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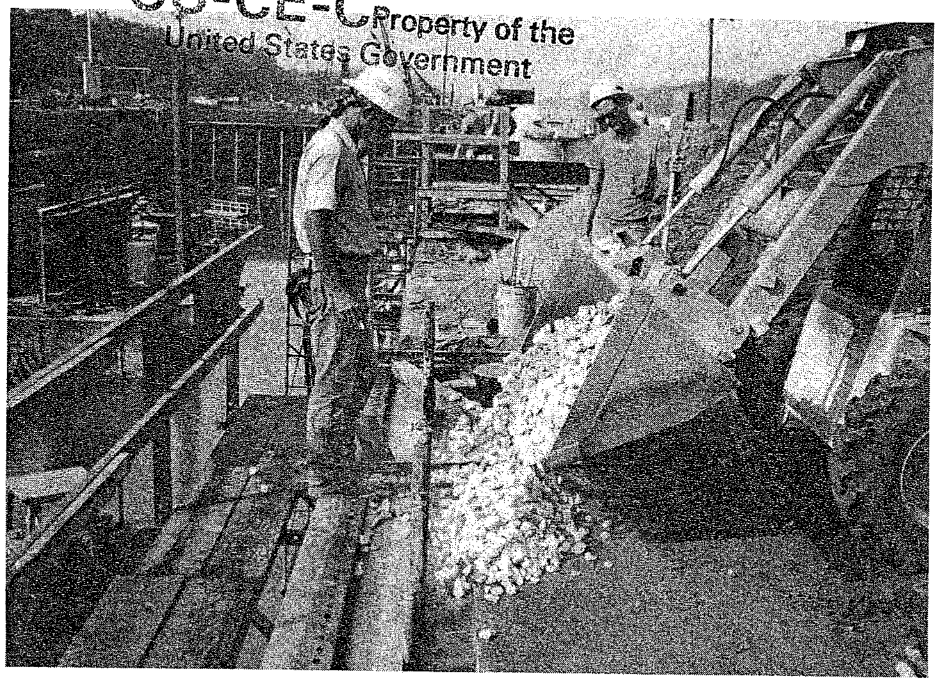

Prewashed, coarse aggregate being placed in water-filled form

Rehabilitation of Peoria Lock Using Preplaced-Aggregate Concrete

by
George J. Mech, P.E.
US Army Engineer District, Rock Island

Peoria Lock and Dam, which was completed in 1939, is located on the Illinois River a few miles downstream from Peoria. The lock is 110 ft wide by 600 ft long with 32-ft-high lock walls. The upper and lower guide walls are 500 ft long.

CONDITION SURVEY

During the summer of 1985, Geotechnical Branch personnel performed a concrete condition survey on the lock walls. This survey included reviewing all available reports (basically, periodic inspection reports), visually inspecting and photographing all exposed surfaces, mapping cracks, sounding the surface, and taking cores. Five 6-in.-diam cores were taken from selected areas, logged, and photographed. Two cores were sent to the Missouri River Division Laboratory for petrographic examination to determine the cause of deterioration and the compressive strength of the concrete.

The petrographic examination indicated that cycles of freezing and thawing were the predominant cause of damage to non-air-entrained concrete. The depth of deterioration was 7 to 8 in. Approximately 1 to 2 in. of the lock wall surface had already been lost as a result of surface abrasion of the damaged concrete. Consequently, the total depth of damage was 9 to 10 in. after approximately 48 years. The compressive strength of the sound concrete was 5,500 to 6,500 psi.

REPAIR MATERIAL

Because the deterioration was so extensive, a decision was made to completely rehabilitate the lock walls. In an effort to reduce cracking in the replacement concrete, as experienced in other recent rehabilitations, District personnel decided to use preplaced-aggregate concrete (PAC) for the repair work. Shrinkage for PAC is about one-half or less than that of conventional concrete.

The mixture proportions listed below used in conjunction with coarse aggregate produce 1 cu yd of PAC grout. Flow for this mixture is 26 sec.

Material	Mixture Proportions
Cement	540 lb
Pozzolan	140 lb
Fine aggregate	650 lb
Water	320 lb
Fluidifier	7.87 lb
Air-entraining agent	5 oz

The grout had to have air content of 9 ± 1 percent and a compressive strength of 4,000 psi at 28 days.

Aggregate gradings used were as follows:

	Cumulative Percent Passing	
Sieve Size	Coarse Aggregate	Fine Aggregate
3 in.	100	
2.5 in.	90-100	
2 in.	45-75	
1.5 in.	0-30	
1 in.	0-6	
No. 8		100
No. 50		15-45
No. 100		1-10

The contract for the rehabilitation of Peoria Lock was awarded on 14 August 1986 for approximately $14.5 million. Of this amount, approximately $600,000 was for PAC. Another $100,000 was for conventional concrete to be used in the lock walls. The 60-day lock-closure period, stipulated in the contract and coordinated with the barge operators who use the Illinois River, was set for July and August 1987.

REPAIR PROCEDURE

A minimum of 12 in. of concrete was removed by explosive blasting. High-pressure water was used to clean wall surfaces, and then anchors and reinforcing steel were installed. Forms for the PAC were installed on individual monoliths. Typically the resurfaced areas were about 10 ft high and 40 ft wide.

Grout injection pipes (10 per monolith) and observation pipes (3 per monolith) were set vertically on 4-ft and 12-ft centers, respectively, in each form (Figure 1). Forms were filled with water to reduce breakage of coarse aggregate as it was placed in the form. As much prewashed coarse aggregate as possible was placed in the forms to maximize point-to-point contact of aggregate particles and to reduce the amount of grout required to fill voids. It is estimated that the PAC contained 2,700 lb of coarse aggregate in each cu yd.

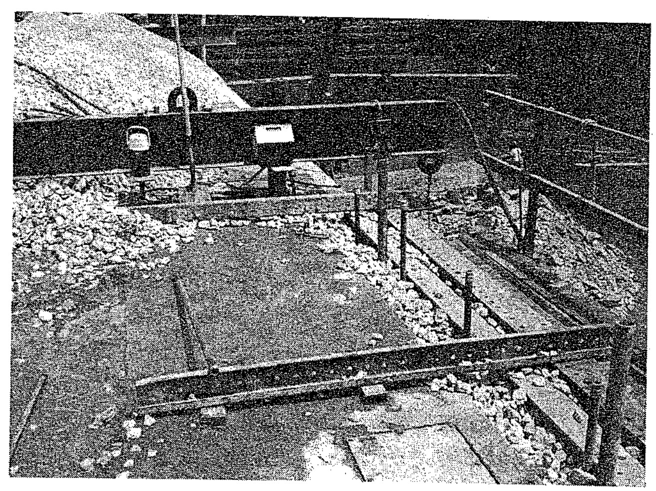

Figure 1. Panel ready for grout injection. Sounding wells, grout injection pipes, and coarse aggregate visible

To ensure that the grout surface rose uniformly within the form, injection was begun in a pipe near the end of the form and then progressed across the form to other injection pipes. Typically the angle of repose of the grout was 1:10. The grout plant operator was in constant radio contact with the foreman at the monolith being resurfaced, adjusting pumping requirements as needed (Figure 2).

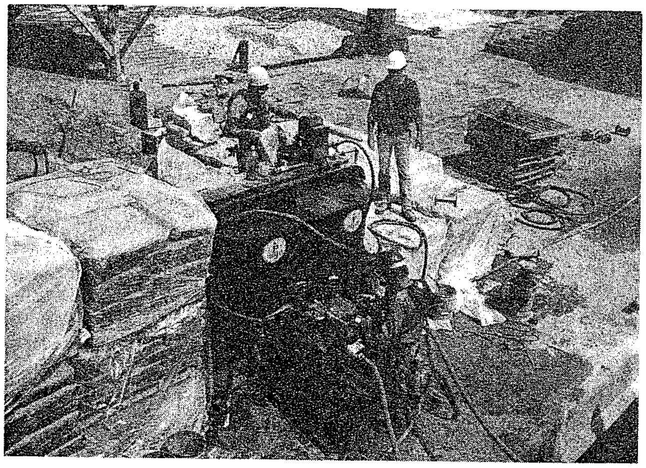

Figure 2. Grout mixer and pump. Grout materials being measured into the mixer

The forms were vibrated externally by laborers using hand-held equipment and moving back and forth across the front of the form. This work was complicated by the laborers having to work around form whalers. Also, having only two working platforms for each form resulted in laborers having to handle vibrating equipment at shoulder/head height for a considerable length of time.

After approximately 8 to 10 hr of pumping, the grout would "daylight" at the top of the panel (Figure 3). Sufficient additional grout was pumped to ensure no dilution of the grout at the surface. Three-eighths- to one-half-inch aggregate was worked into the top surface, and then the surface was broom finished. The forms were removed 24 to 48 hr after the completion of grouting operations.

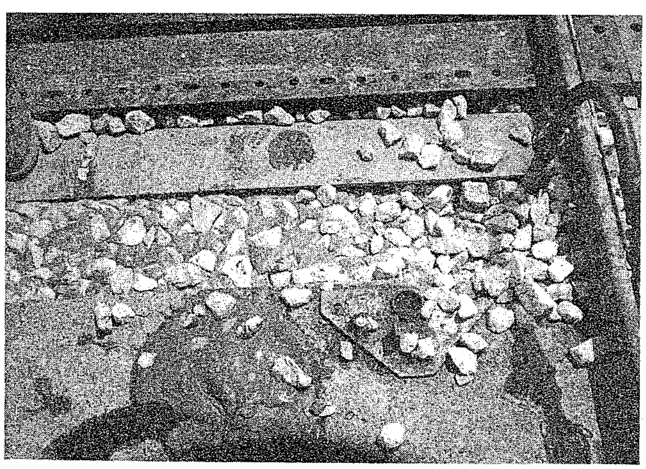

Figure 3. Grout "daylighting" at the top of a form

The PAC was moist-cured for 7 days. The contractors set up a soaker system on top of the lock wall which allowed water to flow down the resurfaced face of the lock wall (Figure 4).

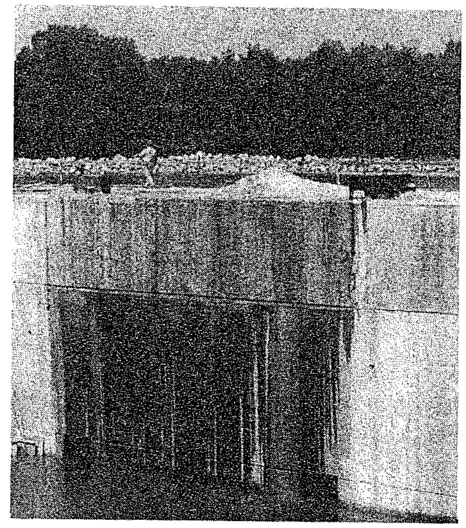

Figure 4. Moist curing of a resurfaced monolith

TEST RESULTS

Typical test results on the grout and concrete cylinders are given below.

Specimen Type	Compressive Strength, psi 7 Days	Compressive Strength, psi 28 Days
2-in. mortar cubes	3,550-4,300	5,620-6,240
PAC cylinders	4,070-4,530	4,410-4,780
Conventional concrete	3,160-4,260	4,140-5,340

DISCUSSION

Some problems were experienced during the lock wall resurfacing. Forms on two of approximately 30 monoliths had to be reset because the anchors holding the forms to the lock wall failed. Also, there was some cracking in the PAC. Some of the cracks can be traced to monoliths on which the contractor had problems with the soaker system used for moist curing. Temperatures during this period ranged between 95 and 100 degrees.

Some defects (vugs) occurred on the concrete surface. Some of the vugs are the result of the method used to vibrate the forms and changing the grout flow requirement from 18 sec to 26 sec. Additionally, in some areas where PAC was to be used, conventional concrete was used because of the extensive armor that was placed in the lock wall, the difficulty in forming the areas, and the need to reopen the lock on time.

The bid price for 610 cu yd of PAC at Peoria Lock was $960 per cu yd, which included form work, aggregate, placement, grouting operation, and finishing. Typically, bid prices for conventional concrete used on other rehabilitation projects in the District have been in the range of $450 to $650 per cu yd and higher for difficult construction situations.

The PAC surface has been subjected to two winters with cycles of freezing and thawing and two years of abrasion from barge traffic. Up to now the surface has performed well.

For further information, contact George Mech at (309) 788-6361, Ext. 288.

George Mech is currently Chief of the Geotechnical Branch in the Rock Island District's Engineering Division. He has 15 years of experience with the Corps of Engineers, working in the New Orleans and Rock Island Districts and the European Division. He received his B.S.C.E. degree from Iowa State University, his M.S.C.E. degree from Oklahoma State University and has attended the US Army Corps of Engineers sponsored course in Concrete Materials at Purdue University. He is a registered Professional Engineer in the states of Iowa and Louisiana.

The Repair of Large Concrete Structures by Epoxy Resin Bonding

by
Dr. Donald A. Bruce, Technical Director,
Nicholson Construction Company

Cracking of any concrete structure is usually a matter of concern. When the structure in question is a major dam, the problem may be especially troublesome and sensitive.

The extent of the cracking is usually difficult to discern and often incompletely understood. For example, the dam foundation or abutment may perform differently than anticipated, or the dam itself may behave in a nonmonolithic manner. There may be cyclic processes at work generated by temperature or hydrostatic fluctuations. There may also have been intrinsic flaws in the concreting practices and materials, affecting over time the structural integrity and fundamental quality of the dam. It may even be the case that unforeseen problems arise from the adoption of new construction techniques and practices in dams of novel concept.

It has long been standard practice to attempt to fill major cracks by injecting cement-based grouts, and smaller aperture fissues with "chemical grouts," including silicates, phenols, and acrylates. Most recently, use has been made of various polyurethane grouts. These attempts have met with mixed results and have often needed repeating at frequent intervals because the brittle nature of the grout has not been compatible with the tendency of the structure to continue straining.

The state of practice in the control of cracking in concrete structures has been summarized by Darwin (1980), and in 1984 he reviewed further the causes, evaluation, and repair methods. He wrote that the method selected for repair should clearly be based on that aspect of the structure that needs remediation — strength or stiffness or water tightness or appearance or protection from aggressive solutions in the environment. Darwin also recorded that cracks as narrow as 0.002 in (0.05 mm) could be sealed and bonded by injection of epoxy resin.

There are difficulties in conducting such sealing and rebonding operations when conditions prevent substantial drawdown of reservoir level. These difficulties include:

- Inflow of cold water at high velocity and pressure
- Segregation, dilution, and displacement of grouts
- Matching grout properties to the often very irregular fissure geometry
- The need to avoid using high injection pressures with grouts of long setting times.

Such repair attempts are in a sense irreversible, as an inefficient repair attempt with the wrong material will greatly reduce the success potential of any subsequent attempt at treatment, no matter how conscientiously executed.

There are three basic elements in ensuring effective treatment:

- One must first make every effort to understand the cause of the problem. This understanding* involves a detailed review of all the geological, constructional, and behavioral data available. Often this research forms the basis for executing a new phase of exploration (by coring) and monitoring.
- Once the probable cause for the cracking has been determined, the repair material can be selected. The repair material must be a true Binghamian fluid, not a suspension of particles. It must harden as soon as practical after injection to deliberately limit and control flow distances. It must have a reasonably constant and controllable viscosity until hardening; this viscosity must reflect the anticipated crack width. It must have minimal shrinkage on hardening.

  It must be durable, and it is usually required to bond efficiently to wet surfaces, under high hydrostatic or dynamic heads, often in low temperatures and so must have high tensile and shear strengths. It is usually advantageous to have modulus of elasticity significantly less than that of the concrete. It must have low surface tension in order to ease penetration into fine fissures. It must be easily and safely handled, with minimal environmental problems.
- The performance of the grouting and of the structure should be continuously monitored during the repair. In this way, the grouting parameters can be varied as needed to optimize the procedure.

CASE HISTORIES

Epoxy resin grouting has been used to seal cracks in many major, high dams (Muzas, Campos, and Yges 1985). Particular case histories include Atazar (Eschevarria and Gomez 1982), Zeuzier (Berchten 1985), and Cabril (Portuguese National Commission Working Group 1985).

A recent application has been to repair an old concrete dam in the Eastern United States (Figure 1). The repair was highly successful. However, since such repairs are usually as delicate politically as they are technically, the owner in this case wishes to retain the anonymity of the project pending further seasons of acceptable performance.

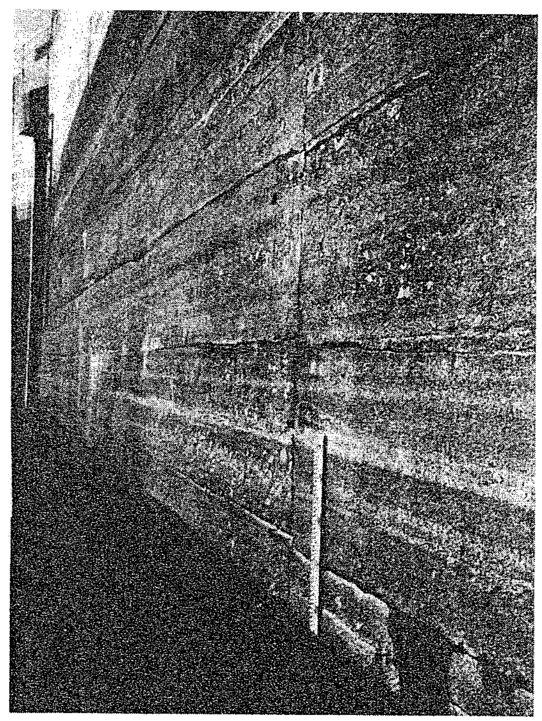

Figure 1. Upstream face of dam showing horizontal lift joints and vertical construction joints between blocks

This project involved a 60-year-old, 320-m-long, 65-m-high concrete arch, with gravity abutments and two spillways. Substantial leakage has been experienced from the first impoundment. Despite major structural modifications to the dam and repeated phases of cement grouting in the horizontal lift

* A good understanding of the role of restraint, volume change, and reinforcement on the cracking of massive concrete is given by Cannon (1973). A general summary of knowledge of mass concrete is given by Mass (1987).

joints, the situation continued to deteriorate. By mid-1987, leakage in the left side alone had reached over 4,000 L/min and was entering the lower drainage gallery at higher pressures and over larger areas than before. Seepages on the downstream side of the gallery were also noted. Following the structured analytical approach as outlined above, treatment was concentrated on a 23-m-long section in the most critical area and was conducted from within the 2.4- by 2.2-m lower gallery, running about 3 m above the foundation and 4.5 m back from the upstream face (Figure 2). Fans of primary holes, up to 6 m long, were cored at regular intervals upstream from the gallery to investigate the suspect joints. These holes confirmed that the water flows were travelling through the joints: the concrete itself was materially sound. Many holes intercepted flows of up to 400 L/min at full hydrostatic head.

After all the primary holes had been drilled (Figures 3 and 4) and the data carefully considered, the systematic epoxy resin grouting program was commenced through special packers fixed in each hole. Resin, injected through one packer, would be observed to travel and connect with the next hole, to which injection would then be transferred. In this way, the continuity of the resin filling could be promoted.

A secondary phase of drilling and grouting was then conducted to demonstrate this continuity and to permit "tightening up" of especially difficult areas. Resin thicknesses of up to 10 mm were found, illustrating the in situ aperture of the joints, while later tertiary check holes — all totally dry — confirmed the penetration of the secondary grout into microfissures.

By the conclusion of the work in the fall of 1988, the total flow into the section grouted was about 120 L/min — virtually all of which was entering the gallery through vertical roof drains, intersecting fissures well above the levels grouted. The concrete of the upstream gallery wall had begun to dry, and flows from secondary, longitudinal roof fissures and from the downstream gallery wall were also stopped completely. This performance has persisted to date, even during the maximum reservoir levels recently experienced for the first time in several years. A fuller description of this work was given by Bruce and De Porcellinis (1989).

FINAL POINT

Grouting techniques have long been used to seal leaks in concrete dams. Advances in drilling, grouting and material technologies have been made during the last decade to the extent that the reliable remediation of major high dams can be conducted. It is highly significant that such treatments, usually carried out under extremely adverse conditions, can be used not only to seal off leakages but to bond the structure together again. This is a major breakthrough in the concept and horizons of dam repair.

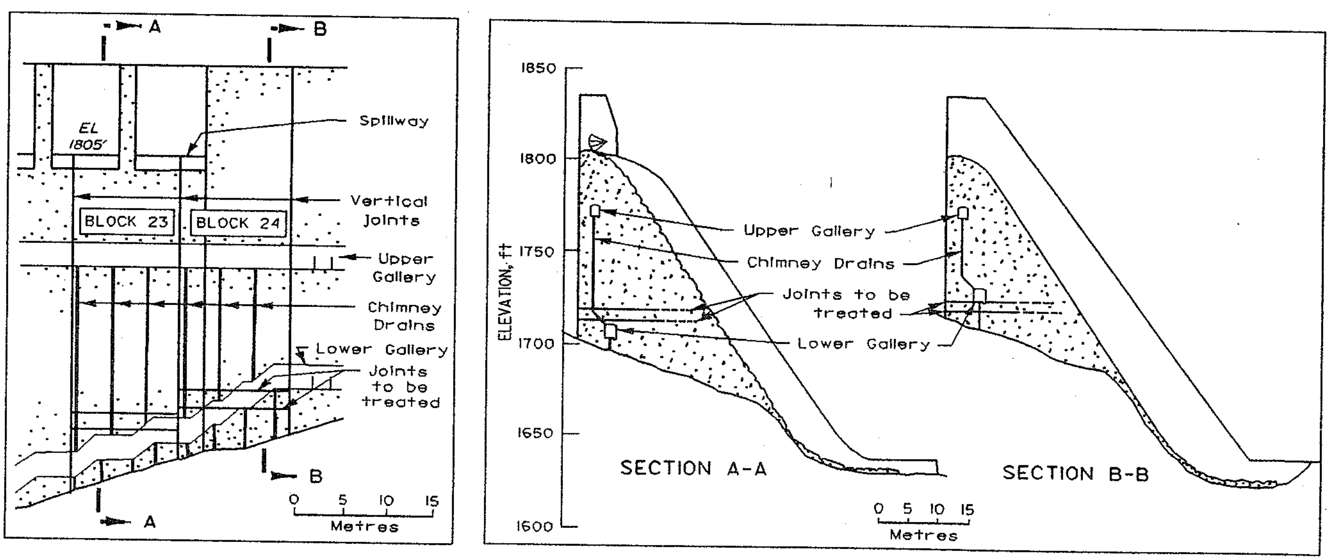

Figure 2. Horizontal joints investigated and treated in Blocks 23 and 24

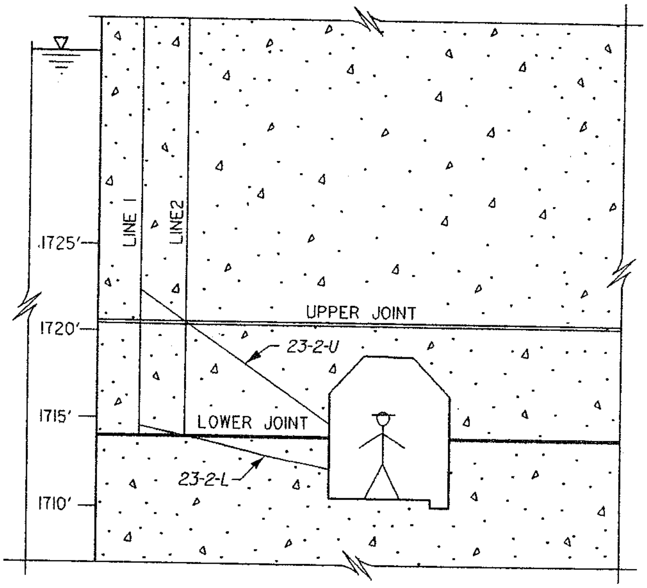

Figure 3. Typical section showing intended joint interception at one station

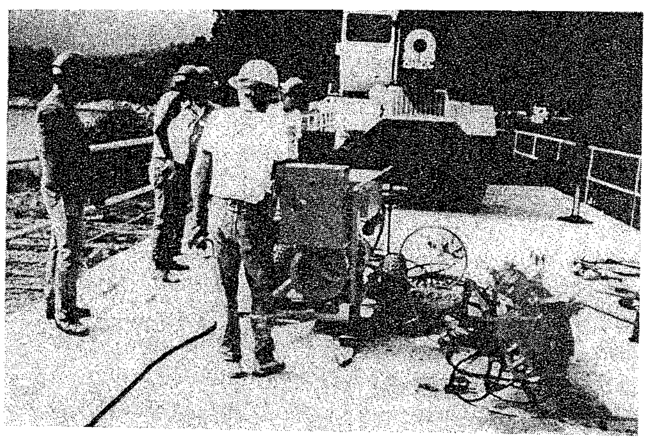

Figure 4. Components of the electrohydraulic coring rig (from right, mast w/head, controls, power pack)

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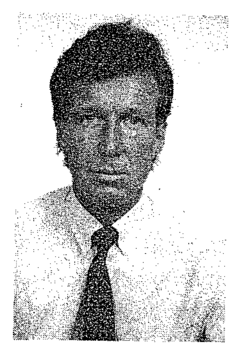

Surface Treatments for Concrete

by
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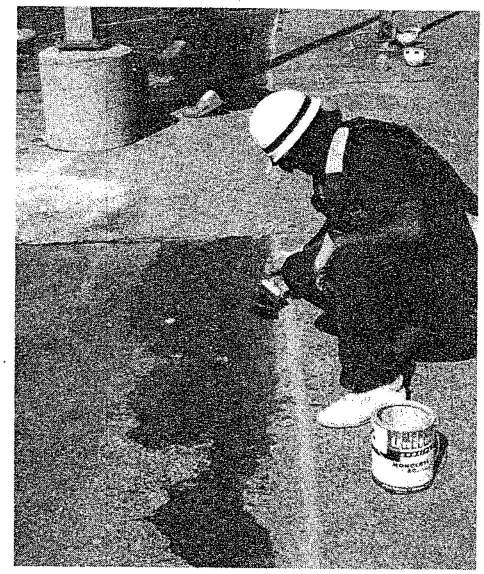
US Army Engineer Waterways Experiment Station, Vicksburg, MS

Freezing and thawing, penetration of salts, weathering, chemical attack, and erosion cause concrete surfaces to deteriorate. Surface treatment of the concrete with a material more resistant to these forces than concrete can slow or even eliminate the rate of deterioration. However, little guidance in the selection and application of these treatments is available.

One of the work units in the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program was designated to evaluate surface treatments that would minimize concrete deterioration. Emphasis was on materials that can reduce or prevent damage to concrete from cycles of freezing and thawing, the major contributing cause of non-air-entrained concrete failure.



Field testing of a penetrating concrete sealer, Brandon Road Lock & Dam, Rock Island District, Illinois

MATERIALS

Surface treatment materials were separated according to viscosity, total solids, manufacturers' recommended use, and chemical composition. The materials were then classified as concrete sealers, concrete coatings, shotcrete, and thin overlays.

Concrete sealers are the preferred surface treatment to minimize or prevent damage from freezing and thawing. Sealers damp proof and slow or prevent the intrusion of salts into concrete. They are usually low in viscosity and total solids. The generic types tested were acrylics, epoxies, polyurethanes, silicates, silanes, silicones, siloxanes, stearates, and those hydrocarbons made from petroleum distillates or oils, excluding linseed oil.

Concrete coatings are used for reducing ingress of water; for protecting against erosion, chemical attack and weathering; and for resisting graffiti. They may be thin polymer systems used for sealing cracks in concrete by topical application. Some may be applied underwater. One difficulty in using coatings is finding materials that can be used on cracked concrete surfaces because cracks migrate through most coatings.

Elastomeric coatings, crack sealants, and low viscosity polymer systems for sealing cracks by topical application were evaluated. Elastomeric coatings can bridge cracks and yield under any crack movement. Manufacturers of these types of coatings recommend routing out wide cracks and then either sealing the cracks before applying the coating or using fabrics under the coating.

Shotcrete was investigated as a coating for deteriorated concrete. Two problems may occur if a conventional shotcrete mixture is used: (1) poor resistance to freezing and thawing and (2) cracking of the material. Therefore, shotcrete with two different latex admixtures was evaluated as a possible solution to these problems.

The study also included a few commercial latex-modified mortars and a number of latex admixtures used to prepare latex-modified mortars. These materials are generally used as thin overlays on existing concrete structures.

TESTS

A surface treatment must prevent water from entering non-air-entrained concrete to protect it from damage caused by freezing and thawing. A published water-absorption test (ASTM C 642-82)* was selected to screen materials for use in surface treatments. Tests used to evaluate the different materials included water vapor transmission (REMR report to be published), resistance to freezing and thawing (ASTM C 672-84)*, bond strength to concrete (ASTM D 4541-84, ASTM C 882-87)*, accelerated weathering (ASTM G 53-84)**, total solids (ASTM D 1259)*, resistance to abrasion (underwater abrasion test), viscosity (ASTM D 1824)*, and dry-to-touch.

TEST RESULTS

Sealers: Results of water-absorption (WA) and water vapor transmission (WVT) tests for the large number of concrete sealers are reported by generic types in percent of the control (uncoated concrete cubes). The average WA for controls was 4.69 percent after 2 days soaking in water; early tests indicate that these specimens had almost reached water saturation after 8 hr. The average WVT for controls was 3.21 percent after 4 days.

Two possible causes of poor performance in the WA tests are low solids content of the sealer and the application rate. With one exception, the five acrylic sealers that performed poorly had solids contents of less than 10 percent.

* American Society for Testing and Materials, 1988 Annual Book of ASTM Standards, Philadelphia, PA.
** 1987 Annual Book of ASTM Standards.

Most of the sealers that performed unsatisfactorily on the WA test were not tested for WVT. Of the ten acrylic sealers tested, seven had WVT values of 50 percent or higher. A search for a criterion for WVT in concrete was not successful. If the criterion, WA <15 percent and WVT >25 percent, had been used in the selection of sealers, very few of the 68 sealers tested would have qualified.

Some of the sealers that performed well on the WA test were selected for the accelerated weathering test (AWT). The results are shown in Table 1. The acrylic sealers were significantly affected by the AWT . They had been expected to perform much better as they are described as having good weatherability. The only explanation for the continued improvement of the two linseed oil-treated test blocks is that the oil continued to polymerize in the heat and UV light.

Tests results showing the resistance of concrete coated with sealers to deicing salts are shown in Table 2. Any rating above "2" was not considered satisfactory. All epoxy resins were effective in preventing scaling. The silanes and siloxanes did not perform as well as expected; the difference in the concrete mixtures used for the two tests could have been a factor.

Coatings: The WA and WVT tests used to evaluate the sealers were also used with the coatings. Most of the coatings effectively prevented water from entering concrete; exceptions included some of the acrylics, some of the cementitious, and one polyurethane. One reason for the high WA of these materials is that thicker coatings of the cementitious and acrylic mastics on the small cubes were

Table 1. Accelerated Weathering Test Results

	Water Absorption, % Before Testing (Material No.)				Water Absorption, % 1,600 hr Testing (Material No.)			
Generic Type	1	2	3	4	1	2	3	4
Acrylic	0.55	0.61	0.72	0.87	2.56	3.12	4.00	3.94
Hydrocarbon	0.47	0.65	0.40		0.94	3.57	4.61	
Linseed Oil*	4.50	1.57			0.54	0.88		
Polyurethane	0.34	0.53	0.22		0.87	1.44	0.87	
Silane	0.52	0.56	0.60	0.44	0.66	0.70	0.80	0.57
Silicone	0.44				0.47			
Siloxane	0.56	0.54	0.59		0.71	0.68	0.73	
Stearate	0.93	0.67			1.96	1.00		

* Material 1 is an emulsion and 2 is linseed oil in mineral spirits.

Table 2. Resistance to Scaling, Concrete Sealers

Generic Type	No. Tested	Visual Rating of Surface (No. Materials for each Rating)					
		0	1	2	3	4	5
Control	2					1	1
Acrylic	9	2	3	3		1	
Epoxy	4	4					
Hydrocarbon	3			1		1	1
Linseed Oil	1			1			
Methyl Methacrylate	1	1					
Polyurethane	5	3					2
Silane	5	1*			1	1	2
Siloxanes	6			1	3	1	1
Stearate	2				1		1

Rating 0-no scaling, 1-slight scaling, 2-slight to moderate, 3-moderate scaling, 4-moderate to severe, 5-severe

* Silane treated surface coated with acrylic sealer.

not uniform, especially over the edges. A few pin holes were observed in some of the thicker water-based acrylics and a few of the polyurethane coatings.

The acrylic coatings had the highest WVT values. Most of the coatings bonded well to concrete. The soft elastomeric coatings, such as the acrylic mastics and silicone, had the lowest bond strength values. These coatings will not be satisfactory where wheeled traffic is expected.

Fourteen coatings were tested for resistance to scaling. All performed satisfactorily except for one cementitious coating and an acrylic coating. The cementitious coating began peeling off the surface after 8 cycles; the acrylic lost bond to the concrete surface.

Four polyurethane graffiti-resistant coatings were tested. They were effective sealers, and graffiti (enamel paint) was removed from them with ease. The coatings were not affected after graffiti had been applied and removed three times. Two-component coatings performed better in the AWT than single-component coatings.

Eight high-molecular-weight methacrylate (HMWM) monomers (viscosity 9 to 33 cp) and one low-viscosity epoxy resin (40 cp) were applied topically and then evaluated as crack sealants. High bond strengths were obtained for all materials, but the epoxy did not penetrate into thin cracks as well as the HMWM. WES worked with the US Army Engineer District, Kansas City, in preparing specifications and guidance for sealing cracks in a bridge deck with HMWM and assisted Air Force personnel in sealing pavements that contained numerous cracks.

Shotcrete: Latex-modified shotcrete was applied to concrete and plyboard to obtain panels for testing. Prisms cut from the panels were tested in accordance with ASTM C 666-84. The mixtures had good bond strength to concrete and durability to rapid freezing and thawing. Dilutions of latex to water ranging from 1:2 to 1:4 were found best for application. A defoamer had to be used with the acrylic latex. Satisfactory compressive and flexural strengths were obtained, with the flexural strength increasing with increases in the amount of latex used. A petrographic examination indicated that the latex actually entrained some air into the shotcrete mixtures. Polypropylene fibers added to some of the mixtures reduced cracking.

Overlays: A number of commercial, prepackaged latex-modified mortars were tested for bond strength, concrete freeze-thaw durability, and flexural and compressive strengths. In addition, these mortars were tested as thin (13 mm) overlays for 1.2-m-long concrete panels. Three of the materials had satisfactory test results. Acrylic latex and styrene-butadiene were used to make two mortar mixtures which were evaluated by being immersed in water for 6 months. The styrene-butadiene latex mixture tested better.

CONCLUSIONS

The test data for surface treatment materials indicate wide differences in the effectiveness of these materials for protecting concrete or minimizing concrete deterioration. However, results of these tests and other tests found in literature allowed the following criteria to be established as guidance in the selection of concrete sealers. Standard specifications have not been established.

Test	Requirement
Water absorption, % of control 7 days	$\leq$15
Water vapor transmission, % of control 7 days	$\geq$25
Accelerated weathering, % difference after aging for 1,200 hours	$\leq$0.50
Scaling resistance (ASTM C 672-84) 50 cycles, 4% $CaCl_2$ solution	Must have a visual rating of 1 or less

Of all the sealers tested, only one hydrocarbon, two siloxane and two silane sealers met the criteria.

Sealers for specific applications will require additional testing; for example, a sealer to be used in an area subject to abrasion will need to be tested for abrasion resistance. However, a sealer that will not be subjected to freezing and thawing will not have to be tested for freeze-thaw resistance.

Results of the study indicate:

- Siloxanes perform well as a generic-type concrete sealer, except in resisting cycles of freezing and thawing.
- Acrylic mastic coatings for treatment of cracked concrete tested well in the laboratory, but field application results are not available.
- Polyester resin coatings tested can be used effectively as abrasion-resistant coatings if applied to dry concrete.
- Only those polyurethanes recommended by manufacturers for sealing concrete surfaces subjected to vehicular traffic performed effectively in laboratory tests.
- The HMWM monomer systems can be used to seal cracks by topical application.
- Two cementitious coatings tested were found effective for waterproofing concrete, from both positive and negative sides, and may minimize concrete deterioration resulting from freezing and thawing. Others tested did not produce the desired results.
- The addition of latex admixtures improves the freeze-thaw durability of shotcrete.
- Polypropylene fibers appear to reduce cracking caused by drying and shrinkage in latex-modified shotcrete.

Testing of the freeze-thaw resistance of siloxanes and other types of sealers continues. Different application rates and concrete mixtures are being used in these tests.

For further information on this subject, contact Tony Husbands at (601) 634-3275 or Fred Causey at (601) 634-3590.

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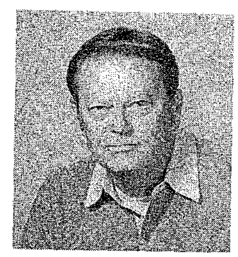

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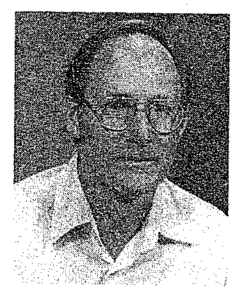

COVER PHOTOS:

Vugs on resurfaced lock wall at Peoria Lock and Dam, as concrete is being moist cured.

Field testing of a penetrating concrete sealer, Brandon Road Lock and Dam, Rock Island District, Illinois.

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