US Army Corps
of Engineers

AN OVERVIEW OF THE REPAIR, EVALUATION, MAINTENANCE AND REHABILITATION (REMR) RESEARCH PROGRAM 1984 - 1989

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Final Report

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The following two letters used as part of the number designating technical reports of research published under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program identify the problem area under which the report was prepared:

	Problem Area		Problem Area
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

Executive Summary

The REMR Research Program was a 6-year, $35-million research effort which was completed in Fiscal Year 1989. The primary objective of the program was to identify and develop effective and affordable technology for maintaining and extending the service life of existing Corps Civil Works structures. For management purposes, the program was broken down into seven broad problem areas: (1) Concrete and Steel Structures, (2) Geotechnical, (3) Hydraulics, (4) Coastal, (5) Electrical and Mechanical, (6) Environmental Impacts, and (7) Operations Management. The report provides an overview of the program and describes selected research results in each of the seven problem areas. Appendix A is a listing of REMR Reports.

The REMR Research Program has clearly demonstrated the benefits of research in getting more value for the dollars spent on repair, evaluation, maintenance, and rehabilitation (REMR) activities. The estimated dollar savings from the use of REMR technology over the next 5 years exceeds $200 million. Because of the successes of the REMR Research Program, the high demand for its products, both within and outside the Corps, and the opportunity for similar successes on other REMR-type problems, a follow-on effort (REMR-II) is recommended.

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Appendix A

Listing of REMR Reports A-1

1 Introduction

This report is a final summary of the Repair, Evaluation, Maintenance, and Rehabilitation Research Program. It is only a brief overview of the highlights of the REMR research program and does not include all research conducted. Comprehensive research results are available in technical reports (Appendix A), The REMR Notebook with three Supplements, and several REMR video reports.

Program Development

The Corps of Engineers operates more than 600 hydraulic structures (lock chambers, flood control dams, powerhouses, etc.) at its civil works projects. About 70 percent of these hydraulic structures are over 20 years of age; 49 percent are more than 30 years old, and 26 percent were constructed prior to 1940. Approximately one-half of the Corps' 269 lock chambers along inland waterways will have reached or exceeded their 50-year-design service life by the turn of the century. Additionally, the Corps of Engineers operates and maintains thousands of miles of roads, breakwaters, jetties, groins, dikes, revetments, levees, and floodwalls in its many civil works projects. Many Corps projects contain electrical and mechanical equipment that is subject to fatigue, wear, corrosion, and inefficiency.

One of the primary responsibilities of the Corps of Engineers is to evaluate, maintain, repair, and rehabilitate these hydraulic structures. As a result of the 1972 National Dam Inspection Act (Public Law 92-367), greater emphasis has been placed on the evaluation and repair of the older hydraulic structures. Experience has shown that repair and rehabilitation of older facilities requires various types of expertise, some of which are different from those required in connection with design and construction of the newer structures.

It is generally less expensive to maintain, repair, or even rehabilitate a structure than it is to build a replacement structure. Projected budgetary constraints in the 1980's meant that the Corps was faced with keeping many of the existing structures in operation well beyond their design service life. As the age of a structure increases, so do its maintenance and repair needs. The Corps' Operations and Maintenance appropriation had been increasing for more than a decade, and in the early 1980's, it was approaching 50 percent of the total civil works' budget. Since so much of its resources were devoted to maintenance and repair activities, it became obvious that research and development in this area provided opportunity to obtain more value for the dollars being spent.

Funds were made available in Fiscal Year 1983 to put together a comprehensive research program. Deficiencies and needs were identified by Corps field personnel and generally fell into three categories: the need for improved technology to quickly and accurately evaluate the existing condition of a Corps project; the need to maintain and repair projects in a cost-effective manner; and the need to lower the cost and time required to rehabilitate structures. As a result, the "REMR Research Program Development Report" was published in February 1983 and was used to successfully seek funding approval for the program as a line item in the Corps' O&M budget.

The REMR Research Program was approved as a 6-year, 35-million dollar research effort, initiated in Fiscal Year 1984.

Objectives

The primary objective of the REMR Research Program was to identify and develop effective, affordable technology for maintaining and extending the service life of existing Corps civil works structures.

Although Corps' needs were the driving force behind the research conducted, much of the results have application outside of the Corps. Accordingly, another the Corps' objective was to make REMR research results available to other Federal agencies, state and local governments, and the private sector. A comprehensive technology transfer program would thus serve to publicize research results to internal and external audiences.

Management Structure

Overall management of the REMR Research Program was provided by the Directorate of Research and Development. An Overview Committee was established at Corps Headquarters to scope and direct the program. A 12-member Field Review Group was formed to provide field input to the program and to assist with technology transfer to the field. A Program Manager was used to oversee the day-to-day activities and direct the technology transfer efforts.

REMR was a broad based research program and for management purposes it was broken down into seven problem areas; (1) Concrete and Steel Structures, (2) Geotechnical, (3) Hydraulics, (4) Coastal, (5) Electrical and Mechanical, (6) Environmental Impacts, and (7) Operations Management. A laboratory problem area leader was designated for each of the problem areas to coordinate and manage the research within their respective area. A Problem Area Monitor from Corps Headquarters' staff was appointed for each problem area to monitor the technical progress on each research study.

2 Research Results

Concrete and Steel Structures

Research conducted under this problem area addressed problems with (1) the evaluation of the present condition of a structure (both above and below the waterline), (2) maintenance, repair and rehabilitation of concrete and steel structures, and (3) surveillance and monitoring for structural safety. Results from individual studies are described below.

In Situ Repair of Concrete. Repair of concrete in hydraulic structures generally involves removing the deteriorated concrete and replacing it with new, cast-in-place concrete. The objective of this study was to identify materials and methods that would allow in situ treatment of deteriorated concrete without the necessity for removal. The initial step was a feasibility study to identify both the types of deterioration most prevalent in concrete hydraulic structures and the existing materials and methods commonly used for repair and rehabilitation. Once this information was collected, it was evaluated to determine the applicability of the various systems to the in situ repair of concrete hydraulic structures. Of the repair techniques identified as being applicable to in situ repair, the pressure injection technique was selected for detailed evaluation. This procedure has been used extensively for repair of single, continuous cracks in structural concrete, but experience in pressure injection of mass concrete containing an internal network of multiple, interconnecting cracks has been minimal.

Figure 1. Field test of the in situ repair procedure on a pier at Dam No. 20, Mississippi River.

An in situ procedure was developed in the laboratory and demonstrated at Dam No. 20 and Dam No. 13 on the Mississippi River. An evaluation of the concrete before and after injection indicated that the injection procedure worked well and the concrete areas injected were considered successfully repaired. Therefore, in situ repair of mass concrete seems to be a viable alternative to conventional concrete removal and replacement.

As a result of this research, the Rock Island District used pressure injection for rehabilitation of 38 tainter gate piers at Dam No. 20. Instead of removing and replacing 11 ft of the pier stems as originally planned, only the top 1.5 ft were removed to allow replacement of the service bridge seats and to improve drainage on top of the piers. Pressure injection was used to rehabilitate the remainder of the structure. The cost savings attributed to the use of the in situ repair procedure at Dam No. 20 are $1.2 million.

Stability of Existing Concrete Gravity Structures on Rock. Reevaluations of several aging concrete gravity structures revealed that many of these structures did not meet the Corps' stability criteria for new structures. Even though these structures had performed well for many years with no sign of instability, the response was to strengthen these structures by the use of anchors, a very expensive endeavor. REMR research results showed that the stability criteria used for these existing structures was overly conservative. The Corps' stability criteria for existing concrete gravity structures was changed based on research results. The revised criteria use a 3-phased approach that, when justified by site conditions, allows reduction of earth pressures and credit for shear stresses that develop in the backfill as deformations occur. Also, when the remaining service life is short and the consequences of failure are not severe, the minimum factor of safety can be relaxed samewhat for different loading conditions. The revised criteria will save many of the Corps' concrete gravity structures from unneccessary and expensive structural rehabilitation.

In FY87, this research was used by Corps Headquarters to conclude that Eisenhower and Snell Locks on the St. Lawerence Seaway were structurally stable. The estimated cost for the structural rehabilitation of these two locks was $14 to $17 million. Another example of savings resulting from this research is Troy Lock and Dam in the New York District. Troy Lock and Dam did not meet the old stability criteria and was being considered for structural rehabilitation. When the revised criteria were applied, Troy was found to meet the criteria, and structural rehabilitation will not be performed. The savings resulting from the elimination of unnecessary anchoring work is estimated to be $3 to $4 million.

Continuous Monitoring System for Structural Safety of Large Dams. The normal behavior of a dam needs to be understood so that abnormal behavior can be detected. Precise daily studies of dam motion were not previously feasible because the measurements could not be automated. Under this work unit, a continuous monitoring system was developed that uses the Navstar Global Positioning System to determine three-dimensional differential movements at up to eight points on a structure. Each position is then compared to an original position to determine the total amount of movement. Accuracies of +/- 5 millimeters in the three-dimensions are possible. The monitoring and data recording equipment is linked together with telephone lines, R-232 cable, or fiber optic cable. No system operator is required, and real-time structural deformations may be monitored at remote locations such as a district office. A prototype system was installed and demonstrated at Dworshak Dam in the Walla Walla District from July to September 1989.

Precast Concrete Stay-in-Place Forming System. The general approach to lock wall rehabilitation has been to remove 1 to 3 ft of concrete from the face of the lock wall and replace it with new air-entrained concrete. One of the most persistent problems using this approach is cracking in the replacement concrete. A detailed numerical model study revealed that the cracking is due to the restraint provided by the large mass of concrete remaining in the lock wall. Shrinkage of the resurfacing concrete as it cures is resisted by the existing concrete, and cracks develop.

It was postulated that by using precast concrete as a stay-in-place form for the replacement concrete, cracking problems could be eliminated. A range of design alternatives were evaluated through a process of value engineering, and horizontal precast panels constructed of conventional precast quality concrete were selected for detailed quantitative investigation. The panels were designed to be tied to the lock monolith along the top and bottom edges using form ties designed to support the loads of the infill concrete placement.

Two 1/2-scale lock-wall monoliths were used for a demonstration of the constructability of this system and resulted in some minor design changes. The precast concrete stay-in-place forming system is a viable method for lock wall rehabilitation. In addition to providing a concrete surface of superior durability with minimal cracking, the estimated construction cost is about 15 percent less than conventional forming and concrete placement. Another advantage of the system is the potential reduction in the length of time that a lock must be closed to traffic during rehabilitation. With proper detailing, sequencing, and scheduling of work activities, the rehabilitation work may be accomplished with minimized impact on normal lock traffic.

Precast concrete panels were used for the resurfacing of Lock No. 22 on the Mississippi River and are being considered for use at Troy Lock on the Hudson River.

Figure 2. Precast stay-in-place forming system used at Lock No. 22, Mississippi River.

The precast concrete stay-in-place forming system was also evaluated as a system that could be used for resurfacing lock walls without dewatering the lock chamber. This would allow the lock to remain operational. It could be closed for short periods to resurface one or two monoliths at a time and be opened for navigation between these periods. The details of this operation and the design for a barge mounted cofferdam that would be used to dewater the work area have been documented.

Underwater Surveying. The underwater portion of a concrete structure is often located in a hostile environment, making the assessment of the condition of the concrete difficult. Our objective was to provide information on accurate and inexpensive survey systems and techniques by which a comprehensive assessment can be made. As a part of this effort, a high-resolution acoustic-mapping system for performing rapid, accurate surveys of submerged, horizontal surfaces was developed from jointly sponsored research with the Bureau of Reclamation. The system makes possible, without dewatering of the structure, comprehensive evaluation of top surface wear on such horizontal surfaces as aprons, sills, lock chamber floors, and stilling basins where turbulent flows carrying rock and debris can cause abrasion-erosion damage.

Figure 3.
Survey boat equipped with high-resolution acoustic mapping system.

The high-resolution acoustic mapping system is now commercially available. It has been used successfully for underwater mapping at Chief Joseph, Ice Harbor, Pine Flat, Daguerre Point, and Folson Dams. It can be used in water depths of 5 to 40 ft and produces survey results with accuracies of +/- 2 in. vertically and +/- 1 ft laterally. The limitations of the system are that it can only be used in calm water environments (a tilt of the survey vessel of more than 5 degrees will cause the system to shut down) and it cannot pick up deep depressions less than 2 ft in diameter. Information was also assimilated and published on underwater inspections, underwater cleaning tools, remotely operated vehicles, and short pulse radar for underwater inspections.

Nondestructive Testing. Nondestructive testing of concrete allows the inspection of larger areas at less costs than coring and provides more information than a visual inspection. A comprehensive REMR technical report describes the available techniques, their applications, advantages, and disadvantages.

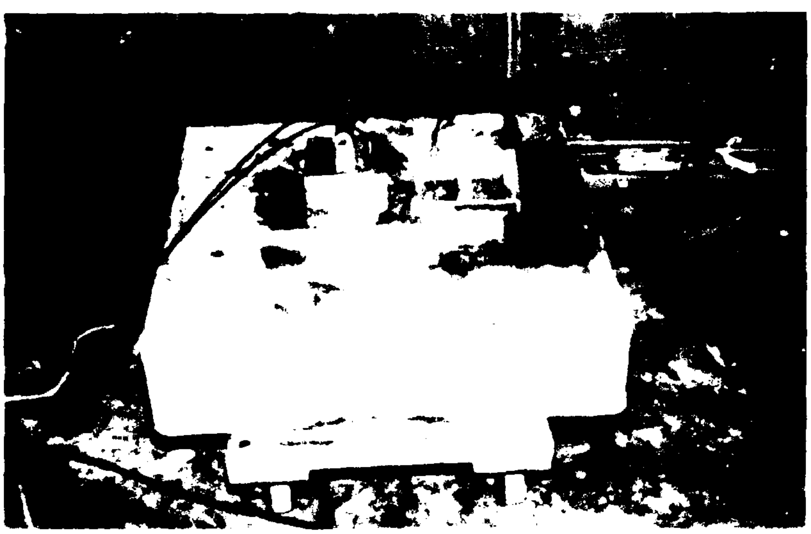

Figure 4. Prototype pulse-echo system transmitter and receiver during laboratory tests.

A new, improved prototype ultrasonic pulse-echo system was developed for the evaluation of concrete structures where only one surface is accessible. The system uses piezoelectric crystals for both signal generation and detection. The 200-kilohertz two-transducer system has a signal-to-noise ratio of 18. The weight and dimensions of the improved system have been reduced by 90 percent from the prior state-of-the-art system. The system, which has the shortest pulse length on record, works well in making thickness measurements of portland-cement concrete (< 12 in.) and can indicate the presence of reinforcing steel, voids, and inferior quality concrete both above and below water.

To keep civil works metal structures fully functional and safe, a thorough inspection procedure must be implemented. A guide for the selection of an appropriate test method for metal structures was published. The guide includes information on the theory, applications, advantages, and disadvantages of each nondestructive testing method. Case histories are included which describe how nondestructive testing procedures can enhance inspection routines.

Surface Treatments to Minimize Concrete Deterioration. 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. Various surface treatments were evaluated with emphasis 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.

The test data for surface treatment materials indicate wide differences in the effectiveness of these materials for protecting concrete or minimizing concrete deterioration. Criteria were established for use as guidance in the selection of concrete sealers.

Underwater Concrete Repairs. A large part of the cost of repairing the underwater portions of concrete structures is devoted to dewatering the structure so conventional concrete placing techniques can be used. A review of the state-of-the-art techniques for underwater repair suggested that concrete could be effectively placed underwater by pumping when newly developed anti-washout admixtures were used and thus dewatering cost could be eliminated.

Concrete mixtures were developed in the laboratory using these new admixtures to minimize the reduction in concrete quality that is normally associated with the placement of concrete underwater. In addition, several repair concepts (e.g. use of precast elements) and various underwater concrete placement techniques (e.g. inclined tremie, pumping, etc.) were identified.

An eroded section of the end sill of the stilling basin at Red Rock Dam was successfully repaired using an underwater concrete mixture pumped underwater to the repair area. Estimated savings resulting from the elimination of the need to dewater the structure for the repair was $500,000.

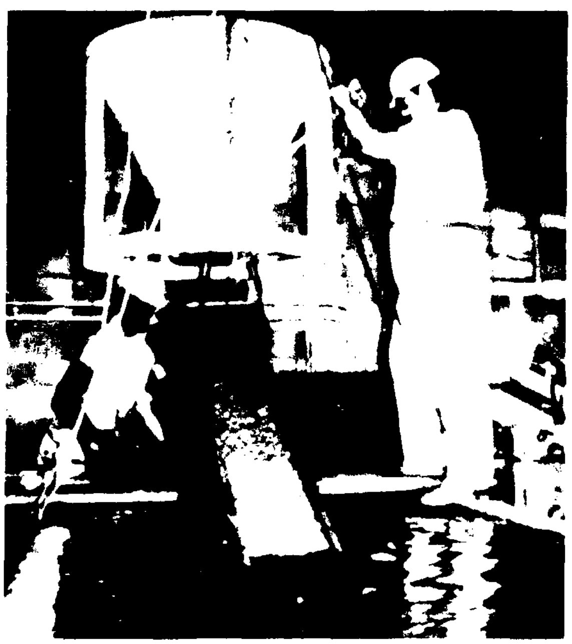

Figure 5. Laboratory test of underwater concrete mixture using an inclined tremie..

Instrumentation Automation for Concrete Structures. Automation of instrumentation at existing concrete structures can increase the timeliness and accuracy of data and can reduce man-hour requirements. It can also permit the instruments to be monitored from a remote location or from the district office. Information was accumulated on commercially available hardware and software, and guidance was developed on the use of these products for instrumentation automation.

This technology was demonstrated at Beaver Dam near Eureka Springs, Arkansas where pressure cells, weirs, joint meters, and piezometers were automated. Prior to the automation of the 84 piezometers, it took a team of field personnel 4 hours to read the piezometers which can now be read in less than a minute.

Maintenance and Repair Materials Data Base. The number of commercially available materials touted for maintenance and repair of concrete and steel structures is enormous and continues to grow. The number of products available and product manufacturers' claims on the applicability of their products to maintenance and repair problems makes the selection of an appropriate material difficult. To assist personnel in the selection of materials, a maintenance and repair materials data base was developed and is accessible by remote terminal. It provides the user with a means to (1) identify products for use in concrete and steel structures that may be applicable for specific types of repairs and (2) obtain supplemental information from the manufacturer, the Corps of Engineers, and other sources regarding the use, application, limitations, and technical properties of the products.

Products in the data base are identified as end-use or additive. An end-use product is a material that is used-as-purchased to make a repair, whereas an additive product is a material used in an end-use product. Help options provide definitions of product categories and uses for end-use and additive products.

Concrete Joint Repair Test Apparatus. Joints in concrete hydraulic structures tend to deteriorate faster than other parts of the structure and are more difficult to repair, especially if they are leaking water. Many different materials and techniques have been used to repair joints, with the majority of them lasting only a short time. The lack of an appropriate test procedure that would allow laboratory evaluation of these materials and techniques resulted in expensive and often unsuccessful prototype applications.

Under the REMR Program, a unique laboratory apparatus was designed and built to permit the testing of materials and techniques in the laboratory under the environmental conditions they will face in a prototype application. This apparatus can also be used to test crack repair procedures for cracks that are leaking or flowing water with up to 100 ft of head.

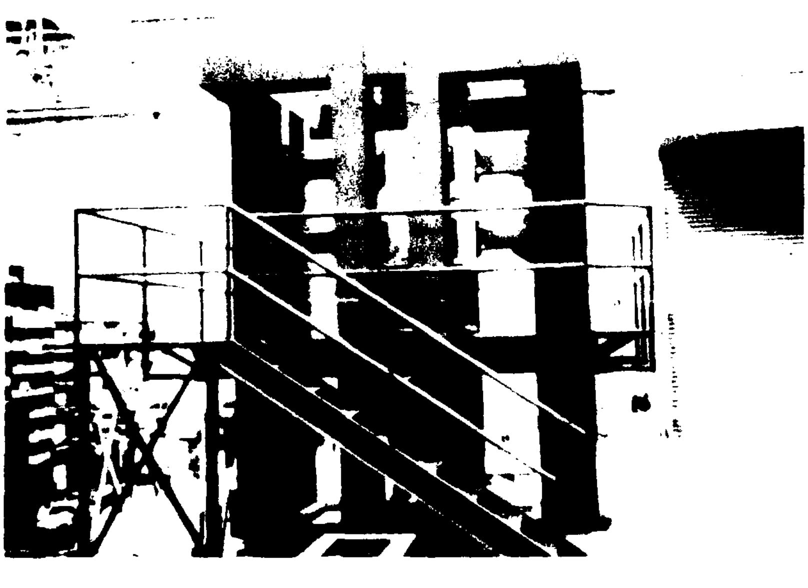

Figure 6. Laboratory joint and crack repair test apparatus.

Geotechnical

Primary concerns under the geotechnical problem area were remedial treatments for foundation problems.

The Improvement of Foundation Soils Susceptible to Liquefaction. Liquefaction of foundation soils can cause catastrophic failure or limit the usefulness of a project. It is now known, through new and improved testing procedures, that many Corps structures are located on liquefiable foundations. Techniques applicable for remedial treatment of the foundations of existing structures were identified, and guidance was provided for their selection and use. Two of the more promising techniques are sand compaction piles and stone columns. The relative costs of these techniques are moderate and they provide (a) vertical support, (b) drains to relieve pore water pressure, and (c) shear resistance in horizontal and inclined directions. Stone columns were used to improve foundation conditions at Steel Creek Dam, Georgia, and sand compaction piles were used by the Pacific Ocean Division in two military projects in Japan.

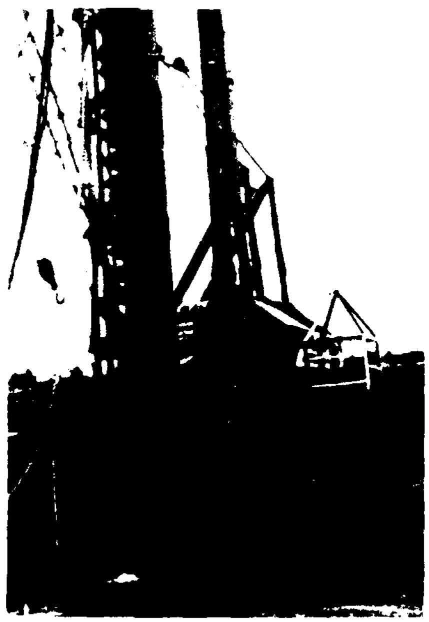

Figure 7. Equipment used to install stone columns to improve foundation conditions.

Restoration of Relief Wells. Relief wells, a safety feature when installed at a structure, can become clogged by chemical or biological incrustation allowing uplift pressures to increase beneath the structure. A procedure was developed for restoring the efficiency of these wells using a process called "Blended Chemical High Temperature" or BCHT. The Corps has approximately 5,000 relief wells that must be treated periodically or replaced. The BCHT process will extend the maintenance interval for these wells by at least 1 year and will result in annual savings of $500,000.

An example of additional savings is the relief wells at the New Alton Pumping Station Project in the St. Louis District. Standard cleaning methods failed to bring these wells up to the required 80 percent of original capacity. The BCHT process was demonstrated to be capable of successfully cleaning the wells, thus eliminating the expense of replacement wells. The cost difference between restoration and possible replacement of as many as 60 wells at this site was estimated to be $1.5 million.

Figure 8. Treatment of relief wells at the New Alton Pumping Station.

Control of Adverse Levee Underseepage. Underseepage control measures designed and constructed according to established criteria have proven inadequate at many sites. Improved guidelines were developed for special foundation conditions and levee alignments. Computer programs have been developed that will allow the user to evaluate various remedial alternatives for controlling adverse levee underseepage and estimate the construction costs of these alternatives. The developed programs allow analyses that are not restricted to the boundary conditions assumed in the conventional, closed form solution, i.e., two foundation layers of uniform thickness with horizontal boundaries. Guidance was also developed for inspection and control of levee underseepage during flood conditions.

Remedial Cutoffs and Control Methods. Seepage related to embankment dams can be a serious problem, and remedial control methods are limited and expensive. Laboratory tests and guidance was developed for determining when seepage is a serious problem and likely to lead to severe damage of the structure. Corps dams lo-

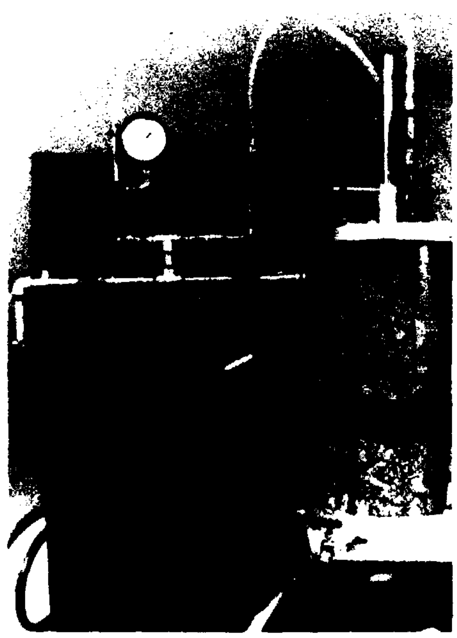

Figure 9. Modified No Erosion Filter Test being conducted in the laboratory.

cated within glacial regions where widely graded soils may have been used as core materials were inventoried. Mud Mountain Dam, Washington, was selected as the prototype project for this study, and research to determine the erosion characteristics of the core material yielded a modified "No Erosion Filter Test." This test can be used to determine if the chimney drain material is adequately sized to seal any cracks that may develop in the core material of the dam.

Guidance was developed on recently developed remedial seepage control methods such as plastic concrete cutoff walls, reinforced earth berms, and jet grouted cutoff walls.

Expert System for Remedial Seepage Control. Leakage and underseepage are continuing problems at many Corps structures. An expert system was developed for diagnosing seepage problems associated with earth, rockfill, concrete and roller compacted concrete dams. The user is prompted for a description of his problem, given a diagnosis, and presented with some possible remedial actions. The user may also link, via the expert system, to a data base containing case histories of dams maintained by the US Army Corps of Engineers. Each of the dams in the data base has had one or more seepage problems. The case histories may be accessed by problem type (e.g. wet spots, abnormally high piezometric readings, turbid seepage, etc.) and thus provide the user with information about the ways seepage problems similar to the one at hand have been solved.

Allowable Movements and Performance Criteria. A major deficiency existed in (1) the ability to evaluate the need for remedial measures for structures that are undergoing continuing movements, and (2) the ability to predict or verify the effectiveness of remedial measures. Design and analysis methods for newer structures do not predict or provide useful criteria for tolerable movements of older structures.

A computational procedure capable of predicting failure mechanisms in earth structures has been developed. This valuable new tool is important because it: (1) ties the stability of a structure to displacements that can be observed in the field, and (2) provides a method for evaluating the effectiveness of remedial measures. The analysis procedure has been developed into a comprehensive code for two-dimensional analyses of soil-structure interaction and embankment problems. It was used for an analysis of allowable movements for sheet-pile I walls for the New Orleans District. The results showed that it was not feasible to limit wall movements by use of expensive, stiff sheet-pile sections and excessive sheet-pile lengths, as prescibed by existing design criteria. An alternative design criterion, which accommodates larger movements, was adopted.

Grouting for Foundation Repair and Rehabilitation. Foundation grouting has long been an accepted procedure for improving foundation conditions. The objective of this effort was to evaluate and develop modern methods of foundation grouting to improve quality control and reduce costs.

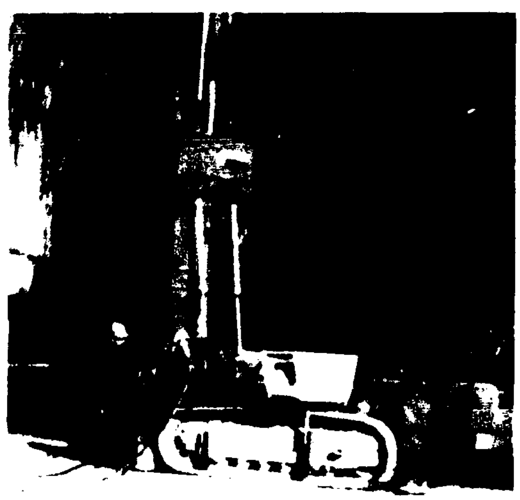

Figure 10. Drill rig instrumented with "Drilling Parameter Recorder."

Several products were developed under this effort including a comprehensive technical report on consolidation grouting of rock masses.

A computerized grout control and monitoring system was developed under a joint effort with the Bureau of Reclamation. The use of this system is expected to substantially reduce the number of changed condition claims by grouting contractors.

A method to evaluate rock properties prior and subsequent to grout injection was developed. A drill rig instrumented with a drilling parameter recorder is used to predict groutability, and an acoustic emission monitoring system is used for mapping grout location. Test grouting on this method was conducted at Little Dell Dam, Utah.

Rock Erosion in Spillway Channels. Until now the Corps did not have a technically sound methodology for predicting the rate of erosion on unconsolidated indurated or semi-indurated materials that exist in many spillway channels. An understanding of the combined effects of the geometry, pressure differentials, and velocity was used to develop guidance for predicting erosion potential of high-level emergency spillways. This guidance can be used for judicious decision making concerning O&M expenditures for remedial treatments.

Significant progress was made in understanding the headward erosion that has been observed in unlined emergency spillways in rock. Model studies showed that headward erosion is most severe when an airpocket exists below the overflow nappe at below atmospheric pressure. This pulls the plunging water closer to the toe of the knickpoint where severe erosion occurs and causes the knickpoint to move upstream. Venting the airpocket results in the overflow shooting farther from the toe of the knickpoint and results in less erosion and a slower upstream migration of the knickpoint. The application of this technology in critical flow situations could very well prevent the loss of a reservoir impoundment and the severe flooding that would occur from such an event.

Figure 11. Erosion at Saylorville Spillway, Des Moines, Iowa.

An understanding of the mechanics of spillway channel erosion was used to develop remedial treatment technology for problem spillways. This technology was used to develop the remedial treatment plans for the Saylorville Spillway and resulted is significant dollar savings over the cost of lining the spillway.

Geophysical Techniques. Existing structures complicate and limit routine application of standard engineering geophysical techniques for foundation assessments.

New geophysical methods are being developed and standard methods can be adapted that allow definitive and cost-effective application to existing structures.

Field procedures, data processing methods, and interpretation methods were developed or adapted for high-resolution seismic reflection, ground penetration radar, microgravity, and self potential methods. Two field test sites were selected and the methods applied to the assessment of various structure and foundation problems. At the Lockport Approach Dike on the Illinois Waterway, near Joliet, Illinois, a ground penetrating radar survey detected possible seepage paths through the dike, verified the location of the concrete core wall, and assessed its condition. At Dike 1, Beaver Dam, Arkansas, a comprehensive foundation assessment was conducted. The geophysical methods applied at Dike 1 succeeded in mapping seepage paths and delineating the complex geology. Based on the results of the geophysical surveys and other geotechnical investigations the rational design of a concrete cutoff wall to eliminate anomalous seepage was possible.

During this project, the REMR technology was applied at two sites under other funding. A ground penetrating radar survey was conducted at the Tomb of the Unknown Soldier in Arlington Cemetery, and a microgravity survey was conducted in the Great Pyramid of Cheops, Giza, Egypt. The Tomb is an existing structure of great national and patriotic significance, while the Great Pyramid is one of the oldest existing structures built by man.

Also, a comprehensive assessment of the foundation of Mill Creek Dam near Walla Walla, Washington, was conducted using REMR technology. The Mill Creek Dam assessment mapped major anomalous zones in the foundation that will contribute to the planning for remedial measures.

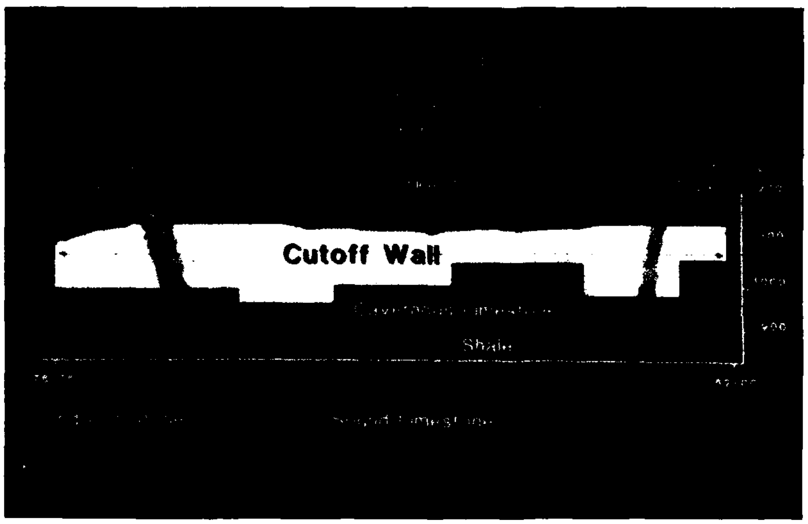

Figure 12. Results from geophysical studies were used to design a concrete cutoff wall at Beaver Dam, Arkansas.

Hydraulics

Under the hydraulics problem area investigations were conducted on ways to minimize scouring problems and to improve navigation conditions and operational capabilities.

High-level Emergency Spillways. The Corps has numerous high-level emergency spillways without downstream energy dissipaters. Many of these spillways have the potential for excessive scour that threatens the safety of the spillway.

A combination of model and prototype experiences were used to identify and demonstrate several causes of excessive scour and to identify potential structural solutions. Guidance was developed for evaluating existing high-level emergency spillways from a hydraulic standpoint and for making structural modifications to prevent excessive scour downstream. Energy dissipation within the concrete-lined section of the emergency spillway channel is preferable to dissipation in the natural channel. This guidance was used by the Fort Worth District for the rehabilitation of the Grapevine Spillway.

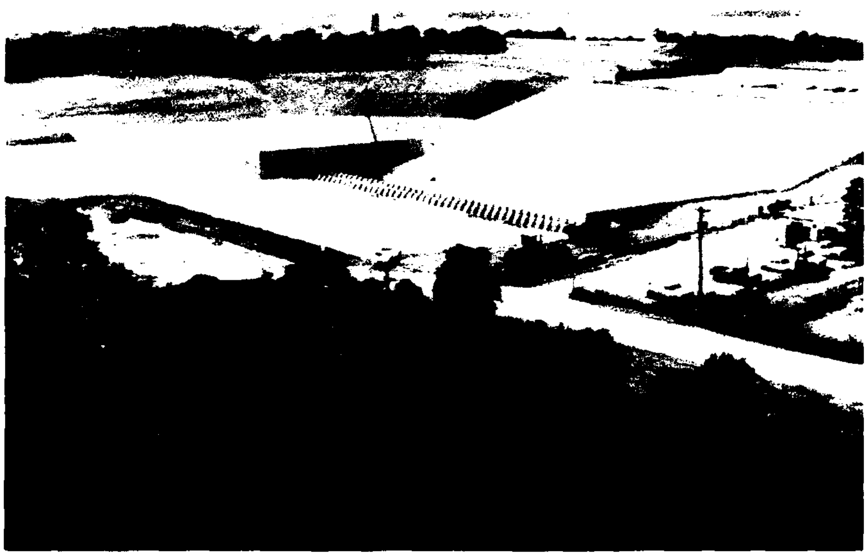

Figure 13. The extended chute of the rehabilitated spillway, Grapevine Lake, Texas.

Scour Downstream from Stilling Basins. Numerous older hydraulic structures have experienced excessive scour downstream from the stilling basin or spillway apron. Most of the structures were constructed several decades ago and will be required to operate for several more decades. Without adequate repair or rehabilitation of the area downstream from these structures, they could be undermined.

Methods to repair scour damage downstream from navigation dam stilling basins were investigated for uncontrolled fixed-crest and gated projects. From a review of previous model studies, the causes of scour below the various types and shapes of spillways were identified and scour protection methods were developed. Additionally, several repair options were developed that include the use of grout-filled fabric bags, use of sunken barges filled with grouted riprap, modification to the spillway apron by adding an end sill, and construction of a secondary stilling basin immediately downstream. A secondary stilling basin will usually result in significant dollar savings over the cost of replacing an inadequate stilling basin.

Corps districts can use this information to design an economical and functional scour protection plan for the remainder of a project's life. A good scour protection design will reduce and possibly eliminate maintenance costs previously required. Some of the repair techniques investigated under this study have been used at Emsworth, Montgomery, and Dashields Dam, Ohio River, at Lock and Dam No. 2, Monongahela River, and at Lock and Dam No. 7, Allegheny River.

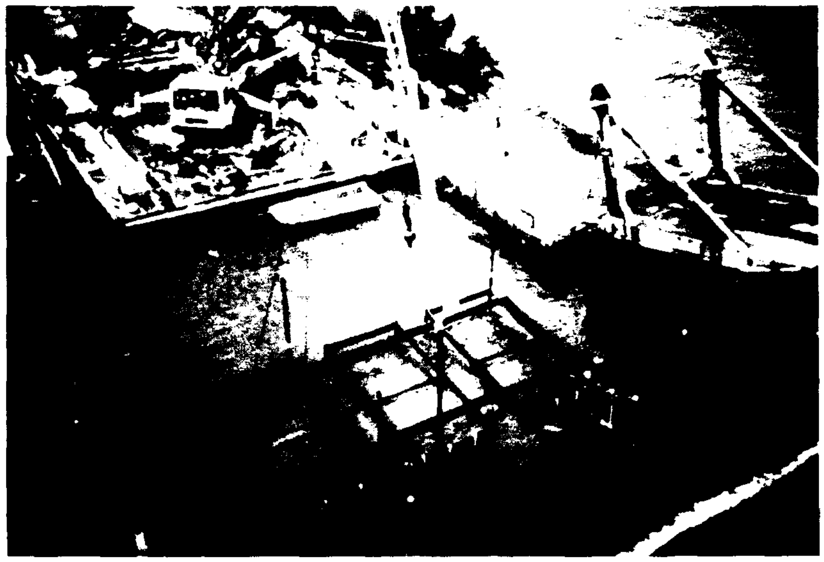

Figure 14. Grout-filled fabric bags being used to repair a scour area at Emsworth Dam.

Elimination of Unfavorable Flow Conditions Near Hydraulic Structures. Adverse approach flow can accelerate the need for repair, increase the cost of maintenance, and reduce the effective life of a structure. In many cases it is cheaper to modify the approach than to pay the long-term costs that would result from continued operation under existing flow conditions. The modifications, however, must achieve the greatest benefit with the simplest and least expensive remedial measures.

In the past, each modification under consideration was usually tested in the laboratory with a physical model. The expense of model building and testing often limited the number of alternatives that could be explored. Under the REMR Program, a two-dimensional hydrodynamic computer code called STREMER was developed for analysis of approach flows. STREMER can be used as an inexpensive means for screening the efficiency of various structural designs and operations prior to physical model development and testing, thus reducing physical model tests by at least 25 percent. A physical model can then be used for the ultimate testing and refinement of the best option.

STREMER was used in the design of the approach to the intakes of the rediversion of the Clover Fork River at Harlan, Kentucky. It was also used to look at erosion problems above and below Grand Pass on the Mississippi River.

Floating Debris Control. Floating debris is a continual problem for all users of water bodies. It is destructive to locks, dams, bridges, electric plants, municipal water systems, and even recreational boaters. Wetlands, fish-spawning grounds, and streambanks can be disturbed by floating debris. Various methods for collecting, controlling, removing, and disposing of floating debris were identified and documented.

Figure 15. Trash rake at Chief Joseph Dam, Bridgeport, Washington, operated by a gantry crane; it scrapes debris from the trash rack while moving down the rack face.

Repair of Navigation Training Structures. Recent inventories revealed that there are 10,652 Corps training structures located in shallow-draft, non-tidal-influenced riverine areas, and some 554 training structures located in tidally influenced, deep-draft areas. The repair of both estuarine and riverine navigation training structures is a significant maintenance cost within the Corps. This has included the repair of stone dikes, pile dikes, and closure structures damaged as a result of normal wear and tear, floating debris, impact from navigation, flood flows, or undermining due to currents.

Figure 16. This training structure on the lower Columbia River was one of those identified as no longer needed.

Present repair practices are sufficient for making physical repair to the training structures; however, identification of structures no longer fulfilling their design purpose is also a means for better allocating scarce resources. Refinements to the existing TABS-2 hydrodynamic-sedimentation numerical system assisted in the identification of training structures in the lower Columbia River and the Southwest Pass of the lower Mississippi River. These structures no longer provided the channel maintenance function for which they had been designed and, therefore, could be removed from the annual maintenance cycle. Significant O&M savings were achieved in the Southwest Pass area. The TABS-2 refinements can also be used to assist in the prediction of which training structures can be expected to have severe erosion problems, thereby achieving timely repair before more costly structure failure occurs.

Coastal

Evaluation, repair, and rehabilitation techniques for coastal structures such as jetties and breakwaters were investigated under the coastal problem area.

Sealing of Permeable Breakwaters and Jetties. Rubble-mound breakwaters and jetties are intended to protect harbors and navigation channels from excessive wave energy and to prevent shoaling of channels and boat mooring areas by littoral material. The cores of many such Corps coastal structures have deteriorated and become permeable to such an extent that they do not serve, or only partially serve, their original intended function.

A cost-effective alternative to traditional methods of rubble-mound structure sealing (i.e. dismantling to rebuild core sections, chinking layers along surfaces, additional armoring layers, etc.) was determined to be drilling and grouting (sealing) a vertical barrier curtain along the center line of the structure from the bottom to approximately mean higher high water.

Sealing permeable breakwaters or jetties should be approached from the standpoint of preventing wave or sand movement through the structure and not from the requirement of imparting structural stability or strength. In planning a sealing operation, a quantitative determination must be made of the wave energy or sand passing through the structure to ascertain economic benefits.

Based on the technology available through this study, Broward County sealed the South Jetty at Port Everglades, Florida, with chemical grout. Use of this technology versus the conventional use of chinking material and a covering layer of armor stone resulted in a savings of $314,000.

Figure 17. Sealing of the south jetty at Port Everglades, Florida.

Reducing Wave Runup and Overtopping. Problems associated with runup and overtopping have occurred on about 20 percent of the Corps' coastal structures. Problems from runup and overtopping range from (1) excessive wave action on the lee side of breakwaters and jetties, (2) flooding and erosion on the backside of seawalls, sea dikes, and bulkheads, to (3) backside subsidence, erosion, and sometimes collapse of revetments.

Mathematical models and flume studies were used to evaluate and rank the hydraulic performance of a number of seawall/revetment configurations. For existing revetments, it was found that an attached low berm fronting a rubble revetment significantly decreases wave runup and overtopping. This technology was used at the Temple Emanuel project on the Chicago waterfront and resulted in a 12-percent savings over the costs of the traditional high berm revetment. Based on experience at the Temple Emanuel project, a low berm revetment was proposed for approximately 28 miles of highly developed shoreline along the Chicago lake front.

Figure 18. Low berm revetment installed at Temple Emanuel to decrease wave runup and overtopping.

Rehabilitation of Rubble-Mound Structure Toes. Many breakwater failures have been attributed to failure of the toes of these structures. No firm guidance existed to aid Corps personnel in designing toe berms and most design work was carried out using limited local field experience with past successes and failures.

A series of two-dimensional and three-dimensional breakwater stability physical model experiments was developed and conducted to address the sizing of toe berm and toe buttressing stone in breaking wave environments. The two-dimensional tests focused on sizing of toe stone on rubble-mound structure trunks exposed to 90-degree wave attack, i.e. wave orthogonals perpendicular to structure crest. Toe berm armor stone sizing for oblique wave attack on rubble-mound structure heads and trunks was examined in the three-dimensional model tests. Guidance for sizing toe berm armor stone was developed for a range of wave and still-water level conditions. Guidance for sizing of toe buttressing stone was addressed for a limited set of incident wave conditions on structure trunks. Use of this new guidance should eliminate wave induced toe berm failures and result in significant dollar savings for the Corps.

Evaluation of Damage to Underwater Portions of Coastal Structures. Effectiveness of techniques for inspection and evaluation of underwater damage is limited by the severe conditions encountered in the zone surrounding coastal structures, including high wave energy, strong currents, and low underwater visibility. Current technology and methods for performing inspections were examined, including diver and crane surveys, underwater video, and commercially available side scan and other sonars. Guidance was developed, through testing and experience in actual field conditions, on the selection and use of these techniques. Training was provided to Corps personnel, and the guidance was used in evaluation of underwater parts of Humboldt and Crescent City jetties on the California coast.

Since none of the available technology is entirely satisfactory, an effort was undertaken to develop an underwater survey system that would be less dependent on favorable conditions and provide less subjective results. A prototype system called the Coastal Structure Acoustic Raster Scanner (CSARS) has been designed, constructed, and improved through field trials. Results, thus far, have been promising.

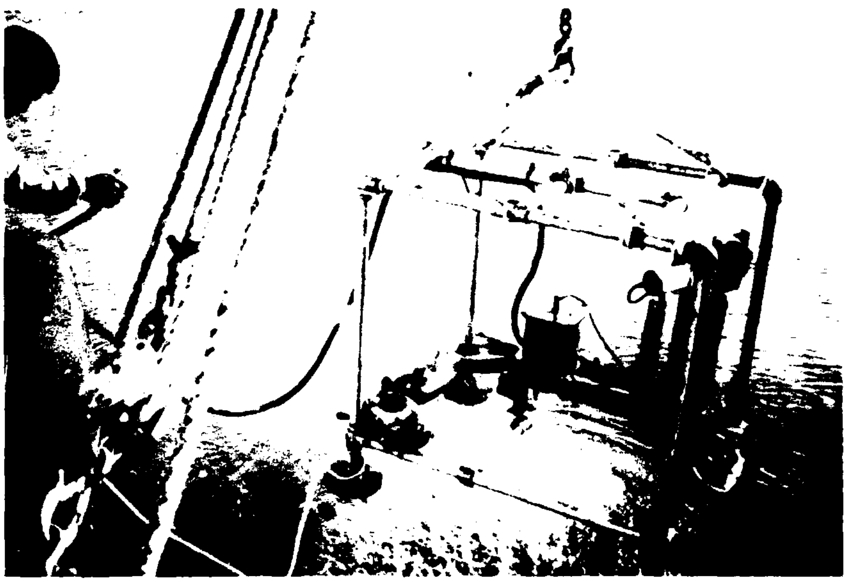

Figure 19. The Coastal Structure Acoustic Raster Scanner is raised from a breakwater after surveying.

Use of Dissimilar Armor for Repair and Rehabilitation.

Model tests have shown that overlays of concrete units such as dolosse and tribars over stone require larger sizes than if the structure were originally designed for those particular units. Thus, the design guidance for new structures is inappropriate for use in the design of repairs and rehabilitations involving dissimilar armor.

Stability tests were conducted of dolos overlays of stone-armored, dolos-armored, and tribar-armored breakwater and jetty trunks subjected to breaking waves. Tests were also conducted of tribar overlays of stone-armored breakwater and jetty trunks and dolos overlays of stone-armored breakwater heads subjected to breaking waves. The results from these tests can be used to design appropriately sized armor units for repair and rehabilitation of breakwaters and jetties.

Electrical & Mechanical

Maintenance techniques and replacement materials and procedures for the electrical and mechanical parts of Corps projects were studied under this problem area.

Control of Roosting Birds and Bird Waste. Management strategies for bird-pest populations that cause extensive economic losses or represent serious threats to human health or safety have been well researched. However, small-scale or local bird nuisance or damage problems have not been as thoroughly addressed, particularly in controlled experiments.

The methodologies to control or manage most bird pests are relatively well known and to varying degrees they are species and site specific. Nevertheless, there must usually be some fine-tuning by experienced and preceptive pest managers to effectively solve a specific problem or problems. An integral part of any pest management program is the assessment and monitoring of potential environmental hazards.

A comprehensive REMR report on this subject is available that includes information on the types of damage caused by various pest species, human health hazards, general bird management strategies, and specific species recommendations. The report is an excellent source of bird control information and is being used by the Animal Damage Control Section of the US Department of Agriculture, Army installations, Naval bases, and private consultants, as well as by Corps field offices.

Evaluation of Hydroelectric Generators. Increasing numbers of hydroelectric units are going to need rewinding because of advancing age and problems with thermosetting insulation systems. There was a need for guidance to help the field offices determine when to rewind generators.

Electrical tests and test equipments, when used along with thorough visual inspections in a regular insulation-maintenance program, can extend insulation life and reduce unscheduled outages, thus reducing the possibility of loss of revenue from the sale of power and major equipment damage. A routine inspection and testing program can find minor problems that can be corrected before they become major. A regular inspection and testing program can indicate the present condition of the insulation and can reveal the need for special tests and long-term trends.

Industry-accepted visual inspections and electrical tests were documented, guidance was developed for determining when a generator should be rewound, and a recommended program for periodic routine inspections and testing was developed.

Underwater Applied Coatings. Eleven proprietary protective coatings of differing composition all formulated for application to damp or immersed surfaces were tested to determine their applicability for underwater maintenance painting. The putty-like splash-zone compounds, developed in the 1960s, were easy to apply, but the application was slow and expensive. The materials formed thick protective coatings, but could not be used in water below 60 degrees Fahrenheit.

The products formulated for underwater application by brush or roller were generally more difficult to apply than indicated in the suppliers' advertisements. However, once applied they formed tightly adhering protective films to properly prepared surfaces. Abrasive blasting was found to be the best method for underwater surface preparation.

While these underwater coatings are not capable of the level of protection provided by coatings applied above water, they can be used to increase the service life of corrosion prone structures when dewatering is impractical.

Figure 20. An underwater coating is applied to test panel.

High-solids Coatings. Air pollution regulations are becoming increasingly restrictive of the amount of volatile organic compounds in paint systems. The vinyl paints the Corps uses contain high percentages of these compounds that will likely prohibit their use in the future. High-solids coatings contain less volatile organic compounds and are attractive environmentally.

The objective of the study was to identify and evaluate durable high-solids coatings for use on hydraulic structures exposed to immersion in low-velocity, nonabrasive waters. It was generally recognized that current technology is not available to produce high-solids coatings that will withstand high-velocity, abrasive waters.

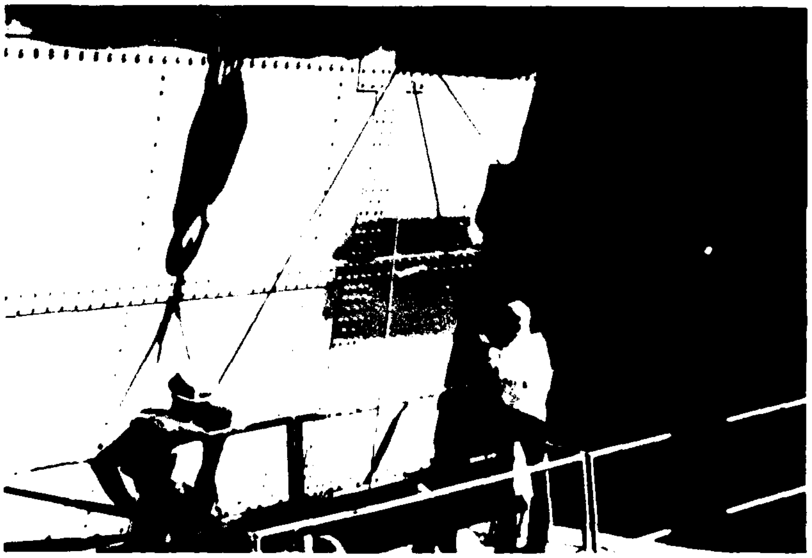

Figure 21. Application of High-solids Epoxy System to a Test Section on a Tainter Gate at Dam No. 17, Mississippi River.

Twenty-four coatings were tested in the laboratory and four of these were selected for field application to the downstream waterline area of a tainter gate at New Boston, Illinois. The high-solids epoxies were judged to be easily applied by painting contractors with average experience. They can be applied for about one-half of the cost of standard vinyl coating systems and should perform well when used in low-abrasive environments.

Lubricants for Hydraulic Structures. Uniform guidance regarding the specification and use of lubricants for hydraulic structures was not available. A survey of all Corps installations having hydraulic structures was conducted to determine current lubrication practices and problems. Equipment manufacturers and lubricant producers were contacted to obtain state-of-the-art information for determining and obtaining appropriate lubricants.

A REMR Technical Report discusses lubrication principles and the properties of lubrication oils and greases. The information provided is further defined as it pertains to national and international lubricant specifications. With this information the engineer can effectively select the type of lubricant necessary for a specific application. Tables are provided which cross reference proprietary products and can be used to reduce inventories of equal products and promote competition in lubricant procurement.

Figure 22. Exposed gears in need of lubrication.

Use of Ceramic Anodes to Prevent Corrosion. Silicon-iron and graphite anodes that have been used for the past 30 years are brittle, cannot be machined or welded, and have very high consumption rates. As a result, large anodes have been required, their size making them vulnerable to debris or ice damage, as well as prone to field installation problems.

In response to these problems, a new type of anode based on a conductive ceramic was developed. This new anode is proving to be a major technological breakthrough in corrosion prevention, since the consumption rate of conducting ceramic materials such as ferrites is 200 times lower than that of currently used silicon-iron and graphite anodes. The advantage of this is the ability to use smaller anodes, thus minimizing their exposure to impact damage and allowing placement in areas where larger anodes cannot be installed. Other advantages of ceramic anodes include their ability to be installed by non-specialized workers, they are less expensive than silicon-iron anodes, and they can be installed underwater.

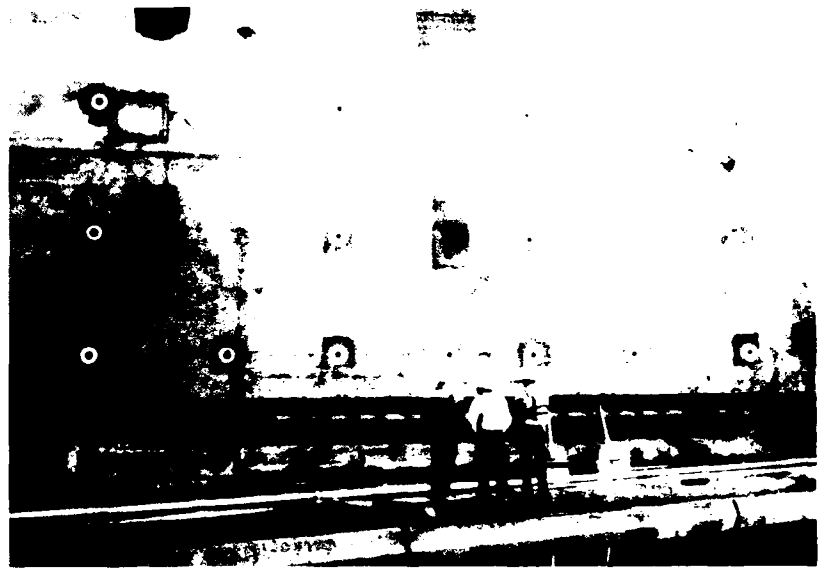

Figure 23. Ceramic anodes installed on a lock gate.

Stainless Steels for Locks, Dams, and Hydroelectric Plant Applications. Carbon steels and low-alloy steels have been the primary materials used to construct locks, dams, and hydroelectric plants. To a much lesser extent, components for these facilities were fabricated from 400-series martensitic stainless steels, and 300-series austenitic stainless steels.

After a thorough investigation into the mechanical properties, corrosion resistance, and cost of eight wrought stainless steels, it was concluded that no single stainless steel can offer optimum performance under all conditions and that selection of the steel must consider all factors. General guidelines were developed regarding the use of stainless steels for locks, dams, and hydroelectric plant applications.

Environmental Impacts

A significant part of the effort under this problem area was to evaluate the potential impact on the environment of the materials and techniques investigated under the other problem areas. An environmental review of all the technology produced under the REMR Research Program was conducted, and mitigating and remedial alternatives were recommended when necessary.

In addition, several documents were produced to assist field personnel in the environmental assessment of maintenance, repair, and rehabilitation efforts at Corps projects. Guidance was developed for compliance with environmental laws while conducting REMR activities.

Effects of Vegetation on the Structural Integrity of Levees. Current Corps guidelines for levee maintenance and operation limit vegetation on the embankment to sod-forming grasses of 2- to 12-in. heights to provide for the structural integrity, inspectability, and unhindered flood fight access to levees. This study was conducted to investigate the relationship between vegetation (woody plant species) and the structural integrity of river levees.

The study was limited to a 6-mile reach of a sandy, channel levee along the Sacramento River near Elkhorn, California. For this particular levee section, it was found that plant roots reinforce the levee soil and increase shear strength in a measurable manner. A shear strength increase or root cohesion can be estimated from the root biomass per unit volume or alternatively from the root-to-area ratio. Both infinite slope and circular arc stability analyses were performed on the landward and riverward slope for steady seepage and sudden drawdown conditions, respectively. These analyses showed that even low root concentrations as measured along selected transects in the sandy levee sufficed to make the slope more secure under "worst case" scenario conditions.

Operations Management

A computer-aided system (the REMR Management System) for managing REMR activities for civil works structures was developed. The system consists of three modules: the Basic Functions module, Condition Evaluation and Rating module, and the Consequence Modeling module. The Basic Functions module contains the procedures for data management and life-cycle cost analysis. The Condition Evaluation and Rating module contains a collection of condition evaluation procedures for various types of structures. The Consequence Modeling module includes tools useful for long-term planning.

The REMR Management System is designed as a planning tool and an information system for project-level management. It provides procedures for condition inspection and evaluation, data management, and economic analysis.

These procedures can be used to prioritize REMR activities based on condition, select maintenance and repair (M&R) alternatives based on performance, and compare the cost of various M&R alternatives based on life-cycle costs. The REMR Management System promotes faster, more objective, condition-oriented performance of REMR work.

Condition evaluation and rating systems were developed for four types of structures. These structures are: timber dikes, steel sheet-pile structures, lock miter gates, and the concrete in navigation lock walls. All four systems use the same rating scale: a rating of 70 to 100 indicates that no immediate action is required for the structure to function properly; a rating of 40 to 69 requires an economical analysis of repair alternatives to determine appropriate maintenance actions; and a rating of 0 to 39 requires a detailed evaluation of the structure to determine the type of repair, rehabilitation, or reconstruction required.

3 Conclusions

Technology Transfer

There is no single, most successful, method of transferring technology. What works well for one type of technology and one type of user may not work so well for others. Therefore, a successful technology transfer effort for a large research program must use a combination of methods. Methods used to transfer REMR technology include: technical reports, workshops, training courses, video reports, demonstrations, an electronic bulletin board, computer data bases, briefings, articles in technical journals, input to engineering manuals, Executive Notes, an information exchange bulletin, and a collection of technical notes in fact sheet format published as The REMR Notebook.

The information exchange bulletin was appropriately named The REMR Bulletin. Unlike some newsletters and bulletins that concentrate on current and upcoming events and, thus, quickly become outdated, The REMR Bulletin concentrates on technical articles on maintenance and repair procedures and materials. Each article includes the name and telephone number of a person to contact for additional information.

The REMR Notebook is a loose-leaf notebook containing fact sheets on materials, techniques, and equipment. Early in the REMR Research Program the need surfaced to make REMR technology readily available to users. With 50 individual studies and well over 100 technical reports being generated, it was necessary to present the technology in a concise form. The REMR Notebook was developed for that purpose. The idea was to present a particular technology without all the background data that is included in a technical report. The technical notes, limited to a few pages, provide the basic information and include references and a point-of-contact for additional information. A notebook of this nature is a very effective medium for the immediate transfer of technology on a large research effort.

Summary

The Corps was one of the first Federal agencies to recognize the need for research to address the nation's deteriorating infrastructure. The Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program was implemented to address that need and has clearly demonstrated the benefits of research in getting more value for the dollars spent on maintenance and repair activities. After its fifth year, the program was credited with dollar savings that exceeded the full 6-year cost of the original program, and by the end of the sixth year was credited with savings of more than $68 million. These figures are based on first-time uses of only a portion of the technology being produced. Additional savings and benefits accrue each time the technology is applied. Estimated savings over the next 5 years exceed $200 million for the Corps alone.

In addition to dollar savings, the program has resulted in other benefits such as improved safety and reliability, reduced manpower requirements, and improved operational capabilities. The technology that resulted from this research program is expected to continue to widely benefit the Corps, other Government agencies, and private industry.

4 Recommendations

The REMR Research Program has clearly demonstrated the benefits of research in getting more value for the dollars spent on repair, evaluation, maintenance, and rehabilitation activities. Because of the successes of the REMR Program, the high demand for its products both within and outside the Corps and the opportunity for similar successes on other REMR type problems, it is recommended that a follow-on effort (REMR-II) be initiated.

It is recommended that the REMR-II program be a 7-year, $35-million effort. It will address new and different needs which have been identified by Corps field offices. REMR-II will concentrate on problems and areas which have the potential for large payoffs and widespread applications. Much of the technology that will be produced will have application outside the Corps to other types of infrastructures. A significant effort will be devoted to the coordination and sharing of this technology with other federal agencies, state and local governments, and the private sector.

The continued safe and efficient operation and maintenance of Corps projects is essential to the economic well-being of the country. The cost associated with the evaluation, maintenance, repair, and rehabilitation of Corps of Engineers projects have become a major part of the Ccrps' budget. The REMR-II Research Program will help to ensure that the Corps gets the maximum value for the dollars expended.

Appendix A

APPENDIX A

Listing of REMR Reports

Number	Date	Title	AD Number
		CONCRETE AND STEEL STRUCTURES PROBLEM AREA (CS)	
REMR-CS-1	Sep 84	Engineering Condition Survey of Concrete in Service, by Richard L. Stowe, and Henry T. Thornton, Jr.	AD A148 893
REMR-CS-2	Apr 85	The Condition of Corps of Engineers Civil Works Concrete Structures, by James E. McDonald and Roy L. Campbell, Sr.	AD A157 992
REMR-CS-3	Jul 86	Latex Admixtures for Portland Cement Concrete and Mortar, by Dennis L. Bean and Tony B. Husbands.	AD A171 352
REMR-CS-4	Nov 86	Repair of Waterstop Failures: Case Histories, by James E. McDonald.	AD A176 937
REMR-CS-5		Instrumentation Automation for Concrete Structures	
	Dec 86	Report 1 Instrumentation Automation Techniques, by John Lindsey, David Edwards, Aubrey Keeter, Tom Payne, and Roger Malloy.	AD A178 139
	Jun 87	Report 2 Automation Hardware and Retrofitting Techniques, by Aubrey Keeter, Byron Stonecypher, Tom Payne, Mathew Skerl, Jim Burton, and James Jennings.	AD A192 753
	Jun 87	Report 3 Available Data Collection and Reduction Software, by Brian Currier and Marta H. Fenn.	AD A192 094
	Apr 89	Report 4 Demonstration of Instrumentation Automation Techniques at Beaver Dam, Eureka Springs, Arkansas, by Edward F. O'Neil.	AD A208 571
REMR-CS-6	May 87	In Situ Repair of Deteriorated Concrete in Hydraulic Structures: Feasibility Studies, by Ronald P. Webster and Lawrence E. Kukacka.	AD A182 297

Number	Date	Title	AD Number
REMR-CS-7	Jul 87	Design of a Precast Concrete Stay-In-Place Forming System for Lock Wall Rehabilitation, by ABAM Engineers, Inc.	AD A185 081
REMR-CS-8	Nov 87	Procedures and Devices for Underwater Cleaning of Civil Works Structures, by Carmela A. Keeney.	AD A188 814
REMR-CS-9	Apr 89	Inspection of the Engineering Condition of Underwater Concrete Structures, by Sandor Popovics and Willie E. McDonald.	AD A208 295
REMR-CS-10	Dec 87	Development of Nondestructive Testing Systems for In Situ Evaluation of Concrete Structures, by Henry T. Thornton, Jr. and A. Michel Alexander.	AD A191 312
REMR-CS-11	Jan 88	In Situ Repair of Deteriorated Concrete in Hydraulic Structures: Laboratory Study, by Ronald P. Webster and Lawrence E. Kukacka.	AD A190 303
REMR-CS-12	Mar 88	Factors Related to the Performance of Concrete Repair Materials, by Lawrence I. Knab.	AD A192 818
REMR-CS-13	Dec 87	Rehabilitation of Navigation Lock Walls: Case Histories, by James E. McDonald.	AD A192 202
REMR-CS-14	Dec 87	A Demonstration of the Constructibility of a Precast Concrete Stay-in-Place Forming System for Lock Wall Rehabilitation, by ABAM Engineers, Inc.	AD A195 471
REMR-CS-15	Aug 88	Analysis of Concrete Cracking in Lock Wall Resurfacing, by C. Dean Norman, Roy L. Campbell, Sr., and Sharon Garner.	AD A198 437
REMR-CS-16	Jan 88	Repair of Dam Intake Structures and Conduits: Case Histories, by Roy L. Campbell, Sr and Dennis L. Bean.	AD A192 819
REMR-CS-17		Surface Treatments to Minimize Concrete Deterioration	
	Apr 88	Report 1 Survey of Field and Laboratory Application and Available Products, by Dennis L. Bean.	AD A195 069
REMR-CS-18	Apr 88	Evaluation of Concrete Mixtures for Use In Underwater Repairs, by Billy D. Neeley.	AD A193 897

Number	Date	Title	AD Number
REMR-CS-19	Sep 88	Review of the State of the Art for Underwater Repair Using Abrasion-Resistant Concrete, by Ben C. Gerwick, Inc.	AD A199 793
REMR-CS-20	Feb 89	Evaluation of Vinylester Resin for Anchor Embedment in Concrete, by James E. McDonald.	AD A206 847
REMR-CS-21	Apr 89	In Situ Repair of Deteriorated Concrete in Hydraulic Structures: A Field Study, by Ronald P. Webster, Lawrence E. Kukacka, and Dave Elling.	AD A208 913
REMR-CS-22	Aug 89	Monolith Joint Repairs: Case Histories, by James G. May and James E. McDonald.	AD A212 814
REMR-CS-23	Jan 90	Evaluation of Polyester Resin, Epoxy and Cement Grouts for Embedding Reinforcing Steel Bars in Hardened Concrete, by J. Floyd Best and James E. McDonald.	
REMR-CS-24	Sep 89	Reliability of Steel Civil Works Structures, by Paul F. Mlakar, Sassan Toussi, Frank W. Kearney and Dawn White.	AD A212 922
REMR-CS-25	Jan 90	Spall Repair of Wet Concrete Surfaces, by J. Floyd Best and James E. McDonald.	
REMR-CS-26	Oct 89	Analysis of a Short Pulse Radar Survey of Revetments Along the Mississippi River, by Steven A. Arcone.	AD A213 501
REMR-CS-27		User's Guide: Maintenance and Repair Materials Data Base for Concrete and Steel Structures, by Richard L. Stowe and Roy L. Campbell, Sr.	
REMR-CS-28		Concepts of Installation of the Precast Stay-in-Place Forming Systems for Lock Wall Rehabilitation in an Operational Lock, by ABAM Engineers, Inc.	
REMR-CS-29		Methods of Evaluating the Stability and Safety of Gravity Earth Retaining Structures Founded on Rock, by R. M. Ebeling, G. W. Clough, J. M. Duncan, and T. L. Brandon.	
REMR-CS-		Evaluation of Civil Works Metal Structures, by Frederick Kisters and Frank Kearney.	

Number	Date	Title	AD Number
REMR-CS-		Evaluation of Overturning Analysis for Concrete Structures on Rock Foundations, by Shannon and Wilson, Inc.	
REMR-CS-		Incorporation of Wall Movement and Vertical Wall Friction In the Analysis of Rigid Concrete Structures on Rock Foundations, by Shannon and Wilson, Inc.	
REMR-CS-		Underwater Stilling Basin Repair Techniques Using Precast or Prefabricated Elements, by R. D. Rail.	
REMR-CS-		In Situ Repair of Deteriorated Concrete in Hydraulic Structures: Epoxy Injection Repair of a Bridge Pier, by R. P. Webster, L. E. Kukacka, and D. Elling.	
REMR-CS-		Laboratory Evaluation of Concrete Mixtures and Techniques for Underwater Repairs, by Billy D. Neeley, Kenneth L. Saucier, and Henry T. Thornton, Jr.	
REMR-CS-		Estimation of Concrete Service Life, by Larry M. Bryant and Paul F. Mlakar.	
REMR-CS-		Properties of Silica-Fume Concrete, by James E. McDonald.	
REMR-CS-		Anchor Embedment in Hardened Concrete Under Submerged Conditions, by James E. McDonald.	
REMR-CS-		Evaluation and Repair of Concrete Structures: Annotated Bibliography 1978 - 1988, by James E. McDonald and Willie E. McDonald.	
Unnum	Jan 87	Proceedings of REMR Workshop on Assessment of the Stability of Concrete Structures on Rock, 10-12 September 1985, compiled by William F. McCleese.	AD A185 644
Unnum	Aug 89	Sonar Probing of Concrete, by John H. Mims and Robert R. Unterberger.	N/A
		COASTAL PROBLEM AREA (CO)	
REMR-CO-1	Dec 86	Stability of Rubble-Mound Breakwater and Jetty Toes; Survey of Field Experience, by Dennis G. Markle.	AD A180 108

Number	Date	Title		AD Number
REMR-CO-2	Jan 89	Prototype Experience with the Use of Dissimilar Armor for Repair and Rehabilitation of Rubble-Mound Coastal Structures, by Robert D. Carver.		AD A204 081
REMR-CO-3		Case Histories of Corps Breakwater and Jetty Structures		
	Jan 88	Report 1	South Pacific Division, by Robert R. Bottin, Jr.	AD A192 294
	Sep 88	Report 2	South Atlantic Division, by Francis E. Sargent.	AD A200 458
	Jun 88	Report 3	North Central Division, by Robert R. Bottin, Jr.	AD A198 436
	Sep 88	Report 4	Pacific Ocean Division, by Francis E. Sargent, Dennis G. Markle, and Peter J. Grace.	AD A199 879
	Nov 88	Report 5	North Atlantic Division, by Ernest R. Smith.	AD A207 146
	Nov 88	Report 6	North Pacific Division, by Donald L. Ward.	AD A203 865
	Jan 89	Report 7	New England Division, by Francis E. Sargent and Robert R. Bottin, Jr.	AD A204 082
	Jan 89	Report 8	Lower Mississippi Valley Division, by Francis E. Sargent and Robert R. Bottin, Jr.	AD A204 083
	Jan 89	Report 9	Southwestern Division, by Francis E. Sargent and Robert R. Bottin, Jr.	AD A204 084
REMR-CO-4	Feb 88	Stability of Dolos and Tribar Overlays for Rehabilitation of Stone-Armored Rubble-Mound Breakwater and Jetty Trunks Subjected to Breaking Waves by Robert D. Carver and Brenda J. Wright.		AD A192 487
REMR-CO-5	Jun 88	Stability of Dolos Overlays for Rehabilitation of Dolos-Armored Rubble-Mound Breakwater and Jetty Trunks Subjected to Breaking Waves, by Robert D. Carver and Brenda J. Wright.		AD A195 392

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REMR-CO-6	Aug 88	Stability of Dolos Overlays for Rehabilitation of Tribar-Armored Rubble-Mound Breakwater and Jetty Trunks Subjected to Breaking Waves, by Robert D. Carver and Brenda J. Wright.	AD A198 877
REMR-CO-7	Oct 88	Methods to Reduce Wave Runup and Overtopping of Existing Structures, by John P. Ahrens.	AD A200 455
REMR-CO-8	Apr 89	State-of-the-Art Procedures for Sealing Coastal Structures with Grouts and Concretes, by David P. Simpson.	AD A208 884
REMR-CO-9	May 89	Stability of Dolos Overlays for Rehabilitation of Stone-Armored Rubble-Mound Breakwater Heads Subjected to Breaking Waves, by Robert D. Carver.	AD A208 577
REMR-CO-10	Aug 89	Study of Breakwaters Constructed One Layer of Armor Stone Detroit District, by John R. Wolf.	AD A212 631
REMR-CO-11		Underwater Inspection of Coastal Structures Using Commercially Available Sonars, by William Kucharski and James E. Clausner.	
REMR-CO-12	Sep 89	Stability of Toe Berm Armor Stone and Toe Buttressing Stone on Rubble-Mound Breakwaters and Jetties, by Dennis G. Markle.	
REMR-CO-13		Laboratory Techniques for Evaluating Effectiveness of Sealing Voids in Rubble-Mound Breakwaters and Jetties with Grouts and Concretes, by David P. Simpson and Jeffrey L. Thomas.	
REMR-CO-		Field Evaluation of Port Everglades, Florida Jetty Rehabilitation, by Julie Dean Rosati and Thomas A. Denes.	
REMR-CO-		Repair of Localized Armor Stone Damage on Rubble-Mound Structures: Coastal Model Investigation, by Donald L. Ward and Dennis G. Markle.	
REMR-CO-		Rehabilitation of Permeable Breakwaters and Jetties by Void Sealing: Summary Reports, by David P. Simpson, Julie D. Rosati, Lyndell Z. Hales, Thomas A. Denes, and Jeffrey L. Thomas.	

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		ENVIRONMENTAL IMPACTS PROBLEM AREA (EI)	
REMR-EI-1	Nov 86	Applicability of Environmental Laws to REMR Activities, by Jim E. Henderson and Linda D. Peyman.	AD A177 322
REMR-EI-2	Nov 86	Bibliography of Environmental Research Related to REMR, by Nelson R. Nunnally.	AD A177 069
REMR-EI-3	Aug 88	Compliance Requirements for Environmental Laws Applicable to REMR Activities, by Jim E. Henderson and Linda D. Peyman-Dove.	AD A200 193
REMR-EI-4	Aug 88	Seasonal Regulation of Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Activities, by Mark W. LaSalle, John Nestler, and Andrew C. Miller.	AD A198 016
REMR-EI-		Methods and Procedures to Support the Environmental Methodology for REMR Activities, by Jim E. Henderson.	
REMR-EI-		The Effects of Vegetation on the Structural Integrity of Levees, by Donald H. Gray, Anne MacDonald, Thomas Thomann, Imogene Blatz, and F. Douglas Shields, Jr.	
		ELECTRICAL AND MECHANICAL PROBLEM AREA (EM)	
REMR-EM-1	Sep 87	A Review of Bird Pests and Their Management, by Anthony J. Krzysik.	AD A190 195
REMR-EM-2	Sep 87	Evaluation of Bird Pest Problems at U.S. Army Corps of Engineers Civil Works Projects, by Anthony J. Krzysik.	AD A191 173
REMR-EM-3	Oct 88	Underwater Applied Coatings: A State-of-the-Art Investigation, by R. W. Drisko and J. R. Yanez.	AD A201 712
REMR-EM-4	Sep 89	Hydroelectric Generator and Generator-Motor Insulation Tests, by Robert H. Bruck and Ray G. McCormack.	AD A212 924
REMR-EM-5	Aug 89	Lubricants for Hydraulic Structures, by Ward B. Clifton and Alfred D. Beitelman.	AD A212 923

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REMR-EM-6		Mechanical Properties and Corrosion Behavior of Stainless Steels for Locks, Dams, and Hydroelectric Plant Applications, by Ashok Kumar, James R. Myers, and Ali A. Odeh.		
Unnum	Jun 89	Proceedings of REMR Workshop on Management of Bird Pests, by Anthony J. Krzysik.		AD A210 086
		GEOTECHNICAL PROBLEM AREA (GT)		
REMR-GT-1	Sep 84	Mathematical Analyses of Landside Seepage Berms, by Reginald A. Barron.		AD A150 014
REMR-GT-2	Aug 85	Improvement of Liquefiable Foundation Conditions Beneath Existing Structures, by Richard H. Ledbetter.		AD A160 695
REMR-GT-3		Geotechnical Aspects of Rock Erosion in Emergency Spillway Channels,		
	Aug 86	Report 1	by Christopher P. Cameron, Kerry D. Cato, Colin C. McAneny, and James H. May.	AD A173 163
	Sep 88	Report 2	Analysis of Field and Laboratory Data, by Christopher P. Cameron, David M. Patrick, Kerry D. Cato, and James H. May.	AD A203 774
	Sep 88	Report 3	Remediation, by Christopher P. Cameron, David M. Patrick, Craig O. Bartholomew, Allen W. Hatheway, and James H. May.	AD A203 775
	Dec 89	Report 4	Geologic and Hydrodynamic Controls on the Mechanics of Knickpoint Migration, by James H. May.	
		Report 5	Summary of Results, Conclusions, and Recommendations, by Christopher P. Cameron, David M. Patrick, James H. May, John B. Palmerton, Colin C. McAneny, Allen W. Hatheway, Craig O. Bartholomew, Christopher C. Mathewson, and Kerry D. Cato.	
REMR-GT-4	Nov 87	State of the Art for Design and Construction of Sand Compaction Piles, by Richard D. Barksdale.		AD A188 816

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REMR-GT-5	Sep 87	Inspection and Control of Levee Underseepage During Flood Fights, by Robert W. Cunny.		AD A188 324
REMR-GT-6		Geotechnical Applications of the Self Potential (SP) Method		
	Mar 88	Report 1	The Use of Self Potential in the Detection of Subsurface Flow Patterns in and Around Sinkholes, by Ronald A. Erchul.	AD A194 524
	May 89	Report 2	The Use of Self Potential to Detect Ground-water Flow in Karst, by Ronald A. Erchul and Dennis W. Slifer.	AD A209 399
	Feb 89	Report 3	Development of Self-Potential Interpretation Techniques for Seepage Detection, by Robert W. Corwin and Dwain K. Butler.	AD A207 704
		Report 4	Numerical Modeling of Spanomalius: Documentation of Program SPPC and Applications, by Michael J. Wilt and Dwain K. Butler.	
REMR-GT-7	Dec 87	Applications of the State of the Art of Stone Columns--Liquefaction, Local Bearing Failure, and Example Calculations, by Richard D. Barksdale.		AD A191 606
REMR-GT-8	Jul 88	Review of Consolidation Grouting of Rock Masses and Methods for Evaluation, by R. Morgan Dickinson.		AD A198 209
REMR-GT-9	Mar 88	A Survey of Engineering Geophysics Capability and Practice in the Corps of Engineers, by Dwain K. Butler, Ronald E. Wahl, Nolan W. R. Mitchell, and Gregory L. Hempen.		AD A194 520
REMR-GT-10	Jul 89	High Resolution Seismic Reflection Investigatons at Beaver Dam, Arkansas, by Thomas L. Dobecki, Tanya L. Mueller, and Monroe B. Savage.		AD A211 228
REMR-GT-11	Sep 89	Levee Underseepage Analysis for Special Foundations Conditions, by Thomas F. Wolff.		
REMR-GT-12	Sep 89	Re-Evaluation of the Sliding Stability of Concrete Structures on Rock with Emphasis on European Experience, by K. Kovari and P. Fritz.		

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REMR-GT-13	Sep 89	Levee Underseepage Software User Manual and Validation, by Robert W. Cunny, Victor M. Agostinelli, Jr., and Hugh M. Taylor, Jr.	
REMR-GT-14		Surface Roughness Characterization of Rock Masses Using the Fractal Dimension and the Variogram, by James R. Carr.	
REMR-GT-		Evaluation of the Rehabilitation Program for Relief Wells at Leesville Dam, Ohio, by Glenn Hackett and Roy E. Leach.	
REMR-GT-		Application and Testing of Resin Grouted Rock Bolts, by Timothy S. Avery and James E. Friant.	
REMR-GT-		Plastic Concrete Cutoff Walls for Earth Dams, by Thomas W. Wahl, Joseph L. Kauschinger, and Edward B. Perry.	
REMR-GT-		Repair Works for Uplift and Seepage Control in Existing Concrete Dams, by Jose O. Pedro, Abel Mascarenhas, Luis Sousa, Luis Rodrigues, Henrique Silva, and Antonio Castro.	
Unnum	Jan 88	Proceedings of REMR Workshop on New Remedial Seepage Control Methods for Embankment-Dams and Soil Foundations, by Edward B. Perry.	AD A191 073
Unnum	Jul 89	Proceedings of REMR Symposium on Remedial Treatment of Liquefiable Soils Beneath Existing Structures, by Richard H. Ledbetter.	AD A212 067
Unnum	Jul 89	Proceedings of REMR Workshop on Research Priorities for Drainage System and Relief Well Problems, by Roy E. Leach and Hugh M. Taylor, Jr.	
		HYDRAULICS PROBLEM AREA (HY)	
REMR-HY-1	Jul 86	Annotated Bibliography for Navigation Training Structures, Compiled by Walter E. Pankow and Robert F. Athow, Jr.	AD A173 303
REMR-HY-2	Jun 87	Floating Debris Control; A Literature Review, by Roscoe E. Perham.	AD A184 033
REMR-HY-3	Sep 88	Elements of Floating Debris Control Systems, by Roscoe E. Perham.	AD A200 454

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REMR-HY-4	Mar 89	Effects of Geometry on the Kinetic Energy of a Towboat and Barges in a Navigation Lock, by Sandra K. Martin.	AD A207 057
REMR-HY-5	Mar 89	Explicit Numerical Algorithm for Modeling Incompressible Approach Flow, by Robert S. Bernard.	AD A207 176
REMR-HY-6	Oct 89	Inventory of River Training Structures in Shallow-Draft Waterways, by David L. Derrick, Herbert W. Gernand, and James P. Crutchfield.	
REMR-HY-		STREMR: Numerical Model for Depth-Averaged Incompressible Flow, by Robert S. Bernard.	
Unnum		Proceedings of REMR Workshop on Repair and Maintenance of Shallow-Draft Training Structures, by David L. Derrick.	
		OPERATIONS MANAGEMENT PROBLEM AREA (OM)	
REMR-OM-1	May 86	Evaluation of Existing Condition Rating Procedures for Civil Works Structures and Facilities, by Enno Koehn and Anthony M. Kao.	AD A170 391
REMR-OM-2	Sep 88	REMR Managment System, by H. Thomas Yu and Anthony M. Kao.	AD A200 728
REMR-OM-3	Jun 89	User's Manual: Inspection and Rating of Steel Sheet Pile Structures, by Lowell Greimann and James Stecker.	AD A210 411
REMR-OM-4	May 89	A Rating System for the Concrete in Navigation Lock Monoliths, by Rupert E. Bullock.	AD A208 304
REMR-OM-5	Sep 89	Timber Dike Management System, by H. Thomas Yu and Anthony M. Kao.	
REMR-OM-6	Dec 89	Network Level REMR Management System for Civil Works Structures: Concept Demonstration on Inland Waterways Locks, by Michael J. Markow, Sue McNeil, Dharma Acharya, and Mark Brown.	AD A217 031
REMR-OM-		Maintenance and Repair of Sheet Pile Structures, by Lowell Greimann, James Stecker, and Kevin Rens.	
REMR-OM-		Inspection and Rating of Miter Lock Gates, by Lowell Greimann, James Stecker, and Kevin Rens.	

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REMR-OM-		Lock Wall: A Microcomputer-Based Maintenance and Repair Management System for Concrete Navigation Lock Monoliths, by David T. McKay and Anthony M. Kao.	
REMR-OM-		Development of a Condition Rating Procedure for Rubble-Mound Breakwaters and Jetties, by Don Plotkin, D. D. Davidson, and Joan Pope.	
REMR-OM-		Maintenance and Repair of Miter Lock Gates, by Lowell Greimann, James Stecker, and Kevin Rens.	