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The REMR Bulletin

News from the Repair, Evaluation, Maintenance, and Rehabilitation Research Program

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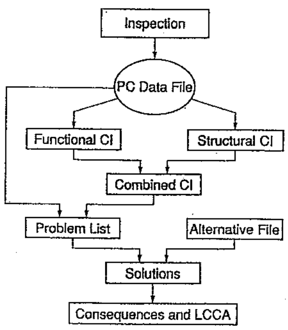
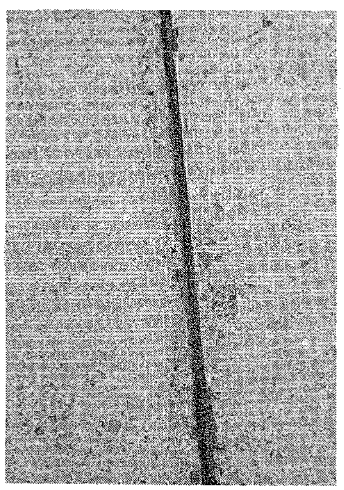
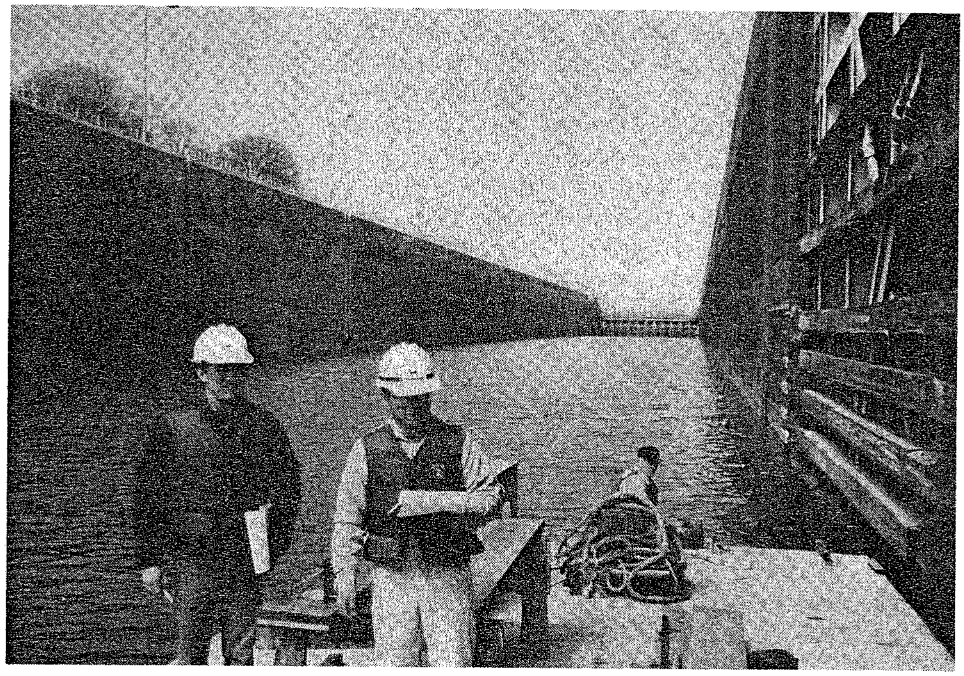






Condition inspection of a concrete lock monolith

RESEARCH PROGRAM

Automating Maintenance and Repair— the REMR Management Systems for Civil Works Structures

Structures are generally built to last a specific time, and then to be replaced. However, with use and proper maintenance, structures can last for a considerable length of time, as Roman and other facilities from ancient civilizations show.

The Corps of Engineers is responsible for a large number of civil works structures. Many of these facilities are now, or will soon be, reaching the end of their design service life. Through the years, large amounts of funds are needed to maintain and repair these facilities so they will continue to serve or to function as intended. In almost all cases, it is cost effective to search for ways to extend the service life of a facility, since the Corps has limited resources for constructing replacement facilities. Since funds for maintenance and repair must also be carefully allocated, it is imperative to develop efficient management systems for Corps structures.

Under the REMR Research Program, management systems are being developed to help managers maintain the best facility condition for a given budget level. The systems are designed to be decision-support tools for determining when, where, and how to allocate maintenance, repair, and rehabilitation dollars most effectively.

Life Cycle Cost Comparison Through Condition Index

It is important to realize that in order to assess the condition of a structure in a manner that enables its comparison to other like structures' condition, a uniform rating procedure must be in place. Thus, the Condition Index (Fig. 1), a numerical indicator of facility condition and function level, provides quantitative and consistent means for describing the condition of a structure. This allows comparing and monitoring structures over time. It also makes it possible to determine the most cost-effective time to perform maintenance, to determine the effect of repeated maintenance as compared to a single major rehabilitation, as well as to predict future facility conditions, once sufficient data is collected.

As an example, how this works for comparing the benefits of different maintenance policies can be seen in Figure 2. The left portion of the graph tracks a facility's condition from its brand-new state to year 44, with the Condition Index going from 100 to 60. A floor of 50 is assumed to be the minimum acceptable condition level. Projections indicate that this level will be reached during the next 3 or 4 years. Policy 1 and Policy 2 depict two approaches for repair or rehabilitation. Policy 1 would upgrade the structure to an Index of 90, hold that for about 10 years and then fall to 50 within another 20 years. Under Policy 2, the facility would be repaired or rehabilitated to a Condition Index of 75 and fall to the floor of 50 in 14 years, at which time the same upgrade measures would be repeated. Repair and rehabilitation cost and results, over time, can be compared by using this approach.

REMR Management Systems Components

Computer programs tailored for specific structures comprise the REMR Management System program. To date, CONCRETE LOCKWALL, STEEL SHEET PILE, and MITER LOCK GATE Programs exist. Software is available from the US Army Engineer Waterways Experiment Station's component of the Corps' Electronic Computer Program Library and from US Army Construction Engineering Research Laboratory. User Manuals and related reports can be obtained from US Army Construction Engineering Research Laboratory.

REMR Management Systems typically consist of four modules: inventory, condition inspection and assessment, maintenance and repair alternatives,

Zone	Condition Index	Condition Description	Recommended Action
1	85 to 100	*Excellent:* No noticeable defects. Some aging or wear may be visible.	Immediate action is not required.
	70 to 84	*Very Good:* Only minor deterioration or defects are evident.	
2	55 to 69	*Good:* Some deterioration or defects are evident, but function is not significantly affected.	Economic analysis of repair alternatives is recommended to determine appropriate action.
	40 to 54	*Fair:* Moderate deterioration. Function is still adequate.	
3	25 to 39	*Poor:* Serious deterioration in at least some portions of the structure. Function is inadequate.	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Safety evaluation is recommended.
	10 to 24	*Very Poor:* Extensive deterioration. Barely functional.	
	0 to 9	*Failed:* No longer functions. General failure or complete failure of a major structural component.	

Figure 1. REMR condition Index scale

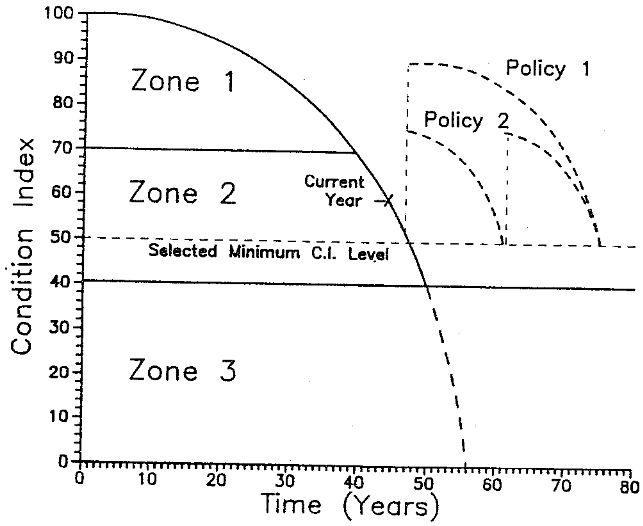
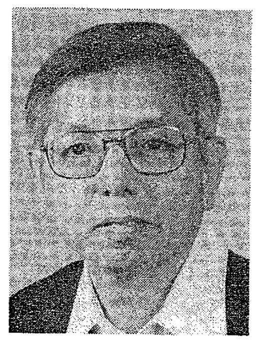


Figure 2. Example of comparison between two repair or rehabilitation policies for a monitored structure

and life cycle cost analyses. The inventory stores data elements such as structure/component type, construction date, location and physical dimensions of facilities. For each type of structure, experts have developed inspection procedures and an algorithm that expresses the Condition Index numerically, in a consistent and repeatable manner. This uniformity allows ranking of condition of similar structures throughout a District, a Division, or the Corps.

The data bases contain a collection of known maintenance and repair alternatives for any given component for which a Condition Index algorithm has been developed. New alternatives, as well as actual maintenance and repair data for a given structure, may be added by the user. In the life cycle cost analyses module, various economic plans can be developed. Plans that explore the expenditures needed to produce a desired condition level, within a specific time frame, are available.

More information about the REMR Managements Systems is available from Dr. Anthony M. Kao, Problems Area Leader for the Operation Management Problem Area of the REMR Research Program, telephone (217) 398-5486.



Dr. Anthony M. Kao is a research structural engineer and a team leader in the Engineering and Materials Division of the US Army Construction Engineering Research Laboratory, Champaign, Ill. He holds B.S. and M.S. degrees in civil engineering from the University of Illinois and a PhD degree in structural engineering from Iowa State University. Dr. Kao has more than 30 years of engineering experience and currently serves as problem-area leader in Operations Management for the REMR research program. He is a member of the American Society of Civil Engineers and the American Concrete Institute. Dr. Kao is a Registered Professional Engineer in the State of Illinois.

Wanted: Articles that Describe REMR Activities

The REMR Bulletin will print articles about REMR technology application and other REMR activities.

Material is published with the author's byline. Contribution from all REMR problem areas are welcome. The bulletin has a circulation of approximately 2,800. Occasionally, REMR-published articles are reprinted in other publications, thus multiplying the readership considerably.

Manuscripts may be submitted in either draft format or on floppy disk (Word Perfect 5.0 or 5.1, Word Star 3, or ASCII). Photos and illustrations enhance any submission and are requested, although not as a prerequisite for acceptance. A biographical sketch of the author accompanied by a head and shoulders, passport style photo will also be needed.

For more information call Elke Briuer, (601) 634-2587, or send your manuscript to Commander and Director, US Army Engineer Waterways Experiment Station, ATTN: CEWES-SC-A (TTS), 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

Preparation, Application, and Inspection of Coatings for Concrete

based on an article by
Stephen G. Pinney, P.E., S. G. Pinney & Associates*

Concrete prepared with the same raw materials may vary from one placement to the next because of variations in cement, sand and gravel, non-uniform mixing, the degree of vibration, and weather conditions. Therefore, concrete must be treated as a non-homogeneous material during the application or inspection of coatings.

In addition, concrete surfaces may contain bug holes, fins, tie-rod holes, and form joints; they may be contaminated with chemical compounds, form release agents, air-entraining materials, efflorescence, or laitance; they may contain excessive moisture. Any of these conditions can cause coatings to delaminate. The protective coating inspector must take appropriate actions to insure that chemical compounds and the physical condition of the concrete do not cause the coating system to fail.

Cautions During Concrete Forming and Curing

The method of placement affects the surface texture of concrete and the chemical compounds present. If it is known in advance that the concrete is to be coated, precautions can be taken. For example, when forms are used, they are normally precoated with form-release agents that consist of petroleum compounds. These agents may be transferred to the surface of the concrete and can be detrimental to a coating. To eliminate this problem, the forms can be protected with hard coatings or lacquers so that no material is left on the concrete. Also, if the forms are tightly butted, concrete will not enter the joints and form fins that will have to be removed later.

Surfaces of concrete floors are smoothed with a board, a trowel, or a broom. Each of these techniques results in a surface that is reasonably void-free, and each creates a different texture. The steel trowel technique frequently results in an extremely smooth, shiny surface too difficult to coat. A broom should be used after the steel trowel to improve coating adhesion and the coefficiency of friction for pedestrian traffic.

Protective coatings will not adhere to surface hardeners. If a surface has received a hardener, it must be roughened by abrasive blasting before a coating is applied.

Since concrete is porous by nature, it sometimes contains excess moisture. Moisture may remain in existing concrete walls for extended periods of time. On vertical placements, water is retained by the forms, and it is intentionally added on horizontal placements during the initial curing process. Before a protective coating is applied, sufficient time must pass to allow the excess moisture to evaporate. This time will vary but is normally not less than 28 days.

After curing, concrete must be checked for excess moisture beneath the surface. The most effective test for excessive moisture within concrete is the Plastic Sheet Method. This method is described in ASTM D 4263. It is advisable to perform the test on representative sections of each placement used to complete the concrete structure to be coated.

Surface Preparation

Surface preparation of concrete may involve any or all of the following operations:

- removing fins and protrusions
- removing surface contaminants
- roughening the surface to improve adhesion
- filling tie-rod holes
- filling voids

Fins, protrusions, and some laitance can be removed by stoning or power grinding. Stoning involves scouring the surface with a carborundum or other type of abrasive brick.

Before general surface preparation, surface contaminants such as form oils and efflorescence must be removed. Normal surface preparation procedures will drive these contaminants into the concrete, causing residual contamination and coating failures.

Oil and grease can be removed with an alkaline cleaner or with steam and a detergent. These processes suspend petroleum products. Solvent cleaning is not recommended. Efflorescence can be removed by wire brushing.

Chemically contaminated concrete must be neutralized prior to complete surface preparation. Acidic surfaces are neutralized with an alkaline cleaner and rinsed with fresh water. An alkaline surface is normally cleaned with steam or a detergent.

Methods for determining the presence and extent of contamination on concrete are available. In the *Journal of Protective Coatings and Linings*, R. Nixon (Nov 1988) describes methods of testing concrete in pulp and paper mills for acidic attack, deterioration by carbonation, caustic attack, and sulfate attack. These methods can be applied to many industrial settings. In the same publication, W. Ashmore (Nov 1986) and R. McDaniel (Jul 1989) describe tests that use acid etching to determine suitable surface preparation for existing concrete for which no information is available. These tests help determine whether or not chemical cleaning can or should be used.

After a concrete surface has been chemically cleaned, it should be tested to determine that residual chemicals have been removed and its pH will allow it to accept a coating. ASTM D 4262 is a "Standard Test Method for Determining pH of Chemically Cleaned or Etched Concrete Surfaces." Two readings should be taken on random sections of every 500 sq ft of concrete.

After the surface has been chemically cleaned, general surface preparation can be started. Preparation includes roughening the surface and removing any remaining loose material or laitance. Methods include abrasive blasting, air blasting without abrasive, water blasting, acid etching, or power tool cleaning.

Abrasive blasting (Fig. 1) is the most effective method of surface preparation. Care must be taken that the blast nozzle is held far enough from the surface to prevent excessive concrete removal. Reducing the blasting pressure is not recommended because productivity is greatly reduced.

Acid etching works well on nonsurface-hardened floors but is difficult on vertical surfaces. Acid etching does roughen the surface but does not remove laitance or other loose material. Typically, a 10 percent solution of muriatic (hydrochloric) acid is used. The concrete should be prewet to assure uniform etching. One gallon of solution is spread on 50 to 75 sq ft of concrete and allowed to stand for two to three minutes. The surface should be immediately rinsed with fresh water to avoid formation of salts. The procedure should be repeated until the concrete has the texture of fine sandpaper. The surface should be thoroughly rinsed following each etching and checked with pH paper according to ASTM D 4262 after the last etching.

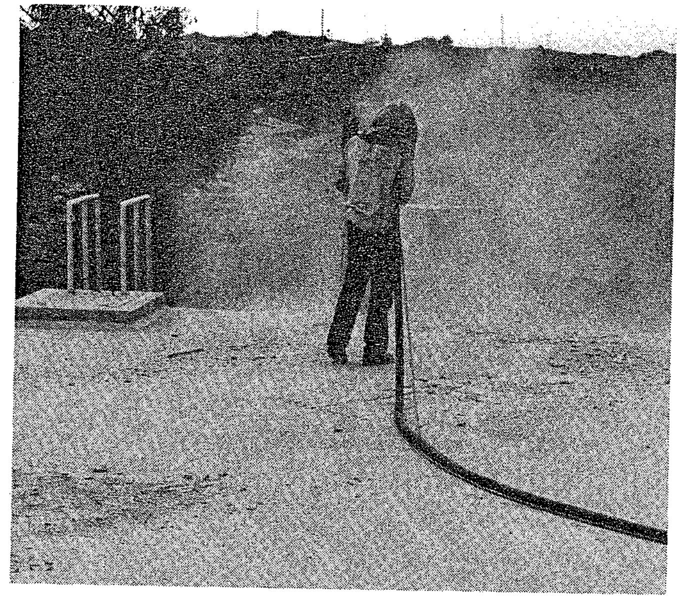


Figure 1. Sandblasting a concrete surface in preparation for coating application

Safety hazard to workers and the disposal of contaminated cleaning fluids are the major disadvantages of acid etching. Workers should wear goggles, protective clothing, rubber gloves, and boots. Mixing buckets should be plastic, and the acid should be added to the water, not visa versa.

Recommended practices for preparing concrete surfaces are described in ASTM D 4260, "Practice for Acid Etching Concrete"; ASTM D 4258, "Practice for Surface Cleaning Concrete for Coating"; ASTM D 4261, "Practice for Surface Cleaning Concrete Masonry for Coatings"; and ASTM D 4259, "Practice for Abrading Concrete."

Selection and Application of Coatings

Coating system selection for a concrete substrate is based on the type of service involved. Coatings for concrete generally fall in one of the following categories: fillers, surfacers, topcoats, or linings for immersion.

Sealers and penetrants are frequently colorless, silicone-based coatings that soak into the pores of concrete and may fill very small holes. They may be used for dust control or protection against water

Figure 2. Application of sealer to surface of the roof of a concrete water-storage tank, using squeegees

permeation. They may be applied by brushing, rolling, spraying or with a squeegee (Fig. 2).

The term "filler" normally applies to coatings applied over a rough surface such as concrete block. A filler is used to reduce roughness in preparation for a topcoat. Fillers are normally high solids, water-based materials applied by rollers.

Surfacers are selected when a smooth, chemically resistant surface is required prior to topcoating. Surfacers are normally epoxy materials that fill all voids in concrete, if properly applied. They are very high solids materials that do not shrink significantly during curing.

Fillers and surfacers may be topcoated with a variety of coatings. Interior coatings that require cleaning normally contain a chemically cured epoxy. A coat of polyurethane may be added to improve ultraviolet resistance of exterior coatings.

Linings or coatings subjected to immersion (Fig. 3) are generally thick film systems such as bituminous compounds or composite systems of various combinations of polyester, vinylester, epoxy, and chopped or mat-type fiberglass. Construction details for concrete that is to be lined are critical because concrete in tension can crack, and the lining must be capable of remaining intact.

Concrete is inherently alkaline, so it is necessary to select coatings with good alkali resistance. Oil-based coatings should never be used because the lime in concrete reacts with oil in paint to form soap. The result is delamination of the coating at the substrate.

Coating Inspection

Tests for coating thickness, adhesion, and continuity can be conducted by the coatings inspector. The inspector can nondestructively verify coating thickness by multiplying wet film thickness by the percent of the volume of the solids of the coating (if no thinner is added) or by knowing the quantity of material applied to a given area and calculating the average thickness. ASTM D 4414 describes the use of the wet film gage.

When a notch gage is used to verify wet film thickness, several precautions are necessary to ensure accurate readings. The gage must be clean; it must be perpendicular to the surface; the surface must be flat, and the notch gage must be used immediately after paint application. A delay will allow solvents to evaporate, causing the wet film thickness reading to be lower than it should be.

A Tooke Gage is used to measure dry film thickness. It provides an accurate measurement but requires patching the damaged test area. It is a destructive test that involves cutting an angular groove in the coating all the way to the substrate. The use of the Tooke Gage is described in ASTM D 4138. It can be used for coating thicknesses up to 50 mils.

If the Tooke Gage is to be used, contrasting colors for each layer should be specified. If colors are limited, the primer and the substrate may be similar in color. An examination of texture will help the user distinguish prime coat from substrate; typically, the substrate will have a rougher texture. Because the Tooke Gage measures the actual dry film thickness, it is often preferred over the notch gage when dry film thickness is critical.

Average dry film thickness can be calculated from the amount of surface area coated by one gallon of coating and the percent of solids per gallon of coating. This method is based on one gallon of a 100-percent-solids coating covering 1,604 mil sq ft. The percent solids per gallon of coating is multiplied by 1,604 and then divided by the area covered with one gallon of coating. The accuracy of this method depends largely on how evenly the coating is applied.

Destructive methods for testing adhesion are described in ASTM D 3359 and ASTM D 4541. ASTM D 3359, which uses a cross-cut test, is most commonly used. Two methods are included in the test. Method A, which calls for an X-cut through the film to the substrate, can be used at the job site. Method B, which uses a lattice cut through the film to the substrate, is more suited for laboratory testing. It is not recommended for film thicknesses greater than 5 mils. The test described in ASTM D 4541 is used to measure the amount of perpendicular force that a coating can tolerate. It provides a more quantitative adhesion value.

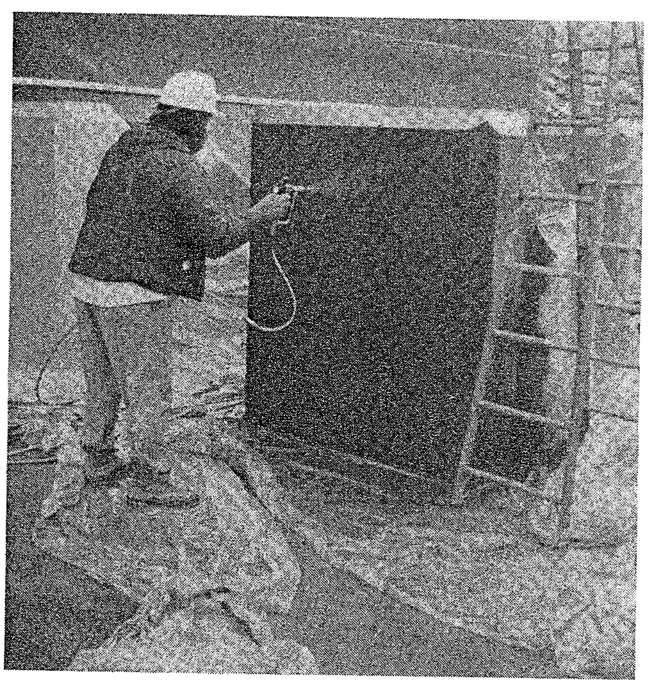


Figure 3. Polyurethane coating applied by spraying on baffle blocks in a stilling basin

Coating continuity can be inspected visually on new or existing concrete. New concrete with a coating thickness of 20 mils or less may be inspected with low voltage, wet sponge, holiday detectors if the concrete has not completely hydrated. Moisture in the concrete provides the medium for conductivity. Voltage testing for coating continuity is described in National Association of Corrosion Engineers Standard RP 0187-88.

Conclusion

Successful coating of concrete requires attention to many details of surface preparation, application, and inspection. Additional information can be obtained from the Steel Structures Painting Council, The National Association of Corrosion Engineers, and the American Concrete Institute.

For more information, write to Stephen G. Pinney, P.E., 473 S.E. Verada Ave, Port St. Lucie, FL 34983.

Reference

American Society for Testing and Materials. 1990. *1990 Annual Book of ASTM Standards*, Philadelphia, PA.

Stephen G. Pinney is a registered professional engineer in several states; a NACE Certified Coating Inspector, Corrosion Specialist and Instructor; and a National Board of Registration Certified Nuclear Coating Engineer. He chairs ASTM's D-33 Coatings for the Power Generation Industry, and is active on a number of committees related to his expertise. Pinney holds an M.S. in Business Management, and B.S. degrees in Civil Engineering and Agricultural Engineering.

COVER PHOTOS:

Schematic of a maintenance and repair analysis adaptable to a variety of structures

Properly prepared concrete surface ready for coating

The REMR Bulletin is published in accordance with AR 310-2 as one of the information exchange functions of the Corps of Engineers. It is primarily intended to be a forum whereby information on repair, evaluation, maintenance, and rehabilitation work done or managed by Corps field offices can be rapidly and widely disseminated to other Corps offices, other US Government agencies, and the engineering community in general. Contribution of articles, news, reviews, notices, and other pertinent types of information are solicited from all sources and will be considered for publication so long as they are relevant to REMR activities. Special consideration will be given to reports of Corps field experience in repair and maintenance of civil works projects. In considering the application of technology described herein, the reader should note that the purpose of *The REMR Bulletin* is information exchange and not the promulgation of Corps policy; thus guidance on recommended practice in any given area should be sought through appropriate channels or in other documents. The contents of this bulletin are not to be used for advertising, or promotional purposes, nor are they to be published without proper credits. Any copyright material released to and used in *The REMR Bulletin* retains its copyright protection, and cannot be reproduced without permission of copyright holder. Citation of trade names does not constitute an official endorsement or aproval of the use of such commercial products. *The REMR Bulletin* will be issued on an irregular basis as dictated by the quantity and importance of information available for dissemination. Communications are welcomed and should be made by writing the Comander and Director, US Army Engineer Waterways Experiment Station, ATTN: Elke Briuer (CEWES-SC-A), 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, or calling 601-634-2587.

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