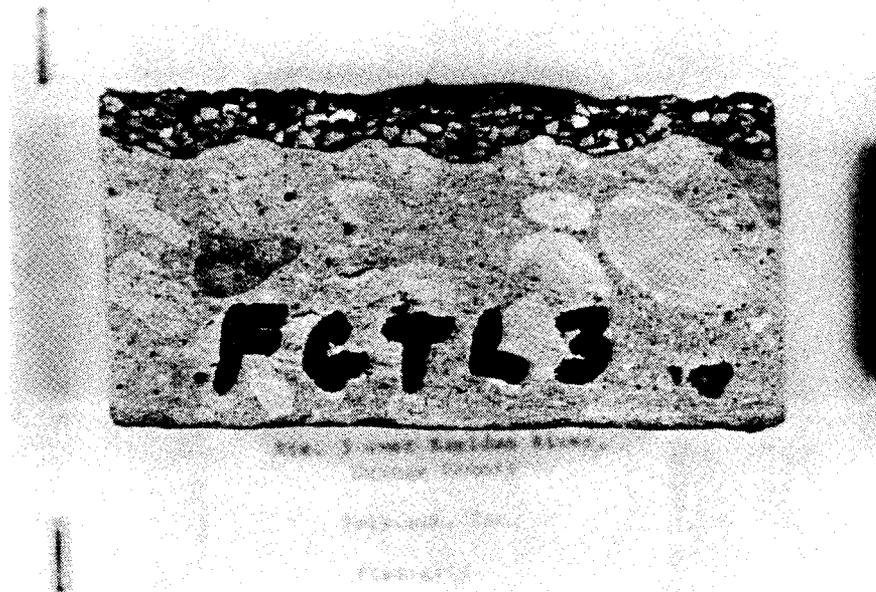


Figure 28. A core with epoxy urethane concrete overlay provides an excellent example of proper surface preparation. The overlay is bonded to the coarse aggregate rather than to a thin layer of weak surface mortar.



Figure 29. A slump test (ASTM C143) can provide an indication of the workability of hydraulic cement concrete. The temperature and the air content of the concrete should also be measured and recorded.

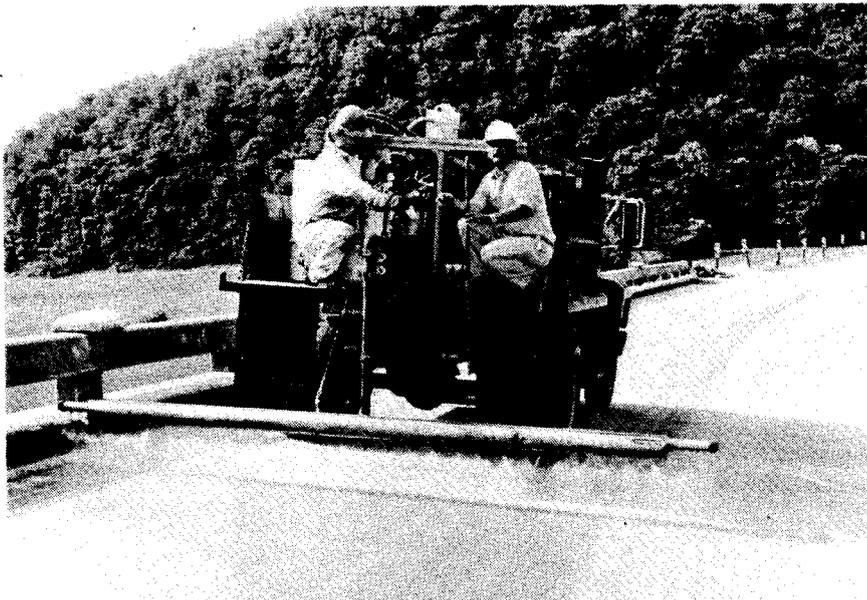


Figure 30. A 100 ml paper cup attached to the end of a wooden pole can be used to obtain a 50 ml sample of resin so that the gel time can be measured. Consistent gel times in the range of 10 to 20 minutes provide an indication that resins are being mixed properly and should cure properly in a multiple-layer polymer overlay. The viscosity of the resin should be measured in the laboratory prior to approving the material for use.

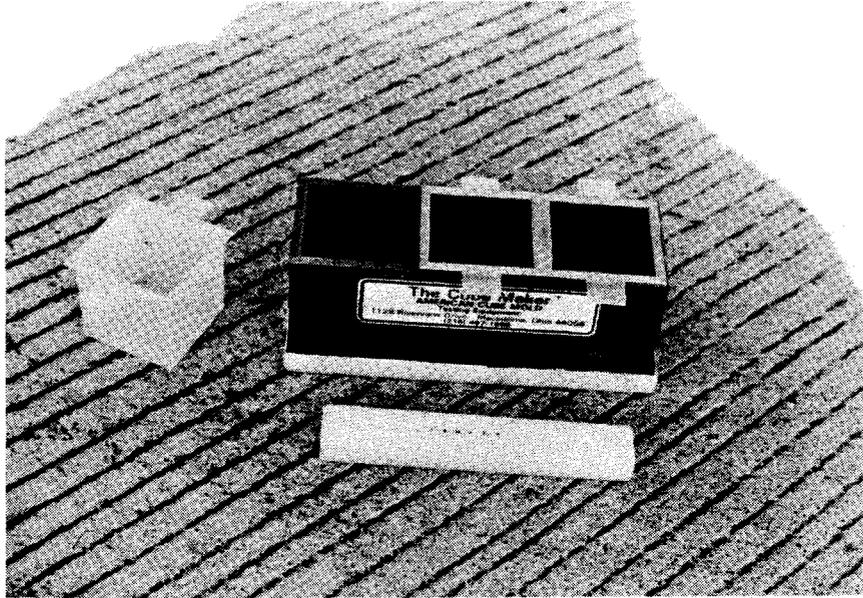


Figure 31. A two-inch cube mold with plastic liners can be used to make mortar cubes that can be tested for compressive strength.

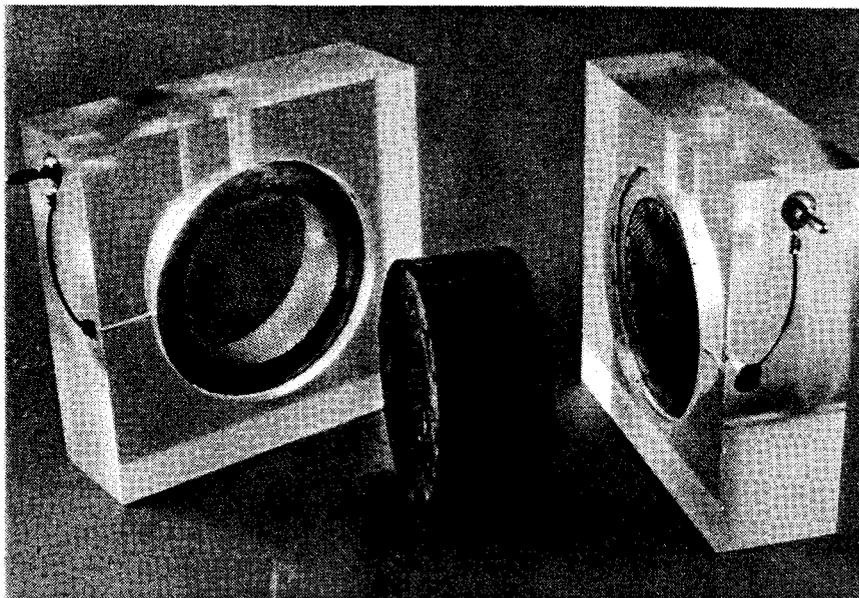


Figure 32. A 2-in thick by 4-in diameter specimen ready to be placed between two plastic cells to measure its permeability to chloride ion (AASHTO T277).

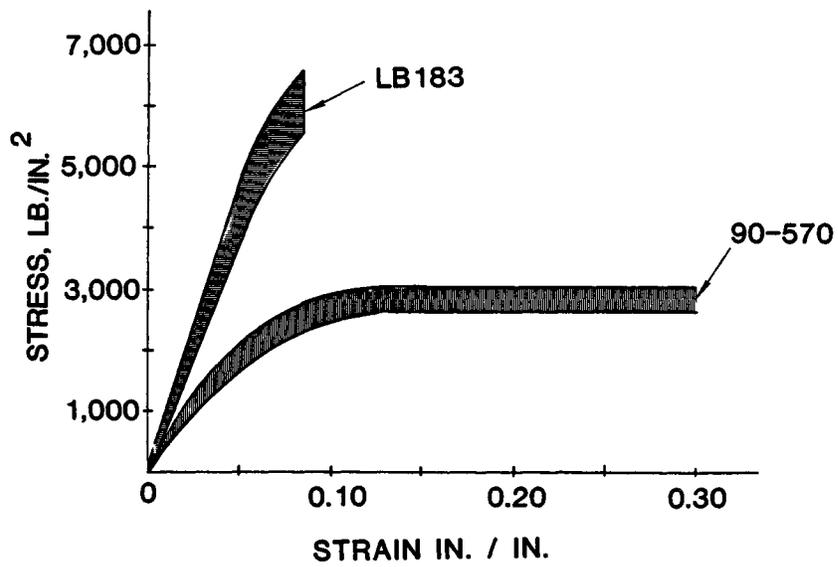


Figure 33. Stress v. strain curves for neat tensile specimens of polyester styrene showing the difference between a brittle high strength binder (LB183) and a more flexible low strength binder (90-570) typical of that used in a multiple-layer polymer overlay.



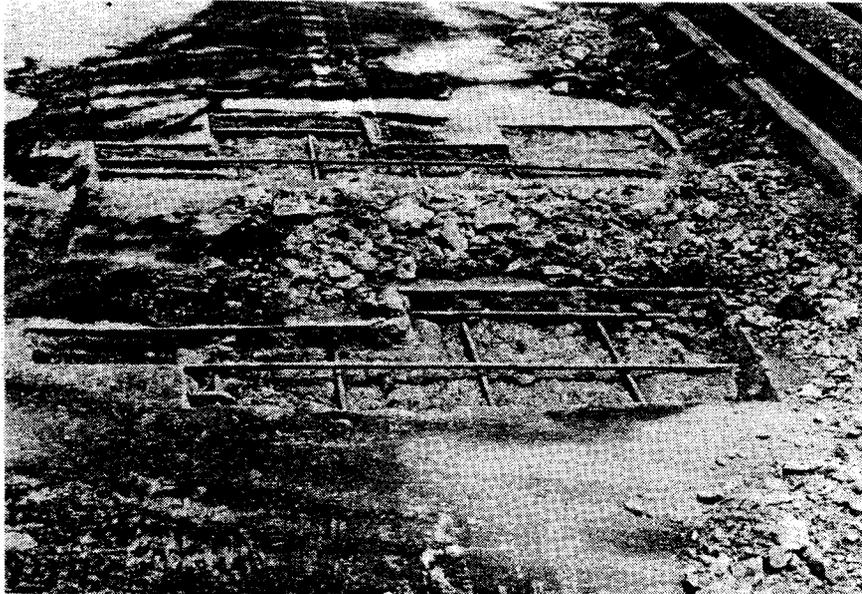


Figure 1. Class II surface preparation required for Type B patches (approximately 1/2 deck thickness). Note that the area to be patched has been squared up, the perimeter has been sawed to a depth of 1 in, the concrete has been removed with pneumatic hammers to a depth of 1 in. below the rebar, and the surfaces of the concrete and reinforcement have been blasted with slag.

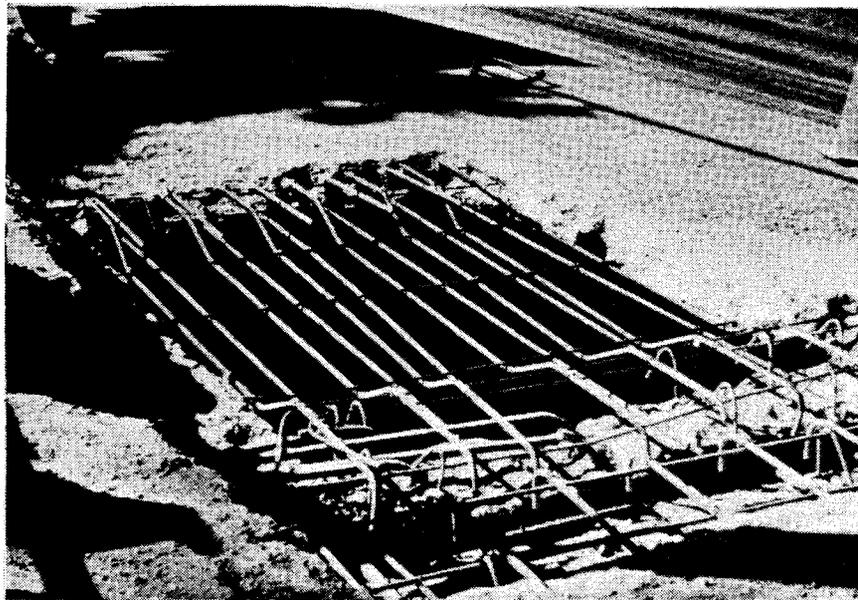


Figure 2. Class III surface preparation required for Type C patches (full depth). Forms may be suspended from reinforcing steel (areas  $< 3 \text{ ft}^2$ ) or supported by blocking from beam flanges.



Figure 3. Type D patches (epoxy mortar) are used for shallow repairs ( $\leq 3/4$  in deep). Areas to be patched shall be dry and shall be primed with neat epoxy prior to placing the mortar.

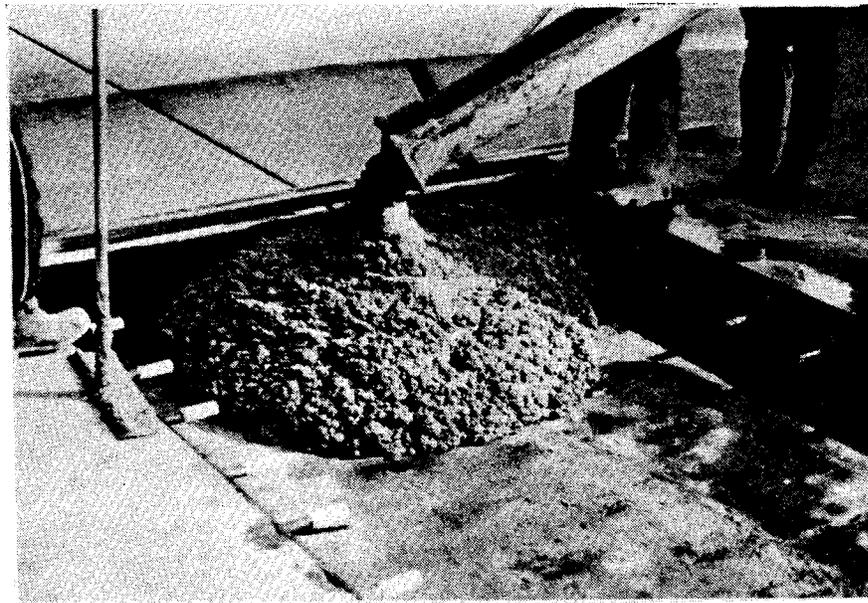


Figure 4. Ready-mix concrete is usually used for large full-depth patches such as large Type C patches or full-depth pavement patches as shown here. Areas to be patched shall be prepared and concrete placed as specified in Sections 416.07 and 416.08 of the Road and Bridge Specification.



Figure 5. The ready-mix concrete should be consolidated with internal vibrators, struck off, textured with a broom as shown here (other textures may be specified) and covered with burlap and polyethylene or liquid membrane curing material. When the patches must be opened to traffic in much less than 24 hrs, the ready-mix concrete is usually made with Type III cement and accelerating admixtures or special high early strength blended cements.



Figure 6. Prepackaged rapid hardening cementitious materials are usually used for Type A, Type B, and small Type C patches. A mortar mixer (shown here) may be used if coarse aggregate is not used to extend the mixture. The rapid-hardening materials are very sensitive to the quantity of water used. The calibrated containers shown here should be used to measure out the required weight of water.



Figure 7. A wheelbarrow is usually used to transport mixed ingredients a short distance to the patch site.



Figure 8. The mixture is usually poured from a wheelbarrow into the cavity. Internal spud vibrators are used to consolidate the concrete.

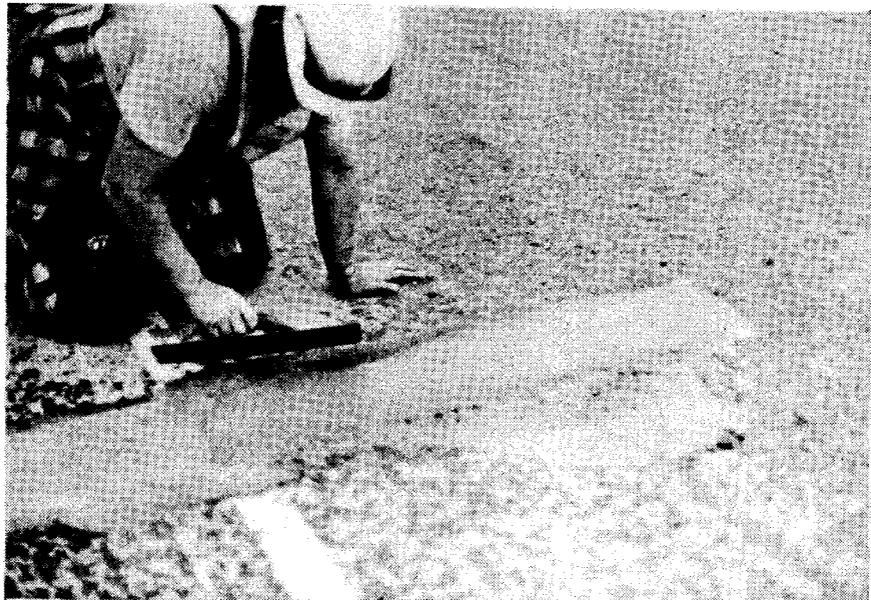


Figure 9. A straightedge or float can be used to level the concrete.

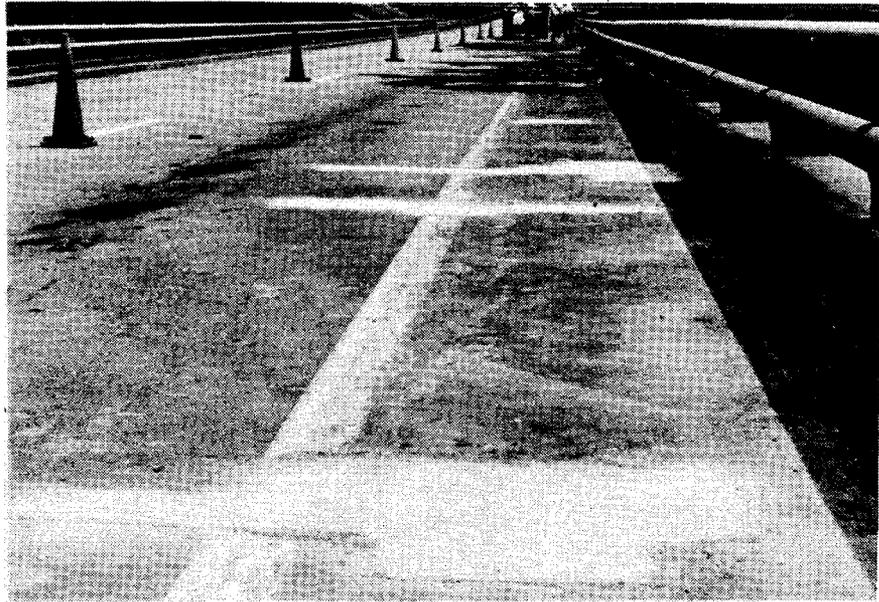


Figure 10. Liquid membrane curing material or other curing material should be applied as quickly as possible after striking off the patching mixture to prevent the evaporation of water from the mixture, which can cause plastic shrinkage cracks.



Figure 11. High molecular weight methacrylate resin can be applied to the surface of a bridge deck with brooms to fill random cracks such as those caused by plastic shrinkage. An effort should be made to brush the resin into the cracks until the cracks appear to be filled by the brooming action and the force of gravity. Sand must be broadcast onto the resin to provide an acceptable skid number. The sand may be omitted if the resin is applied to a grooved or tined surface, but care must be taken to ensure that the resin does not fill the grooves (see Figure 14 pg 2-8).



Figure 12. High molecular weight methacrylate can be applied to a crack. For satisfactory filling of the crack, it should be free of debris and wider than 0.1 mm. Also, best results can be obtained by filling cracks when they are open the widest at the surface (temperatures between 55°F and 70°F and between 1:00 a.m. and 10:00 a.m). High molecular weight methacrylate will not cure satisfactorily at temperatures below 55°F.



Figure 13. A pressurized spray can be used to apply high molecular weight methacrylate resin to a crack. For best results, a brush should be used to work the resin into the crack.

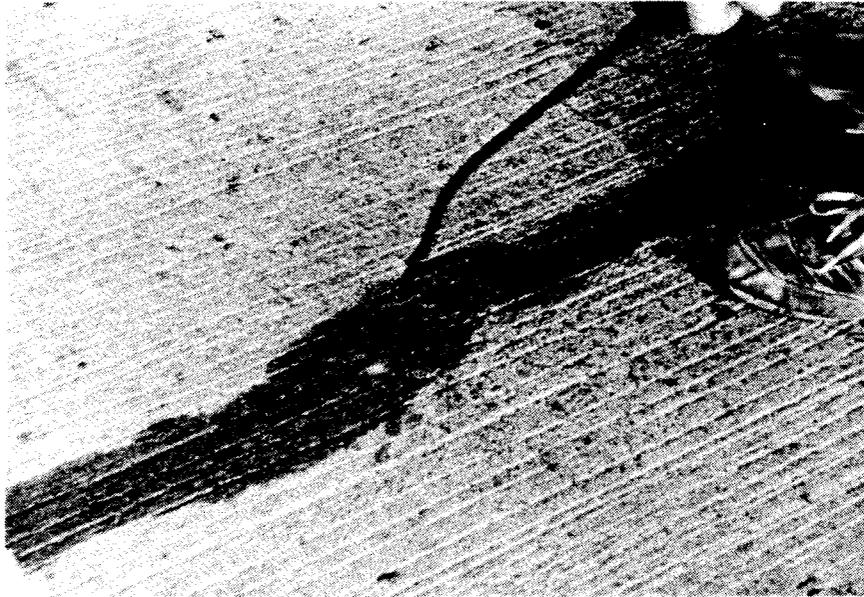


Figure 14. High molecular weight methacrylate resin is here applied to a crack in a deck with a tined texture. Excess resin should be spread with a broom to prevent filling the grooves, which can cause a reduction in skid resistance.

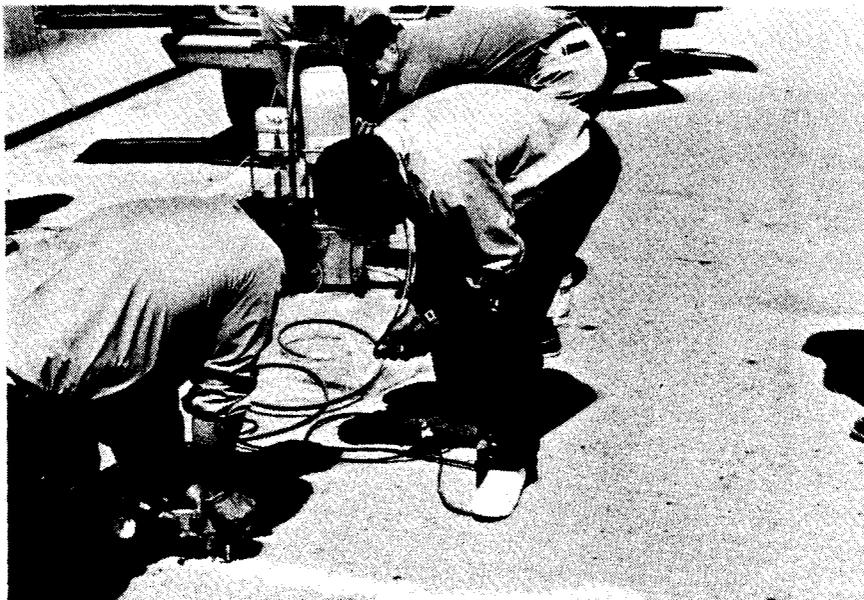


Figure 15. A two-component epoxy is here injected into a crack under pressure. Prior to injecting the epoxy, the crack should be covered above and below with a viscous paste-like epoxy and injection ports should be spaced at a distance equal to the depth of the crack to be injected. The requirements for successful filling of a crack cited under Figure 12 (pg 2-7) are also generally applicable to pressure injection.



Figure 16. Vacuum injection can be used to fill cracks with a methacrylate resin. Prior to introducing the resin, steel entry ports should be placed on the crack surface, the cracks are covered above and below with a viscous paste-like epoxy, and a vacuum is applied to the cracks through the ports. The requirements for successful filling of a crack cited under Figure 12 (pg 2-7) are also generally applicable to vacuum injection.





Figure 1. A mobile concrete mixer can be placed on a deck surface that has been prepared for application of a latex modified concrete overlay. The surface should be scarified, patched, sandblasted (48 hours prior to application of overlay), sprayed with water, and covered with polyethylene at least 1 hour prior to placement to obtain a sound, clean, saturated surface dry condition (saturated deck with no free water on the surface). The truck usually has compartments that contain coarse aggregate, fine aggregate, cement, latex, and water. The ingredients are usually conveyed to an auger type mixer and mixed just prior to being discharged onto the deck surface. The truck must be calibrated to provide the desired mixture. District Materials personnel should approve the calibration. Requirements for preparing the concrete surface and placing and curing the concrete can be found in Sections 404.16 and 416.09 of the Road and Bridge Specification.

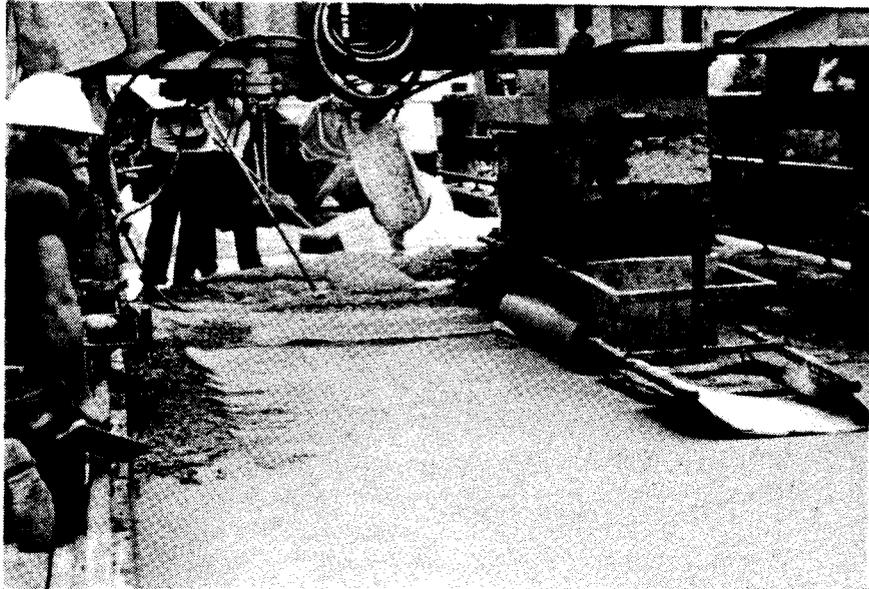


Figure 2. The latex modified concrete should be discharged onto the deck surface as the layer of polyethylene is rolled back. Brooms should be used to brush the mortar fraction of the concrete into the base concrete just ahead of the placement. A transverse rotating drum-type screed that moves back and forth can be used to consolidate, strike off, and finish the concrete. Internal spud vibrators should be used to consolidate the concrete along the edges (the centerline and the parapet), in deep pockets (patches), and adjacent to joints. Hand floats may be used to strike off and finish the concrete along the edges.

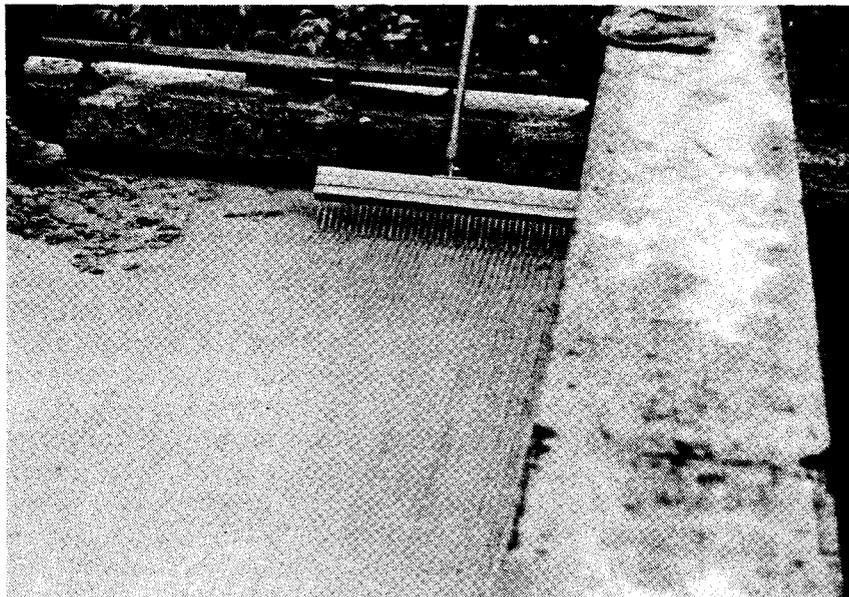


Figure 3. A tining device should be pulled across the surface as soon as possible after the finishing operation is complete to produce grooves that are approximately  $1/8$  in wide and  $1/8$  in deep and 1 in apart to produce a surface with a high skid resistance. The hardened concrete may be sawed to produce grooves.

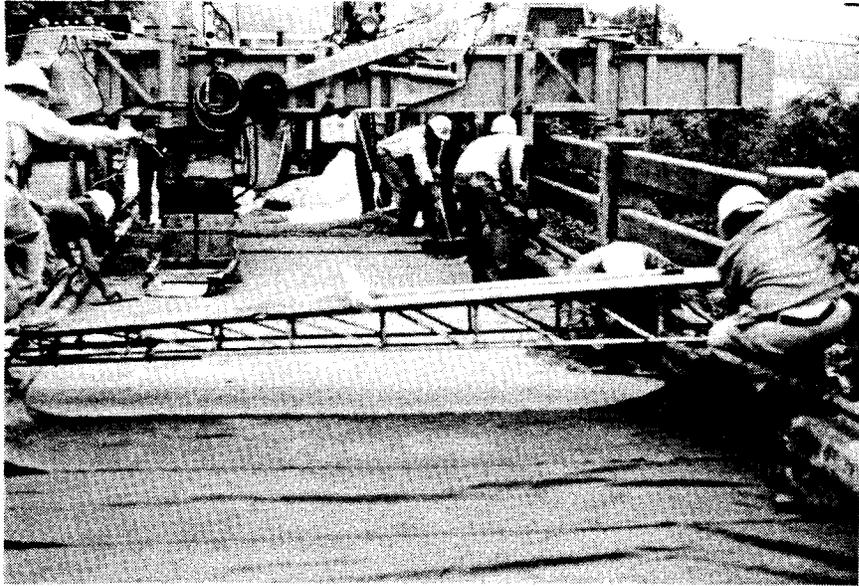


Figure 4. Wet burlap should be applied to the surface as soon as the tining operation is complete. The burlap should be applied as soon as possible to prevent evaporation of water from the mixture, which can cause plastic shrinkage cracks.

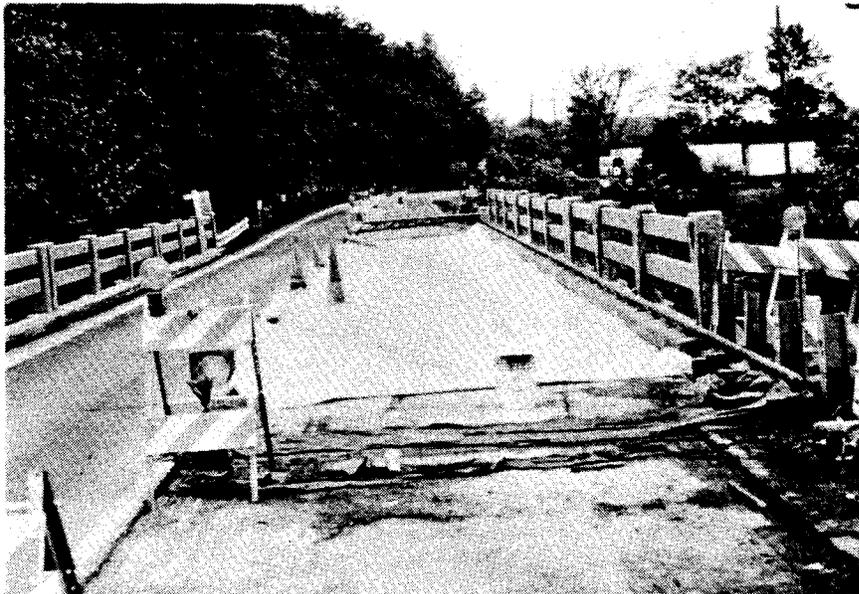


Figure 5. The wet burlap should be covered with polyethylene as soon as possible to prevent water from evaporating from the burlap. The wet burlap and polyethylene should be left in place for 24 to 48 hours. The burlap should be kept moist during the curing period.

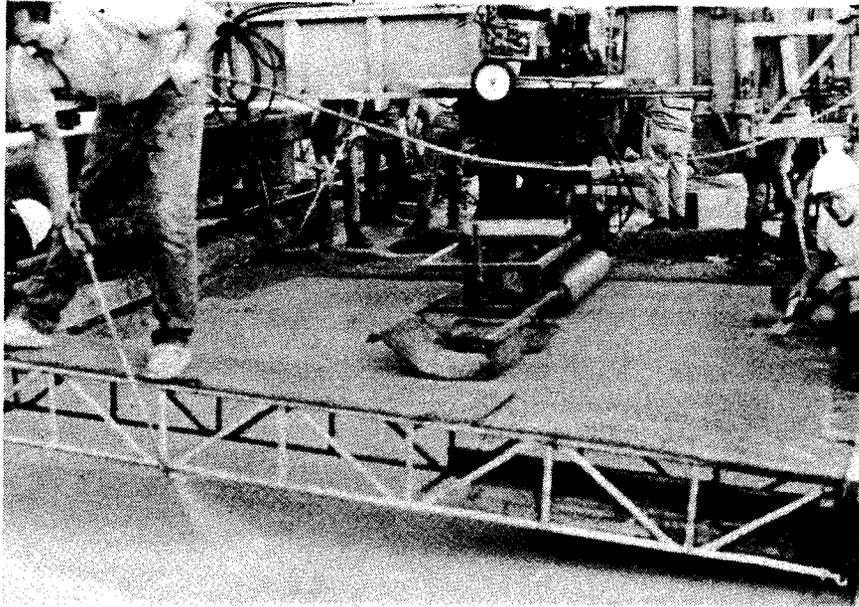


Figure 6. Liquid membrane curing materials applied at a rate  $\geq 1$  gal per 200 ft<sup>2</sup> have been recently used on an experimental basis to successfully cure latex modified concrete.

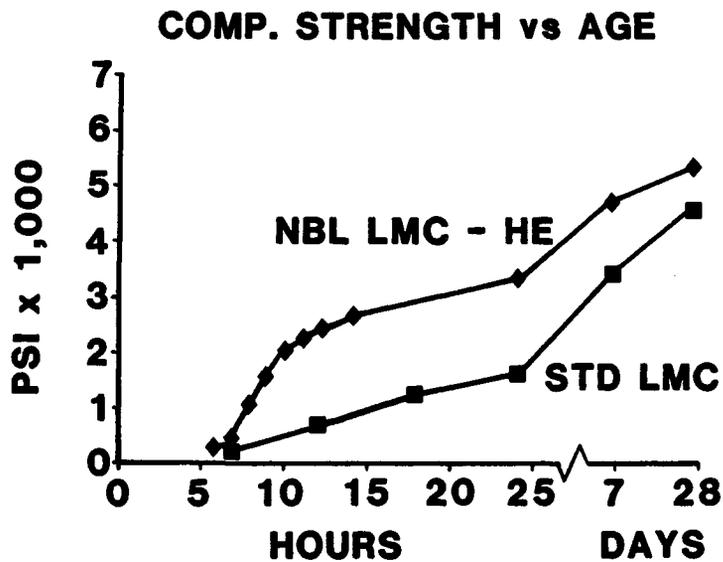


Figure 7. Latex modified concrete batched with Type III cement has been successfully used to increase the early age compressive strength of overlay mixtures. The figure compares the compressive strength development of the high early strength mixture with that of the standard latex modified concrete mixture. Typically, 3 or 4 days are required to obtain 3,000 psi for the standard latex mixture as compared to 24 hours for the high early strength mixture. A compressive strength of 3,000 psi is required to open the overlay to traffic.

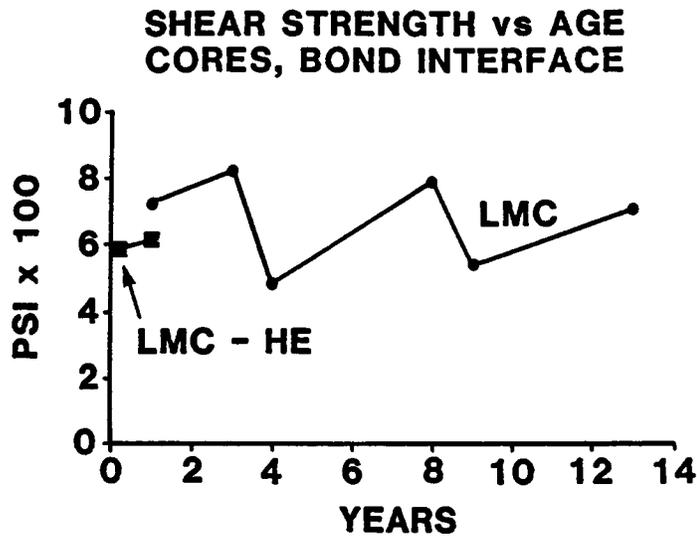


Figure 8. The results of guillotine shear bond strength tests on 4-in-diameter cores taken from latex modified concrete overlays ranging in age from 24 hours (high early strength mixture) to 13 years are shown. The data indicate that high bond strengths in the range of 500 to 800 psi have been obtained and maintained on the representative sample of overlays evaluated. Delaminations can occur when bond strengths drop below 200 psi.

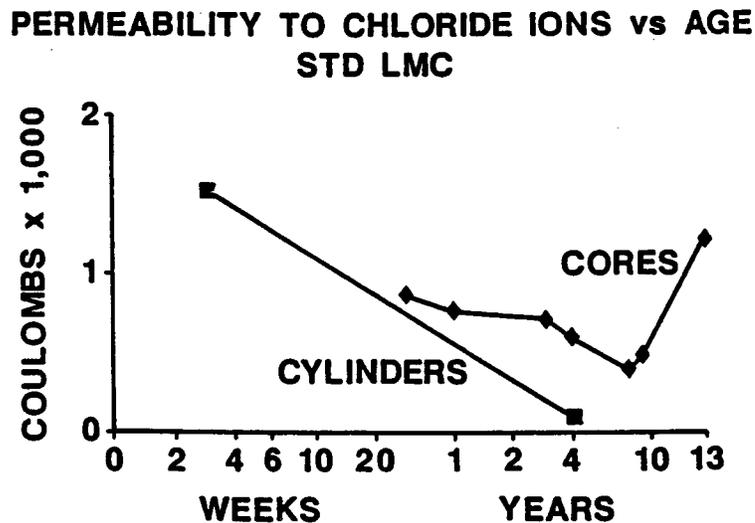


Figure 9. The results of tests for permeability to chloride ion (AASHTO T277) on cylinders made of latex modified concrete and on cores taken from bridge decks indicate that permeability at 6 weeks of age and later is less than 1,000 coulombs, and the permeability decreases with age.

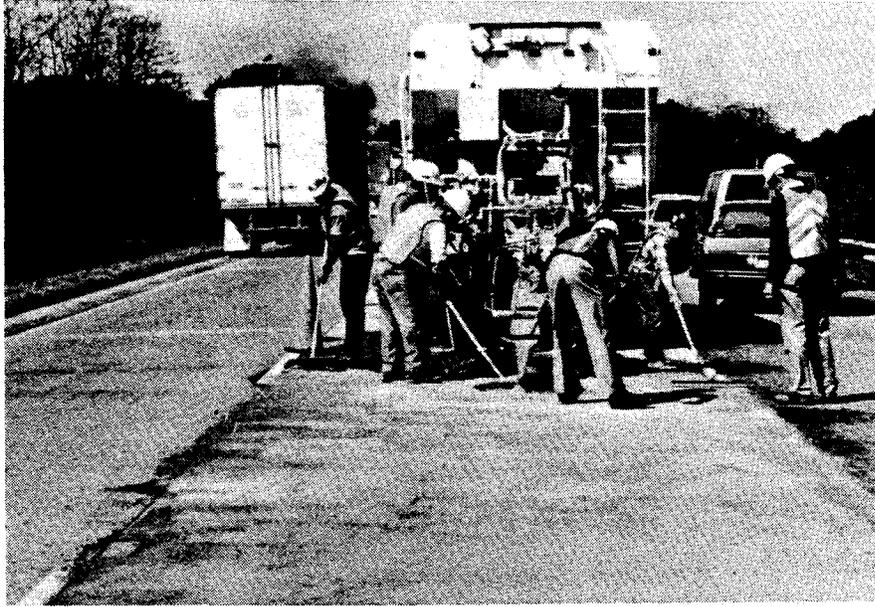


Figure 10. A latex modified slag slurry overlay is applied to a concrete pavement to increase its skid resistance. The surface should be shotblasted prior to placing the slurry (see Figure 15, pg. 1-8).



Figure 11. A latex modified slag slurry overlay may be applied to a bridge deck to increase the skid resistance. Brooms should be used to brush the slurry into the shotblasted surface.



Figure 12. The latex modified slag slurry should be struck off and pulled forward with gage rakes set to provide a  $3/16$  in to  $1/4$  in thick slurry. For increased skid resistance slag should be broadcast onto the struck off surface. The slurry should be protected from drying by prompt application of wet<sub>2</sub> burlap and polyethylene when the evaporation rate exceeds  $0.05 \text{ lb/ft}^2/\text{hr}$ .

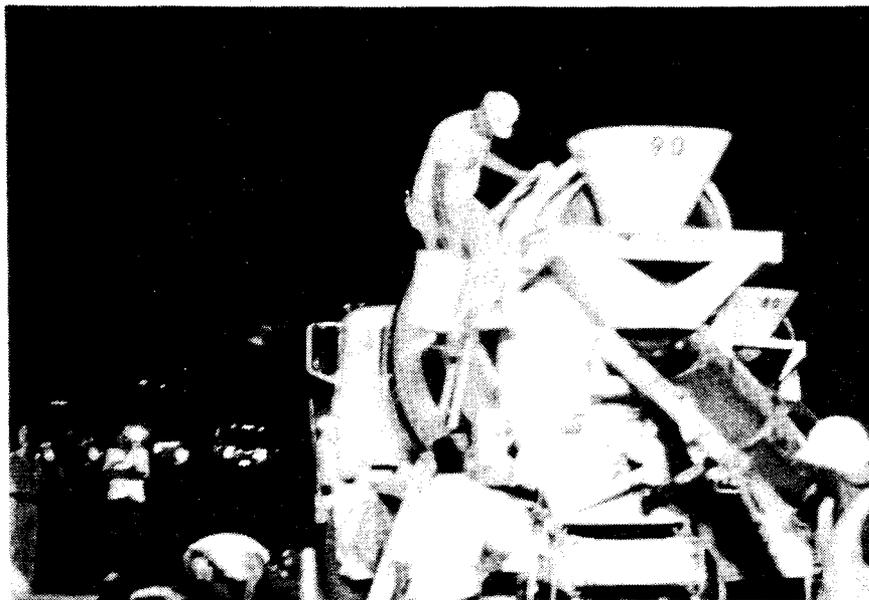


Figure 13. Portland cement concrete mixtures containing silica fume and admixtures other than latex emulsion are usually delivered to the job site as ready-mix concrete. The silica fume admixture is usually added at the plant but additional high range water reducing admixture is sometimes added at the job site to increase the workability of the concrete.



Figure 14. A concrete mixture containing silica fume is here discharged onto the deck surface. The surface has been prepared in the same way it would be prepared for a latex modified concrete overlay (see Figure 1, pg. 3-1). The installation of the overlay is the same as described in Figures 2 through 6 (pg. 3-2 through 3-4) for a latex modified concrete overlay. Compressive strengths greater than 3,000 psi can be obtained in 24 hours with concrete mixtures containing 7 to 10 percent silica fume. Both latex modified concrete and concrete containing silica fume can be used to produce overlays with a permeability to chloride ion (AASHTO T277) of less than 1,000 coulombs.

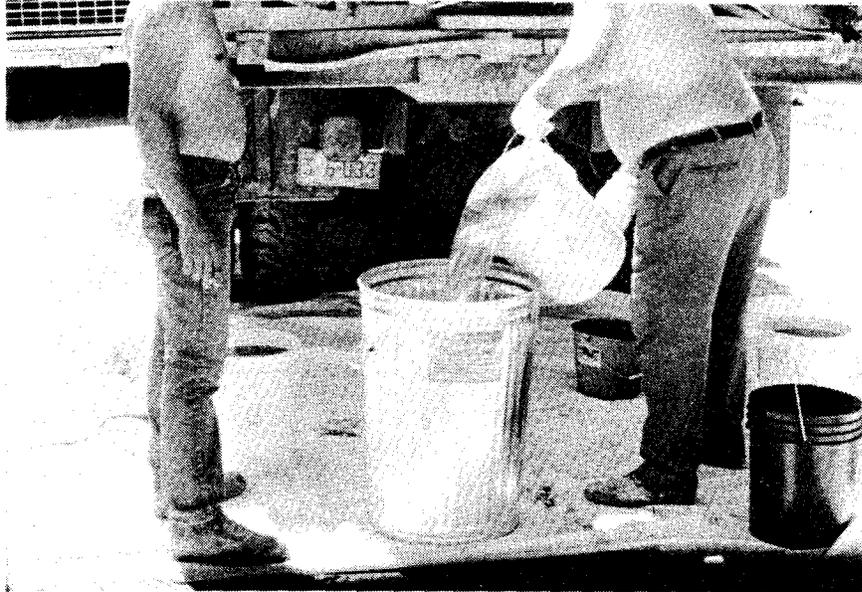


Figure 15. Binders for epoxy concrete overlays are usually 1 to 1 or 2 to 1 mixtures. Care should be taken to carefully measure out the desired quantity of component A and component B. The components should be added to a mixing container and mixed with a paddle type mixer for several minutes (or as recommended by the manufacturer) to insure complete mixing.



Figure 16. Epoxy should be applied to the deck surface immediately after it is mixed and spread over a premarked area with notched squeegees to insure a uniform application at the specified application rate. Prior to placing the epoxy overlay, or any type of polymer overlay, the surface should be shotblasted to remove oil, carbonation, laitance, weak surface mortar, and other materials that can interfere with the bonding of the overlay (see Figure 15, pg. 1-8).



Figure 17. An epoxy urethane mixture is here spread over the deck with notched squeeeges. Basalt aggregate is here broadcast to excess from the back of a dump truck.

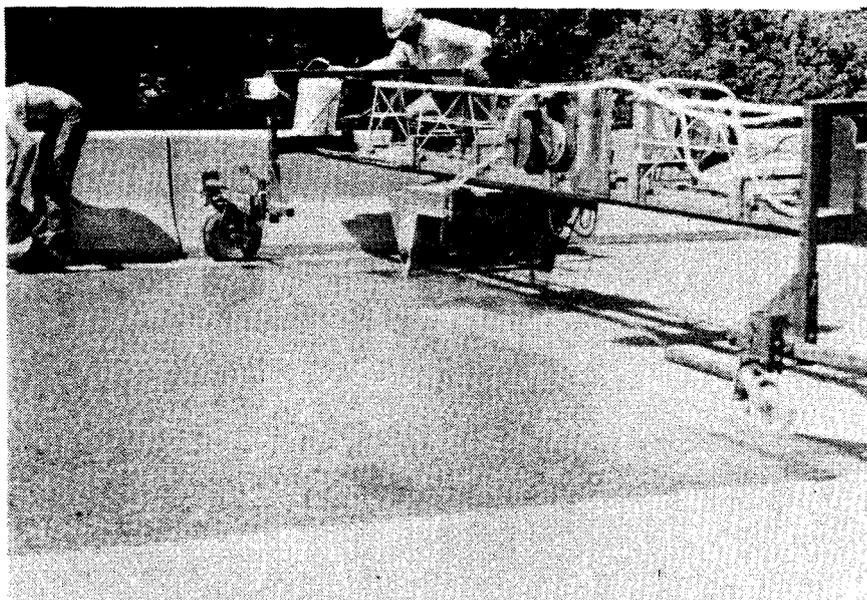


Figure 18. An aggregate spreader oscilates in the transverse direction broad-casting basalt aggregate to excess onto an epoxy urethane binder. The aggregate should be placed within 5 minutes after the binder is mixed.



Figure 19. High molecular weight methacrylate primer should be applied to a deck surface approximately 1 hour prior to application of the first layer of polyester styrene resin for a multiple-layer polyester/methacrylate overlay. (The primer must gel on the surface of the deck prior to placing the polyester styrene resin). Workers should wear rubber gloves and boots and impermeable clothing to keep polymer materials off their skin. Skin that is exposed to polymer materials should be washed immediately with soap and water or as recommended by the polymer supplier.

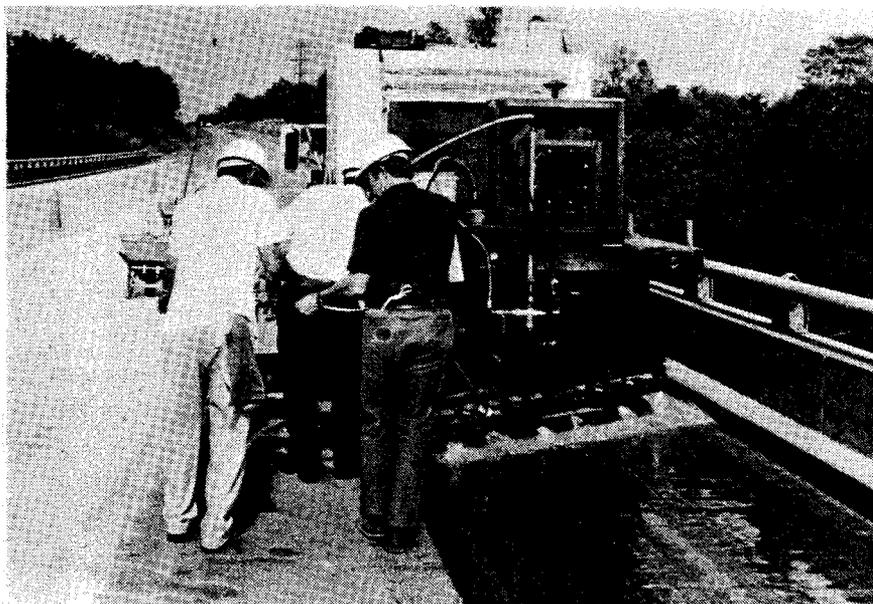


Figure 20. Polyester styrene resin can be applied with spray bar.

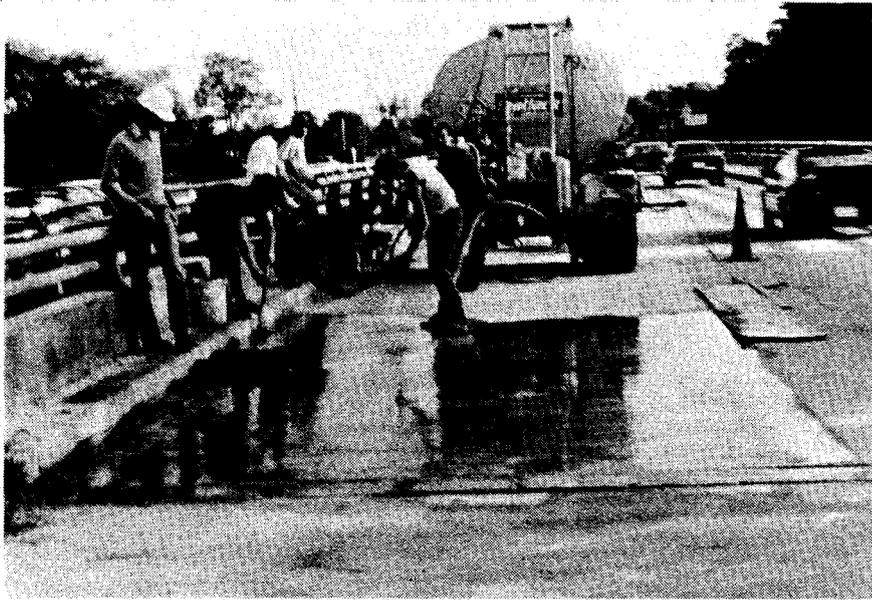


Figure 21. Polyester styrene resin can be applied with spray gun.



Figure 22. Aggregate can be applied to excess using a wing spreader.

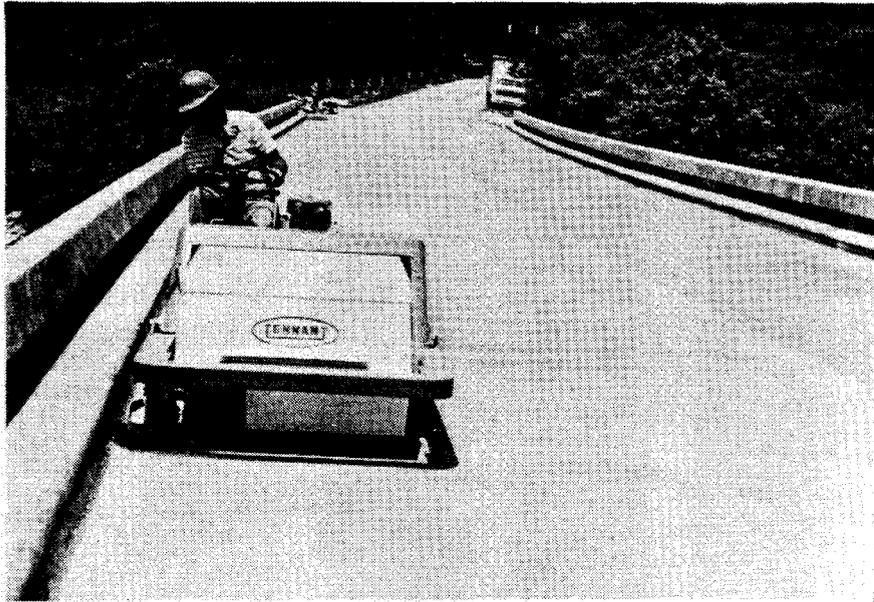


Figure 23. A sweeper-broom type vacuum truck can be used to remove excess aggregate prior to placing the next layer of a multiple-layer polymer overlay.



Figure 24. An epoxy urethane binder that has been blended with positive displacement pumps and mixed with an in-line static mixer is here deposited onto the surface with a wand. Squeegee can be used to spread the resin over the required area and aggregate can be broadcast to excess with shovels from the back of a dump truck.

### TENSILE BOND STRENGTH vs AGE

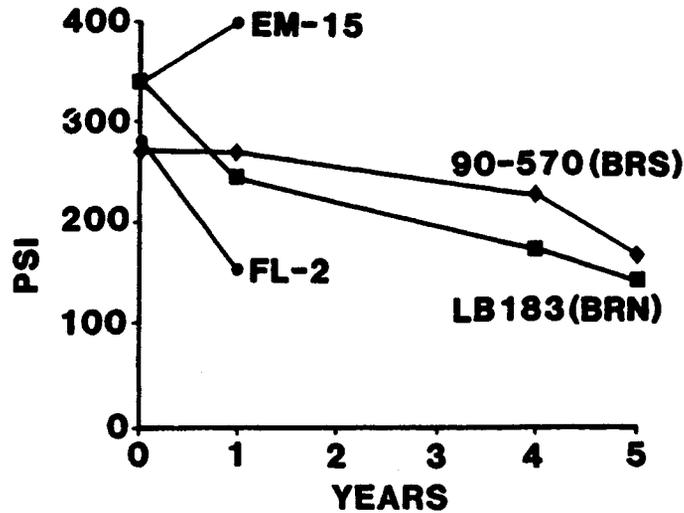


Figure 25. Tensile bond strength (ACI 503R) as a function of time for typical multiple-layer polymer overlays. Properly constructed overlays should remain bonded for at least 10 years. Delaminations can occur when bond strengths drop below 100 psi.

### PERMEABILITY OF CHLORIDE IONS vs AGE and No. THERMAL CYCLES 90-570 BEULAH ROAD

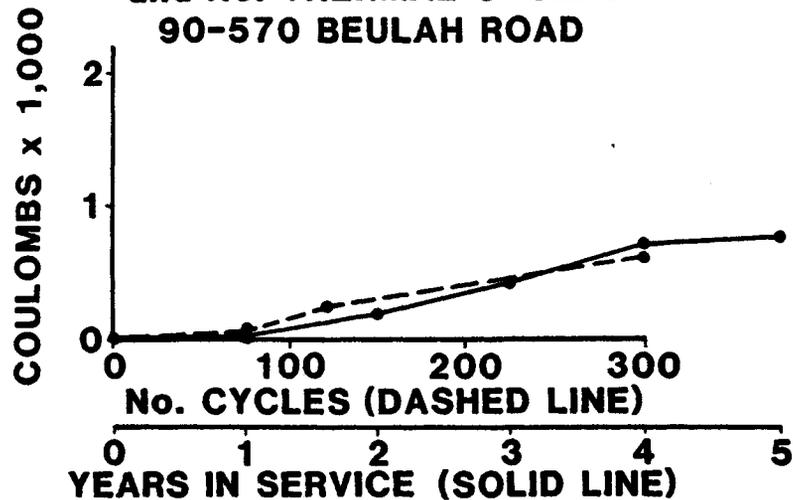


Figure 26. Permeability to chloride ion (AASHTO T277) for a polyester styrene multiple-layer polymer overlay as a function of time. The permeability increases with age but should be less than 1,000 coulombs for 10 years for properly constructed overlays.

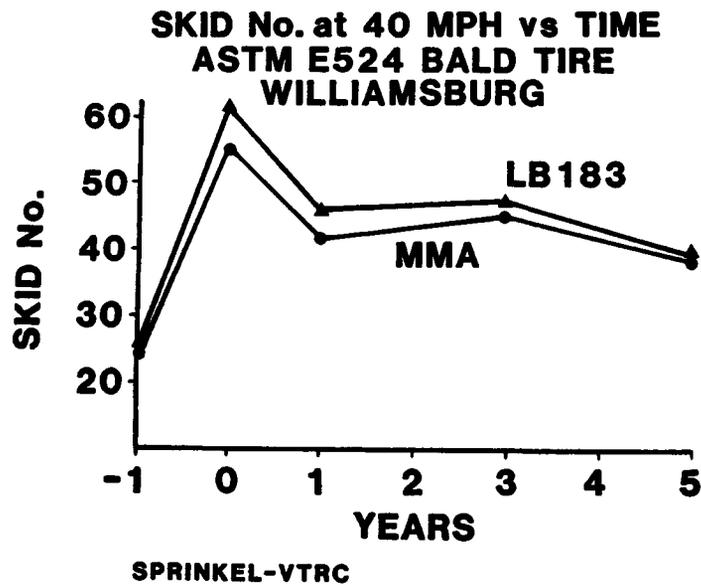


Figure 27. Bald tire skid number (ASTM E524) as a function of time for typical multiple-layer polymer overlays. Properly constructed overlays should provide acceptable skid resistance for more than 10 years even on high-traffic-volume bridges.

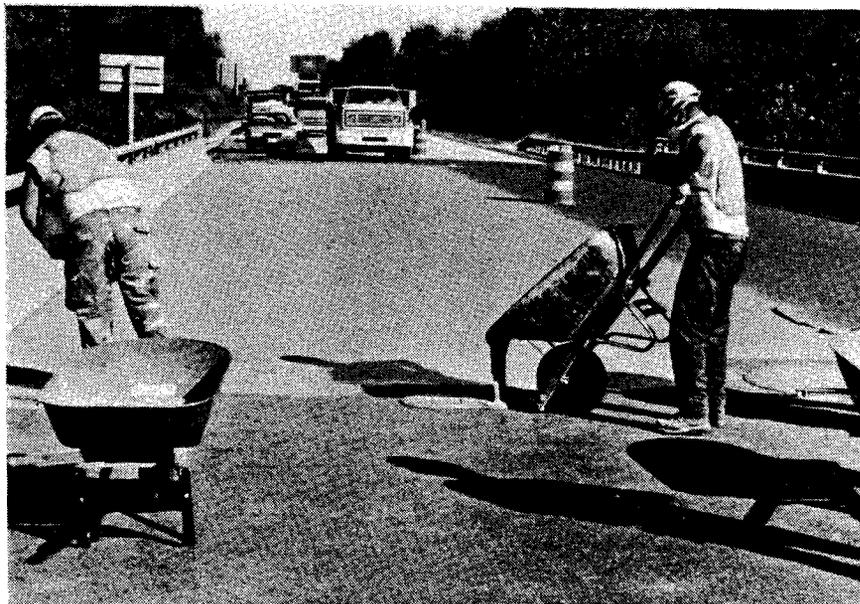


Figure 28. Methyl methacrylate aggregate slurry mixed with mortar mixers is here applied to shotblasted surface that was primed at least 1 hour earlier with a methyl methacrylate primer. The primer must be cured prior to placing the slurry.



Figure 29. A methyl methacrylate slurry overlay should be struck off with gage rakes set to provide a  $\frac{3}{16}$  in thick layer of slurry.



Figure 30. Aggregate should be broadcast to excess onto the slurry within 5 minutes after the slurry is placed.



Figure 31. A mechanical sweeper can be used to remove excess aggregate prior to placing a seal coat of methyl methacrylate. The seal coat must cure for at least 30 minutes prior to opening the methyl methacrylate slurry overlay to traffic.



Figure 32. Polyurethane primer can be applied with roller approximately 1 hour prior to placing a premixed polyester amide para resin concrete overlay. The primer must cure prior to the placement of the overlay.



Figure 33. Polyester amide para resin is here added to the concrete mixer.

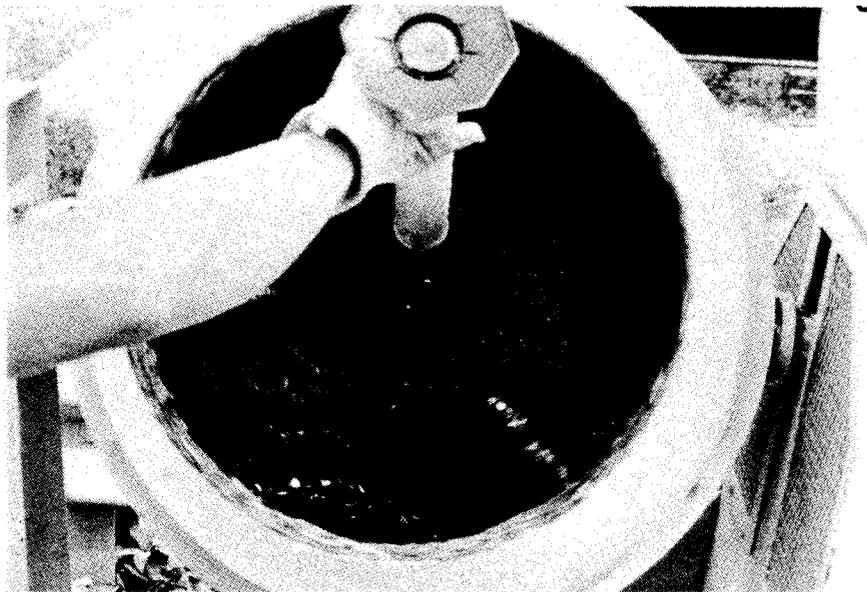


Figure 34. Methyl ethyl ketone peroxide initiator is here added to the mixer.



Figure 35. Prepackaged aggregate is here added to concrete mixer.

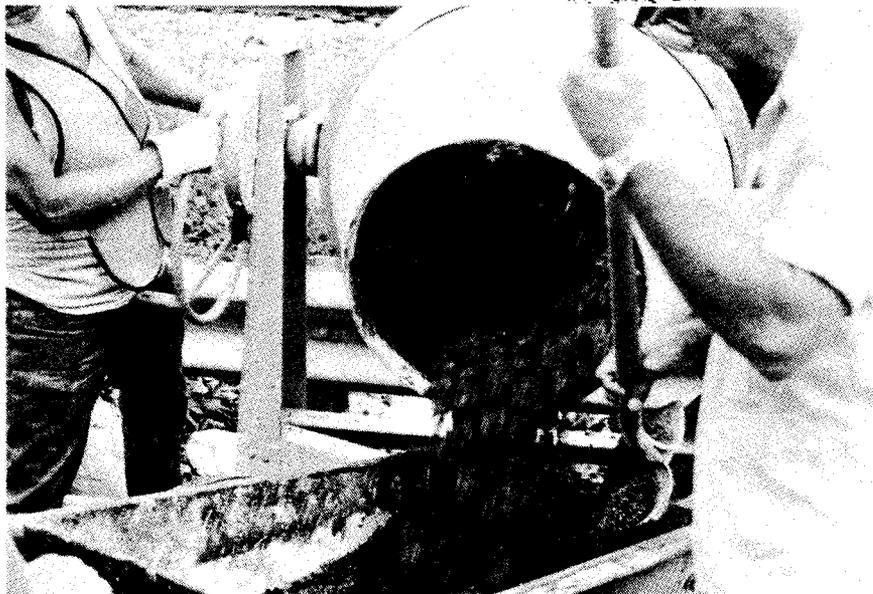


Figure 36. Polyester amide para resin concrete is here discharged into buggy.

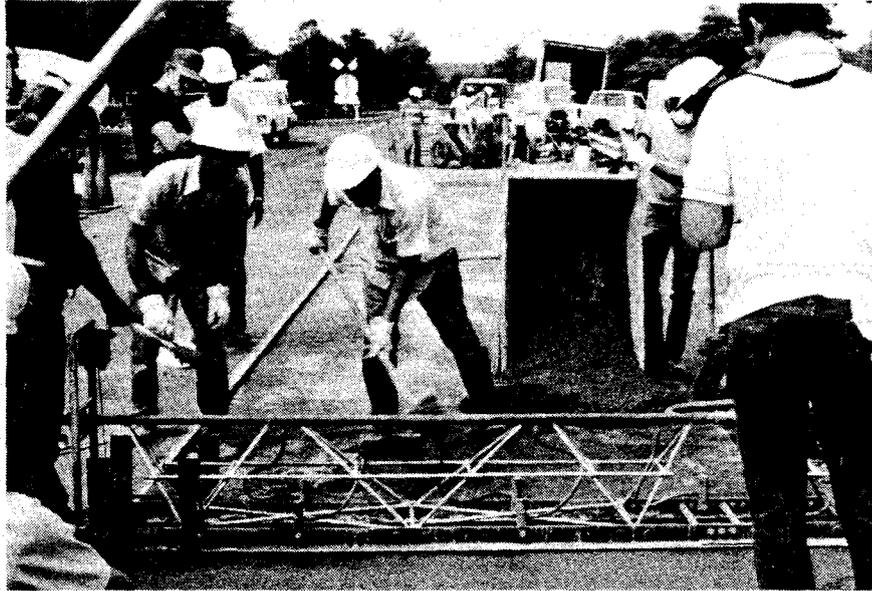


Figure 37. Polyester amide para resin concrete may be consolidated and struck off with a transverse vibrating screed.

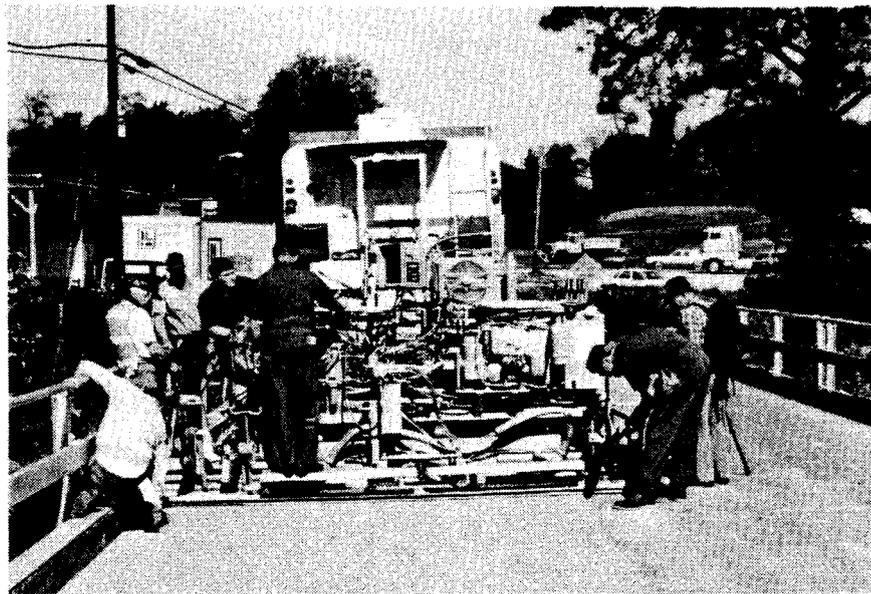


Figure 38. A vibrating slip form paver can be used to apply a premixed polyester styrene resin concrete overlay to a deck that has received a polyester styrene resin primer approximately 1 hr earlier. A mobile concrete mixer can supply freshly mixed concrete to the paver.



Figure 39. A front-end loader can be used to fill the slip form paver with premixed conductive polyester styrene resin concrete for conductive polymer overlay.

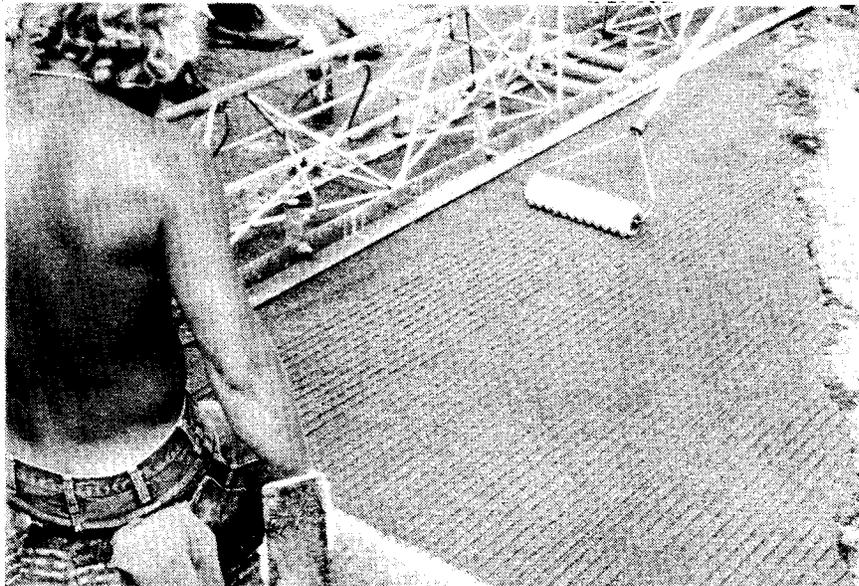


Figure 40. Grooves that provide high skid resistance can be applied with a plastic roller to a freshly placed polymer concrete overlay. Grooving must be done immediately after the screed passes because the premixed polymer concrete gels in approximately 20 minutes.

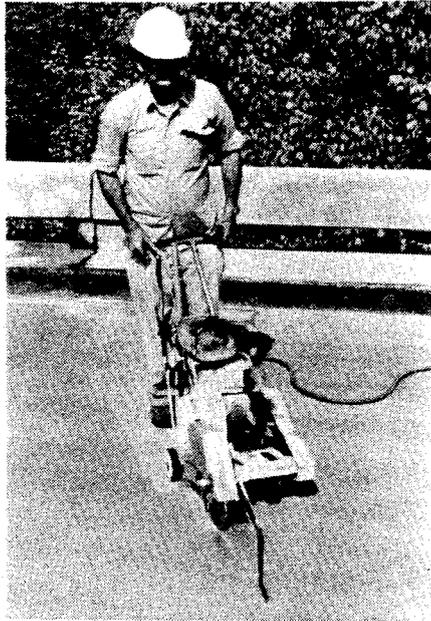


Figure 41. For convenience, polymer concrete overlays may be placed over the joints. The overlay must be sawed over the joint the same day the overlay is placed so that movements of the adjacent spans do not crack and delaminate the overlay.

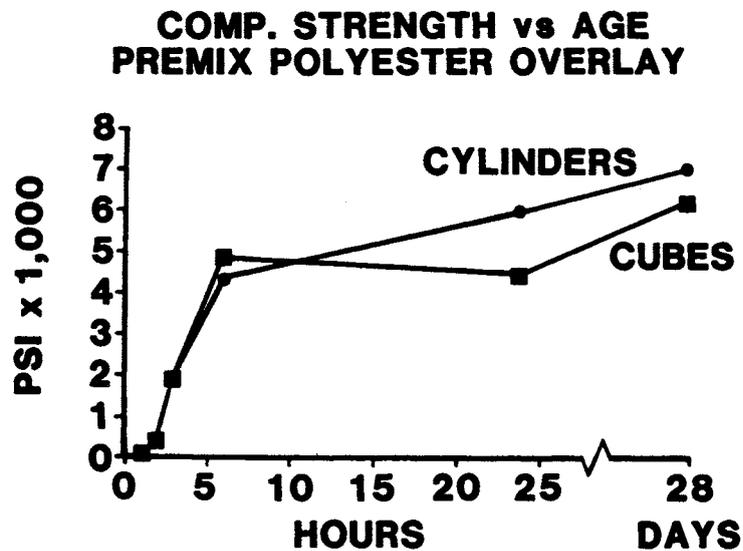


Figure 42. Premixed polymer concrete overlays typically develop the 3,000 psi compressive strength required to be opened to traffic in 3 to 4 hours.

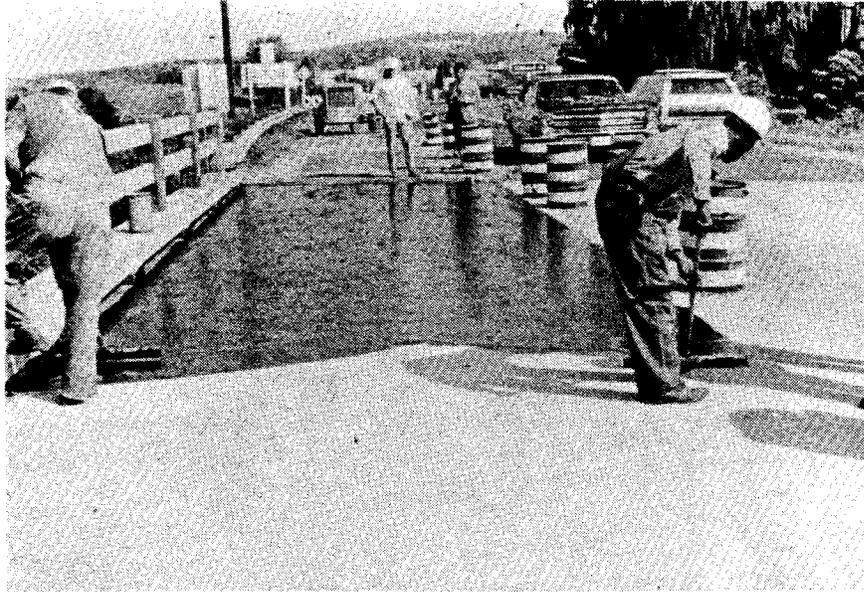


Figure 43. Squeeeges can be used to apply a primer to a shotblasted deck prior to placing the prefabricated membrane for Class II waterproofing.



Figure 44. A prefabricated membrane should be placed on the primer. Care must be exercised to lap the joints to minimize wrinkles in the membrane and to eliminate air pockets under the membrane.

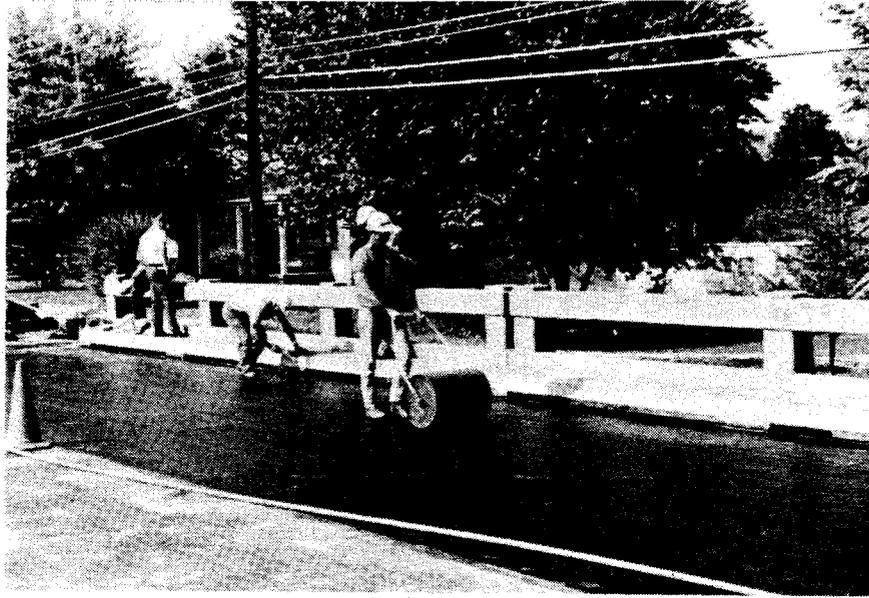


Figure 45. A roller should be used to press the membrane into the primer and to eliminate air pockets.



Figure 46. A bituminous concrete overlay should be placed and compacted over the membrane prior to opening the lane to traffic.



Figure 47. A 12-in wide sheet membrane can be placed on the primer to protect the keyways between precast concrete slabs. The entire deck surface should be covered with a tac coat and a bituminous concrete overlay.

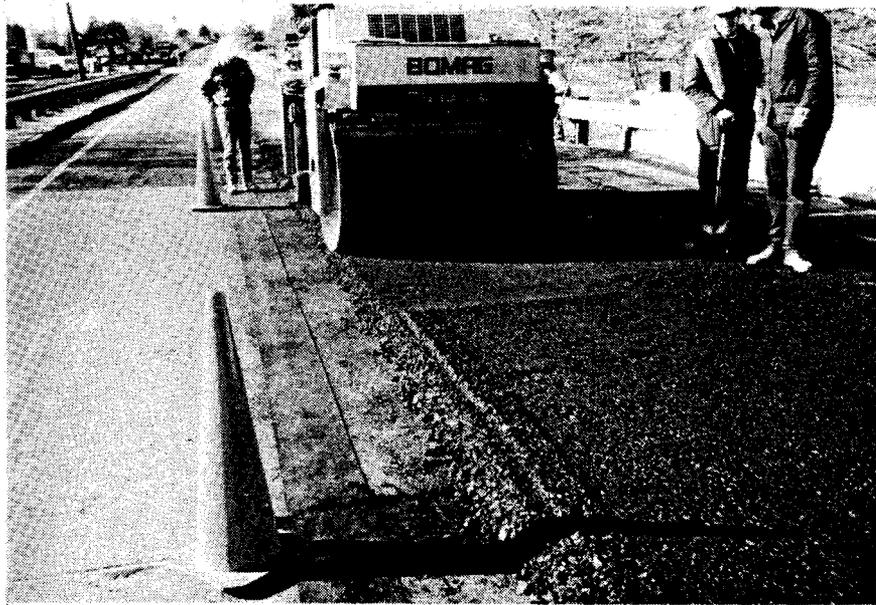


Figure 48. A bituminous concrete overlay should be compacted over the precast concrete slabs with sheet membrane over the keyways.

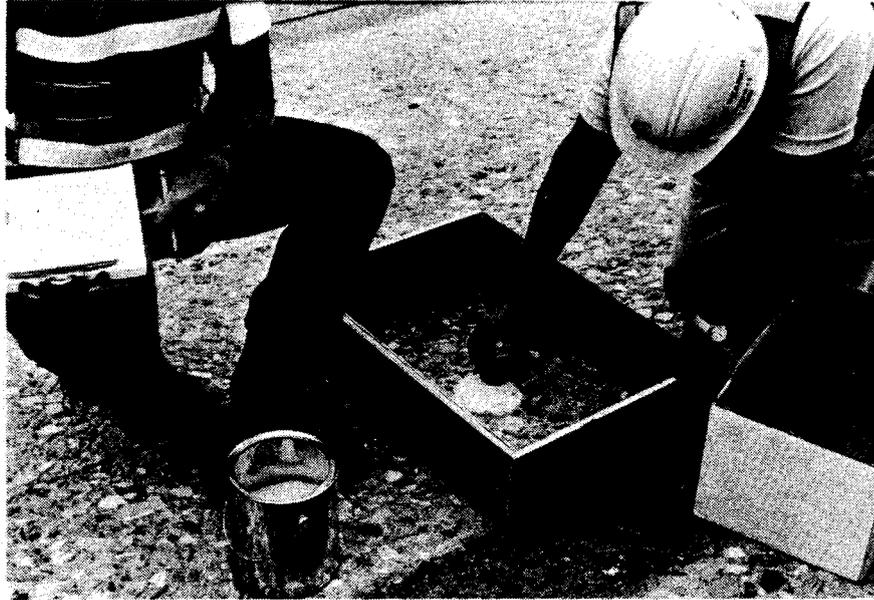


Figure 49. Prior to placing a penetrating sealer or coating, the surface must be shotblasted (see Figure 15, pg. 1-8) to remove materials that may interfere with the penetration and bonding of the sealer and to produce enough relief in the surface to provide good skid resistance. Tined surfaces (see Figure 14, pg. 2-8) usually have adequate relief and require less shotblasting. A sand patch test (ASTM E965) can be used to measure the relief in the blasted surface.



Figure 50. High molecular weight methacrylate coating can be applied with an airless sprayer. Note that the spray gun operators are wearing impermeable boots, gloves, and coveralls and canister masks.