November 1992

US Army Corps of Engineers
Waterways Experiment Station

Annotated Bibliography of REMR Technical Reports

Through September 1992

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	

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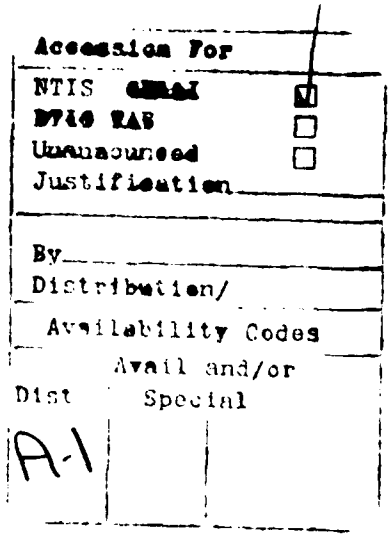

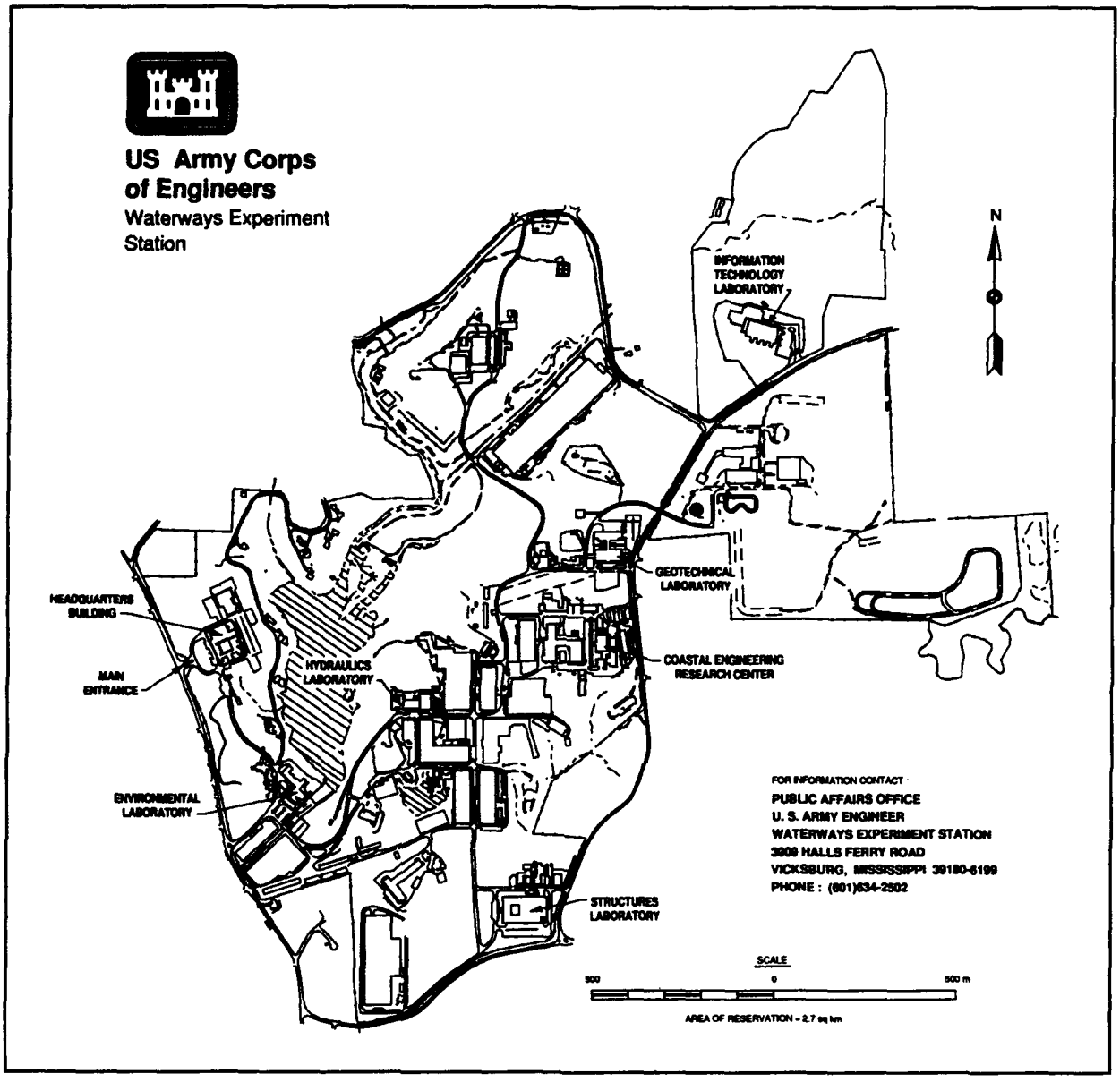

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Preface

This annotated bibliography was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Program Management of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. Mr. William F. McCleese, Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES), was the REMR Program Manager. The REMR Directorate of Research and Development Coordinator in HQUSACE was Mr. Jesse A. Pfeiffer, Jr., and members of the REMR Overview Committee were Mr. James E. Crews and Dr. Tony C. Liu.

This bibliography was compiled by Ms. Lee T. Byrne, REMR Technology Transfer Specialist, WES, under the direct supervision of Mr. McCleese and under the general supervision of Mr. Bryant Mather, Director, SL; Mr. James T. Ballard, Assistant Director, SL; and Mr. Kenneth L. Saucier, Chief, Concrete Technology Division, SL.

At the time of the publication of this report, Dr. Robert W. Whalin was Director of WES. COL Leonard G. Hassell, EN, was Commander.

Introduction

This annotated bibliography includes information about technical reports published to date under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The entries are intended as an aid to engineering, construction, and maintenance personnel who are responsible for the repair, evaluation, maintenance, and rehabilitation of the Nation's aging infrastructure.

Each entry provides the bibliographical data necessary to locate a copy of the report (report number, title, publication date, author(s), place of publication, and ADA number[1]). In addition, an informational abstract is provided and is designed to give research objective(s), methodology, results, and conclusions, where applicable. Key words and an index are also included.

[1]REMR technical reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. When ordering, please include the ADA number.

Contents

Concrete and Steel Structures

REMR-CS-1

"Engineering Condition Survey of Concrete in Service." 1984 (Sep). By Richard L. Stowe and Henry T. Thornton, Jr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A148 893

The overall objective of the investigation documented in this report was to develop information essential to the continued safety of concrete used in Civil Works structures, such as flood control and multipurpose dams, navigation locks and dams, powerhouses and appurtenant structures, floodwalls, pumping stations, and similar structures. Specific objectives included development and evaluation of materials and techniques for repair and rehabilitation of Civil Works structures, development of engineering guidance to evaluate and monitor safety of structures, and development of design and construction methods for rehabilitating older structures to comply with current structural design criteria.

This report summarizes pertinent inspection procedures and methods of evaluation that have been presented in publications by the Corps of Engineers and other agencies and are used to evaluate concrete in service. Experience gained at the Waterways Experiment Station in conducting condition surveys is also included. Inadequacies associated with concrete structures and foundations are described. Techniques that have a potential for determining the extent and cause of inadequacies in concrete structures are presented. Where techniques are presented, principles, advantages, limitations, and examples of application are discussed.

KEY WORDS: Concrete Structures, Condition Evaluation, Condition Survey,

REMR-CS-2

"The Condition of Corps of Engineers Civil Works Concrete Structures." 1985 (Apr). By James E. McDonald and Roy L. Campbell, Sr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A157 992

At the time this report was published, the Corps of Engineers operated and maintained 536 dams and 260 lock chambers at 596 sites. Sixty percent of these hydraulic structures were over 20 years of age, more than forty percent were more than 30 years old, and approximately 30 percent were more than 40 years old. With a relatively limited number of new construction starts anticipated, many of these structures were being and would continue to be kept in operation well beyond their original design lives. The primary objective of this study was to develop quantitative information on the present condition of the concrete portions of these structures.

Two computerized databases were compiled. The structure-description database contains basic information (location, category, age, purpose, etc.) on 766 projects. The damage and repair database contains information on the current condition of the concrete in the Corps' Civil Works structures as determined through detailed reviews of over 2,000 periodic inspection reports.

To assist in the analysis, a number of computer programs were developed to manipulate and search the databases. The analysis concentrated on the types of deficiencies observed, the cause (if reported), location within the structure, and degree of damage. Also, if the deficiency had been repaired, the material or technique or both that were used and the performance were analyzed.

In cases of severe damage, there was a general correlation between the average age of structures and the number of deficiencies. This correlation indicates that the number of deficiencies requiring repair will increase as the average age of Corps structures increases. Deficiencies most often observed were concrete cracking, seepage, and spalling. It was also concluded that development of equipment, materials, and techniques to evaluate and correct these deficiencies should be emphasized. Findings indicate that dams and locks will require emphasis on repair and rehabilitation in addition to normal maintenance activities.

KEY WORDS: Concrete Deficiencies, Concrete Structures, Condition Evaluations, Damage to Concrete, Hydraulic Structures, Maintenance of Concrete, Repair of Concrete

REMR-CS-3

"Latex Admixtures for Portland Cement Concrete and Mortar." 1986 (Jul). By Dennis L. Bean and Tony B. Husbands, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A171 352

The objective of this investigation was to collect data about latex admixtures and to corroborate some of the literature findings by means of limited laboratory testing. A literature search was conducted to gather information about latex admixtures. Laboratory testing was conducted to verify the information obtained in the literature search, and the results of this testing are provided.

The results of limited testing of different latex modifiers in the Waterways Experiment Station (WES) laboratory basically agreed with the literature findings. The results of a bond test indicated that the surface of concrete or hardened latex-modified mortars (LMM) does not need to be primed to obtain good adhesion. The percentage of polymer in the LMM does affect the water vapor transmittance (breathability) of the specimen. A higher percentage of polymer will reduce the vapor transmittance of the hardened mortar.

The underwater submersion data revealed that immersion did not weaken the mortar tested at WES when allowed to air-dry sufficiently before testing. If the absorbed moisture in the LMM could evaporate after the specimen was removed from the water, the strengths were returned to their expected values. However, this may not be true for all acrylic latex modifiers; some may contain ethyl or methyl acrylates that are hydrolyzed when submerged in water.

The results of the freezing and thawing testing of mortar patches showed that some latex mortars performed much better than others. Visual examination of the patches indicated that the principal cause of degradation was separation of the patches from the test panels.

KEY WORDS: Concrete Overlay, Concrete Repair Material, Latex Modifiers, Polymer

REMR-CS-4

"Repair of Waterstop Failures: Case Histories." 1986 (Nov). By James E. McDonald, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A176 937

The primary objective of this study was to identify materials and techniques that have been used in the repair of waterstop failures. Based on a review and evaluation of current practices, a secondary objective was to identify those areas where research is needed to supplement existing technology.

Although the information obtained from the various sources varied widely from project to project, attempts were made to obtain a description of the project, cause and location of the leakage, descriptions of repair materials and techniques, and results of follow-up evaluations. Sufficient information to prepare a case history was obtained from 20 projects, several of which involved multiple repairs. In addition, limited information on three other repair projects is included.

Leakage through monolith joints reported herein ranged from minor flows to more than 600 gal/min. In general, leakage was the result of waterstop defects including excessive movement of the joint that ruptures the waterstop, honeycomb areas adjacent to the waterstop resulting from poorly consolidated concrete, contamination of the waterstop surface that prevents bond to the

concrete, puncture of the waterstop or complete omission during construction, and breaks in the waterstop due to poor or no splices.

More than 80 different materials and techniques were used, individually and in various combinations, to repair the waterstop failures reported herein. Some appear to have been successful, whereas many have failed. Because of a lack of appropriate test methods and equipment, most materials have been used in prototype repairs with limited or no laboratory evaluation of their effectiveness in the particular application. A definite need exists for development of testing procedures and equipment to allow systematic laboratory evaluation of waterstop repair techniques prior to application in prototype structures.

KEY WORDS: Concrete, Hydraulic Structures, Monolith Joints, Repair, Water Leakage, Waterstops

REMR-CS-5, Report 1

"Instrumentation Automation for Concrete Structures; Instrumentation Automation Techniques." 1986 (Dec). Prepared by John Lindsey, David Edwards, Aubrey Keeter, Tom Payne, and Roger Malloy, WYLE Laboratories, Hampton, VA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A178 139

This is Report 1 of a series entitled "Instrumentation Automation for Concrete Structures." It provides a guide to determining the requirements for and the subsequent design, assembly or fabrication, installation, checkout, operation, and maintenance of data acquisition and reduction systems for use at or in large concrete hydraulic structures. This series is intended to be used by individuals and organizations in the Corps of Engineers who are engaged in design, configuration, implementation, and retrofitting of automated data collection systems for concrete structures. It is equally appropriate to apply the techniques discussed herein to instrumentation for earth embankment dam projects. The methods and equipment referenced in this report are described in detail in Report 2.

KEY WORDS: Automated Data Collection Systems, Automatic Control, Concrete Construction, Concrete Structures, Hydraulic Engineering, Hydraulic Structures

REMR-CS-5, Report 2

"Instrumentation Automation for Concrete Structures; Automation Hardware and Retrofitting Techniques." 1987 (Jun). Prepared by Aubrey Keeter, Byron Stonecypher, Tom Payne, Mathew Skeri, Jim Burton, and James Jennings, WYLE Laboratories, Hampton, VA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A192 753

This is Report 2 of a series entitled "Instrumentation Automation for Concrete Structures." This report is a guide to commercially available sensors, instruments, and equipment that will automate measurements of structural behavior and environmental conditions at large concrete structures, along with the suggested methods to replace or retrofit existing instruments at Corps structures. This report on automation hardware and retrofitting techniques is a catalog for selecting instrumentation and automatic data processing (ADP) hardware to be used to instrument and monitor concrete structures. It may be used in the process of designing and installing automated instrumentation monitoring systems on new structures as well as retrofitting existing instrumentation.

Due to the many options that exist in selecting the appropriate hardware, the procedures in Report 1 of the series for determining system requirements should be closely followed. Also, available software listed in Report 3 will influence system selection.

KEY WORDS: Automatic Data Processing, Computer Programs, Concrete Construction, Hydraulic Structures, Measuring Instruments

REMR-CS-5, Report 3

"Instrumentation Automation for Concrete Structures; Available Data Collection and Reduction Software." 1987 (Jun). Prepared by Brian Currier and Marta H. Fenn, WYLE Laboratories, Hampton, VA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A192 094

This is Report 3 of a series entitled "Instrumentation Automation for Concrete Structures." This report describes available software packages for data acquisition and reduction instruments. It serves as a guide in selecting software for equipment that is described in Report 2 of this series and identifies commercially available software packages that are applicable to data acquisition and reduction instruments that may be used by the Corps of Engineers.

KEY WORDS: Automatic Data Processing, Computer Programs, Concrete Construction, Hydraulic Structures, Measuring Instruments

REMR-CS-5, Report 4

"Instrumentation Automation for Concrete Structures; Demonstration of Instrumentation Automation Techniques at Beaver Dam, Eureka Springs, Arkansas." 1989 (Apr). By Edward F. O'Neil, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A208 571

The purpose of this demonstration program is to supplement the information provided in the set of reports on automation, as well as to provide an opportunity to describe how a particular installation was handled and how the instruments performed. By providing an actual field installation to reinforce

the written techniques, the instrumentation community will have a better understanding of the process of instrumentation automation and therefore be more familiar with its time and labor-saving capabilities.

The instrumentation automation system at Beaver Dam in northwest Arkansas is presented in this report, the fourth in the series "Instrumentation Automation for Concrete Structures." Included are discussions of the types of data selected for automated collection, the automation system as a whole, and the instruments used and how they fit into the overall system. The automated method of data collection is compared with the previous method used. Also included are descriptions and comparisons of two automated plumbline monitoring systems that were installed and tested during the demonstration program.

The installation of the data acquisition system at Beaver Dam supported the purposes of the study. This system, which automated the reading of over 80 piezometers, 9 weirs, and 20 uplift pressure gages, the movement of 2 cracks in the monolith walls of the dam, and both headwater and tailwater elevations, demonstrates the ability to bring electronic instrumentation and civil engineering sensors together as a unit to improve data monitoring and collecting techniques.

KEY WORDS: Computers, Crack Measurement, Dam Safety, Data Acquisition, Installation Techniques, Instrumentation Automation, Instruments, Monitoring, Piezometers, Plumblines, Safety Sensors, Uplift Pressure, Weirs

REMR-CS-6

"In Situ Repair of Deteriorated Concrete in Hydraulic Structures: Feasibility Studies." 1987 (May). Prepared by R. P. Webster and L. E. Kukacka, Brookhaven National Laboratory, Upton, NY, for US Army Engineer Waterways, Experiment Station, Vicksburg, MS. AD A182 297

The specific objectives of this study were to evaluate existing methods and materials for use in the in situ repair of deteriorated concrete hydraulic structures, as well as to identify new materials and develop new concepts.

Surveys disclosed a wide range of repair methods and materials currently available for the in situ repair of cracked and spalled concrete. Crack repair methods include pressure injection, routing and sealing, stitching, addition of reinforcement, drilling and grouting, flexible sealing, grouting, drypack mortar, crack arrest, polymer impregnation, and overlays and surface treatments. Methods for repairing spalled concrete include coatings, concrete replacement, grinding, jacketing, shotcreting, prepacked concrete, and thin-bonded or unbonded overlays. Repair materials include bituminous materials, portland cement concrete, mortar and grouts, epoxies, expandable mortars, grouts and concretes, linseed oil, latex-modified concrete, and polymer-concrete materials.

From an evaluation of the repair techniques and materials identified, five procedures (three crack repair techniques and two techniques for repairing spalled concrete) were identified as being the most applicable for in situ repair of concrete hydraulic structures. The selected techniques include pressure injection, polymer impregnation, and addition of reinforcement. In conjunction with these repair procedures, thin reinforced overlays and shotcrete can be used to repair spalled concrete surfaces as well as to resurface a cracked structure after it has been repaired.

From this evaluation, the following three repair techniques were identified as best suited for in situ repair procedures: pressure injection, polymer impregnation, and addition of reinforcement. Case histories illustrating the application of each technique are presented. Recommendations are made for work to be performed to make these systems more applicable to the repair of hydraulic structures.

KEY WORDS: Concrete, Cracking, Hydraulic Structures, In Situ Repair, Polymer Impregnation, Postreinforcement, Pressure Injection, Spalling

REMR-CS-7

"Design of a Precast Concrete Stay-in-Place Forming System for Lock Wall Rehabilitation." 1987 (Jul). Prepared by ABAM Engineers, Inc., Federal Way, WA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A185 081

The objectives of the stay-in-place precast concrete form rehabilitation project are to develop a repair concept that provides superior durability, minimizes the lock closure duration, accommodates all of the normal lock hardware and appurtenances, and can be implemented at a wide variety of navigation lock sites throughout the United States. To accomplish these goals, the system must satisfy a well-defined set of durability, functional, constructability, and cost/schedule criteria. Establishing the criteria and baselines for evaluating the performance of the system is an integral part of the project and was used in value engineering analyses of the individual elements of the system.

The project was a two-phased effort. The first phase, which is the subject of this report, focused on engineering development. The second phase was a demonstration project implemented following successful completion and evaluation of the Phase I work. Phase I, Concept Development, was performed in four tasks, which were organized as a filter system to maximize the number of possible options that were considered and used to test each option against a definitive set of criteria. Value engineering analyses and contractor input were used to select the final concept that optimizes the return investment. In Task 1, the project objectives and criteria were defined and quantified. In Task 2, the range of possible solutions were generated and qualitatively evaluated against the criteria. The purpose of Task 3 was to refine the preferred concept by definitive testing against the objectives, and in Task 4

the final plans, specifications, and estimates for the Phase II demonstration project were prepared.

The stay-in-place forming system consists of horizontal precast panels constructed of conventional precast quality concrete. The panels are tied to the monolith along the top and bottom edges with form ties designed to support the loads of the infill concrete placement. Infill concrete is proportioned for optimum workability and minimization of shrinkage and thermal strains. The panel design may be adapted to allow for work to proceed in a "wet," operational lock, but disruption of normal lock traffic would be expected. Lock hardware and appurtenances are integrated into the panel design to the maximum extent possible, resulting in the need to develop special armor hardware that will not compromise the integrity of the panels. Other standard lock hardware and appurtenances may be readily incorporated into the rehabilitation project that uses the precast system.

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.

KEY WORDS: Concrete, Concrete Design, Lock Wall Rehabilitation, Precast Concrete, Stay-in-Place Forms

REMR-CS-8

"Procedures and Devices for Underwater Cleaning of Civil Works Structures." 1987 (Nov). Prepared by Carmela A. Keeney, Naval Civil Engineering Laboratory, Port Hueneme, CA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A188 814

The objective of this study was to survey underwater cleaning techniques and devices for possible application to Corps Civil Works structures.

This report summarizes underwater cleaning procedures and devices that are appropriate to use on Civil Works structures. The cleaning systems evaluated encompassed several different types that are characteristic of those that are commercially available. Three general types of cleaning tools (hand tools, powered hand tools, and self-propelled cleaning vehicles) are discussed. The application, advantages, disadvantages, and operation of each type of equipment are considered, along with recommendations for those tools best suited for specific conditions.

The selection of the best system for a cleaning task depends upon the type of structure being cleaned, the construction material of the structure, the type

and amount of fouling to be removed, the environmental conditions, and the objective or purpose of the cleaning (for visual inspection, nondestructive evaluation, paint removal, maintenance, repairs, etc.). The report provides a listing of cleaning tools recommended for different types of material, fouling, and surface area.

KEY WORDS: Abrasive Injection, Air Lifts, Diver Tools, Dredging, High-Pressure Waterjet, Hydraulic Tools, Underwater Cleaning

REMR-CS-9

"Inspection of the Engineering Condition of Underwater Concrete Structures." 1989 (Apr). Prepared by Sandor Popovics, Drexel University, Philadelphia, PA, and Willie E. McDonald, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A208 295

The overall objective of this study was to present information essential to the evaluation and monitoring of the engineering condition needed for continued safety of underwater Civil Works structures. Specific objectives were to summarize the typical types of deterioration that occur in underwater concrete structures, provide engineering guidelines for inspecting the condition of underwater structures, and provide guidelines for interpreting inspection data.

As recommended in the report, the inspection and evaluation of the engineering condition of underwater structures are preceded by a comprehensive review of the design of the structure and the construction techniques and materials used as well as its operation and maintenance history. Information is obtained from available engineering data on the structure and from onsite investigation. This report summarizes these activities, pertinent inspection procedures and techniques, and methods of evaluation used by the Corps of Engineers and the Waterways Experiment Station. Methods and procedures developed by other agencies and individuals for the evaluation of concrete Civil Works structures are also included. Standardized and other methods that have proven satisfactory for inspection are emphasized. Methods that have potential for detection of the extent and cause of inadequacies in underwater concrete structures are also provided.

A condition survey is performed to determine whether the underwater structure meets design criteria under the prevailing service conditions and whether the structure can perform satisfactorily in the future. This report provides engineering guidance for conducting a condition survey of a concrete structure underwater.

The evaluation of the condition of a concrete structure underwater is much more complex than that of a structure above the water level. Before the structure can be evaluated and diagnosed, pertinent data and other information must be obtained. Obtaining these data is much more complicated when performed underwater than when performed above the water, and it is more

than putting together a team with the necessary technical expertise to evaluate the problem. Expertise is also needed in the underwater collection and recording of the pertinent information. In the case of an underwater structure, the technical team is usually supplemented with data collectors who are trained divers and/or operators of remotely operated underwater vehicles.

KEY WORDS: Concrete, Concrete Deterioration, Concrete Structure, Condition Evaluation, Condition Survey, Inspection, Underwater Inspection

REMR-CS-10

"Development of Nondestructive Testing Systems for In Situ Evaluation of Concrete Structures." 1987 (Dec). By Henry T.Thornton, Jr., and A. Michel Alexander, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A191 312

The objective of this work unit was to develop nondestructive testing (NDT) techniques and systems for the assessment of the condition and performance of concrete structures. The overall approach for the investigation consisted of five concurrent tasks: (a) to develop NDTs to detect the presence, depth, and extent of rebar, cracks, or inferior quality material within concrete structures and locate voids within (or underneath) concrete structures where only a single surface is accessible; (b) to screen and investigate systems and technology presently available that might be applicable to mapping and profiling of underwater concrete structures; (c) to develop engineering guidance to establish a uniform method for evaluating the condition and safety of existing concrete structures; (d) to assess the use of a structure's vibration signature (obtained by the impact-resonance technique) as a field inspection tool; (e) to investigate the feasibility of using modal analysis in conjunction with a finite element program as a method for assessing the deterioration, structural integrity, and stability of a concrete structure.

An effort was made to develop an ultrasonic pulse-echo system for the investigation and evaluation of the interior of concrete structures. The large pulse-echo transducer fabricated at Ohio State University (OSU) was obtained for study. Experimental transducers were fabricated and bandwidths were altered and optimize. Transducer area and frequency of operation were determined, and various piezoelectric materials were studied; acoustic and electrical matching were employed to optimize signal strength and signal-to-noise (S/N) ratio. The final prototype transducers were constructed of lead metaniobate (EC-82) and lead zirconate titanate (PZT-5H). The transducer area and mass was reduced by 90 percent, and the S/N ratio was increased by 200 percent when compared with the OSU transducer. The pitch-catch prototype configuration was used to successfully measure the thickness of a 90-1/4-in. concrete test slab with an S/N ratio of 18. The system is presently useful for making thickness measurements on concrete pavements and floor slabs. Limited tests have shown that a metal plate and a plastic pipe can be located in a concrete slab of 9 in. thickness or less. Also, a thickness measurement was made on concrete by generating wide-band acoustic (sonic

and ultrasonic) energy by an impact hammer and detecting the echoes with a low Q resonant receiver centered at 180 kHz.

Increased emphasis is being placed on the development of underwater concrete repair techniques. The extent and location of damage must be known in order to determine what steps should be taken to correct the damage and to prepare valid cost estimates. Therefore, a high-resolution acoustic mapping system was developed that will provide, without dewatering, an accurate and comprehensive evaluation of top surface wear on horizontal surfaces (such as aprons, sills, lock chamber floors, and stilling basins) where turbulent water flow carrying rocks and debris may have caused erosion or abrasion damage.

A study was performed to develop engineering guidance to establish a uniform method for evaluating the condition and safety of existing concrete structures. Vibration signatures were obtained from various large structures with the impact-resonance technique. Comparative analyses provided indications of the general conditions of the structures. Mode shapes, resonant frequencies, and damping factors were measured on a prototype concrete wall before and after the wall was subjected to blast loading. Results obtained before and after the blast were compared. Results from damping measurements made on a large dam and on cylinders made of similar concrete were also compared. These comparisons demonstrated that modal characteristics can be used to note changes in the boundary conditions and the elastic modulus of a concrete structure.

KEY WORDS: Concrete Structures, Condition Survey, Dam Safety, Evaluation, Impact-Echo, Nondestructive Tests, Pavement Thickness, Piezoelectrics, Transducer Development, Ultrasonic Pulse-Echo, Underwater Surveys

REMR-CS-11

"In Situ Repair of Deteriorated Concrete in Hydraulic Structures Laboratory Study." 1988 (Jan). Prepared by R. P. Webster and L.E. Kukacka, Brookhaven National Laboratory, Upton, NY, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A190 303

The primary objectives of Phase Two of the Brookhaven National Laboratory (BNL) program were to experimentally evaluate and develop new methods and materials for the in situ repair of cracked concrete hydraulic structures by pressure injection and polymer impregnation. A laboratory-scaled test program was developed to evaluate the effectiveness of selected injection adhesives to repair air-dried and water-saturated cracked concrete and polymer impregnation repair techniques for use in in situ repair of cracked concrete hydraulic structures.

The BNL, under contract to the Corps of Engineers, developed a laboratory-scaled testing procedure in Phase Two of the BNL Research Program to evaluate two crack repair methods: pressure injection and polymer impregnation. Four tasks were developed as guidelines for research: selection of

monomer systems, optimization of impregnation techniques, evaluation of physical and mechanical properties, and optimization of pressure injection techniques.

Eight adhesives were selected for evaluation for use in injection repair procedures: three epoxies, an emulsifiable polyester resin, furfuryl alcohol, a furan resin, a high molecular weight (HMW) methacrylate, and a polyurethan. Tests were conducted to evaluate the effectiveness of polymer impregnation as a means of repairing cracked concrete.

In general, the test results indicate that pressure injection can be used to effectively restore the integrity of air-dried and water-saturated cracked concrete. Polymer impregnation can be used to improve the quality of the concrete surrounding the crack network. However, its effectiveness in sealing the crack network depends on the viscosity of the impregnant used. The two methods, pressure injection and polymer impregnation, can be used in conjunction to effectively repair and improve the overall quality of the structure to be rehabilitated.

KEY WORDS: Concrete, Cracking, Hydraulic Structures, In Situ Repair, Polymer Impregnation, Pressure Injection, Spalling

REMR-CS-12

"Factors Related to the Performance of Concrete Repair Materials." 1988 (Mar). Prepared by Lawrence I. Knab, National Bureau of Standards, Department of Commerce, Gaithersburg, MD, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A192 818

This report provides the status of information on the performance of materials containing polymers used to repair portland-cement concrete, including performance requirements, degradation factors, properties related to performance, and pertinent existing test methods and their parameters. Research needs related to developing performance tests and criteria are also given.

Based on a review of the literature, including research, standards, and specifications, the following factors related to performance were identified for the repair material types considered: performance requirements, degradation factors and their effects on the performance of the repair materials, properties that can be related to performance, and test methods and the parameters that can be used to measure these properties. The following types of repair materials that contain polymers were covered in detail: sealant type materials for repairing active cracks, polymer adhesives, polymer mortars and concretes for repairing spalls and dormant cracks and placing overlays. This report is intended to be the first step in the process of developing performance tests and criteria for materials to repair concrete.

KEY WORDS: Concrete, Cracking, Overlays, Performance, Polymers, Repair Materials, Sealants, Spalling, Test Methods

REMR-CS-13

"Rehabilitation of Navigation Lock Walls: Case Histories." 1987(Dec). By James E. McDonald, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A192 202

The objective of this study was to develop, review, and analyze selected case histories involving rehabilitation of navigation lock walls. Information on the rehabilitation of navigation lock walls was obtained through review of periodic inspection reports, visits to project sites, and discussions with project personnel, designers, and contractors. Although the information obtained from the various sources varied widely from project to project, attempts were made to obtain a description of the project, the cause and extent of concrete deterioration, descriptions of rehabilitation materials and procedures, rehabilitation costs, and performance to date of the rehabilitated lock walls. Based on a review and analysis of the information obtained, recommendations for future rehabilitation were developed, and areas that could benefit from research were identified.

Applications of the various rehabilitation systems and their performance to date are described in selected case histories, which include Lock No. 5, Monongahela River; Marseilles Lock; Old Lock No. 14, Mississippi River; Dresden Island Lock; Lock and Dam No. 3, Monongahela River; Lock and Dam No. 1, Mississippi River; Lower Monumental Lock; Emsworth Locks; Lockport Lock; and Brandon Road Lock.

The general approach in lock wall rehabilitation has been to remove the deteriorated concrete and replace it with concrete or shotcrete. Explosive blasting has been used successfully at several Corps projects and appears to be the most cost-effective and expedient means for removing large quantities of concrete. Once the deteriorated concrete has been removed, conventional cast-in-place concrete has been used as the replacement material in most lock wall rehabilitation projects. Other replacement systems that have been used or proposed include shotcrete, preplaced-aggregate concrete, and precast concrete stay-in-place forms. In addition, several materials including latex-modified concrete, polymer mortars and grouts, conventional shotcrete, and latex-modified, fiber-reinforced shotcrete have been used as thin overlays on existing lock walls.

KEY WORDS: Case Histories, Cast-in-Place Concrete, Concrete, Concrete Removal, Concrete Durability, Navigation Locks, Precast Concrete Stay-in-Place Forms, Stay-in-Place Forms

REMR-CS-14

"A Demonstration of the Constructibility of a Precast Concrete Stay-in-Place Forming System for Lock Wall Rehabilitation." 1987(Dec). Prepared by ABAM Engineers, Inc., Federal Way, WA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A195 471

The purpose of the demonstration described in this report was to evaluate the feasibility of the stay-in-place forming system without the risk and investment of undertaking a full-scale lock rehabilitation.

One approach to minimizing the cracking problem in lock wall resurfacing is to use precast panels as stay-in-place forms. A precast panel rehabilitation system was designed by ABAM Engineers, Inc., in Phase I of a contract with the Waterways Experiment Station (WES). Phase II was a constructibility demonstration in which eight panels were precast and erected on two one-half scale simulated lock wall monoliths at WES. The purpose of the demonstration was to evaluate the feasibility of the stay-in-place forming system without the risk and investment of undertaking a full-scale lock rehabilitation.

The concrete form panels of varying sizes were precast in Colorado and shipped by truck to the installation site at WES. Typical lock hardware incorporated into the precast panels included horizontal armor, vertical corner armor, and a one-half scale line hook. One panel was essentially prototype size (6 by 30 ft) and weighed approximately 15,500 lb. Work associated with the installation of the precast panels included surface preparation on the test monoliths, erection and alignment of the panels, and welding tie connections. The panels were attached to the test monolith with epoxy-grouted, weldable-grade reinforcing steel welded to steel plates embedded in the panels.

All aspects of the installation are described herein, and a reassessment of the cost and schedule developed during Phase I is provided. As-built measurements are provided to demonstrate the ability of this repair procedure to meet the required tolerances. Improvements to the precast forming system that will benefit future work are identified, and additional features that require more research and final design have been noted.

In addition to providing a concrete surface of superior durability with minimal cracking, the estimated construction cost is very competitive with the cost of conventional forming and concrete placement. Also, this repair system can be implemented with intermittent lock openings that would eliminate the lengthy and continuous closures required for conventional repairs. Results of this work demonstrate that precast concrete stay-in-place forming system is a viable method for lockwall resurfacing.

KEY WORDS: Concrete, Conduit, Erosion, Intake Structure, Precast Concrete Stay-in-Place Forms, Stay-in-Place Forms, Water Leakage

REMR-CS-15

"Analysis of Concrete Cracking in Lock Wall Resurfacing." 1988 (Aug). By C. Dean Norman, Roy L. Campbell, Sr., and Sharon Garner, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A198 437

The general objective of this study was to develop new and improved materials and design/construction techniques for use in navigation lock rehabilitation. The specific objectives were to determine and evaluate parameters that significantly affect cracking in resurfacing slabs.

An aging constitutive model for concrete including creep, shrinkage, and cracking was used in a general-purpose heat transfer and structural analysis finite element (FE) code to predict the response of concrete overlays placed on lock wall surfaces. Several thermal stress analyses were performed using varying parameters to evaluate the effects on producing or inhibiting cracking in the resurfacing slab. Based on the results of the parameter study, the most desirable values for key parameters are recommended.

Model predictions corresponded well with test results. In all of the analyses, shrinkage had a dominant effect on cracking. Ambient temperature, thickness of overlay, and use of a bond breaker also significantly affected cracking. Lowering the placement temperature of the concrete overlay delayed but did not prevent cracking when shrinkage was included in the FE analyses. Ambient temperatures can have a significant effect on cracking when these temperatures are at rather extreme values. With ambient temperatures very low (e.g., 25 °F), cracks occur at the face of the resurfacing slab, whereas when ambient temperatures are very high (e.g., 100 °F), cracks occur along the interface of old and new concrete. In essentially all of the analyses, shrinkage had a very significant effect on cracking. In every case, the effects of shrinkage were the same, the only difference being the time when the cracking occurred. Also, thickness of overlay slab has a significant effect on cracking, and for the 36-in. slab, no cracking was observed within the analysis time period. Cracking can be reduced or inhibited when a low-friction interface is developed between the old and new concrete.

KEY WORDS: Aging, Concrete, Concrete Constitutive Model, Cracking, Creep, Lockwalls, Overlays, Shrinkage, Thermal Effects

REMR-CS-16

"Repair of Dam Intake Structures and Conduits: Case Histories." 1988 (Jan). By Roy L. Campbell, Sr., and Dennis L. Bean, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A192 819

The purpose of this study was to provide detailed information on current practices in the repair of intake structures and conduits that can be used in the evaluation and selection of repair materials and techniques and in the planning and managing of the repair work.

Based on a survey of inspection reports, 29 percent of the maintenance and repair problems at Corps dams were observed in intake structures and conduits. Repairs to these structures did not perform as desired in better than 40 percent of the reported efforts and with better than 21 percent reported as failed. A number of products whose manufacturer's literature indicated that their products were suited for application in a wet environment such as that found in intake structures and conduits failed. In some instances, the repair technique was at fault. In others, the product failed to perform as indicated.

This report documents selected repair efforts to intake structures and conduits and presents them in a case history format that includes a project description and a history of the repair efforts. The project description identifies principal project features and gives a detailed description of the deficiency being repaired to include its history and cause (if known). The description of repair efforts are presented chronologically for each project and include a detailed description of the repair products and techniques used and the performance of the repair (if known).

The two most common types of concrete deficiencies being repaired were leakage from cracks and joints and cavitation erosion damage to conduit passageways immediately downstream of gates. The most successful method documented for reducing leakage through both cracks and joints was chemical (urethane) grouting. The most successful method documented for withstanding cavitation damage was resurfacing of damaged area with the use of a quartz product. Laboratory testing is needed to further substantiate the potential of the quartz product for cavitation repair. Also, because this product is extremely expensive, it may be more economical to repeat the resurfacing on a routine basis using an inexpensive patching material. Evaluation of repairs to other types of deficiencies were not conclusive.

KEY WORDS: Case Histories, Concrete, Conduit, Erosion, Intake Structure, Water Leakage

REMR-CS-17, Report 1

"Surface Treatments to Minimize Concrete Deterioration; Survey of Field and Laboratory Application and Available Products." 1988 (Apr). By Dennis L. Bean, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A195 069

The objective of this study was to obtain information on the types of current surface treatment materials available, chemical compositions, and properties, and the performance of these materials in service conditions. A literature search was conducted for information about materials used to protect concrete. A field survey of concrete surface treatments that had been applied to concrete on Corps projects was conducted to evaluate the performance of the different materials used. This survey was conducted by reviewing periodic inspection reports from the Districts and Division offices that are on file with

the Office, Chief of Engineers, US Army. The remainder of information on surface treatments was provided by personnel in the District/District offices.

Little information was found concerning field testing and evaluation of these materials. However, there were several reports describing laboratory testing and results of different chemical compounds and brand-name products. Case histories of materials applied on Corps projects are documented within.

The data obtained from the literature search will be useful in the selection of treatments for the laboratory study being conducted. The water-absorption test data will provide a means of selecting the materials that merit further testing. From the information obtained from the case histories, the treatments providing positive results indicate a good material for that particular application. However, negative results may not necessarily indicate a poor material; possible reasons to be considered for the negative results are surface preparation, application rates, and climatic and surface conditions. The test for resistance to freezing and thawing should be mandatory to fully evaluate a sealant or coating. Because the concrete in existing structures is not identical to freshly prepared laboratory specimens, some products that perform well in a laboratory environment on freshly prepared specimens may not necessarily be as effective on old concrete that has been carbonated.

KEY WORDS: Abrasion, Coating, Concrete, Concrete Deterioration, Erosion, Hydraulic Structures, Sealers, Stone Consolidants, Surface Treatments, Vapor Transmittance

REMR-CS-17, Report 2

"Surface Treatments to Minimize Concrete Deterioration; Laboratory Evaluation of Surface Treatment Materials." 1990 (Sep). By Tony B. Husbands and Fred E. Causey, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A227 373/8/XAB

The objective of this study was to investigate the effectiveness of various types of surface treatments used for protecting and repairing concrete subjected to aggressive agents in the environment by laboratory testing and to develop information and guidance on the selection and application of these surface treatments.

Many different types of surface treatments were evaluated under this work unit including concrete sealers, coatings, polymer systems, thin overlays, and shotcrete. Emphasis was placed on materials that could be applied to the surface to reduce or prevent damage to concrete by freezing and thawing. Polymer systems for sealing cracks by topical application and elastomeric coatings for coating cracked concrete were evaluated. Other coatings for protecting concrete from erosion, chemical attack, and graffiti were evaluated. Latex admixtures for shotcrete and mortar for thin overlays were investigated.

Coatings and concrete sealers for protecting concrete from damage by freezing and thawing were tested for their effectiveness to seal concrete from water intrusion, ability to breath (passage of water vapor), resistance to freezing and thawing, and resistance to weathering and moisture. Latex-modified mortars and shotcrete were tested for resistance to freezing and thawing, bond to concrete, and other properties measured. Other tests for materials included bond strength to concrete, viscosity, abrasion resistance, tack free time, gel time, and resistance to weathering.

The test data for surface treatment materials indicate a wide difference in the performance of these materials for protecting or minimizing concrete deterioration. Criteria can be established based on these test results and others found in literature for guidance in the selection of these materials. Limits could be established for the effectiveness of materials to prevent or significantly reduce water intrusion into concrete, breathability of the surface treatment, resistance to freezing and thawing, accelerated weathering test, and other tests for specific applications, such as abrasion resistance, chemical resistance (to specific chemicals), bond strength, tensile strength, elongation, viscosity, solid content, and gel time.

KEY WORDS: Abrasion, Coatings, Concrete, Dampproofing, Freezing and Thawing, Latex Admixtures, Sealers, Shotcrete, Surface Treatments, Vapor Transmission, Water Absorption

REMR-CS-18

"Evaluation of Concrete Mixtures for Use in Underwater Repairs." 1988 (Apr). By Billy D. Neeley, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A193 897

The objectives of this work were to develop concrete mixtures that are suitable for placement underwater, are resistant to washout, and have a high resistance to abrasion-erosion.

A series of concrete mixtures were proportioned to be suitable for placing underwater and to have high washout and abrasion-erosion resistance. A combination of low water-cement (W/C), high cement contents, fly ash, and silica fume were used to increase the abrasion-erosion resistance of the concrete. Antiwashout admixtures (AWA) were used to enhance the resistance of the concrete to washout. The concrete mixtures were tested for slump, air content, washout, two-point workability, compressive strength, and abrasion-erosion resistance.

The results of the tests were used to determine the combination of materials necessary to produce concrete with the desired properties. Concretes suitable for traditional placements can be unsuitable for placement underwater in thin lifts, especially those having a high W/C ratio; however, increased cement and sand contents can be essential to placements underwater in thin lifts. Concrete mixtures having low W/C are more resistant to abrasion-erosion and

tend to be more resistant to washout. The type of high-range water-reducing admixtures (HRWR) affects the washout characteristics and abrasion-erosion resistance of the concrete mixtures. Concrete mixtures can be made more resistant to washout with the addition of the proper type and amount of AWA. Some AWAs and HRWRs can be incompatible.

There is some evidence that the presence of fly ash in concrete mixtures can improve washout and abrasion-erosion resistance and that the presence of silica fume in the concrete mixtures can improve washout resistance. The two-point workability apparatus can be useful in measuring some properties of fresh concretes, but it cannot be used alone. The results of these tests can provide guidance in selecting the proper concrete mixtures that have improved abrasion-erosion resistance and are suitable for placement underwater in thin lifts.

KEY WORDS: Abrasion-Erosion Resistance, Antiwashout Admixtures, Concrete Mixtures, High-Range Water Reducers, Underwater Placement of Concrete

REMR-CS-19

"Review of the State of the Art for Underwater Repair Using Abrasion-Resistant Concrete." 1988 (Sep). Prepared by Ben C. Gerwick, Inc., University of California, Berkeley, CA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A199 793

This review was conducted on an international level to identify new techniques and potential areas of research that might lead to more abrasion-resistant materials and more effective repair methods and that would avoid the high cost and disruptions associated with dewatering.

Technical areas covered in the study include concrete mixture proportion, concrete placement methods and equipment, compaction of concrete in place, underwater survey and inspection, surface cleaning, surface preparation including cutting and grinding, polymer concretes and coatings, and support vehicles.

The techniques reviewed are considered appropriate for the repair of hydraulic structures subjected to severe abrasion, especially stilling basins of dams. Recommendations resulting from the study can be divided into two areas: repair methods that use current state-of-the-art technology and repair methods that may require further development but may yield superior results.

No one technique will be the most efficient and cost effective for all underwater repair jobs. Abrasion can impose stringent performance requirements upon the wearing surface of a stilling basin. Repeated repairs make guaranteeing the soundness of the underlying layers difficult; therefore, more sophisticated, higher performance repair methods that can provide a more wear-resistant surface should be considered, even though these techniques

may require more initial planning and expense. In general, denser, stronger, and more ductile materials provide greater abrasion resistance. Indications are that cement-based repair materials may be easier to apply if suitable abrasion resistance can be obtained.

KEY WORDS: Concrete Admixtures, Hydro-Valve, Pneumatic Valves, Polymer Concretes, Robotics, Support Vessels

REMR-CS-20

"Evaluation of Vinylester Resin for Anchor Embedment in Concrete." 1989 (Feb). By James E. McDonald, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A206 847

The purpose of this study was to evaluate the load-carrying capacity of anchors embedded in concrete with Hilti's HEA vinylester resin capsules. Anchors installed in vertical drill holes under dry and submerged conditions were tested to determine tensile and shear load capacities. Anchors installed in vertical drill holes under dry and submerged conditions were tested to determine tensile and shear load capacities.

For the range of parameters in this study (hole condition, embedment length, and test age), results of pullout tests on threaded-rod anchors installed in dry holes were remarkably consistent with an overall average tensile capacity of 105 kips at 0.1-in. displacement and an average ultimate load of approximately 125 kips. In comparison, results of pullout tests on anchors installed under submerged conditions were relatively erratic with an overall average tensile capacity of 36 kips at 0. Obviously, the tensile load capacity of anchors embedded in concrete with vinylester resin capsules is significantly reduced when the anchors are installed under submerged conditions. At a displacement of 0.1 in., the tensile capacity of anchors embedded under submerged conditions was approximately one-third that of similar anchors embedded in dry holes.

Overall, ultimate shear capacities ranged from 73.5 to 93.2 kips with an average of 82.2 kips. Excluding the results of two tests, the upper- and lower-bound values, ultimate shear capacities ranged from 77.0 to 85.6 kips with an average of 81.9 kips. Accordingly, ultimate shear capacities were all within 10 percent of the average, regardless of embedment length, installation condition, and testing age.

The significantly reduced tensile load capacity of anchors embedded in concrete with vinylester resin capsules under submerged conditions should be recognized in any design of anchor systems for underwater applications. For the types of anchors and installation conditions described herein, an ultimate tensile load of 24 kips is recommended for design of underwater anchor systems subjected to short duration loads. This load was determined by reducing the overall average tensile capacity of 0.1-in. displacement by the

standard deviation. Appropriate factors of safety should be used to calculate the maximum allowable tensile load.

KEY WORDS: Concrete Anchors, Concrete Repair, Shear Tests, Tensile Tests, Vinylester Resin

REMR-CS-21

"In Situ Repair of Deteriorated Concrete in Hydraulic Structures: A Field Study." 1989 (Apr). Prepared by R. P. Webster, L. E. Kukacka, and D. Elling, Brookhaven National Laboratory, Upton, NY, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A208 913

The purpose of this study was to develop and evaluate pressure injection procedures in the field. Once developed, the procedures were evaluated in a small-scale field test at Lock and Dam No. 20 on the Mississippi River, Canton, MO.

A series of large-scale laboratory tests were run on three highly cracked concrete shielding blocks (8-1/3 ft high by 5-1/3 ft wide by 3 ft thick) with crack patterns similar to those observed in the pier stems at Lock and Dam No. 20. The same pressure injection repair procedure was used in all the tests, and upon completion of the injection repair work, fifteen 3-in. cores were removed from the blocks. A large-scale laboratory test was also conducted on a cracked section of a 15-ft-high cracked concrete retaining wall. Evaluation of repair work on the large concrete retaining wall was based upon visual examination, ultrasonic pulse velocity measurements, and mechanical testing of cores removed from the wall. The procedures were then evaluated in a small-scale field test at Lock and Dam No. 20.

Visual examination of the 3-in. cores removed from the blocks indicated that, with the exception of several cracks in two cores, all of the cracks appeared to be completely filled with epoxy. Values for splitting tensile strength averaged 608 pounds per square inch (psi), compared with an average of 546 psi for cores taken from uncracked areas. Preliminary ultrasonic pulse velocities taken across the crack on the 15-ft-high concrete retaining wall averaged 9,065 ft/sec, those in uncracked sections averaged 13,710 ft/sec, and postinjection velocities averaged 13,180 ft/sec. Visual examination of the cores removed from the wall showed that the cracks extended a minimum of 12 in. into the wall and appeared to contain 80- and 100-percent epoxy. Results of the splitting tensile strength tests averaged 693 psi, compared with 659 psi for the uncracked controls.

After completion of the large-scale laboratory tests, a small-scale field test was performed on Pier No. 27 at Lock and Dam No. 20. A visual examination of three cores taken after completion of the injection repair work indicated that 80 to 90 percent of the crack network within these cores had an average pulse velocity of 11,759 ft/sec, compared with visible epoxy within its crack

network. The splitting tensile strength of the repaired cores averaged 513 psi compared with 548 psi measured for an uncracked control. In general, the laboratory and field test results demonstrate that pressure injection repair techniques can restore the integrity of cracked concrete hydraulic structures.

KEY WORDS: Concrete, Cracking, Field Test, Hydraulic Structures, In Situ Repair, Pressure Injection

REMR-CS-22

"Monolith Joint Repairs: Case Histories." 1989 (Aug). By James G. May and James E. McDonald, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A212 814

The primary objective of this study was to identify materials and techniques used to repair deteriorated monolith joint deficiencies other than joint sealant failures or seepage. A secondary objective was the identification of areas in which further research is needed to supplement existing technology.

Information on the repair of monolith joints for seven case histories was obtained through review of the Waterways Experiment Station (WES) damage and repair database for Corps Civil Works structures, review of periodic inspection reports, visits to project sites, and discussions with project personnel. Case histories are included for the Lower Monumental Lock and Dam; Dresden Island Lock and Dam; Martis Creek Lake Dam; Emsworth Locks and Dams; Lock and Dam No. 2, Mississippi River; Algiers Lock; and Bayou Sorrel Lock.

Although the information obtained from the various sources varied widely from project to project, attempts were made to obtain a description of the project, the cause and extent of monolith joint deterioration, descriptions of repair materials and procedures, and performance to date of the repaired monolith joints.

Spalling is the most common deficiency for monolith joints in locks and dams when seepage and joint sealant failure are not considered. Spalling is followed by distortion and cracking. Spalling is also the most common deficiency listed in the case history repairs. Although damage from impacts and cycles of freezing and thawing are the primary causes of deficiencies in the case history repairs, settlement is the primary cause listed in the WES damage and repair database. For dams, settlement is followed by erosion, temperature, and maintenance faults. For locks, settlement is followed by weathering, shrinkage, and construction faults. No entries are listed under impact damage in the database.

The following areas must be addressed to make a successful monolith joint repair: evaluation of the joint; determination of the cause(s) of the deficiency; selection of the repair technique and material; preparation of design memoranda, plans, and specifications; and execution of the plan. Field repairs should

continue to be monitored and evaluated for effectiveness. A variety of techniques have been used to successfully repair monolith joints. Presently, there is limited understanding of what constitutes the optimum repair technique with respect to cost, constructability, and durability. Additional research is necessary to determine the optimum repair technique.

KEY WORDS: Case Histories, Concrete, Hydraulic Structures, Monolith Joints, Spalling

REMR-CS-23

"Evaluation of Polyester Resin, Epoxy, and Cement Grouts for Embedding Reinforcing Steel Bars in Hardened Concrete." 1990 (Jan). By J. Floyd Best, Tennessee Valley Authority, Knoxville, TN, and James E. McDonald, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A218 347

The purpose of this investigation was to evaluate the effectiveness of cement, epoxy, and polyester resin grouts used to embed reinforcing steel bars in hardened concrete under a variety of placing and curing conditions. The following parameters were determined for each grout: physical characteristics of the grouts, effects of temperature and moisture on early service performance, long-term pullout strength under varying curing conditions, creep strain of grout under sustained loading in both wet and dry environments, and effects of hole roughness and cleanliness on grout performance.

Beyond 1 day age, all grouts developed pullout strengths approximately equal to the ultimate strength of the reinforcing-bar anchor when the grouts were placed under dry conditions, regardless of curing conditions. With the exception of the polyester resin grout placed under submerged conditions, pullout strengths were essentially equal to the ultimate strength of the anchor when the grouts were placed under wet or submerged conditions.

The overall average pullout strength of polyester resin grout placed and cured under submerged conditions was 35 percent less than the strength of the same grout placed and cured under dry conditions. The largest reductions in pullout strength, approximately 50 percent, occurred at ages 6 and 16 months. Also, the overall average pullout strength of polyester resin grout placed and cured under submerged conditions was approximately one-third less than the strength of epoxy and cement grout placed under wet and submerged conditions, respectively, and cured under submerged conditions.

Polyester-resin-grouted anchors exhibited significantly higher creep than that exhibited by epoxy- and cement-grouted anchors under both wet and dry conditions. Creep data should be considered in the selection of an anchorage grout where the frictional resistance and bond between the surfaces of the two masses to be anchored together are important. Extra care should be taken to clean all percussion-drilled holes prior to grouting, particularly when epoxy or cement grout is to be used as the anchoring material.

Although the epoxy grout performed well in these tests when placed in wet holes, it should be noted that the manufacturer does not recommend placement under submerged conditions. This recommendation and the significantly reduced pullout capacity of polyester resin grout under submerged conditions appear to make cement grout the logical choice for submerged applications.

KEY WORDS: Anchor Grouting Systems, Concrete Anchors, Creep, Drilling, Pullout Strength, Underwater Repair

REMR-CS-24

"Reliability of Steel Civil Works Structures." 1989 (Sep). By Paul F. Mlakar, Sassan Toussi, Frank W. Kearney, and Dawn White, US Army Construction Engineering Research Laboratory, Champaign, IL. AD A212 922

The purpose of this study was to describe the development of a structural reliability function and illustrate its use to assess the condition of Corps steel structures. A general, probabilistic procedure for evaluating the reliability of a structure and for using that as an index of its integrity is described. The procedure is then applied to three types of sheet-pile structures that are representative of Corps-maintained facilities, namely, the O'Brien Lock and Dam, Illinois; Point Pleasant Canal, New Jersey; and port structures in Israel.

In the application of the procedure to three different types of sheet-pile structures, emphasis has been placed on using the available and familiar formulation but in a probabilistic manner. The results indicate that rehabilitative cost avoidances may be achieved if the procedure is used in lieu of traditional deterministic practices.

The three-step procedure developed herein is recommended for use in evaluating the safety of existing sheet-pile and other metal structures operated and maintained by the Corps of Engineers. The reliability of structures as calculated by this procedure should be used as a component of the condition index of the information system under development to manage REMR activities in Corps field offices. The procedure could be adapted to the particular characteristics of concrete structures to establish a consistent evaluative condition index for these features.

KEY WORDS: Condition Index, Maintenance Management, Steel Sheet-Pile Structures

REMR-CS-25

"Spall Repair of Wet Concrete Surfaces." 1990 (Jan). By J. Floyd Best, Tennessee Valley Authority, Knoxville, TN, and James E. McDonald, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A218 708

Because of the nature of the hydraulic structures over which the Corps of Engineers has responsibility, there are frequent requirements to repair spalled or eroded concrete that is underwater, close to the waterline, or in areas from which it is difficult to divert flow or dry the concrete. The purpose of this investigation was to evaluate the effectiveness of commercially available products in repair of concrete with wet surfaces.

Slant-shear bond and compressive strength tests were conducted on each of the 22 materials recommended for repair of spalls in wet concrete. Based on the results of these screening tests, eight materials were selected for additional laboratory tests including bonding capacity in direct tension, bonding capacity under flexural stress, resistance to abrasion, resistance to cycles of freezing and thawing, impact resistance, and thermal compatibility with concrete. Test results and material costs were used in developing a rating system to compare the relative performance of the various materials.

Overall performance ratings indicate two materials, an epoxy and a cement-based product, were nearly equal in outperforming the other products tested. Whether to specify the epoxy or the cement-based product for a given repair will likely depend on the specific project requirements and critical material properties.

KEY WORDS: Cement, Epoxy, Erosion, Material Properties, Spall Repair, Underwater Repair, Wet Concrete Surfaces

REMR-CS-26

"Analysis of a Short Pulse Radar Survey of Revetments Along the Mississippi River." 1989 (Oct). Prepared by Steven A. Arcone, US Army Cold Regions Research and Engineering Laboratory, Hanover, NH, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A213 501

A short pulse radar survey was conducted in McKellar Lake directly across from the Corps' dock facility at Ensley Engineer Yard. The intent was to examine radar responses to revetments placed on the bottom of the lake to retard erosion and to determine if such responses could be interpreted as indicative of erosion within the revetments themselves.

A radar transmitting a pulse with a center frequency of about 60 MHz was towed on the water surface both alongshore and on/off shore. To about the 25-ft depth, the results showed excellent bottom profiling that apparently conformed to the general performance expectations of this system. Severe direct coupling between transmit and receive antennas masked responses from depths of 11 ft or less. Several diffraction hyperbolae distinctly originating from the bottom may have been caused by discontinuities in the revetments. Unfortunately, no ground truth investigations were carried out by the survey

party to ascertain the exact cause, and no maps showing the exact location of the survey are available.

Several recommendations are made to improve the quality of data from future surveys.

KEY WORDS: Radar, Revetments, Short Pulse Radar Survey, Underwater Survey

REMR-CS-27

"User's Guide: Maintenance and Repair Materials Data Base for Concrete and Steel Structures." 1989 (Dec). By Richard L. Stowe and Roy L. Campbell, Sr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A220 386

The Maintenance and Repair Materials Data Base for Concrete and Steel Structures was developed to facilitate the identification and selection of repair products. It provides Corps of Engineers personnel with a single point of access for information on products available in the United States and includes information from three sources: manufacturers, Corps of Engineers, and other Federal and State agencies. It contains information regarding the use, application, limitation, and technical properties of products. Available Corps technical data, case histories, and new product entries are being regularly added as part of the continuing maintenance of the data base.

The data base is located and maintained at the Waterways Experiment Station (WES), Vicksburg, MS, and can be accessed through a remote personal computer and modem using a telecommunication package to dial and communicate with the WES host computer. All user operations are menu driven. The written and displayed documentation in this user's guide and on the display screen is user friendly. This guide contains instructions on the use of the data base and examples of searches that can be performed.

KEY WORDS: Concrete and Steel Structures, Concrete Repair, Data Base, Repair Materials

REMR-CS-28

"Concepts for Installation of the Precast Concrete Stay-In-Place Forming System for Lock Wall Rehabilitation in an Operational Lock." 1989 (Dec). Prepared by BERGER-ABAM Engineers, Inc., Federal Way, WA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A220 399

Previous efforts in the design of a precast concrete panel stay-in-place forming system for repair of navigation lock walls resulted in a limited implementation of this repair procedure in an actual lock. The purpose of this

investigation was to develop additional concepts for installation of stay-in-place forms in an operational lock.

In an operational lock, it is not possible to dewater or lower the tailwater level, and thus, some wall rehabilitation work must be performed underwater. In addition, it is necessary for the work to be coordinated around scheduled lock openings, and all ancillary lock equipment must be maintained in an operational condition.

During this study, operational and design criteria were developed to serve as the basis for design. A number of repair concepts that satisfied the criteria were identified. Schedule and cost estimates were prepared for the various concepts that served as the basis for selection of a preferred concept.

An installation procedure using a cofferdam was selected as the preferred repair method. A final design was completed for this concept. The design included the preparation of drawings and specifications for the repair of a generic lock to demonstrate the various aspects of the repair procedure. Cost and schedule assessments were part of this work.

The results of this developmental effort suggest that it is feasible to repair deteriorated navigation lock walls in an operational lock with only minor impact on costs. For the generic 600-ft-long by 110-ft-wide lock, repair costs are estimated at $140 (1989 dollars) per sq ft and require 16 weeks for completion, assuming 5-day work weeks with 12-hr days.

Although the concepts described herein were developed specifically for installation of stay-in-place forms in an operational navigation lock, they are potentially applicable to other concrete walls requiring repair underwater. Potential applications include tailrace wingwalls, floodwalls, and stilling basin walls.

KEY WORDS: Concrete Design, Lock Walls, Precast Concrete, Stay-in-Place Forms, Underwater Repair

REMR-CS-29

"Methods of Evaluating the Stability and Safety of Gravity Earth Retaining Structures Founded on Rock." 1992 (Mar). By R. M. Ebeling, US Army Engineer Waterways Experiment Station, Vicksburg, MS, and G. W. Clough, J. M. Duncan, and T. L. Brandon, Virginia Polytechnic Institute and State University, Blacksburg, VA. AD A229 429

The objective of this study was to investigate the accuracy of the procedures employed in the conventional equilibrium method of analysis of gravity earth-retaining structures founded on rock, using the finite element method of analysis. This study was divided into two phases: The objective of the first phase, reported herein, was to develop, through a series of preliminary analyses, analytical procedures for modeling separation of the base of a

monolith from its foundation and apply this procedure to a limited number of earth retaining structures.

A number of procedures were evaluated based on their accuracy and computational efficiency. These analyses were performed using following loads, loads of predetermined magnitude and independent of the movement of the monolith. The accuracy of the analysis procedures was determined by comparing the results with the results of conventional equilibrium analysis.

As part of this study, a literature study was made to compile information on the properties of rock masses, thereby providing a basis for selecting rock properties for use in finite element analyses.

The finite element method of analysis of earth retaining structures was used to investigate the progressive development of cracks at the interface between the base of the monoliths and their foundation; factors that control the extent of the area of contact between the base of the monoliths and their foundation; magnitude and distribution of stresses developed on the front, back, and along the base of the monoliths; factors that influence the movements of the monoliths and the effect of wall movements on the magnitude and orientation of resultant forces acting on the wall; and development of shear forces acting on the front and back of the wall as a result of the placement of the soil fill against the wall.

The results of the following load analyses show that when the loss of contact along the base of a wall is modeled in the finite element analysis, the calculated values of effective base contact area and maximum contact pressure are somewhat larger than those calculated using conventional equilibrium analyses. The mobilized base friction angle values calculated using the two methods are in precise agreement.

Comparisons between the results of backfill placement analyses using the finite element method and the conventional equilibrium analyses indicate that conventional analyses are very conservative. The finite element analyses indicate that the backfill exerts downward shear loads on the backs of retaining walls. These shear forces have a very important stabilizing effect on the walls. Expressed in terms of a vertical shear stress coefficient ($K_v = \tau_{xy}/\sigma$), this shear loading ranged in value from 0.09 to 0.21, depending on the geometrical features and the values of the material parameters involved in the problem.

Another important factor not considered in the conventional equilibrium method is that the displacements of the wall have a significant influence on the distribution of both the stabilizing and destabilizing forces exerted on the wall. In general, as the wall moves away from the backfill, the lateral forces exerted on the wall by the backfill decrease, and the lateral forces exerted on the front of the wall by the toe fill increase.

KEY WORDS: Analysis, Earth Pressures, Earth-Retaining Structures, Finite Element, Retaining Walls, Rock Foundation, Soil-Structure Interaction, Stability

REMR-CS-30

"In Situ Repair of Deteriorated Concrete in Hydraulic Structures: Epoxy Injection Repair of a Bridge Pier." 1990 (Sep). Prepared by R. P. Webster, L. E. Kukacka, and D. Elling, Brookhaven National Laboratory, Upton, NY, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A229 429

Presented are the results of the fourth and final phase of a research program directed toward identifying in situ repair procedures to be used in the rehabilitation of cracked concrete hydraulic structures. The laboratory phase of this investigation was directed towards the following: identification and development of a better method of attaching injection ports to the concrete; evaluation of methods to drill down into the crack network to facilitate the penetration of epoxy into the interior of the crack network; repair and modification of the epoxy injection machine; and evaluation of the long-term freeze-thaw durability of cracked concrete beams that were repaired by epoxy injection.

The emphasis of the laboratory and field research performed in Phase Four was directed toward the optimization of equipment and materials to be used with pressure injection repair techniques. Once optimized, the repair procedure was demonstrated in a field test performed at Lock and Dam No. 13 on the Mississippi River, Fulton, IL.

Repair work was limited to the lower 12 ft of Pier 13. The deterioration in this area was characterized by an extensive crack network, large sections of drumming concrete, and excessive amounts of efflorescence on the exterior faces. Epoxy injection into the pier included the following procedures: preliminary ultrasonic pulse velocity measurements, sandblasting, installation of injection ports and sealing of pier surfaces, preinjection ultrasonic pulse velocity measurements, injection of crack network, postinjection ultrasonic pulse velocity measurements, and cores taken for mechanical analysis.

Hydrostatic pressure tests showed that molded injection ports mounted within a drilled port hole can withstand pressures of 200 to 275 psig before leaks begin to develop around the perimeter of the injection ports. Surface-mounted ports withstand pressures between 50 and 50 psig, depending upon the type of port. Wet drilling using a hollow drill stem and bit was the most effective method for drilling port holes. An evaluation of the resistance of cracked concrete beams that had been repaired by epoxy injection to 200 cycles of freezing and thawing demonstrated that epoxy injection very effectively restores structural integrity.

KEY WORDS: Bridge Pier, Concrete, Cracking, Field Test, Hydraulic Structures, In Situ Repair, Pressure Injection

REMR-CS-31

"Evaluation of Civil Works Metal Structures." 1991 (Jan). By Frederick H. Kisters and Frank W. Kearney, US Army Construction Engineering Research Laboratory, Champaign, IL. AD A232 865

This report provides guidelines on the selection of appropriate nondestructive testing (NDT) methods and elements that should be specified on an NDT contract. This information is intended as an aid to engineers who oversee construction, operations, and maintenance and repair inspection practices at Civil Works projects. The subjects included are advantages and disadvantages of each NDT method, guidelines on how these inspection methods should be used, and contract specifications. The NDT methods discussed are visual, liquid penetrant, magnetic particle, ultrasonic particle, ultrasonic, radiographic, and eddy current inspections. Since corrosion detection is an important part of an NDT inspection survey, this report presents discussions of corrosion detection, evaluation, and equipment needed. Appendix A contains brief discussions of the causes of metal deterioration and identifies new techniques that can be used to identify potential problems. Case histories that describe how NDT procedures can enhance inspection routines are also included in the report.

KEY WORDS: Case Histories, Civil Works Structures, Corrosion, Evaluation, Metal Deterioration, Nondestructive Testing

REMR-CS-32

"Properties of Silica-Fume Concrete." 1991 (Mar). By James E. McDonald, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A235 369

This study was conducted to determine those properties of silica-fume concrete that might affect cracking and to develop guidance to avoid or minimize cracking problems associated with the use of silica-fume concrete in future repair projects.

Two major applications of silica-fume concrete within the Corps of Engineers were to repair abrasion-erosion damage in the stilling basin at Kinzua Dam and in the concrete lining of the low-flow channel, Los Angeles River. In each case, concrete cracking occurred during the repair. Apparently, this cracking has not significantly affected the performance of the concrete in resisting abrasion-erosion damage. However, such cracking could limit the use of silica-fume concrete in other repair and rehabilitation applications.

Tests included compressive and tensile splitting strengths, modulus of elasticity, Poisson's ratio, ultimate strain capacity, uniaxial creep, shrinkage, coefficient of thermal expansion, adiabatic temperature rise, and abrasion erosion.

None of the material properties of silica-fume concrete reported herein, with the possible exception of autogenous shrinkage, indicate that this material should be significantly more susceptible to cracking as a result of restrained contraction than conventional concrete. In fact, some material properties, particularly ultimate tensile strain capacity, would indicate that silica-fume concrete should have a reduced potential for cracking.

Silica fume offers potential for improving many properties of concrete. However, the very high compressive strength and resulting increase in abrasion-erosion resistance are particularly beneficial in the repair of hydraulic structures. These concretes should be considered in repair of abrasion-erosion susceptible locations, particularly in those areas where locally available aggregate might not otherwise be acceptable.

The potential for cracking of restrained concrete overlays, with or without silica fume, should be recognized. Any variations in concrete materials, mixture proportions, and construction practices that will minimize shrinkage or reduce concrete temperature differentials should be considered. Where structural considerations permit, a bond breaker at the interface between the replacement and existing concrete is recommended.

KEY WORDS: Abrasion-Erosion Resistance, Concrete, Cracking, High-Strength Concrete, Hydraulic Structures, Material Properties, Silica Fume

REMR-CS-33

"Anchor Embedment in Hardened Concrete Under Submerged Conditions." 1990 (Oct). By James E. McDonald, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A234 384

The purpose of this study was to determine the pullout capacity of anchors with increased embedment lengths and to evaluate the potential of a revised anchor installation procedure to eliminate the problem of resin and water mixing in the drill hole during anchor insertion.

Anchors embedded in hardened concrete under submerged conditions with prepackaged adhesive capsules exhibit significant reductions in tensile load capacity compared with anchors installed under dry conditions. This relatively poor performance of anchors with embedment lengths up to 24 in. is the result of water in the drill hole mixing with adhesive. Although insertion of the adhesive capsule or cartridge into a submerged drill hole will displace the majority of the water in the hole, water will remain between the walls of the adhesive container and the drill hole. Insertion of the anchor traps this water in the drill hole and causes it to become mixed with the adhesive.

An anchor installation procedure that eliminates the problem of resin and water mixing in the drill hole is described herein. Basically, this procedure uses resin in both bulk and capsule form to displace the water in a drill hole prior to anchor insertion and spinning. Pullout tests on vertical and horizontal anchors embedded in vinylester resin with this revised installation procedure

resulted in tensile capacities near the yield load of the anchors for both dry and submerged installations.

KEY WORDS: Concrete Anchors, Concrete Repair, Tensile Tests, Underwater Repair, Vinylester Resin

REMR-CS-34

"Laboratory Evaluation of Concrete Mixtures and Techniques for Underwater Repairs." 1990 (Nov). By Billy D. Neeley, Kenneth L. Saucier, and Henry T. Thornton, Jr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A231 195

The objectives of this study were to examine the cohesive and flowable parameters of selected concrete mixtures under different placement situations, estimate the parameters necessary for successful underwater placement, examine the quality of bonding of the repair concrete to the existing concrete, and examine the effect of underwater placement upon the abrasion resistance of the concretes.

Concrete mixtures were placed underwater using six placement techniques. A washout test was used to determine the relative amount of cement paste lost when the concrete is exposed to a large volume of water. The two-point workability test was used to evaluate the relative workability properties of the concretes. The slump, tremie flow, and air content were also measured. The test method for abrasion-erosion resistance of concrete (underwater method) was used to determine the abrasion-erosion resistance of each concrete. A point-load tensile test was used to determine the bond strength of the repair concrete to the existing concrete.

The results indicated that cohesive, flowable, abrasion-resistant concrete that will bond well to existing concrete can be placed underwater by available methods if proper materials are used and precautions are taken. Antiwashout admixtures (AWA) and silica fume can be used to reduce segregation and dilution with the water. AWA will reduce washout of fines in fresh concrete allowed to free-fall through 3 ft of water, but dilution will occur. Thus, this technique is not recommended for repair of underwater concrete. The degree of workability and washout resistance necessary for a successful concrete placement will depend upon the type of equipment used in the placement.

Concrete containing AWA and water-reducing admixtures (WRA) placed at the point of use will bond securely to hardened concrete and sustain only relatively small loss of fines if the bonding surface is clean. Even so, anchors should probably be used to ensure that the new concrete remains in place. Fluid concrete with good cohesion will move laterally for short distances, again with only minimal dilution. Concrete so placed can be worked underwater to a rough finish. As with any underwater concrete work, agitation and movement should be minimized. Indications are that abrasion resistance of

concrete placed and finished underwater equals that of concrete placed in air once the laitance is abraded from the surface.

The thickness of the underwater repair will be limited due to thermal stresses associated with the high cementitious material content of the concretes. The maximum allowable thickness of the repair concrete should be determined by thermal stress considerations prior to the concrete placement. Multiple layers of concrete could be used if the repair area is deeper than thermal conditions will allow to be filled in one layer. The thickness of the layer, or layers, of abrasion-resistant underwater concrete should be relatively uniform. Void areas that are deep, relative to the repair as a whole, should be filled with an underwater concrete having a lower cementitious material content to an average level of the repair area.

KEY WORDS: Abrasion-Erosion Resistance, Antiwashout Admixtures, Concrete, Concrete Mixtures, High-Range Water Reducers, Underwater Inspection, Underwater Placement

REMR-CS-35

"Predicting Concrete Service Life in Cases of Deterioration Due to Freezing and Thawing" 1991 (Mar). Prepared by Larry M. Bryant and Paul F. Mlakar, JAYCOR, Vicksburg, MS, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A235 616

A procedure for predicting the service life of nonair-entrained concrete subject to damage due to freezing and thawing has been developed and addresses both the known and uncertain qualities of the relevant material properties, environmental factors, and model of degradation due to freezing and thawing using a probabilistic method. This procedure was demonstrated by hindcast application to two structural features at Corps Civil Works structures that exhibited an appreciable degree of measurable damage due to freezing and thawing. Required data for application of the procedure (e.g. temperature and concrete properties) were available for these features, which were representative of typical Corps projects. The two features selected as case studies were the middle wall and land wall at Dashields Lock.

The procedure was applied using the available data for each case study. One- (1-D) and two-dimensional (2-D) thermal analyses were used to determine the thermal response of each wall and the resulting probabilities of critical temperature. Simplified seepage analyses provided the probabilities of critical saturation. The annual probability of damage and the predicted service life were determined from the joint probabilities of critical temperature and critical saturation throughout the structure.

Sensitivity of concrete service life prediction to the uncertainties of input factors was discussed. Implications of physical test procedures and discussion of future needs for concrete service life prediction were examined.

Several important conclusions can be reached from this study. Current procedures for thermal modeling and analysis appear quite adequate for predicting temperatures in a concrete structures. Although 2-D analyses are better for determining complex thermal response, in many cases a series of much simpler 1-D analyses provide a very good estimation of temperatures. The external temperature inputs to a thermal analysis (i.e. water and air temperatures) were shown to be well represented by sinusoidal curves. In this respect, the internal thermal response of a unit volume of concrete likewise follows a sinusoidal variation. This observation permits a simplified representation of the inputs and results of the thermal response and also simplifies application of 1-D analyses. An examination of the temperature distribution for any point in the structure indicated that the primary contributor to uncertainty of response was the annual variation of temperature. This important observation permits the probabilistic analysis to use the results of only a single thermal analysis at the mean values of the input factors.

The procedure developed and presented herein provides excellent agreement with observed damage due to freezing and thawing at the two sites studied. The general trends of location and spatial variation of damage are very similar to observations and measurements at the two sites. More encouragingly, the actual magnitudes of damage predicted by the procedure compare favorably with the previous measurements. This result provides the strongest indication that the procedure is rational and would enhance the ability of the Corps to predict service life at its many other concrete structures.

KEY WORDS: Concrete, Deterioration, Freezing and Thawing, Reliability, Service Life

REMR-CS-36

"Evaluation and Repair of Concrete Structures: Annotated Bibliography, 1978-1988." Vols. I and II. 1991 (Jun). By James E. McDonald and Willie E. McDonald, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A242 218/6/XAB (Vol. I) and AD A242 219/4/XAB (Vol. II)

This bibliography covers the period from 1978 through 1988 and contains 2,062 annotated references on evaluation and repair of concrete structures. The bibliography includes four sections relating to (1) concrete durability and causes of deterioration, (2) procedures for evaluating the condition of existing structures, (3) maintenance and repair materials, and (4) maintenance and repair techniques. Subject and author indexes are also included.

KEY WORDS: Bibliography, Concrete, Deterioration, Durability, Evaluation, Maintenance and Repair Materials, Maintenance and Repair Techniques

REMR-CS-37

"Underwater Repair of Concrete Damaged by Abrasion-Erosion." 1992 (Dec). Prepared by Kamal Henry Khayat, University of California, Berkeley, Berkeley, CA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A245 901

Traditional concretes and placement techniques used for massive underwater placements, such as bridge piers, rely on depositing the concrete beneath freshly cast concrete. This technique prevents it from flowing through water where it would segregate and intermix with the surrounding water, resulting in a significant reduction in quality. However, in this case, because of the limited depth of typical abraded scour holes and the need to frequently move the placement device, the concrete may have to flow a short distance through water. The objective of this research was to develop concrete mixtures and placement methods to repair typical scour holes underwater.

Guidelines for selecting concrete-making materials and additives were established, and new tests for assessing various properties were developed to complement existing ones. Approximately 70 concretes were evaluated to optimize mixture proportions.

The four most promising fluid concretes and one control concrete were selected to fill small and relatively shallow depressions underwater using the conventional tremie and the proposed inclined tremie methods. Concrete was placed in the laboratory in a test box with the bottom specially shaped to simulate a small scour hole. Surface profiles and in-place mechanical properties of eight underwater-cast slabs and one slab that was cast above water were evaluated to compare concrete mixtures and placement techniques.

Two fluid concretes were developed and used to cast two moderately congested reinforced beams underwater. Field placements were conducted to repair a rough-edged hole measuring 16 by 2.5 by 2.5 ft underwater. Another field experiment was conducted to cast two 22- by 10- by 1.3-ft slabs underwater. In-place concrete properties, proper spacings between discharge points, limitations on dropping concrete in water, and proper batching and mixing sequences were determined.

Stiff, highly washout-resistant concretes that can be dropped a short distance in water and then compacted into place with heavy rollers were developed to repair very thin (6-in.) scour holes. Three underwater compaction trials were conducted to determine in-place properties of the cast slabs and establish optimum concrete lift thicknesses and consolidation efforts.

Methodologies detailing construction procedures were developed, and a database was designed and implemented to facilitate the selection of promising concretes for repairs.

This research shows that concrete structures with scour holes of various depths and sizes can be successfully repaired underwater. Flat and durable surfaces can be secured with in-place compressive strengths exceeding 8,000

psi and relative density values close to 100 percent of control concrete that has been cast and consolidated above water. These concretes and construction procedures can provide economical, safe, and durable repairs to underwater structures.

KEY WORDS: Abrasion-Erosion Resistance, Antiwashout Admixtures, Concrete, Concrete Mixtures, High-Range Water Reducers, Tremie Methods, Underwater Placement, Washout Resistance

REMR-CS-38

"Underwater Stilling Basin Repair Techniques Using Precast or Prefabricated Elements." 1991 (Dec). Prepared by R. D. Rail, Naval Civil Engineering Laboratory, Port Hueneme, CA, and H. H. Haynes, Haynes and Associates, Oakland, CA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A245 900

The purpose of this study was to investigate methods of repairing stilling basins of hydraulic structures underwater, thereby eliminating costly dewatering operations, and to develop a plan to evaluate products or concepts. The effort focused on methods using precast concrete or prefabricated steel panels. The maximum water depth considered was 70 ft.

This report reviews underwater repairs of the Old River Low Sill Control Structure, Upper St. Anthony Falls Lock, and Kinzua Dam. An overview of the required underwater construction tasks is presented (preplanning, mobilization, surface preparation, installation of field anchors and panel supports, installation of panels, concrete placement, and inspection). Construction methods for underwater repairs are discussed, including the use of divers, wall enclosures, caissons, cofferdams, abovewater platforms, and submersibles. Panel design factors considered are abrasion resistance, uplift forces, joints, and weight. Other panel considerations include shapes, joints, bond, and supports. Repair schemes, such as large-area, partial-area, small-area, and baffle block repairs, are described.

Several findings evolved from this study: (a) it is feasible to rely on divers in underwater repair projects because most stilling basins have low-water depths of 40 ft or less; (b) steel panels or composite steel-concrete panels are preferred to concrete panels because the abrasion resistance of steel is superior to that of concrete and the weight of steel panels is considerably less than that of concrete panels; (c) if steel is selected, design details become important to assure that the steel panels remain serviceable under vibration and uplift forces from high-velocity water flow and impact from rocks in turbulent water; (d) surface cranes can handle larger steel panels than concrete panels because of the lower weight of steel panels; therefore, fewer joints are used between panels, and less work is required of the divers.

KEY WORDS: Precast Concrete, Prefabricated Steel Panels, Stilling Basins, Underwater Stilling Basin Repair,

Unnumbered

"Proceedings of REMR Workshop on Assessment of the Stability of Concrete Structures on Rock, 10-12 September 1987." 1987 (Jan). Compiled by William F. McCleese, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A185 644

The REMR Workshop on Assessment of the Stability of Concrete Structures on Rock was conducted to define problems with the Corps' stability criteria and procedures and to identify research needs that would address these problems. The proceedings provide a summary of the papers presented and the activities, conclusions, and recommendations of five working groups. Each working group was assigned one of the following subject areas:

— Shear strength selection procedures and the use of these parameters for evaluating the stability of existing concrete structures.

— Foundation exploration procedures for acquiring test samples and identifying weakness in the foundation for evaluating the stability of existing concrete structures.

— Computation of forces and methods of analysis for evaluating the stability of existing concrete structures on rock.

— Instrumentation and monitoring procedures for the purpose of evaluating the stability of existing concrete structures cn rock.

— Procedures for selecting and designing systems to improve stability.

KEY WORDS: Concrete Construction, Research, Rocks, Stability

Geotechnical Applications

REMR-GT-1

"Mathematical Analyses of Landside Seepage Berms." 1984 (Sep). Prepared by Reginald A. Barron, Guilford, CT, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A150 014

The study described herein extends solutions for mathematical analyses of seepage berms presented in earlier studies which were concerned mainly with seepage berms with a coefficient of permeability equal to that of the landside top blanket. Included are cases where the berm permeability is not that of the top blanket. In one case, the solution of the differential equation has not been obtained, and an approximation has been developed using finite differences. Supplements 1-3 to this report present solutions for seepage berms with constant slope of upper surface, riverside seepage berms, and general cases and short berms, respectively.

A plot of the required seepage berm width, B, versus the ratio of the permeability of the berm to the top blanket, $\overline{K}$, for various safety factors indicates B is very sensitive to $\overline{K}$ for ≤ 1. When the uplift safety factor varies from 1.5 at the landside levee toe to 1.0 at the landside seepage berm toe, the berm width is only slightly greater than that for a uniform safety factor of 1.0. If the uplift safety factor is greater than 1.0 at the berm toe, then as the top blanket becomes thinner, the berm width becomes longer. Thus, other methods of underseepage control should be investigated to determine whether they may be more economical.

When the seepage berm is impervious, the berm width is a maximum. When the seepage berm is infinitely pervious, the berm width is a minimum. Therefore, seepage berms should be constructed of the most pervious soils available (with adequate provisions for control of surface erosion and internal piping) in the interest of economy.

Because of the great difficulty in determining the permeability of the foundation, top blanket, and seepage berm, the mathematical solutions presented in this report should be used only as a guide to good engineering judgment. A range of permeability values should be used rather than average values.

KEY WORDS: Levee Underseepage, Mathematical Analysis, Permeability, Seepage Berms, Seepage Control

REMR-GT-2

"Improvement of Liquefiable Foundation Conditions Beneath Existing Structures." 1985 (Aug). By Richard H. Ledbetter, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A160 695

The purposes of the present study were to determine what relevant experiences exist in treating liquefiable soil conditions and may be applicable for use beneath existing structures, determine the feasibility and effectiveness of techniques for improving liquefiable foundation conditions in order to assure safety against earthquake excitation, and develop guidelines for laboratory and field experiments.

The stabilization and improvement of liquefiable soils beneath existing structures are currently feasible within the state of knowledge and assumptions concerning liquefiable soils and earthquake excitation. This can be done directly or indirectly to mitigate the effects of liquefaction and to assure safe performance. At the present, there has been essentially no experience with remedial actions in liquefiable soils at existing structures, and no general method is applicable for all conditions. Each site is unique and will require specific engineered solutions. This report presents and briefly discusses methodologies that have been deemed potentially applicable for remediating liquefiable soils beneath existing structures. A comprehensive bibliography on the feasible methods is included. The most important factors for construction in choosing remedial methods/techniques are the verifiability of improvement and stabilization and the assurance that the method itself will not create unsafe and unstable conditions under static and dynamic loading.

KEY WORDS: Admixture Stabilization, Compression, Injection and Grouting, In Situ Deep Compaction, Liquefaction, Pore-Water Pressure Relief, Remedial Treatments, Soil Reinforcement, Soils, Thermal Stabilization

REMR-GT-3, Report 1

"Geotechnical Aspects of Rock Erosion in Emergency Spillway Channels." 1986 (Aug). By Christopher P. Cameron, Kerry D. Cato, Colin C. McAneny, and James H. May, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A173 163

The overall objective of this investigation was to develop procedures for the detection, prediction, prevention, and repair of rock erosion in emergency spillway channels. Specific objectives were to establish an empirical database documenting all erosive emergency spillway overflow events at Corps projects by accumulating detailed information from historical accounts or site visits; to assess the magnitude, severity, and potential impact of

erosion-related problems in emergency spillway channels; to determine the adequacy of the currently available database and of the methods used to predict erosion in spillway channels; to assess and document remedial measures implemented to solve or impede erosion in emergency spillway channels; and to identify research needs for specific problem areas in erosion prediction.

The problem of rock erosion in unlined emergency spillway channels is described. Recent Corps and non-Corps case histories that illustrate the potentially hazardous impacts of excessive erosion in discharge channels are included as are the various factors controlling erosion and other responses to emergency spillway overflow. Research programs designed to improve geotechnical capabilities with respect to selection of cost-effective preventive and remedial measures in discharge channels where the risk of excessive erosion appears high are also discussed.

Response to emergency spillway overflow is controlled by a variety of hydraulic and geologic factors including flood frequency and magnitude, engineering design, discharge channel gradient(s), discontinuity of earth materials, and erodibility of earth materials. A major controlling factor of erosion in spillway discharge channels lined by sedimentary strata appears to be the interrelated effect of stratigraphic discontinuity and channel gradient change(s). These factors combine to initiate and control headward migration of knickpoints, where resistant sedimentary layers are undercut by scouring of softer, underlying strata. In terms of erodability of earth materials, the scale of the hydraulic forces generated during emergency spillway overflows suggests that rippability and litho-stratigraphic discontinuity may serve as a good point of departure in describing the relative resistance to erosion of rocks lining discharge channels.

Responses to emergency spillway flow include channel floor and bank erosion, sediment transport and deposition, and overbank flooding. Erosion of the material underlying unlined channels is the most serious of spillway flow impacts, since channel floor degradation can undermine spillway structures and threaten reservoir integrity. Responses to emergency spillway are not limited to the immediate area of the dam, however. Spillway overflow can act to cause stream thresholds (which limit change on the system) to be exceeded in the main channel into which spillway overflow exits and can influence or induce changes for significant distances downstream. Several case histories provide ample evidence that knickpoint migration and headcutting can be initiated at a point considerably downstream from a control structure. Sediment deposition can build bars and deltas in spillway discharge channels, at the exit channel-main channel confluence, and in downstream reaches of the main channel. Deposition in the main channel may impede passage of reservoir overflow and, by deflecting flow into the channel banks, cause irregular channel widening. This impact could conceivably initiate or accelerate erosion of streambanks and levees, impact navigation, endanger ecological balances, and increase the danger of overbank flooding.

KEY WORDS: Erosion, Hydraulic Structures, Spillways

REMR-GT-3, Report 2

"Geotechnical Aspects of Rock Erosion in Emergency Spillway Channels; Analysis of Field and Laboratory Data." 1988 (Sep). Prepared by Christopher P. Cameron and David M. Patrick, University of Southern Mississippi, Hattiesburg, MS; Kerry D. Cato, Texas A&M University, College Station, TX; and James H. May, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A203 774

The objectives of this work unit were (a) to identify the geotechnical and hydraulic parameters influencing the rate and mechanisms of erosion in unlined emergency spillway channels; (b) to identify channel response to emergency spillway flow and to assess the nature, magnitude, and severity of downstream impacts; (c) to develop methods of predicting erosion in unlined emergency spillway channels; (d) to develop cost-effective remedial and preventive measures to minimize the problem of severe erosion in unlined emergency spillway channels; and (e) to maintain and update an observational database that documents important erosive spillway overflow events at Corps projects.

Field and laboratory studies of erosion in unlined emergency spillways channels excavated in rock have demonstrated that erosional processes operating in these spillway channels are similar to those operating in natural stream channels and that rock discontinuities are critical factors in the initiation and extent of erosion. Knickpoint formation and headcutting are typical erosion processes. Fractures, faults, joints, dip orientation, igneous contacts, veins, bedding planes, inconformities, bed pinch outs, and facies changes are types of structural or stratigraphic discontinuities that must be characterized if present. The analysis of 14 Soil Conservation Service and 2 Corps of Engineers dams that have experienced emergency spillway flow revealed that the extent of erosion at these sites could be categorized in terms of volumetric and horizontal erosion rankings. These ranking parameters provide insight as to the seriousness of the erosion threat at a particular dam and may be used to give priority for remediation. Generally, the ranking parameters were more closely correlatable with the geometry of the spillway channel than with the hydraulics of the spillway flow event. Preliminary laboratory studies using a recirculating, tilting flume and simulated earth materials configured as a knickpoint (waterfall) demonstrated that maximum undermining and erosion of a stratified, two-layer system was a function of the ratio of water depth to knickpoint height and the venting condition of the waterfall. The maximum erosion did not occur at peak discharge but occurred when the discharge passed through windows or thresholds on the rising and falling limbs of the hydrograph which were, in turn, controlled by the ratio (above) and venting.

These field and laboratory investigations have substantiated the need for detailed geological information at sites experiencing spillway flow, detailed documentation of the results of spillway flow, and model studies in which spillway geometries are evaluated in terms of geology and nature and spacing of discontinuities.

KEY WORDS: Channels, Erosion, Geology, Headcutting, Knickpoint, Spillways

REMR-GT-3, Report 3

"Geotechnical Aspects of Rock Erosion in Emergency Spillway Channels; Remediation." 1988 (Sep). Prepared by Christopher P. Cameron and David M. Patrick, University of Southern Mississippi, Hattiesburg, MS; Craig O. Bartholomew and Allen W. Hatheway, University of Missouri, Rolla, MO; and James H. May, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A203 775

This report primarily addresses remediation of erosion in rock; however, selected remediation measures for soils and overburden are also presented since these unlithified materials are usually closely associated with rock in emergency spillway channels. This report provides documentation and assessment of remedial measures implemented or contemplated to solve or impede erosion in emergency spillway channels.

Remediation design is highly site-specific and must be cost-effective, address public safety, and provide continued reservoir operations. Selection of remedial technique(s) must be established by site-specific characterization of the rocks forming an unlined spillway channel in terms of rock composition(s), hardness, structural and stratigraphic discontinuities, and precursor erosion elements, all of which determine rock erodibility and its rate. Erosion probability indices based on methods that combine rock mass parameters (composition, hardness, structural discontinuity, etc.), which determine "rippability," with lithostratigraphic continuity may allow for site-prioritization in terms of the need for remedial and preventive techniques.

Potentially useful remedial engineering techniques include cement-based methods such as grouting, shotcrete, soil cement/roll crete, and high-strength unreinforced and reinforced concrete, as well as rock bolts, wire mesh, gabions, and riprap. Potentially useful erosion preventive measures include construction of energy dissipators and cut-off walls and the removal of vegetation and other obstacles to flow. Flow rerouting, the relief of uplift pressures, and the placement of geotextiles and natural grasses (especially in poorly lithified rocks and soils) may also offer useful alternatives. The majority of these remedial techniques have been used previously in various erosion protection schemes (e.g., stream banks, canals, levees, etc.); however, their use in unlined emergency spillway channels has not been extensive and there is little documentation available. The selection of a particular remedial technique will depend upon site conditions and costs that are highly variable for a given method.

KEY WORDS: Cement-Based Materials, Erosion, Erosion Probability Index, Hydraulic Structures, Rock Mass, Spillways

GT-3, Report 4

"Geotechnical Aspects of Rock Erosion in Emergency Spillway Channels; Geologic and Hydrodynamic Controls on the Mechanics of Knickpoint Migration." 1989 (Dec). By James H. May, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A216 749

The purpose of this research was to study knickpoint erosion phenomena with respect to the combined effects of the geologic and hydrodynamic controls.

In order to study the mechanisms working at the knickpoint, several obstacles had to be overcome. First a material had to be developed that would erode like rock but would keep the eroding water clear so that the failure mechanisms could be observed. Sodium silicate and gelatin-cemented gravel in combination with Plexiglas were used to simulate knickpoints in layered rock. Next, a hydraulic flume had to be modified to accommodate layered samples. The designed drop structure, which was constructed in streams or channels to dissipate erosive energy, was used as an analog to study the knickpoint phenomena. The research revealed that the potential for headward knickpoint erosion is controlled by the geometry of the knickpoint, the velocity of eroding water, and the pressure underneath the nappe. The geometry of the knickpoint is in turn controlled by the site-specific geology. The erosion rate was found to increase significantly when the thickness of the erodible lower layer in a two-layer model exceeded the diameter of the back roller at the toe of the knickpoint.

It was found that headward erosion in the flume could be controlled or completely stopped by controlling the pressure underneath the nappe. Headward erosion was orders of magnitude greater when the area underneath the nappe was not vented to the atmosphere. The development of an unvented condition was found to cause rapid headward erosion at low conditions well below the maximum discharge.

KEY WORDS: Erosion, Headcutting, Hydraulic Structures, Knickpoint, Rock, Rock Mass, Spillways

REMR-GT-3, Report 5

"Geotechnical Aspects of Rock Erosion in Emergency Spillway Channels; Summary of Results, Conclusions, and Recommendations." 1990 (Sep). Prepared by Christopher P. Cameron and David M. Patrick, University of Southern Mississippi, Hattiesburg, MS; James H. May, John B. Palmerton, and Colin C. McAneny, US Army Engineer Waterways Experiment Station, Vicksburg, MS; Allen W. Hatheway and Craig O. Bartholomew, University of Missouri, Rolla, MO; and Christopher C. Mathewson and Kerry D. Cato, Texas A&M University, College Station, TX. AD A228 781

This document is a final report of a series of REMR reports that summarizes 5 years of research on erosion in unlined emergency spillway channels. An observational database was developed to document cases of spillway erosion using data from site visits, periodic inspection reports, videos of spillway flow, and the literature. The database showed that severe erosion occurred at discharges that were less than 10 percent of project maximum floods, and at velocities that were greater than those recommended by current guidelines; spillway channel erosion was driven by processes similar to knickpoint migration (headcutting) in natural stream channels; and the occurrence of stratigraphic and structural discontinuities in the spillway foundation were important factors in controlling the occurrence and extent of erosion.

Laboratory flume studies using simulated earth materials were conducted to investigate knickpoint migration at a waterfall. The waterfall consisted of an erosion-resistant layer overlying a material of low erosion resistance. The geometric and hydraulic conditions at the waterfall were mathematically defined using a vented, erosion-dissipating drop structure as an analog. The flume studies showed that erosion and headcutting were maximized when the waterfall became unvented, the ratio of stage height-to-height of waterfall was 1:8 or less, the ratio of thickness of the erosion-resistant layer to height of backroller was greater than 1:5, and there were structural discontinuities in the resistant layer. Furthermore, the model studies and computer simulations showed that erosion did not accompany peak discharge, but rather it occurs on the lower portions of the rising and falling limbs of the hydrograph.

These findings support the observation that severe erosion may occur at discharges significantly lower than project maximum flood or spillway design flood. The evaluation of spillway channels having experienced erosion or suspected to be susceptible to erosion requires preparation of detailed engineering geologic maps and cross sections showing distribution of rock and rock mass properties, particularly lithostratigraphic and structural discontinuities; data from borings including geophysical logs; and information relative to the flood history of the facility (including hydrography). Spillway erosion is a site-specific problem. The extent of erosion in a spillway may be described and compared with other sites by horizontal and volumetric erosion rankings that, respectively, show the relative amount of headcutting toward the spillway crest and the relative amount of material eroded from the spillway channel. Erosion susceptibility, similar to spillway evaluation, must emphasize rock-mass ratings or classification systems (e.g. rippability) which, when combined with lithostratigraphic discontinuity and hydraulic data, may provide indices indicative of conditions conducive to severe erosion. Remedial and preventive measures at sites having experienced erosion should be designed and emplaced to secure and protect rocks at the top and face of the knickpoint; gabions, rockbolts, and standard cement-based techniques are the most commonly used.

KEY WORDS: Erosion, Headcutting, Hydraulic Structures, Knickpoint, Rock, Rock Mass, Spillways

REMR-GT-4

"State of the Art for Design and Construction of Sand Compaction Piles." 1987 (Nov). Prepared by Richard D. Barksdale, Georgia Institute of Technology, Atlanta, GA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A188 816

The objective of this work unit was to determine the feasibility and effectiveness of techniques for soil improvement of liquefiable foundation conditions under existing structures. The study described in this report focuses on sand compaction piles as one potential method for improving marginal sites for stability, liquefaction, and settlement applications. They also act as drains for static loading and accelerate primary consolidation.

Sand compaction piles have been employed extensively in Japan for many years to improve land reclaimed from the sea. The advantages and disadvantages of using sand compaction piles are compared with other vibro-compaction techniques such as stone columns. Methods are described for construction of sand compaction piles on land and over water. Design theories are given for the use of sand compaction piles at sites underlain by both cohesionless and cohesive soils. For sites underlain by cohesionless sand, procedures are presented for estimating the increase in standard penetration resistance in both the sand compaction pile and the surrounding sand. Techniques are described for estimating stability and one-dimensional consolidation settlement of sites underlain by cohesive soils that have been improved with sand compaction piles. Finally, typical applications of sand compaction piles are described, and practical design criteria and practices are given.

KEY WORDS: In Situ Deep Compaction, Liquefaction, Pool Reinforcement, Pore-Water Pressure, Remedial Treatments, Sand Compaction Piles, Soils

REMR-GT-5

"Inspection and Control of Levee Underseepage During Flood Fights." 1987 (Sep). Prepared by Robert W. Cunny, Vicksburg, MS, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A188 324

The primary purposes of this study were to develop guidance for the evaluation of levee underseepage and remedial measures that can be used to control levee underseepage during a flood fight on a short-term basis.

Documented in this report are the basic levee inspection responsibilities and flood-fighting techniques of the Mississippi River Valley Districts (Rock Island, St. Louis, Memphis, and Vicksburg) and the Levee Boards. The need for a consistent terminology for the severity of underseepage, better flood-fight training for young engineers, and better mobility for inspection were the main problems identified in this report.

The following terminology is recommended as a standard to describe the severity of underseepage:

— Light – area is wet.
— Moderate – running water is observed.
— Heavy – pin boils (small pipe openings without sand cones) with running water.
— Sand boils – any pipe opening with sand cones.
— Large boils – sand boils with pipe openings 12 in. or more in diameter (size described by diameter of pipe opening).

Personnel interviewed, documents collected from Corps District offices, and a list of questions related to inspection for underseepage during floods are included in Appendices A, B, and C, respectively.

KEY WORDS: Flood Fighting, Inspection, Levees, Questionnaire, Remedial Treatment, Underseepage

REMR-GT-6, Report 1

"Geotechnical Applications of the Self Potential (SP) Method; The Use of Self Potential in the Detection of Subsurface Flow Patterns in and Around Sinkholes." 1988 (Mar). Prepared by Ronald A. Erchul, Virginia Military Institute, Lexington, VA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A194 524

The purpose of this research was to test and evaluate an indirect geophysical measuring technique called self or spontaneous potential (SP) on a newly developed sinkhole to determine if this method would be able to detect the direction of groundwater flow.

Self potential (SP) measurements were effectively used in the detection of surface and subsurface drainage around a sinkhole. The same SP technique was also able to track an apparent subsurface flow path of over 600 ft from one sinkhole into another sinkhole. Confirmation of the SP data was obtained by visual observation, electrical resistivity measurements, and geological studies. The use of this geophysical technique was evaluated in and around sinkholes in a karst area of west-central Virginia.

The SP electrode configuration consisted of a double ring of electrodes circumferentially located around each sinkhole. Two reference electrodes were used in taking SP measurements. One reference electrode was located outside the rings of electrodes, and the other was located in the center of one of the sinkholes. Once a major drainage path around the sinkhole was detected, an array of electrodes was used to track the flow path.

Although SP data varied significantly for individual electrodes during the 6-month testing period, the relative values between electrodes were consistent. This finding was also true if the position of the reference electrode was changed. It appeared that changes in precipitation and temperature had a great effect on the variation of SP data over the testing period.

KEY WORDS: Electrodes, Flow Path, Geophysical Technique, Self Potential, Sinkhole, Subsurface Drainage, Surface Drainage

REMR-GT-6, Report 2

"Geotechnical Applications of the Self Potential (SP) Method; The Use of Self Potential to Detect Ground-Water Flow in Karst." 1989 (May). Prepared by Ronald A. Erchul and Dennis W. Slifer, Virginia Military Institute, Lexington, VA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A209 339

This report, the second in a series, presents the results of investigations of the environmental effects (temperature, rain, vegetation, etc.) on self potential (SP) measurements with metal electrodes, the relationships between flow quantity and SP magnitudes, and the limitations of the method developed in the preliminary work.

In this study, SP, which is a geophysical method that measures naturally occurring voltage in the earth, was monitored at sites in karst terrain in Virginia. The results were evaluated for effectiveness in detecting and mapping ground-water flow paths and flow rates. The ability of SP to distinguish between shallow flow in soil and regolith and deeper flow through bedrock conduits was examined.

It was demonstrated that soil temperature, soil moisture, and precipitation are major variables influencing SP data. An automated data collection system was devised and used for two tasks: (a) long-term monitoring of SP changes and environmental variables and (b) measuring SP changes induced by the rapid artificial recharge of water into a sinkhole. The SP results were evaluated by comparison with geological observations, electrical resistivity and electromagnetic terrain conductivity surveys, streamflow measurements, and speleological surveys.

Results indicate that SP can effectively locate and track shallow (less than 20 m) ground-water flow paths in karst terrain. A relationship was observed between SP and changes in flow rate where the flow was through porous material, but SP could not be directly related to flow through solutional channels and conduits. However, the presence of conduits may be indicated by SP anomalies where surface soil moisture is drawn into fractures that supply water to conduits at greater depths. The influence of geologic structures on ground-water flow must be considered in interpreting SP results in karst. Further refinement of the SP technique is promising for applications to environmental and geotechnical problems.

KEY WORDS: Electrodes, Flow Path, Geophysical Technique, Self Potential, Sinkhole, Subsurface Drainage, Surface Drainage

REMR-GT-6, Report 3

"Geotechnical Applications of the Self-Potential Method; Development of Self-Potential Interpretation Techniques for Seepage Detection." 1989 (Feb). Prepared by Robert W. Corwin, Harding-Lawson Associates, Navato, CA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS; Foreword by Dwain K. Butler, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A207 704

This report consists of four distinct but complementary parts: (a) a laboratory/field study of environmental effects on self-potential (SP) electrodes and long-term stability of the electrodes; (b) field investigations at Beaver Dam, Arkansas; (c) development of a computer program for interpretation of seepage-related SP field survey data; (d) development of an extensive bibliography and database for acquisition and interpretation of seepage-related SP data.

The Beaver Dam, Arkansas, site was selected as the major field test site for this research. The geotechnical problem at the site was anomalous underseepage in the foundation of a large embankment dike. SP data were effectively used to map the seepage paths.

Three electrodes--nonpolarizing copper-copper sulfate (CS), copper-clad steel (CCS), and lead--were investigated. Of the three, the commercial-grade lead electrodes are least suitable for long-term monitoring of SP. CS electrodes with gelled electrolyte appear capable of surviving at least a few years without maintenance or significant deterioration of physical properties or performance. For SP measurements, CCS electrodes have a lower signal to noise (S/N) ratio than do CS electrodes. Field and laboratory measurements indicate that responses of CCS electrodes to environmental disturbances are an order of magnitude or greater than CS electrodes. The higher noise level is due both to the direct exposure of the metal to the soil as well as the exposure of the unburied portion of the electrodes to solar heating and rainfall. Thus, the considerably higher initial cost and extra effort involved in installation of the CS electrodes are justified, and CS electrodes are recommended for geotechnical applications of the SP method.

The SP contours taken with CS electrodes during high and low pool levels at Beaver Dam are strongly related to seepage flow patterns. Even though the data are affected to some extent by topography and by seasonal changes in soil and pore water resistivity, negative SP anomalies are associated with subsurface seepage flow paths, and positive SP anomalies are associated with areas of seepage outflow. Comparison of CS and CCS SP data indicates a lower S/N ratio for the CCS data and lack of correlation with the CS data in many locations. However, large amplitude SP responses from CCS electrodes, which are apparently correlated with pool level, may be due to input parameters different from those that affect CS electrodes.

Several geometric SP source models are included in a computer program for modeling SP effects. Procedures for using these source models to

iteratively interpret SP field data are discussed. The computer program is used to estimate source depths for the seepage at Beaver Dam.

Included in the report is a bibliography with 144 entries keyed to main topics, such as electrode studies, dam seepage investigations, streaming potential theory, etc.

KEY WORDS: Geophysics, Seepage, Self Potential, Subsurface Fluid Flow

REMR-GT-6, Report 4

"Geotechnical Applications of the Self Potential (SP) Method; Numerical Modeling of SP Anomalies: Documentation of Program SPPC and Applications." 1990 (Mar). Prepared by Michael J. Wilt, University of California, Berkeley, CA, and Dwain K. Butler, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A220 716

This report, the fourth in a series on geotechnical applications of the self potential (SP) method, documents a microcomputer program for the numerical modeling of SP anomalies caused by flow of fluid or heat (primary flows) through a porous medium. The program is applied to the modeling of SP data acquired at Beaver Dam, Arkansas. This model calculation is the first known numerical modeling simulation of SP phenomena caused by anomalous seepage through an earth dam and foundation.

This manual describes the theory and operations of program SPPC. This code is a microcomputer (PC) version of program SPXCPL, which calculates the self potential anomaly due to fluid and thermal sources in geologic media. Fluid and heat flow generate significant electrical potentials due to cross-coupling between fluid and heat flow and the flow of electrical current. The SP anomalies are largest near the primary flow sources and in regions where the cross-coupling coefficients change (geological boundaries). Program SPPC allows for the forward model calculation of primary potential (pressure or temperature) and secondary potential (voltage) for discrete sources of heat or pressure in a two-dimensional model of the earth. The input for the program involves a small mesh where values are assigned for the permeability or thermal conductivity, cross-coupling coefficients, and electrical resistivity. The magnitude and location of the primary sources (fluid or heat flow) must also be specified. The output file provides values for the primary potential and voltage on the surface and throughout the two-dimensional model.

The manual provides a discussion of the input parameters, a section on how to read the output, and some guidance on applying the program to physical problems. The program was validated with an analytical solution of a point pressure source in a homogeneous halfspace. A field example is also shown where SP data collected near a leaky dam site is used to locate the zone of leakage.

KEY WORDS: Geophysics, Seepage, Self Potential, Subsurface Fluid Flow

REMR-GT-7

"Applications of the State of the Art of Stone Columns--Liquefaction, Local Bearing Failure, and Example Calculations." 1987 (Dec). Prepared by Richard D. Barksdale, Georgia Institute of Technology, Atlanta, GA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A191 606

The purpose of this report is to give example calculations and considerations that may be used in the state-of-the-art application of stone columns for improving soils subject to static, earthquake, and postearthquake-reduced strength loading conditions beneath and adjacent to existing structures. Also included are appendixes that are directly pertinent to the application of stone columns for remedial treatment of liquefiable soils.

Also presented is Seed and Booker's method for estimating the dissipation of excess pore pressure in stone column improved ground during strong motion earthquakes. Practical aspects of the effects of radial drainage of various techniques of constructing stone columns are discussed. The capacity for radial drainage may be reduced during construction because of both smear effects and a change in stone column gradation.

A theory for local bearing failure of an isolated stone column subjected to a shear load is given. Also, a number of examples are presented illustrating the solution of bearing capacity, settlement, slope stability, and liquefaction problems for ground that has been improved with stone columns.

KEY WORDS: Remedial Treatments, Settlement, Soil Reinforcement, Soils, Stability, Stone Columns

REMR-GT-8

"Review of Consolidation Grouting of Rock Masses and Methods for Evaluation." 1988 (Jul). By R. Morgan Dickinson, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A198 209

This study was undertaken to review consolidation grouting methods and to look at the application of consolidation grouting as a remedial measure for structures in the Corps. Consolidation grouting may be defined as the injection of grout into discontinuities in a rock mass to control fundamental rock mass properties such as permeability, strength, and deformability. This report re-examines factors affecting the grouting program quality, geologically imposed conditions, grouting methods, and methods to monitor and evaluate the quality of the grouting program. The report also reviews past consolidation grouting projects and describes the execution, performance, and evaluation of the programs.

The study was limited to cementitious grouts injected into a rock mass. Three case histories are presented (Savage River Dam Spillway, Little Goose Lock and Dam, and John Day Lock and Dam). A comprehensive literature

review was conducted to examine geological factors, grouting methods, and techniques for monitoring and evaluating a grout program.

It was found that, although the Corps frequently performs remedial seepage control grouting, remedial consolidation groating has been reported for only these three projects. Many of the findings of the literature review can be applied to cementitious grouting in general. The material identified in the literature review and the case histories are evaluated and summarized.

KEY WORDS: Cement Grouts, Consolidation Grouting, Electronic Monitoring, Grout Evaluation

REMR-GT-9

"A Survey of Engineering Geophysics Capability and Practice in the Corps of Engineers." 1988 (Mar). By Dwain K. Butler and Ronald E. Wahl, US Army Engineer Waterways Experiment Station, Vicksburg, MS; Nolan W. R. Mitchell, US Army Engineer Division, Missouri River, Omaha, NE; and Gregory L. Hempen, US Army Engineer District, St. Louis, St. Louis, MO. AD A194 520

The results of a survey of engineering geophysics capability and practice in Corps Districts and Laboratories are presented and analyzed. The objective of the survey was to make available a convenient inventory of geophysical equipment and expertise to encourage interchange of equipment and expertise and to ultimately elevate the level of practice of engineering geophysics.

This report presents a definition and brief overview of engineering geophysics as well as a historical perspective of engineering geophysics practice and philosophy in general and in the Corps of Engineers. Three factors are given as primary contributors to a dramatic increase in the scope and acceptance of engineering geophysics in recent years: (a) an ever increasing number of practitioners of engineering geophysics have education and training in geophysics; (b) inexpensive and increasingly sophisticated instrumentation and microcomputers make techniques and procedures possible that were previously impractical for engineering geophysics applications; (c) emergence of a new class of high priority geotechnical problems include hazardous waste-site assessment, ground-water pollution, and military arsenal and range clearance and reclamation for which various geophysical methods are ideally suited. The geophysical capabilities of the nine Corps Laboratories are described.

KEY WORDS: Borehold Geophysics, Engineering Geophysics, Equipment, Gravity, Microgravity, Radar, Reflection, Refraction, Resistivity, Seismic, Survey

REMR-GT-10

"High-Resolution Seismic Reflection Investigations at Beaver Dam, Arkansas," 1989 (Jul). Prepared by Thomas L. Dobecki and Tanya L. Mueller, Colorado School of Mines, Golden, CO, and Monroe B. Savage, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A211 228

This study investigates the use of seismic reflection for the evaluation of existing dams and adjacent structures. Beaver Dam was selected for testing the utility of seismic reflection, given the parallel refraction and extensive self-potential (SP) data, ground-penetrating radar, and borehole investigations already performed at this location. An additional purpose in the investigation was to evaluate different instrumentation and data acquisition methodologies to determine optimal means for acquiring such data while retaining high data quality.

Seismic refraction surveys require line lengths four to five times the desired depth of investigation. For many geotechnical applications, these are physical and geometrical constraints that inhibit seismic refraction, such as narrow river valleys, changes in direction of the center line of a dam, or legal inaccessibility to land surrounding a site. The seismic reflection method offers an alternative to refraction for geotechnical site investigations. Typical line lengths for reflection are approximately equal to the desired depth of investigation. In the past, the required data processing, limitations of "engineering seismographs," and inapplicability of oil exploration seismic recording systems to very shallow targets (m) precluded effective utilization of the seismic reflection method for geotechnical applications. Rapid advances in microcomputer technology, development of digital engineering seismographs, development of high-frequency seismic sources, and adaptation of oil exploration field procedures to account for inherent problems of shallow depths of investigation now make shallow, high-resolution seismic reflection surveys a viable tool for geotechnical applications.

Field investigations of shallow, high-resolution seismic reflection methodology at an existing structure site, Dike 1, Beaver Dam, AR, are discussed. Dike 1 is built across a graben with vertical offset in excess of 70 m. The down-dropped block consists of solutioned, cherty limestone. The top of rock is highly irregular, and solution cavities and solution-widened joints exist in the rock. The seismic reflection results effectively mapped the irregular top of rock (3- to 10-m depth), detected previously unknown faults within the graben, and mapped sand stone and shale formations at the "base" of the graben (70- to 75-m depth).

KEY WORDS: Data Processing, Graben, Optimum Offset, Reflection, Refraction, Seepage, Seismic Reflection, Seismic Refraction

REMR-GT-11

"Levee Underseepage Analysis for Special Foundation Conditions." 1989 (Sep). Prepared by Thomas F. Wolff, Michigan State University, East Lansing, MI, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A213 500

This report describes a research study in which techniques were developed for prediction of underseepage conditions for special cases of levee and foundation geometry. The purpose of this research was to develop analysis procedures that are not constrained by some of the assumptions in the conventional procedure. A second purpose was to investigate whether improved performance predictions could be made using the developed procedures.

The differential equations for levee underseepage were derived and programmed in finite difference form for three special cases of boundary conditions. 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. The three computer programs developed to perform underseepage analysis are LEVEE3L for analysis of foundations consisting of three layers of uniform thickness, LEVEEIRR for analysis of foundations consisting of two layers of irregular shape (nonuniform thickness), and LEVEECOR for analysis of underseepage at angles or "corners" in levee alignment.

Capabilities of the techniques and programs are demonstrated by comparing theoretical solutions to observed performance at eight field locations where piezometric data are available. At each location, the field permeability ratio was estimated by varying program input and seeking a match between the program output and actual observed performance.

KEY WORDS: Analyses, Foundations, Geometry Evaluation, Irregular Boundaries, Levees, Numerical Methods, Permeability, Rehabilitation, Underseepage

REMR-GT-12

"Re-Evaluation of the Sliding Stability of Concrete Structures on Rock with Emphasis on European Experience." 1989 (Sep). Prepared by K. Kovari and P. Fritz, Swiss Federal Institute of Technology, Zurich, Switzerland, through the US Army Research Development and Standardization Group, London, UK, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A214 403

This report reviews the main rock mechanics features of the stability of concrete dams against sliding and discusses recent developments regarding the tools of investigation.

The sliding stability of a rock mass forming the foundation or the abutments of concrete dams, of a natural slope, or of a cut cannot be measured directly but merely conjectured. However, the nature of the mechanisms that may lead to a failure and, conversely, remedial measures that may enhance the existing stability are known. Attention must be paid to sliding hazard if the presence of adversely oriented discontinuities with considerable persistence is evident, if movements take place in the rock mass, if high water pressures are measured in faults, and/or if wet spots at critical areas of a slope or downstream of the dam foundation are known to occur. A change in the flow rate of the drains can also be an indication of an unsafe condition. The most effective way (and in many instances, the only practical solution to increase stability against sliding) is to prevent or eliminate the occurrence of excessive water pressure below the foundation or in the faults. The second possibility involves reinforcements by anchoring and shear keys. The third way is removal or placement of rock masses and concrete in critical areas. The problem that arises in practice is to weigh correctly the different pieces of information relating to the assessment of the degree of stability.

KEY WORDS: Dams, European Dams, Instrumentation of Rock Masses, Large Dams, Rock, Rock Mass, Sliding Stability

REMR-GT-13

"Levee Underseepage Software User Manual and Validation." 1989 (Sep). Prepared by Robert W. Cunny and Victor M. Agostinelli, Jr., JAYCOR, Vicksburg, MS; and Hugh M. Taylor, Jr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A214 024

A FORTRAN 77 computer program (LEVSEEP) was developed to analyze levee underseepage on IBM PC compatible microcomputers with an 8087 math coprocessor. This manual contains detailed instructions for the use of the program LEVSEEP and includes general comments and rules for effective use of the program capabilities; instructions for input data, gradient and seepage calculations, and control measures and cost options; and the steps to access the output files through dBASE. The software and associated equipment plots cross sections and piezometer data; calculates seepage flow and substratum pressure; analyzes landside berm, riverside blanket, cutoff, and relief well control measures; and finally, estimates the construction cost of these alternatives. The results of example computer calculations agree favorably with hand solutions.

KEY WORDS: Berms, Calculations, Computer Programs, Cutoffs, Levees, Method of Fragments, Microcomputer Software, Relief Wells, Riverside Blankets, Seepage, Underseepage, Verification

REMR-GT-14

"Surface Roughness Characterization of Rock Masses Using the Fractal Dimension and the Variogram." 1990 (Mar). By James R. Carr, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A225 384

A branch of mathematical topology called fractal dimension analysis and the variogram construction from the theory of regionalized variables are described and applied to natural geologic rock surface descriptive data. The purposes of this application were to determine the applicabilities of the techniques to characterization of the rock surface roughness and the semi-empirical prediction of the surface shear strengths.

Both the fractal dimensions and variograms were determined from data obtained on the DS + 122 slide surface at Libby Dam, MT. The data used were a fine-scale photogrammetric contour map of the joint surface and string line profiles measured on the joint surface. The fractal dimensions were found to exactly reflect the qualitative roughness of the surface and to be directly proportional to the roughness in a numerical comparison. The variograms of the natural surface data demonstrate that roughness elevations are spatially correlated and have a finite spatial continuity. The variogram is also useful for examining asperity magnitude differences across the joint surface. The variogram demonstrated more descriptive ambiguity than did the fractal dimension.

Fractal dimensions of roughness profiles of small rock specimens were calculated and compared with the Joint Roughness Coefficient (JRC) used in the empirical rock shear strength criterion. A least squares relationship was determined:

$$JRC = -1022.55 + (1023.92)\,D$$

with D as the fractal dimension. Thus, the JRC component of the empirical shear strength component can be directly obtained from surface profile data.

KEY WORDS: Discontinuities, Fractal Dimension, Rock Mass, Rock Shear Strength, Roughness, Variogram

REMR-GT-15

"Plastic Concrete Cutoff Walls for Earth Dams." 1991 (Mar). By Thomas W. Kahl, Joseph L. Kauschinger, and Edward B. Perry, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A234 566

This research was conducted to quantify the stress-strain-strength behavior and permeability of plastic concrete, and to develop design data for specifying plastic concrete for use in a diaphragm cutoff wall for an earth dam.

Phase I of this research consisted of evaluating the unconfined compression, tensile, and flexural behavior of plastic concrete as a function of cement and bentonite content versus age. Phase II was conducted to examine the influence of consolidation and horizontal confinement on the stress-strain characteristics, strength behavior, and permeability of plastic concrete to simulate the stress and drainage conditions plastic concrete would be subjected to at the bottom of a tremie placement in a deep trench.

The results of this study indicate that the addition of bentonite clay to conventional concrete significantly increases the ductility and plastic deformation of the concrete while simultaneously reducing its shear strength. The permeability of plastic concrete was found to be the same or less than conventional concrete, and it decreased significantly with consolidation. A design method is given for determining the mix design of a plastic concrete cutoff wall based upon the unconfined compressive strength and/or modulus of the embankment soil.

KEY WORDS: Cutoff Wall, Diaphragm Wall, Ductile Behavior, Earth Dam, Plastic Concrete, Remedial Seepage Control

REMR-GT-16

"Redevelopment of Relief Wells, Upper Wood River Drainage and Levee District, Madison County, Illinois." By J. Kissane, US Army Engineer District, St. Louis, St. Louis, MO, and Roy Leach, US Army Engineer Waterways Experiment Station, Vicksburg MS.

Upgrading of the Upper Wood River levees resulted in their ability to hold back higher river stages, which in turn resulted in increased underseepage. A program of testing and redevelopment of the existing relief wells was undertaken to optimize the efficiency of existing measures, to assist in assessing the need for additional wells, and to assess current well cleaning procedures.

The study resulted in a three-phase program consisting of (a) conventional cleaning procedures, (b) demonstration of a blended chemical high temperature (BCHT) procedure, and (c) a full-scale BCHT treatment on 28 wells. Conventional cleaning consisted of applying varying doses of trisodium phosphate (TSP) and sodium hypochlorite (HTH) to the well. The BCHT procedure introduces in several phases doses of chlorine and acid applied with steam injection.

The results of the study showed that the BCHT procedure was more effective than conventional methods (even when heavy mechanical surging was used). On the demonstration wells, specific capacities were increased to design values with the BCHT procedure after strenuous (to the point of diminishing returns) conventional methods had been applied with limited success.

KEY WORDS: Conventional Cleaning, High Temperature Cleaning, Relief Wells

REMR-GT-17

"Applications and Testing of Resin Grouted Rockbolts." 1992 (Jan). Prepared by Timothy S. Avery and James E. Friant, J. E. Friant and Associates, Seattle, WA, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A245 980

This report focuses on the polyester resin grouted rockbolt and its application as an anchor for securing structures to bedrock or old foundation work. A literature search and laboratory and field tests were conducted to determine any parameter that could affect the general integrity of rockbolts which may now be a critical part of existing structures. This report summarizes the findings on four series of bolt tests and provides general information on the critical factors for resin grouted rockbolt use.

The laboratory and field tests indicated that water interference is confined to a short zone at the resin-to-water interface. Tests employing a grout length of 2 ft or more on No. 6 rockbolts held their yield load, wet or dry. Larger scale testing at the Bonneville Locks showed similar results. At grouting lengths of about 55 in. or more, yield load on a No. 11 rockbolt was reached, wet or dry.

This research found no deficiency in polyester resin grouted rockbolts or anchors, so long as proper procedures governing installations are followed. This report contains suggested procedures and cautions.

KEY WORDS: Anchors, Polyester Resin, Rockbolts, Rock Support, Underwater Construction

REMR-GT-18

"Evaluation of the Rehabilitation Program for Relief Wells at Leesville Dam, Ohio." 1992 (Oct). By Roy E. Leach, US Army Engineer Waterways Experiment Station, Vicksburg, MS, and Glen Hackett, National Ground Water Association, Dublin, OH.

At a relief well and drainage system rehabilitation workshop held in April 1985, it was determined that maintenance methods varied between Districts and that no attempt had been made to document results versus the method used. The Huntington District was planning the rehabilitation of 12 wells at Leesville Dam, Ohio, and agreed to use a composite of the various "common" Corps cleaning methods along with the extra verification procedures needed to document the results. Therefore, the objectives of the study were to document a commonly used Corps well rehabilitation procedure, to provide the needed pre- and postverification data, and to evaluate the results.

For the study, encrustant, bacterial, and water analyses were conducted for use in planning the rehabilitation procedure. Recommended and selected procedures for rehabilitation are presented. Planning criteria required that the chemicals be industry accepted and commonly used with economics being the final governing factor. The procedure used at this site incorporated a long linear phosphate and sodium hypochlorite as chemicals with mechanical agitation with a surge block.

Several factors were considered during the evaluation: (a) the lake level was lowered between some of the pre- and postpump tests; (b) there was no bacterial growth in two wells; and (c) there were hydrogeologic boundary conditions that altered groundwater quality, flow, and available bacterial nutrients from well to well. Although there were immediate benefits, postbacterial analysis showed regrowth had started within 4 months of the rehabilitation. There was no "as installed" specific capacity on record to evaluate overall results. Comparison of before and after pump tests indicated an increase in specific capacity for the eight central wells (W-4 through W-11) considered to be representative of the well system that ranged from 35 to 714 percent with an average value of 236 percent. The remaining four wells are not included in the average values because they are at the end of the system, have less screen length, and appear to be founded in finer sediments.

Based on the findings of this study and the well rehabilitation project, the following conclusions can be made regarding the chemical treatment program used to evaluate the control of iron bacteria in relief wells at Leesville Dam, Ohio:

— The chemical treatment program had an immediate beneficial effect on the hydraulic performance of the relief wells.

— The amount of sand produced by the wells may indicate that the wells were not effectively developed initially, and this fact in turn could be part of the increase in specific capacities.

— The chemical treatment program was not successful in preventing regrowth of iron bacteria in the relief wells. The source of the iron bacteria recolonizing the wells is unknown.

— Long-term control of the iron bacteria in the relief wells at Leesville Dam by the chemical treatment method used in this study will require repeated chemical treatments at regular intervals.

KEY WORDS: Drainage, Drains, Evaluation, Relief Wells, Subsurface, Well Bacteria

Unnumbered

"Proceedings of REMR Workshop on New Remedial Seepage Control Methods for Embankment-Dams and Soil Foundations, 21-22 October 1986." 1988 (Jan). Compiled by Edward B. Perry, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A191 073

Presented are the "Proceedings of the REMR Workshop on New Remedial Seepage Control Methods for Embankment-Dams and Soil Foundations." The workshop was conducted to stimulate exchange of ideas and information among leading practitioners and to provide an authoritative review of the state of the art for potential users. These proceedings include presentations on grouting, flexible membrane linings, drainage measures, jet grouted cutoff walls, reinforced downstream berms, plastic concrete cutoff walls, and ground freezing.

KEY WORDS: Berms, Blankets, Earth Dams, Ground freezing, grouting, Hydrofraise, Jet Grouting, Plastic Concrete, Remedial Seepage Control

Unnumbered

"Proceedings of REMR Workshop on Research Priorities for Drainage System and Relief Well Problems." 1989 (Jul). Compiled by R. E. Leach and H. M. Taylor, Jr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A212 067

At a Corps of Engineers workshop on 16-17 April 1985, research needs for restoration of drainage systems and relief wells for earth and earth-supported structures were discussed and prioritized. Proceedings of the workshop are summarized herein. The primary purpose of the workshop was to identify problems and obtain field input to the direction of future research.

The presentations and resulting discussions produced the following proposed research areas in descending order of priority:

Drainage Systems:
- — Evaluation and rehabilitation of deep horizontal and vertical drains.
- — Geotextile guidance for drains.
- — New products infomration; technology transfer.
- — Evaluation of subsurface problems.

Relief Wells:
- — Maintenance procedures and use of chemicals.
- — Inspection and evaluation methods.
- — Iron bacteria, check and flap valves, wood stave replacements, small flow meters, exploration techniques, and vandalism.

KEY WORDS: Drainage, Drains, Evaluation, Relief Wells, Research, Subsurface

Hydraulics Applications

REMR-HY-1

"Annotated Bibliography for Navigation Training Structures." 1986 (Jul). Compiled by Walter E. Pankow and Robert F. Athow, Jr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A173 303

The objectives of this study were to develop methods for detecting scour damage at navigation training structures, to establish a rationale for defining damaging scour, and to identify and evaluate techniques and equipment for repairing scour damage.

A survey of literature on scour detection, repair, and techniques for repair of navigation training structures was conducted to establish a reference base. This bibliography was generated from the survey and was assembled by searching the titles and volumes on file at the Waterway Experiment Station Information Center and using computer-aided key word searching systems.

During this literature search, it was discovered that most works were old or outdated, were the results of hydraulic model studies, or were theory and design oriented. Other pertinent references were listed as "For Corps of Engineers Use Only" (as in the case of certain design memoranda), or in the case of foreign publications, an English translation was not available. A more general approach was taken to include several applicable model studies and older "historical" references, while limiting the number of pure mathematical works.

The bibliography is divided into three categories: General Overview, Scour and Scour Damage, and Repair Techniques. Each entry has key words listed along with an abstract. Also listed is a REMR interest line that indicates why the publication has usefulness in the REMR Research Program.

KEY WORDS: Bibliography, Debris Booms, Floating Debris, Scour, Trash Racks, Trash Struts

REMR-HY-2

"Floating Debris Control; a Literature Review." 1987 (Jun). By Roscoe E. Perham, US Army Cold Regions Research and Engineering Laboratory, Hanover, NH. AD A184 033

Floating debris can have an extremely harmful effect on certain hydraulic structures such as flood control works and navigation facilities and is consequently an important concern in maintenance and repair activities. The objective of the REMR floating debris control systems study is to provide more functional structures and arrangements for removing floating debris from rivers and streams.

This report assembles information found in published literature about equipment and methods used to control floating debris. The range and extent of floating debris problems and effects are touched upon. Much information was gleaned from various Corps and Bureau of Reclamation technical publications and other literature related to the civil engineering hydrology field. Also included is an appendix on booms, their functions in the water transportation of pulpwood, and results of laboratory tests of various boom designs; this appendix was previously published by the Pulp and Paper Research Institute of Canada and contains much useful information applicable to booms for control of floating debris.

KEY WORDS: Debris Booms, Floating Debris, Trash Racks, Trash Struts

REMR-HY-3

"Elements of Floating-Debris Control Systems." 1988 (Sep). By Roscoe E. Perham, US Army Cold Regions Research and Engineering Laboratory, Hanover, NH. AD A200 454

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 debris. The objective of this report is to briefly describe the various elements found in floating-debris control systems. These elements are described under the general headings: origins of floating debris, collecting floating debris, removing floating debris, and disposing of debris.

Various types of booms, trash racks, trash struts, and deflectors have been used effectively for collecting floating debris. Hand-powered, self-powered, and gantry crane-operated rakes are used to remove the debris from intake gates, bulkheads, deck gratings, and trash rack sections. Heavy debris, such as water-soaked logs or fallen trees, are removed with cranes and hoists, supplemented by such implements as bolt hooks, log chains, and chain saws. Some of the removed debris has value. Many logs are large enough to be used as structural materials or can be dried and cut up for firewood. The debris that cannot be used must be burned, buried, or dumped on the ground surface. All of these processes require careful monitoring so that they are not and do

not create health hazards. Surface dumping should be used only as a last resort.

KEY WORDS: Debris Boom, Debris Deflectors, Debris Disposal, Debris Transport, Removal Equipment, Trash Rakes

REMR-HY-4

"Effects of Geometry on the Kinetic Energy of a Towboat and Barges in a Navigation Lock." 1989 (Mar). By Sandra K. Martin, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A207 057

The objective of this study was to develop a means to protect lock gages from vessel impact and thereby reduce or eliminate the resulting damage. This research defines empirically the hydrodynamic energy produced by a high-mass, low-velocity vessel as it travels into the geometrically restrictive conditions imposed by a lock chamber and compares it with the theoretical potential energy of an instrumented test cable designed to react equally and opposite to the vessel energy at the moment of peak impact.

The energy measured in the resisting systems was compared with the expected energy of a vessel traveling at a known velocity with a known mass. The empirical tests were conducted in a 1:25-scale physical model of a lock chamber and with a 1:25-scale remote-operated towboat and push barges that replicated a typical size US navigation lock facility and vessel. As the model tow traveled into the lock chamber and impacted a rigidly affixed test cable placed in the tow's path, impact parameters were monitored including tension in the cable with time, angles formed at the reactions due to deflection with time, and the approaching speed of the tow.

KEY WORDS: Attached Mass, Kinetic Energy, Lock Barriers, Lock Geometry, Towboats

REMR-HY-5

"Explicit Numerical Algorithm for Modeling Incompressible Approach Flow." 1989 (Mar). By Robert S. Bernard, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A207 176

The purpose of this report was to document and demonstrate the numerical algorithm used in STREMR. The STREMR code is a finite-difference numerical model to two-dimensional depth- or width-averaged flow with boundaries and obstacles of arbitrary shape. By changing the input and the finite-difference grid, the user can investigate the relative effects of such parameters and constraints as shape of boundaries (bank lines), vertical or lateral topography, friction (Manning's n), dikes and training walls, piers and piles, vanes and berms, inlets and outlets, islands, and submerged structures.

The explicit finite-difference algorithm presented is to be used for numerical modeling of incompressible approach flow near hydraulic structures. The existing formulation is a predicator-corrector scheme derived from MacCormack's method. As such, it is applicable for transient flow at low Froude number, and for steady-state subcritical flow at moderate Froude number. The algorithm has been incorporated in the STREMR computer program, which will allow engineers and scientists to simulate the effects of structural modifications and repair measures prior to physical testing. The results of essential benchmark calculations are included herein for verification.

KEY WORDS: Approach Channels, Hydraulic Models, Incompressible Flow, Mathematical Models, Shallow Water, Subcritical Flow

REMR-HY-6

"Inventory of River Training Structures in Shallow-Draft Waterways." 1989 (Oct). By David L. Derrick, Herbert W. Gernand, and James P. Crutchfield, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A214 566

The repair of deep- and shallow-draft training structures has continued to be a significant maintenance cost for Corps-maintained structures. This maintenance includes the repair of dikes and revetments damaged by ice, floating debris, impact from navigation, or undermining due to flow conditions. The objective of this report was to locate, identify, and describe existing Corps-built and -maintained dikes in shallow-draft nontidal-influenced waterways. A survey of the latest Project Maps of all Corps Districts in the continental United States was undertaken. This information was supplemented and confirmed by contacting river engineers working in the Districts. All information presented is current through calendar year 1987.

This report includes a glossary of training structure terms and lists all river training structures currently maintained and used by the Corps throughout the continental United States by District, river, river mile where located, and type of dike.

KEY WORDS: Dikes, Inventory, Riverine, River Training Structures, Training Structures

REMR-HY-7

"Lock Accident Study." 1990 (Sep). By Sandra K. Martin, US Army Engineer Waterways Experiment Station, Vicksburg, MS, and Martin E. Lipinski, Herff College of Engineering, Memphis State University, Memphis, TN. AD A228 627

The objectives of this investigation were to evaluate the costs associated with navigation accidents involving collisions with lock gates and to develop a risk assessment methodology that could provide the basis for conducting cost-effective evaluations of potential structural solutions.

Navigation locks were identified where extensive damages occurred to the locks and the lock gates as a result of vessel collision. Data were collected from several sources in an attempt to quantify all damages resulting from accidents at locks including repair to the lock structure, losses due to delays, and damage to cargo and vessels.

The study findings include the costs to repair 80 locks damaged by vessel impact. The statistics regarding repair costs in this report are based on data obtained from seven District offices for the period from 1977 to 1987. The survey includes locks on the Upper Mississippi and Ohio Rivers and their navigable tributaries such as the Tennessee, Illinois, and Monongahela Rivers. Analyses of databases to obtain quantitative delay and vessel damages were inconclusive. Also included in the report are a barrier system for locks, lock volume data, and the computer program used to download records from a database to a software package. Charts of the relationship between daily variation in average wait times and process times and number of vessel arrivals per day are given.

KEY WORDS: Damages, Impact Barrier, Lock Accidents, Miter Gates, Navigation

REMR-HY-8

"Shallow-Draft Training Structure Current Repair Practices and Repair Guidelines." 1991 (Apr). By David L. Derrick, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A239 045

The objectives of this work unit were to inventory river training structures, document past dike repair work, facilitate technology transfer among Corps Districts through reports and workshops, document current repair methods, and formulate guidelines for structure inspection, record keeping, evaluation, and repair.

This report documents past and present dike repair methods, reports on new technology in the field of dike repair, and formulates guidelines to be used for training structure inspection, repair criteria, record keeping, evaluation, and repair. The following topics are covered for each of the 12 Corps Districts that build and maintain dikes: description of the project; stage, discharge, sediment, and dredging; dike design and construction; inspections; types of dike damage; causes of dike damage; repair criteria; repairs and repair techniques; record keeping, environmental considerations; and new technology. Also included are repair level guidelines and recommended repair planning procedures.

KEY WORDS: Dike, Dike Repair, Dike Maintenance, River Training Structure, River Training Structure Repair

Unnumbered

"Proceedings of REMR Workshop on Repair and Maintenance of Shallow-Draft Training Structures, 24-25 February 1987." 1991 (Apr). Compiled by David L. Derrick, US Army Engineer Waterways Experiment Station, Vicksburg, MS AD A235 666

Presented are the "Proceedings of the Workshop on Repair and Maintenance of Shallow-Draft Training Structures." The repair of riverine shallow-draft training structures has been and will continue to be a significant maintenance cost within the US Army Corps of Engineers The main purpose of the workshop was to gather the working-level river engineers involved in dike repair and provide a forum in which to exchange experience, methodology, and problems faced by each Corps District. A secondary purpose was to enable the people involved in this REMR work unit to gather information and establish contacts within the Districts to accomplish the stated goals of the work unit.

These proceedings provide a summary of the following: the presentations by the Districts, the discussion periods, and the summarization and conclusions. The discussion periods focused on unusual repair techniques used and future research needs in the field of dike repair.

KEY WORDS: Dikes, Notched Dikes, Repair Criteria, Riverine, River Training Structures, Shallow-Draft Training Structures, Training Structures

Coastal Applications

REMR-CO-1

"Stability of Rubble-Mound Breakwater and Jetty Toes; Survey of Field Experience." 1986 (Dec). By Dennis G. Markle, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A180 108

This survey of field experience was designed to present an overview of the coastal rubble-mound breakwaters and jetties built and/or maintained by the Corps that have or have had stability problems related to structure toes.

Design, construction, and operations personnel in Corps Division and District offices were contacted to locate structures that have, are believed to have, or have had toe-related stability problems; to record steps that were taken (if any) to alleviate these problems; and to identify the relative success or failure of the repair or rehabilitation work.

This survey revealed that rubble-mound toe stability is a major repair and rehabilitation problem that can be divided into two major design categories: design of buttressing stone placed at the toe of an armor slope to prevent downslope slippage of primary armor and design of toe berm armor size and geometry that will be stable for incident wave and flow conditions and will prevent, or at least slow down, scour and undermining the toe of a structure.

KEY WORDS: Armor Units, Breakwaters, Jetties, Rubble Mound, Toe Scour, Water Waves, Wave Stability

REMR-CO-2

"Prototype Experience with the Use of Dissimilar Armor for Repair and Rehabilitation of Rubble-Mound Coastal Structures." 1989 (Jan). By Robert D. Carver, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A204 081

The primary objective of this report was to provide a summarized inventory of existing Corps projects that have used dissimilar armor for repair and rehabilitation of rubble-mound coastal structures. A survey of existing Corps

structures that have used dissimilar armor for repair and rehabilitation was conducted. The survey was accomplished by search and study of project index maps, reconnaissance reports, and special reports in conjunction with other work units and follow-up visits to the Districts and Divisions for first-hand discussions and observations.

Results show that in all cases selection of the dissimilar armor type and weight was based on design guidance for new construction, prototype experience, engineering judgment, inferences from model tests of similar structure, or site-specific model tests rather than guidance specific to evaluating the interfacing and stability response of the dissimilar armor.

KEY WORDS: Armor Units, Breakwaters, Jetties, Rubble Mound

REMR-CO-3, Report 1

"Case Histories of Corps Breakwater and Jetty Structures; Report 1, South Pacific Division." 1988 (Jan). By Robert R. Bottin, Jr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A192 294

The purpose of this study was to present case histories of breakwater and jetty structures in the South Pacific Division (SPD) and thus to determine their maintenance and repair history and methods of construction.

Case histories of 28 breakwater and jetty structures in the SPD have been developed to quantify past and present problem areas (if any), to take steps to rectify these problems, and to subsequently evaluate the remedial measures.

The SPD encompasses the entire California shoreline and presently manages approximately 171,870 lin ft of breakwater and jetty structures. These structures are predominantly of rubble-mound construction. Twenty-one of the projects have undergone repair and/or modification during their lifetime. A variety of repair methods have been used, including replacement and/or addition of armor stone, placement of concrete armor units, and use of concrete and concrete caps.

KEY WORDS: Breakwater, Concrete Armor Units, Jetty, Rubble-Mound Structures

REMR-CO-3, Report 2

"Case Histories of Corps Breakwater and Jetty Structures; Report 2, South Atlantic Division." 1988 (Sep). By Francis E. Sargent, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A200 458

The purpose of this study was to present case histories of breakwater and jetty structures in the South Atlantic Division (SAD) and thus to determine their maintenance and repair history and methods of construction.

Chronological histories are presented for 32 breakwater and jetty structures located within the SAD, which encompasses the Atlantic and gulf coasts from North Carolina to Alabama and the Island of Puerto Rico.

Presently, there are approximately 256,000 lin ft of breakwater and jetty structures managed by SAD. Structure cross sections of rubble mound or sand account for most of this total. Seventeen of the structures have undergone repairs or modification during their lifetime. A variety of construction and repair methods have been used, including log and brush mattress (pre-1900s), steel sheet piles, asphaltic and concrete grouts, asphaltic mats, concrete sheet piles, toe aprons, sand tight cross sections, armor stone, and concrete caps.

KEY WORDS: Breakwater, Concrete Armor Units, Jetty, Rubble-Mound Structures

REMR-CO-3, Report 3

"Case Histories of Corps Breakwater and Jetty Structures; Report 3, North Central Division." 1988 (Jun). By Robert R. Bottin, Jr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A198 436

The purpose of this study was to present case histories of breakwater and jetty structures in the North Central Division (NCD) and thus to determine their maintenance and repair history and methods of construction. Case histories are presented for 107 projects that include jetty structures located within NCD, which encompasses the Great Lakes region.

Presently, there are approximately 481,570 lin ft of breakwater and jetty structures managed by NCD. These structures consist of timber crib, stone, sheet-pile, and concrete construction. Many have undergone repair and/or modification during their lifetime. A variety of repair methods have been used, including replacement of wooden structures, addition of stone, use of concrete and concrete caps, and placement of concrete armor units.

KEY WORDS: Breakwater, Concrete Armor Units, Jetty, Rubble-Mound Structures

REMR-CO-3, Reort 4

"Case Histories of Corps Breakwater and Jetty Structures; Report 4, Pacific Ocean Division." 1988 (Sep). By Francis E. Sargent, Dennis G. Markle, and Peter J. Grace, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A199 879

The purpose of this study was to present case histories of breakwater and jetty structures in the Pacific Ocean Division (POD) and thus to determine their maintenance and repair history and methods of construction. Chronological histories are presented for 14 breakwater and jetty structures

located within the POD. Ten of the structures are located in the Hawaiian Island chain, three are situated in the (American) Samoa Island chain, and one is located on Guam, largest of the Mariana Islands.

Presently, there are approximately 26,500 lin ft of rubble-mound structures managed by the POD. Five of the structures have undergone repairs during their lifetime, and one has been modified. A variety of repair methods has been used, including replacing or adding armor stone, placing concrete armor units, and using concrete caps. The structures are typically placed on a firm foundation of coral reef or volcanic materials.

KEY WORDS: Breakwater, Concrete Armor Units, Jetty, Rubble-Mound Structures

REMR-CO-3, Report 5

"Case Histories of Corps Breakwater and Jetty Structures; Report 5, North Atlantic Division." 1988 (Nov). By Ernest R. Smith, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A207 146

The purpose of this study was to present case histories of breakwater and jetty structures in the North Atlantic Division (NAD) and thus to determine their maintenance and repair history and methods of construction. Chronological histories are presented for 58 breakwater and jetty structures located within the NAD, which includes the New York, Philadelphia, Baltimore, and Norfolk Districts. Twelve of the projects are located in an ocean environment, and the remainder are situated in bays, sounds, or rivers.

Presently, there are approximately 161,500 lin ft of breakwater and jetty structures managed by NAD. Structure cross sections of rubble-mound or stone-filled timber crib account for most of this total. Thirty-three of the project structures have been repaired since construction. Other construction materials that have been used include steel, dolosse, concrete cap, concrete block, and timber.

KEY WORDS: Breakwater, Concrete Armor Units, Jetty, Rubble-Mound Structures

REMR-CO-3, Report 6

"Case Histories of Corps Breakwater and Jetty Structures; Report 6, North Pacific Division." 1988 (Nov). By Donald L. Ward, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A203 865

The purpose of this study was to present case histories of breakwater and jetty structures in the North Pacific Division (NPD) and thus to determine their maintenance and repair history and methods of construction.

Chronological histories are presented for 14 breakwater and jetty projects located within the NPD, which includes the Portland, Seattle, and Alaska Districts. The projects currently include 68 breakwaters and 35 jetties. Nearly all of the structures are of rubble-mound construction, although steel pilings, steel sheetpilings, timber pilings, and concrete have also been used. Early structures were built primarily by dumping stone from railroad cars on a tramway constructed above the jetty or breakwater. Where the in situ material provided an insufficient foundation, structures were constructed on blankets of brush or gravel. Otherwise, structures were built directly on the existing bottom material.

New construction, repair, and rehabilitation work carried out on rubble-mound structures in the Alaska and Portland Districts since 1961 have used placed-stone construction techniques. Due to quality control, random armor stone placement is specified for Alaska structures, but use of placed-stone construction is encouraged.

Localized damage from wave attack and scour near the heads of the structures appears to be the major cause of structural deterioration. Most of the jetty rehabilitation consists of rebuilding jetty heads that have been lost because of scour and undermining combined with storm wave-induced armor stone displacement. Typical jetty head rehabilitation includes filling scour holes and forming a bedding foundation with minus 400-lb material and then reconstructing the head with only class "A" stone. Concrete armor units are not used by the Division. Repair work has generally consisted of placement of additional stone, frequently of a larger size. Many of the structures have been raised and/or extended.

KEY WORDS: Breakwater, Jetty, Rubble-Mound Construction, Structural Deterioration

REMR-CO-3, Report 7

"Case Histories of Corps Breakwater and Jetty Structures; Report 7, New England Division." 1989 (Jan). By Francis E. Sargent and Robert R. Bottin, Jr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A204 082

The purpose of this study was to present case histories of breakwater and jetty structures in the New England Division (NED) and thus to determine their maintenance and repair history and methods of construction. Chronological histories are presented for 52 projects located along the New England coastline from northern Maine to western Connecticut and managed by NED.

Presently, NED is responsible for 37 jetties and 46 breakwaters that have a cumulative length of 154,185 ft and are almost entirely of stone construction. Localized damage from wave attack appears to be the major cause of structural deterioration. A total of 36 projects has had structural modifications and/or

repairs since original construction. Almost all the repairs have consisted of placing new stone on the structures.

KEY WORDS: Breakwater, Concrete Armor Units, Jetty, Rubble-Mound Structures, Structural Deterioration

REMR-CO-3, Report 8

"Cast Histories of Corps Breakwater and Jetty Structures; Report 8, Lower Mississippi Valley Division." 1989 (Jan). By Francis E. Sargent and Robert R. Bottin, Jr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A204 083

The purpose of this study was to present case histories of breakwater and jetty structures in the Lower Mississippi Valley Division (LMVD) and thus to determine their maintenance and repair history and methods of construction. Case histories are presented for 10 jetty structures located within the LMVD, which encompasses the gulf coast of Louisiana.

Presently, there are approximately over 153,000 lin ft of jetty structures managed by LMVD. These structures are predominantly of rubble-mound construction. Seven of the projects have undergone repair and/or modification during their lifetime. Most of this work has consisted of placing additional stone to bring structures up to grade. Subsidence of structures, due mainly to unconsolidated silts and clays of the underlying foundation, appears to be the principal cause of deterioration. In particular, the jetties at Southwest Pass have a very extensive repair history.

KEY WORDS: Breakwater, Concrete Armor Units, Jetty, Rubble-Mound Structures

REMR-CO-3, Report 9

"Case Histories of Corps Breakwater and Jetty Structures; Report 9, Southwestern Division." 1989 (Jan). By Francis E. Sargent and Robert R. Bottin, Jr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A204 084

The purpose of this study was to present case histories of breakwater and jetty structures in the Southwestern Division (SWD) and thus to determine their maintenance and repair history and methods of construction. Case histories are presented for 12 breakwater and jetty structures located within the SWD, along the Texas gulf coast.

Presently, the SWD maintains 12 coastal projects that contain a total of 4 breakwaters and 19 jetties with a cumulative length of over 176,000 ft. These structures are predominantly of rubble-mound construction. Concrete caps have been used on the projects, but since 1960 a fairly consistent cross section

of only stone has been used on new and existing projects. The peak period of construction occurred from 1962 to 1966 when three projects were completed and six received major rehabilitations. Although wave forces may be the principal cause of structure deterioration, scour and undermining also appear to be significant.

KEY WORDS: Breakwater, Concrete Armor Units, Jetty, Rubble-Mound Structures

REMR-CO-4

"Stability of Dolos and Tribar Overlays for Rehabilitation of Stone-Armored Rubble-Mound Breakwater and Jetty Trunks Subjected to Breaking Waves." 1988 (Feb). By Robert D. Carver and Brenda J. Wright, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A192 487

An experimental model investigation was conducted to obtain design guidance for dolos and tribar overlays used to rehabilitate stone-armored rubble-mound breakwater and jetty trunks subjected to breaking waves. A more specific objective was to determine the minimum weight of individual armor units (with given specific weights) required for stability as a function of the type of armor unit, sea-side slope of the structure, wave period, wave height, and water depth.

Tests were conducted with breaking wave conditions on no-damage, no-overtopping breakwater trunk and head sections by using sea-side slopes of 1V on 1.5H and 1V on 2H.

It was concluded that:

- Randomly placed dolosse are an acceptable option, provided that a stability coefficient of 12 is used to size the units.
- Dolos stability proved to be sensitive to relative depth (d/L) and relative wave height (H/d) with minimum stability occurring at the lower value of d/L and higher values of H/d, i.e., longer wave periods in shallower water.
- Randomly placed tribars are not recommended at slopes steeper than 1V on 2H; however they may be used at milder slopes with a stability coefficient of 9.
- Uniformly placed tribars are an acceptable option for a 1V-on-1.5H slope, provided they are used in concert with toe buttressing stone, size selection is based on a stability coefficient of 7, and placement of the units replicates that used in the model.
- Tribar stability appears to be insensitive to d/L and H/d for both types of placement.

KEY WORDS: Armor Units, Breakwaters, Jetties, Rubble Mound

REMR-CO-5

"Stability of Dolos Overlays for Rehabilitation of Dolos-Armored Rubble-Mound Breakwater and Jetty Trunks Subjected to Breaking Waves." 1988 (Jun). By Robert D. Carver and Brenda J. Wright, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A195 392

An experimental model investigation was conducted to obtain design guidance for dolos overlays used to rehabilitate dolos-armored rubble-mound breakwater and jetty trunks subjected to breaking waves. A more specific objective was to determine the minimum weight of individual armor units (with given specific weights) required for stability as a function of sea-side slope of the structure, wave period, wave height, and water depth. Tests were conducted with breaking wave conditions on no-damage, no-overtopping breakwater trunk and head sections using sea-side slopes of 1V on 1.5H and 1V on 2H.

It was concluded that:

— Stability showed some dependency on both d/L and H/d, with minimum stability occurring at the lower values of d/L and higher values of H/d, i.e. longer wave periods in shallower water.
— The minimum stability coefficient observed is very similar to that presently recommended for new construction (15.6 versus 15).

KEY WORDS: Armor Units, Breakwaters, Jetties, Rubble Mound

REMR-CO-6

"Stability of Dolos Overlays for Rehabilitation of Tribar-Armored Rubble-Mound Breakwater and Jetty Trunks Subjected to Breaking Waves." 1988 (Aug). By Robert D. Carver and Brenda J. Wright, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A198 877

An experimental model investigation was conducted to obtain design guidance for dolos overlays used to rehabilitate tribar-armored rubble-mound breakwater and jetty trunks subjected to breaking waves. A more specific objective was to determine the minimum weight of individual armor units (with given specific weights) required for stability as a function of sea-side slope of the structure, wave period, wave height, and water depth. Tests were conducted with breaking wave conditions on no-damage, no-overtopping breakwater trunk and head sections using sea-side slopes of 1V on 1.5H and 1V on 2H.

It was concluded that:

— The stability coefficient is independent of sea-side structure slope for slopes of 1V on 1.5H and 1V on 2H.

— Stability showed some dependency on both d/L and H/d with minimum stability occurring at the lower values of d/L and higher values of H/d, i.e. longer wave periods in shallower water.

— The minimum stability coefficient observed significantly exceeds that obtained for new construction.

KEY WORDS: Armor Units, Breakwaters, Jetties, Rubble Mound

REMR-CO-7

"Methods to Reduce Wave Runup and Overtopping of Existing Structures." 1988 (Oct). By John P. Ahrens, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A200 455

The primary objective of this study was to investigate problem areas associated with runup and overtopping occurring on about 20 percent of the Corps' coastal structures. A number of approaches to reducing wave runup and overtopping of coastal structures are presented. Plans to use laboratory model tests to quantify and refine the most promising approaches are discussed.

Three general problems related to wave runup and overtopping are identified and categorized: wave runup and overtopping of breakwaters and jetties, causing excessive wave action on the leeside; wave runup and overtopping of seawalls and bulkheads, causing either flooding or erosion or both behind the structures; and wave runup and overtopping of revetments jeopardizing the integrity or possibly causing failure of the structure.

KEY WORDS: Breakwaters, Revetments, Seawalls, Wave Overtopping, Wave Runup

REMR-CO-8

"State-of-the-Art Procedures for Sealing Coastal Structures with Grouts and Concretes." 1989 (Apr). By David P. Simpson, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A208 884

Many Corps rubble-mound breakwaters and jetties have become permeable to wave transmission and sand transport, conditions that result in increased Operation and Maintenance dredging costs, delays to navigation, and damages to recreational craft and marina facilities. A cost-effective alternative to traditional methods of rubble-structure rehabilitation provides for 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 of permeable structures (almost exclusively rubble mound) by filling significantly large voids is a concept not routinely considered by coastal

engineers. However, the basic underlying technology necessary for closing such large voids and for stabilizing sand within a structure has been developed previously in the grouting field for sealing cracks and fissures in rocks or dam foundations. Adaptation of this technology and promotion of the use of cementitious, chemical, and asphaltic products in coastal structures to reduce wave penetration and sand infiltration were initiated by Waterways Experiment Station in 1986, although specific guidance does not presently exist for sealing breakwaters and jetties by those means. The purpose of this investigation was to develop and convey state-of-the-art knowledge in this area to Corps and other personnel charged with field application responsibility for performing such sealing measures.

Grouting literature was reviewed for information pertinent to sealing voids in coastal rubble-mound structures. Field experience of sealing jetty voids and of grouting the interior of jetties was assimilated.

Materials that have been used previously in void sealing of coastal structures include cementitious sealants, chemical sealants, and asphaltic sealants. Each of these materials has been used with a variety of reactants. Trial mixtures of portland-cement concrete at project sites in California have resulted in a somewhat standardized mix containing coarse aggregate, sand, clay, and accelerators which in turn result in a very stiff concrete for void sealing. Solutions of neat cement and sodium silicate have been used effectively to seal jetty voids. Although initially very thin, solution set time can be controlled to prevent loss due to erosion by currents or to dilution prior to gelling.

The most recent Corps experience in sealing voids in coastal structures occurred when the Jacksonville Disrict sealed the south jetty at Palm Beach Harbor, FL, in 1984 and the San Francisco District sealed the Buhne Point groins at Humboldt Bay, CA, in 1985. Subsequent to that time, Broward County, FL, has sealed the south jetty to Port Everglades Harbor, FL, in 1988, and the Detroit District has completed grouting and rehabilitating the north detached breakwater at Milwaukee Harbor, WI, in 1988. Asphaltic compounds were previously used successfully in Ashbury Park, NJ, in 1963, and a breakwater in the Dominican Republic was recently stabilized in 1983 using an asphaltic concrete. Portions of the north and middle jetties at Mission Bay, CA, were sealed with a cement-sand mixture in 1959 by the Los Angeles District. These projects have been summarized as a means of sharing on-the-job experiences in an area in which little guidance exists outside these specific Corps Districts.

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.

Planning a jetty sealing operation must be based on knowledge of field conditions, mixture characteristics, and equipment capabilities. Proper spacing of grout holes determines drilling costs and the radius of the grouted volume at each hole, and therefore the set time and quantity of the mixture. Contractor capability and/or experience are critical for accomplishing a successful void sealing job at a coastal rubble-mound structure. Having a competent construction inspector is also very important in light of changed field conditions that may dictate that operations be revised while the sealing project is under way.

KEY WORDS: Asphaltic Cements, Breakwaters, Cementitious Sealants, Chemical Sealants, Grout, Jetties, Rubble Mound, Sand Asphalt, Void Sealing

REMR-CO-9

"Stability of Dolos Overlays for Rehabilitation of Stone-Armored Rubble-Mound Breakwater Heads Subjected to Breaking Waves." 1989 (May). By Robert D. Carver, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A208 577

An experimental model investigation was conducted to obtain design guidance for dolos overlays used to rehabilitate stone-armored rubble-mound breakwater and jetty heads subjected to breaking waves. A more specific objective was to determine the minimum weight of individual armor units (with given specific weights) required for stability as a function of angle of wave attack, wave period, wave height, and water depth.

Based on model tests and prototype experience (Crescent City Harbor and Humboldt Bay, California), the investigation concluded that:

- Minimum stability was observed at the 45-deg wave direction.
- Stability proved to be sensitive to both d/L and H/d with minimum stability occurring at the lower values of d/L and higher values of H/d, i.e., longer wave periods in shallower water.
- The stability coefficient appears to decrease slightly as the armor slope becomes flatter; therefore, the following values are recommended for sizing the dolos.

Structure Slope	Stability Coefficient
1V on 1.5H	8
1V on 2H thru 1V on 3.5H	7
1V on 4H thru 1V on 5H	6

KEY WORDS: Armor Units, Breakwaters, Jetties, Rubble Mound

REMR-CO-10

"Study of Breakwaters Constructed with One Layer of Armor Stone, Detroit District." 1989 (Aug). Prepared by John R. Wolf, US Army Engineer District, Detroit, Detroit, MI, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A212 631

This study was carried out to provide documentation of the design, construction, repair, rehabilitation, maintenance, environmental loading, and economic history of one-layer armor-stone breakwaters in the Detroit District and to present cost comparisons for one-layer versus two-layer stone breakwaters. Selected breakwaters were used to discuss original design and constructibility of one-layer breakwaters and to provide a cost comparison with two-layer armor-stone structures.

The information collected for this study indicated that a one-layer design breakwater can perform satisfactorily when properly designed and constructed. The one-layer design must not contain fine material that can work out of the core. Armor stone must be heavy enough to prevent displacement and loss of core stone. Each armor stone in a one-layer breakwater must be set in close contact with the adjacent stones ensuring support and structural integrity. The maximum estimated cost savings based on initial construction of breakwater designs with one layer of armor stone compared with the breakwater designs with two layers of armor stone is from 21 to 32 percent with a 2H on 1V slope and from -8 to 20 percent with a 1.5H on 1V slope for the five examples considered. Three of the five examples are between -2 and 4 percent with the two-layer design breakwater constructed with a 1.5H on 1V slope. This is not a significant difference.

KEY WORDS: Armor Stone, Breakwaters, One-Layer Armor, Specially Placed Armor

REMR-CO-11

"Underwater Inspection of Coastal Structures Using Commercially Available Sonars." 1990 (Feb). By William M. Kucharski and James E. Clausner, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A224 169

A general introduction to side-scan sonar (SSS) and its uses in coastal engineering studies is given, including some operating rules-of-thumb and suggestions based on the authors' experience. There is also a section in which several systems currently on the market are evaluated.

SSS is a valuable tool for coastal engineering, with uses likely to multiply as the technology and experience with it improve. However, quantitative applications are limited. Information on structure slopes, condition of individual armor units, and percentage of units displaced (to name a few examples) is not currently measurable in a repeatable, quantitative way. Nevertheless, the semiquantitative sonograph record can be very informative, particularly to someone who has developed a familiarity with the structure or

feature being viewed from repeated SSS surveys. It is a safer and, in many cases, superior alternative to visual inspection by divers, especially in murky water.

KEY WORDS: Coastal Structure Inspection, Side-Scan Sonar, Underwater Inspection

REMR-CO-12

"Stability of Toe Berm Armor Stone and Toe Buttressing Stone on Rubble-Mound Breakwaters and Jetties; Physical Model Investigation." 1989 (Sep). By Dennis G. Markle, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A213 589

The purpose of this study was to develop suitable design guidance for the sizing of toe berm and toe buttressing stone in breaking wave environments. A series of two-dimensional (2-D) and three-dimensional (3-D) breakwater stability experiments was developed and conducted. The 2-D tests focused on sizing of toe stone on rubble-mound structure trunks exposed to 90-deg 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 3-D 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.

KEY WORDS: Breakwaters, Jetties, Rubble Mound, Toe Buttressing, Toe Stability, Wave Stability

REMR-CO-13

"Laboratory Techniques for Evaluating Effectiveness of Sealing Voids in Rubble-Mound Breakwaters and Jetties with Grouts and Concretes." 1990 (Mar). By David P. Simpson and Jeffrey L. Thomas, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A220 178

This report is the second milestone in a multiyear project to better understand cementitious, chemical, and bituminous materials, and injection techniques applicable to Corps projects that are experiencing detrimental levels of sediment infiltration or wave energy transmission.

The laboratory investigations consisted of tests for injecting sealant materials in a model structure to describe their flow behavior and sealing ability inside a scaled, submerged, rubble-mound structure. Other tasks reported herein include casting specimens of sealant materials, measuring their initial properties, placing those specimens in the prototype environment

for a series of long-term time-dependent durability tests, determining the effects of the environment on the materials, and conversely, determining the effects of the materials on the environment.

The laboratory investigations were conducted to obtain quantitative measurement and qualitative descriptions of the injected materials after they had solidified inside the rubble-mound structure, to perform bio-assay tests on materials with potential for adverse environmental effects, and to initiate a series of long-term exposure tests to estimate the durability of various sealants under real prototype environmental conditions.

The laboratory investigations also included construction of a rubble-mound physical model at a scale sufficiently large so that deviations from similitude would be negligible; preparation of two types of cementitious sealants (WES mixture and Buhne Point mixture), two types of chemical sealants (sodium silicate-cement mixture and sodium silicate-diacetin mixture for sand layer stabilization), and one asphaltic concrete (sand-asphalt mixture), injecting them into the model, and recording for each the quantities, locations of injection, pumping rates, and gel times of the materials; providing specific description of materials by precise recording of components and proportions, and obtaining determinations of standard parameters for the respective materials; recording spread, shape, competency, and continuity of the hardened sealants upon disassembly of the structure; abbreviated bio-assay tests to bracket toxicity effects on the laboratory animal *Daphnia* by levels of concentrations of the sealant materials; casting specimens of each sealant type, performing baseline measurements of parameters that would provide an indication of strength variance with time, including pulse velocity and dynamic modulus of elasticity for the cementitious and chemical sealants, and the Marshall stability test for the asphaltic concrete; and placing specimens in the prototype environment, exposing the samples to cycles of wetting and drying, freezing and thawing, and chemical and biological degradation in the saltwater environment. The durability test specimens were placed at Treat Island, MA; Duck, NC; and Miami, FL.

It was determined that sealing of rubble-mound coastal structures requires that both the construction grouter and the sponsor field inspector be fully experienced with the materials being used for the sealing work and with the characteristics of the medium being sealed. Results indicated aggregate containing cementitious mixtures achieved a more satisfactory final product for sealing a section than did a sodium silicate-cement sealant, provided the aggregate was not so large as to impede pumping or did not seal off the void interconnections. The sodium silicate-diacetin used to fill the voids in the sand layer did not completely solidify the sand to a hard bulbous mass. The dissembled sections showed that concrete mixtures can form such a bulbous mass in a rubble-mound structure when injected under water. Precise monitoring and control of conditions are required when chemical sealants and cementitious sealants containing hardening accelerators are used. Sand-asphalt sealants set hard and bond well, although no means for emplacing this material in production quantities have been developed at this time. Long-term time-dependent evaluations of the durability of these materials under

prototype conditions are continuing by periodic re-evaluations at the field locations.

KEY WORDS: Asphaltic Cements, Breakwaters, Cementitious Sealants, Chemical Sealants, Grout, Jetties, Rubble Mound, Sand Asphalt, Void Sealing

REMR-CO-14

"Repair of Localized Armor Stone Damage on Rubble-Mound Structures; Coastal Model Investigation." 1990 (Sep). By Donald L. Ward and Dennis G. Markle, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A227 014

The purpose of this study was to use small-scale physical model tests for determining and comparing the stability of various methods for repair of localized damage to randomly placed armor stone on rubble-mound structures.

A series of physical model tests were conducted on small-scale rubble mounds to determine the effectiveness of different repair methods. The structures were subjected to wave conditions that caused localized damage to the armor stone. After repairs were made by one of six repair options tested, the structure was again subjected to the wave conditions. Parameters that were varied during the tests included sea-side slope, water depth, and wave period, with wave height chosen to cause moderate damage for the current set of parameters.

Scatter in the results rendered the tests inconclusive regarding the relative effectiveness of the various repair methods, but key factors in the repair of localized armor stone damage were demonstrated.

Much of the stability of these structures is due to the interlocking of armor stones. Shifting or reseating these stones during a repair can weaken the interlocking and decrease the stability of the structure. Similarly, new stone placed on the structure must be properly seated to maximize the interlocking of the new stone with the existing stone to ensure a stable repair.

KEY WORDS: Breakwaters, Jetties, Localized Damage, Rubble Mound

REMR-CO-15

"Field Evaluation of Port Everglades, Florida, Rehabilitation of South Jetty by Void Sealing." 1990 (Oct). By Julie Dean Rosati and Thomas A. Denes, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A229 176

This report presents the results of a monitoring program designed to evaluate the effectiveness of a prototype void and sand-sealing operation.

The Port Everglades, FL, south jetty is a rubble stone structure with large "man-sized" voids. Beach fills placed south of the structure eroded at an extremely high rate, indicating that material was being lost through the structure into the entrance channel, where it was thought to be a contributing factor to navigation channel shoaling. Sealing of the structure with sodium silicate-cement for filling void cavities and with sodium silicate-diacetin for stabilizing sand-filled voids within the structure formed a barrier to sediment infiltration. This procedure had previously been determined to be a cost-effective alternative to losing beach material through the structure, with resulting navigation channel dredging at inopportune intervals. The structure was sealed during September-November 1988. Four site visits were performed as part of the monitoring program: reconnaissance trip, preconstruction experiment, during-construction inspection and observation, and postconstruction experiment. Dye transmission through the structure before and after sealing was the primary indicator of structure transmissibility. Also, current meters were placed in structure voids to indicate net flow through the structure before and after construction sealing.

The dye transmission tests indicated that the unsealed structure was, on the average for all flow conditions measured during both pre- and postconstruction experiments, approximately 4.0 percent transmissible (outlier removed), which reduced to 1.9-percent transmissibility after sealing of the structure was completed (nearly 90-percent certainty). When similar flow conditions are compared, the largest difference in structure transmission between pre- and postconstruction observations occurs during peak ebb flow conditions; however, this difference is statistically significant to a rather low level of certainty (not quite 85 percent). Two dye transmission tests conducted on sealed and unsealed sections of the structure during the construction inspection and observations indicated that structure sealing was nearly 100 percent. Current meter data measured during peak flood and high-water slack condition showed that net flow through the structure in the preconstruction condition was reflected from the sealed structure, further indicating that the structure was less transmissible in the postconstruction condition.

KEY WORDS: Cement Silicate, Grout, Sand Sealing, Sodium Silicate, Transmission

REMR-CO-16

"Rehabilitation of Permeable Breakwaters and Jetties by Void Sealing: Summary Report." 1990 (Oct). By David P. Simpson, Julie D. Rosati, Lyndell Z. Hales, Thomas A. Denes, and Jeffrey L. Thomas, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A229 927

Many Corps breakwaters and jetties have become permeable to sand transport and wave transmission, a condition that results in increased Operations and Maintenance dredging costs and increased risks and delays to navigation. It is apparent that significant first-cost savings could be realized by applying to coastal projects those grouting techniques and sealing

procedures developed in civil and mining engineering for closing voids and fractures, instead of the more expensive method of applying layers of chinking and armor stone to the existing structure. However, the longevity of such grouts and sealants placed in voids in the interior of rubble-mound structures exposed to wave and current conditions is not well known. The term "sealant" is used in this report to describe any material that closes voids in rubble-mound structures and includes grouts as well as very stiff, aggregate-containing cementitious and asphalt materials.

The overall problem under investigation was logically separated into two distinct parts. One part required an evaluation of the effectiveness of materials already being used. The second part entailed the development of guidance on sealant hole drilling, quantities to inject, techniques of injection, and knowledge of material properties to effectively create the needed barrier with the optimum combination of drilling effort and sealant quantities.

This research investigated three different aspects pertaining to sealing voids in rubble-mound structures with grouts and concrete sealants: large-scale laboratory investigation for evaluating the effectiveness of sealant injection into such structures, and bioassay tests of materials with potential for adverse environmental effects; long-term time-dependent durability exposure testing of sealant specimens in three different prototype environments (cold region--Treat Island, MA; moderate region -- Duck, NC; near-tropical region -- Miami, FL); and precise monitoring of the sealing and resulting effectiveness of a prototype rubble-mound jetty (Port Everglades, FL).

Specific objectives of the large-scale laboratory investigation included construction of a rubble-mound physical model at a scale sufficiently large that deviations from similitude would be negligible; preparation of and injection into the model two types of cementitious sealants (WES mixture and Buhne Point mixture), two types of chemical sealants (sodium silicate-cement mixture), recording for each the quantities, location of injection, pumping rates, and gel times of the materials; providing specific descriptions of materials by precise recording of components and proportions, and obtaining determinations of standard parameters for the respective materials; and recording spread, shape, competency, and continuity of the hardened sealants upon disassembly of the structure. Sealants to be evaluated were selected based on their potential to be easily pumped; having a short, controllable set time; ability to resist dilution and dispersion; and chemical stability and structural integrity, once set.

The sealant durability time-dependent tests were formulated to determine how the sealant materials would endure under actual field conditions. Effects of environmental exposure to waves, currents, freezing and thawing, wetting and drying, abrasion, biological influences, and chemical reaction are being evaluated. A monitoring effort of indefinitely long duration was established to determine the performance with time of sealant materials in the field environment. Representative samples of each sealant material evaluated in the physical model rubble-mound structure were cast as specimens and placed in locations with varied climatic conditions. Since the specimen exposure is

direct and unconfined, the tests may actually be more severe and extreme than if the materials were placed inside a structure.

The voids in the Port Everglades, FL, south jetty were sealed with sodium silicate-cement sealant such that it would function as a terminal groin to the John U. Lloyd State Park beach fill. The sand layer beneath the jetty and the voids within the structure which were filled with sand were stabilized with sodium silicate-diacetin sealant. A monitoring plan to ascertain the effectiveness of the sealing project through a field evaluation was conducted by the Coastal Engineering Research Center, Waterways Experiment Station, with the cooperation of Broward County, the State, and the contractor.

The use of synthetic materials continues to draw scrutiny from various environmental advocacy groups. The Corps is in full agreement with such concerns and recognizes the health, safety, and water quality aspects associated with such materials. The Corps is committed to fully understanding all environmental consequences associated with their utilization and will adhere to all standards, specification, and safeguards pertaining thereto.

KEY WORDS: Asphaltic Cements, Breakwaters, Cementitious Sealants, Chemical Sealants, Grout, Jetties, Rubble Mound, Sand Asphalt, Void Sealing

Electrical and Mechanical Applications

REMR-EM-1

"A Review of Bird Pests and Their Management." 1987 (Sep). By Anthony J. Krzysik, Construction Engineering Research Laboratory, Champaign, IL. AD A190 195

This report represents the first phase of research addressing bird problems at US Corps of Engineers Civil Works projects. There were four objectives in this phase: to provide a review of bird problems; to discuss the current methods and state-of-the-art technologies in bird management; to provide a perspective of birds in society and science; and to provide extensive and diverse references for background information, as a bibliography for problem solving, and as a foundation for initiating specific research objectives.

For this phase of work, an extensive literature survey was made. Particular attention was addressed to conference proceedings dealing with bird management and wildlife damage control.

This report provides a descriptive survey of conflicts and problems that birds have caused man, identifies the state-of-the-art methodologies in bird management and control, and examines potential disease risks to humans. Bird problems are related to one or more of the following categories: damages and economic losses, human health and safety, aesthetics, inconveniences, and competition with native species and brood parasitism. Pigeons, starlings, and house sparrows, all introduced from Europe, and several species of native blackbirds (usually in excessive numbers) are responsible for most problems in the United States. Most of the research on bird management has been directed to agricultural and feedlot depredations, winter blackbird-starling roosts, and safety hazards to aircraft; urban bird management strategies have not been adequately researched. Large-scale control measures include habitat modifications, repellents, devices for frightening, and wetting agents. Exclusion, toxic baits, toxic perches, live-trapping, repellents, and devices for frightening are all used to control small-scale or local bird damage problems.

Birds represent a potential, although low, health or disease risk for humans. Most avian pathogens or parasites affect only other birds, and host specificity is often high. Pets, poultry, game species, and aviary specimens have been affected in epidemics. The most important human diseases associated with birds in the United States are histoplasmosis, encephalitis, chlamydiosis, and cryptococcosis. All four of these diseases are potential health hazards at Civil Works projects because of the bird species present and site/habitat characteristics.

KEY WORDS: Bird Pest Problems, Birds, Pest Control

REMR-EM-2

"Evaluation of Bird Pest Problems at US Army Corps of Engineers Civil Works Projects." 1987 (Sep). By Anthony J. Krzysik, Construction Engineering Research Laboratory, Champaign, IL. AD A191 173

This report represents the second phase of research of the bird pest problems at Corps Civil Works projects. The objective of this phase was to assess the nature and magnitude of Civil Works bird problems, quantify the relative magnitude of the problems, identify the bird species responsible, and select Civil Works projects that have the most serious and nationally representative problems.

A questionnaire was designed and distributed nationwide to Corps Civil Works projects to evaluate the nature and magnitude of bird damage and nuisance bird pests. There were 267 responses from individual projects or management offices. Of these, 58 projects/offices reported that they had no significant problems with birds. The 209 projects/offices with bird pests identified a combined total of 783 individual pest problems or bird damage. On the basis of a detailed analysis of questionnaire responses, 29 projects, representing 16 nationwide Corps Districts, were identified as having the severest, as well as most representative, Civil Works bird problems. These Districts and projects were contacted by telephone to further assess their individual problems. Bird damage control authorities were consulted to establish additional contacts with the projects. The consensus of these experts was that most Civil Works bird problems could be controlled with existing established pest management techniques.

The most severe and widespread problem noted during the study was pigeons roosting or nesting on structures such as lock and dam complexes, bridges, and power generating stations. Gulls, swallows, and a few other species were responsible for similar localized problems, usually on a smaller scale. The chief complaint was bird excrement, which was responsible for health hazards, decreased aesthetics, interference with maintenance procedures, safety hazards, and deterioration or corrosion of equipment, materials, and machinery.

Another important problem occurred when starlings, pigeons, and/or house sparrows nested or roosted within buildings. Again, excrement was the

primary concern, but avian ectoparasites and damage to building insulation, electrical circuits, and equipment were also important considerations. Also, starlings and house sparrows nested in crevices associated with Civil Works structures. Their excrement and nests contributed to deterioration and failure in mechanical, hydraulic, and electrical components. Canada geese were another major problem at certain grassy public-use areas because they contaminated and damaged the turf and sometimes caused severe destruction. Minor problems reported were agricultural depredations (mainly from blackbirds), competition with native bird species (mainly from starlings), scavenging, and predation.

KEY WORDS: Bird Pest Problems, Birds, Pest Control, Structures

REMR-EM-3

"Underwater Applied Coating: A State-of-the-Art Investigation." 1988 (Oct). Prepared by R. W. Drisko and J. R. Yanez, Naval Civil Engineering Laboratory, Port Hueneme, CA, for US Army Construction Engineering Research Laboratory, Champaign, IL. AD A201 712

The objective of this study was to test the properties and practicality of underwater applied coatings. Eleven proprietary protective coatings of differing composition, formulated for application to damp or immersed surfaces, and a quick-setting hydraulic cement material were procured for testing to determine their applicability for underwater maintenance painting. They were applied to dry steel, to steel wetted with fresh water, and to steel immersed in fresh and salt water. Variations in test methods included surface preparation (abrasively blasted, water blasted, and wire brushed), application (hand/glove, putty knife, brush, or roller, as appropriate), and water (fresh and salt). The coated steel specimens were subsequently subjected to a pull test to establish the film properties.

Most products were easily applied to dry and wetted steel, but many were applied to immersed steel only with great difficulty. Only the thick splash-zone products and two of the eight brushable products were relatively easily applied to immersed steel. These products all cured to form durable films. Abrasive blasting was the preferred method of surface preparation. Adhesive/cohesive properties determined in pull tests were in most cases about the same in fresh as in salt water.

Two products were also applied by a diver. The first product was easily applied by brush and cured to give a good film. The other, thicker product was more difficult to apply by hand, and the properties of the cured film were inferior to those of specimens applied in the laboratory.

KEY WORDS: Coatings, Hydraulic Cement, Immersed Surfaces, Paints, Steel, Underwater Construction, Underwater Painting

"Hydroelectric Generator and Generator-Motor Insulation Tests." 1989 (Sep). Prepared by Robert H. Bruck, Illinois Institute of Technology, Chicago, IL, and Ray G. McCormack, US Army Construction Engineering Research Laboratory, Champaign, IL. AD A212 924

The first objective of this study was to describe generator-insulation systems used on Corps generators, the effects of operation and service conditions on the insulation, and the visual inspections and electrical tests on generator insulation accepted by industry, the purpose of the tests, how the tests are made, and how the results are interpreted. The second objective was to develop guidance to help Corps Divisions determine when a generator should be rewound and how to uprate generators when they are rewound. The third objective was to survey the Corps on the current practice for insulation inspection and testing and rewind criteria and to develop a recommended program for periodic routine inspection and testing. The fourth objective was to provide a brief summary of Corps experience with thermosetting stator insulation systems.

A comprehensive literature search was made to identify state-of-the-art insulation evaluation technology; a survey was made of insulation maintenance practices throughout the Corps, and the information gathered was used as a basis for this report.

Included are descriptions of the basis for generator ratings, the effect of operating and service conditions, types of insulation systems, and a complete description of visual inspections and electrical tests. Tests covered are the routine and special tests accepted by the industry for insulation systems for the generator stator, rotor, and stator core. A discussion and recommended criteria for rewinding generators are provided along with detailed guidance on criteria for generator uprating.

The field offices with responsibility for hydropower were surveyed about current routine generator insulation testing. Present practices by the Districts and Divisions are summarized. A recommended routine inspection and test program are given. Also included is a summary of Corps experience with thermosetting insulation.

It was concluded that current insulation inspection and testing vary widely between Divisions depending on their own experience and testing philosophy. Well-known electrical tests and readily available test equipment used along with thorough visual inspections in a regular routine insulation-maintenance program can extend insulation life and reduce unscheduled outages, reducing the possibility of loss of revenue from the sale of power and major equipment damage. Increasing numbers of units are going to need to be rewound because of advancing age and problems with thermosetting insulation systems. There is a need for guidance to help the field offices determine when to rewind generators.

KEY WORDS: Electrical Insulation, Hydroelectric Generators

REMR-EM-5

"Lubricants for Hydraulic Structures." 1989 (Aug). By W. B. Clifton and A. Beitelman, US Army Construction Engineering Laboratory, Champaign, IL. AD A213 260

The objective of this work was to determine the Corps' lubrication practices and problems in the areas of lubricating oils and greases and insulating oils and to provide guidance to meet the needs.

A survey was sent to all Corps installations that had hydraulic structures to learn what lubricants were being used by the Corps and what type of equipment was being lubricated. These survey responses were reviewed for type of lubricants used and machinery lubricated. Equipment manufacturers and lubricant producers were contacted regarding lubrication needs, providing state-of-the-art information to aid field installations in obtaining appropriate lubricants. Specific problems indicated by the responses to the survey were addressed.

Conclusions drawn from the survey indicated that (a) lubrication needs are being met with current products; (b) Corps maintenance personnel responsible for lubrication of machinery were observant and aware of the few problems that have occurred and took corrective action; (c) there have been no significant failures of machinery due to improper selection of lubricants; (d) some Corps personnel are confused as to what criteria must be followed in procuring lubricants; and (e) in some cases, technical advisory services provided by oil companies and manufacturers are not used to the fullest extent.

KEY WORDS: Hydraulic Structures, Lubricants, Surveys

REMR-EM-6

"Mechanical Properties and Corrosion Behavior of Stainless Steels for Locks, Dams, and Hydroelectric Plant Applications." 1989 (Dec). By Ashok Kumar and Ali A. Odeh, US Army Construction Engineering Research Laboratory, Champaign, IL. AD A219 490

The objective of this investigation was to present typical mechanical property data, briefly discuss corrosion behavior, and provide general guidelines regarding the use of stainless steels for locks, dams, and hydroelectric plant applications.

Researchers selected 14 stainless steels that may reduce maintenance costs and are becoming more available for Civil Works applications. They investigated these via discussions with Corps personnel and information obtained from various guide specifications and as-built drawings.

The report includes discussions of the problem of corrosion; general corrosion behavior, pitting attack, and concentration cell corrosion; galvanic corrosion; and cavitation. Case studies of the Oahe Dam, Missouri River, and

the Corps' experience with gate seals for 40 dams on the Monongahela, Ohio, Mississippi, Columbia, and Illinois Rivers are also given. A list of suggested materials for components used in Civil Works projects is presented, with preferred options marked.

The investigation indicated that, while stainless steels are viable options for many lock, dam, and hydroelectric plant applications, no single stainless steel available exhibits the desired mechanical properties and corrosion resistance for all applications. Alloys must be carefully selected and specified for a particular application, and the components must be properly designed and fabricated.

KEY WORDS: Cavitation, Corrosion, Dams, Locks (Waterways), Mechanical Properties, Stainless Steel

REMR-EM-7

"High-Solids and 100-Percent Solids Coating: A State-of-the-Art Investigation." 1992 (Jan). By John Baker, Bureau of Reclamation, Research and Laboratory Service Division, Denver, CO, and Alfred D. Beitelman, US Army Construction Engineering Research Laboratory, Champaign, IL. AD A247 557

The Corps of Engineers has used solution vinyl paints for corrosion protection of hydraulic structures on inland waterways for many years. These coatings have an excellent service life; however, liquid paint contains a high amount of solvents. Recently enacted volatile organic compound (VOC) air pollution regulations put severe restrictions on solvents in paints. The purpose of this research was to investigate generic high-solids and 100-percent solids coatings under laboratory conditions and identify coatings, based on their performance in the laboratory tests, as candidates for field testing.

A literature search was conducted to identify generic high-solids and 100-percent solids coating systems that had demonstrated desirable properties in either laboratory or field evaluations. This search was used along with a telephone survey and review of manufacturers' data sheets to identify coatings that would be good candidates for use on hydraulic structures. Testing was conducted on 24 coating systems. The coating samples were applied to solvent-cleaned and media-blasted steel panels. Methods of application were polyfoam applicators, bristle brushing, conventional spraying, airless spraying, and plural component airless spraying. Both basic coating system properties (pot life, etc.) and applied coating system properties (immersion resistance, etc.) were tested.

This investigation provided data on immersion resistance, accelerated weathering resistance, flexibility, pot life, recoating and curing times, methods of application, generic description, recommended film thickness, VOC content, volume of solids, and sequence of coats.

The most severe laboratory test was the saltwater immersion test. Seven coating systems of varied generic types survived this test and the freshwater immersion test without blistering. Six of them are recommended for field testing. Eleven coating systems performed satisfactorily (did not blister) in the freshwater immersion test and are recommended for field testing. Film thickness was not a significant factor in determining coating performance in the immersion tests nor in the accelerated weathering tests.

KEY WORDS: Coatings, High-Solids Coatings

Unnumbered

"Proceedings of REMR Workshop on Management of Bird Pests." 1989 (Jun). Edited by Anthony J. Krzysik, US Army Construction Engineering Research Laboratory, Champaign, IL. AD A210 086

Presented in the "Proceedings of REMR Workshop on Management of Bird Pests" are abstracts of presentations given at a workshop held 27-29 April 1988. The workshop was conducted to introduce Civil Works personnel to the state-of-the-art technology for controlling or managing bird damage and nuisance birds, consistent with environmental protection, and to provide guidelines for obtaining technical and operational assistance from Government agencies responsible for bird damage control. Topics presented include bird problems at Civil Work projects, health and nuisance problems, blackbird-starling roosting problems, bird control methodologies, bird scaring techniques, pigeon control, Canada geese problems, and gull damage.

KEY WORDS: Bird Damage, Birds, Pests

Environmental Impacts

REMR-EI-1

"Applicability of Environmental Laws to REMR Activities." 1986 (Nov). By Jim E. Henderson and Linda D. Peyman, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A177 322

The purpose of this report was to outline several environmental laws and regulations and describe their applicability to REMR activities. The intent was to identify the laws that have legal or regulatory authority over REMR activities and to discuss examples of environmental impacts or circumstances, related to REMR activities, to which the statutes might be applicable.

Statutes and Executive Orders, or their implementing regulations, were examined for applicability to REMR activities. The laws were identified through review of literature on environmental legislation, specific legislation, Engineer Regulations, and other Corps documents (e.g., environmental documents, master plans, and operational management plans). The statutes were classified as compliance statutes, statutes applicable in certain cases, and secondary environmental laws. These reviews and classifications were accomplished from the standpoint of the applicability of a law to proposed agency actions, rather than a strict legal interpretation.

Fourteen laws, regulations, or executive orders that may require compliance actions are identified. For each law, basic information on implementation provisions and REMR activities potentially covered by the law is provided. General information about these laws and state-specific information are available on the Computer-Aided Environmental Legislative Data System (CELDS), developed by the Construction Engineering Research Laboratory, Champaign, IL.

The regulation of Federal agency actions by environmental laws is documented in this report as relevant to REMR activities and to operation and management (O&M) functions in general. The early pollution and natural resource laws were merged into a national commitment to environmental protection and enhancement by the National Environmental Policy Act (NEPA). NEPA requirements for environmental documentation for O&M actions broadened the scope of environmental protection from impact

assessment of new planning projects, the major focus of NEPA, to the full range of Corps planning, construction, and operations activities. The Clean Water Act and other regulatory legislation brought increased responsibility for environmental quality to the Operations divisions in Corps Districts. REMR rehabilitation and maintenance procedures are required to meet the same environmental regulatory and legal requirements as other O&M actions.

KEY WORDS: Aquatic Systems, Debris Removal, Dredged Material Disposal, Dredging, Environmental Impacts, Environmental Laws, Pollution, Waterways

REMR-EI-2

"Bibliography of Environmental Research Related to REMR." 1986 (Nov). By Nelson R. Nunnally, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A177 069

The purpose of this report was to identify potential environmental impacts of REMR activities and to provide a bibliography of all reports and publications pertaining to environmental impacts of operation and management (O&M) techniques produced at Waterways Experiment Station (WES), the Coastal Engineering Research Center (CERC), and the Cold Regions Research and Engineering Laboratory (CRREL).

This report provides an annotated bibliography that assesses the applicability to REMR activities of previous environmental research done by the Corps of Engineers. Environmental reports and publications produced by WES, CERC, and CRREL were reviewed, and those with potential applicability to REMR were included.

The narrative portion of the document contains tables summarizing potential environmental consequences of REMR activities and indicating which bibliographic entries should be consulted for applicable environmental research.

KEY WORDS: Aquatic Systems, Debris Removal, Dredged Material Disposal, Dredging, Environmental Impacts, Pollution, Waterways

REMR-EI-3

"Compliance Requirements for Environmental Laws Applicable to REMR Activities." 1988 (Aug). By Jim E. Henderson and Linda D. Peyman-Dove, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A200 193

This report describes the types of compliance actions mandated by environmental laws applicable to REMR activities. It provides information on

coordination, permits, and documentation efforts for compliance with the environmental laws.

Compliance actions required under the environmental laws are summarized. Information is provided on intent of the law; scope of the law, i.e., what REMR activities are covered by the law and possible exemptions or exclusions; compliance documentation required, that is, the data, analyses, or other documentation required; and sources of assistance/advice.

KEY WORDS: Environmental Compliance, Environmental Laws, Environmental Statutes, Executive Orders, Operation and Maintenance

REMR-EI-4

"Seasonal Regulation of Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Activities." 1988 (Aug). By Mark W. LaSalle, JAYCOR, Vicksburg, MS, and John Nestler and Andrew C. Miller, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A198 016

This report identifies potential environmental impacts associated with REMR activities on structures maintained by the Corps of Engineers. The specific focus is on a possible need for seasonal regulations of these activities intended to protect seasonally occurring and potentially sensitive biological resources on or in the immediate vicinity of structures scheduled for a REMR activity. Any regulation would be based on consideration of regional location, habitat type, and associated organisms.

This report outlines the considerations of potential REMR activities in coastal, reservoir, and riverine habitats. Some REMR activities have the potential to affect environmental quality either directly through handling of construction materials that may affect the surrounding habitat or indirectly through changes in project operation required to complete repairs or inspection. Seasonal considerations are an important aspect of REMR planning since many aquatic organisms have critical life stages, reproductive periods, or migratory patterns that may be disrupted by REMR activities. In addition, terrestrial organisms using habitats adjacent to Corps structures may also be disturbed by repair activities.

The general evaluation procedure outlined herein consists of (a) the development of matrices that incorporate information on structure type (material), potential REMR activities associated with each structure, and potential environmental alterations associated with each activity and (b) a discussion of the potential effect of these alterations on biological communities within the vicinity of a structure. The use of matrices in the evaluation process is outlined and explained, followed by a discussion of potential environmental alterations associated with REMR activities.

KEY WORDS: Environmental Impacts, Evaluation, Habitat, Reservoir, Seasonal Regulation, Waterways

REMR-EI-5

"The Effects of Vegetation on the Structural Integrity of Sandy Levees." 1991 (Aug). By Donald H. Gray, Anne MacDonald, Thomas Thomann, Imogene Blatz, and F. Douglas Shields, Jr., US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A240 267

The purpose of this study was to investigate the relationship between vegetation and the structural integrity of river levees. A specific objective was to determine the distribution of roots within levee embankments, and how these roots alter soil properties of levee embankments and affect their resistance to mass wasting, surficial erosion, piping, etc. With this information, engineering criteria can be developed in the future that may allow additional (particularly woody) vegetation to remain on levee embankments where sufficient effort can be made for levee inspection.

A field study was conducted along a 6-mile reach of a sandy channel levee along the Sacramento River near Elkhorn, CA. Root concentrations and distributions were determined by the profile-wall method in which root cross sections were exposed in the vertical wall of an excavated trench. Transects were excavated running both parallel and perpendicular to the crest of the levee through areas dominated by different woody plant species typical of riparian vegetation.

Lateral plant roots were restricted to, and modified, mainly the first few feet between the surface of a levee. Root area ratios did not exceed 2 percent and generally decreased approximately exponentially with depth. Most of the root biomass was concentrated in the top 2 ft. Voids and pedotubules (infilled holes or conduits) were also mapped in the vertical faces of the trenches at each site. No voids clearly attributable to plant roots were observed.

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 area ration. 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.

Based on these preliminary field studies, woody vegetation does not appear to adversely affect the structural integrity of a levee. Grasses and herbaceous ground cover provide greater amounts of roots at very low depths (under 6 in.) than do woody plants. Consequently, this type of vegetation appears to be just as effective as woody plants in preventing shallow sloughing or surface ravelling. On the other hand, woody roots are stronger and tend to penetrate more deeply; therefore, they are more effective in preventing deeper seated slope failures. Low-lying shrubs and bushes provide the benefits of woody

roots without possible liabilities associated with large trees growing on a levee.

KEY WORDS: Bank Erosion, Earth Reinforcement, Levee, Piping, Plant Roots, Seepage Analyses, Slope Stability, Soil Properties, Vegetation Survey

Operations Management

REMR-OM-1

"Evaluation of Existing Condition Rating Procedures for Civil Works Structures and Facilities." 1986 (May). By Enno Koehn and Anthony M. Kao, US Army Construction Engineering Research Laboratory, Champaign, IL. AD A170 391

The objectives of this study were to (a) ascertain the state of the art of existing evaluation methods and condition indexes in order to determine if any present system can be adapted for use on Civil Works structures and (b) assess the efficiency and reliability of these methods when used by inexperienced personnel.

Numerous Government and private agencies were contacted and a literature search was conducted to determine existing Civil Works maintenance rating procedures used by organizations that maintain these types of facilities. For each data source, a detailed inspection was made of the procedural components involved in maintenance procedures, such as checklists, manuals, rating systems, computer applications, technical and professional requirements, frequency of inspection, and repeatability. Evaluations are included for the maintenance procedures of concrete dams and canals; rock and earth dams; spillways, stilling basins, and outlet works; lock walls, lock gates, and operating equipment; powerhouses and pumping plants; bridges and roads; and miscellaneous facilities.

Most of the procedures studied for this research used checklists for maintenance and review operations, with the exception of TRADOC, FORSCOM, and FEMA. Twelve agencies had developed manuals or explanatory materials for maintenance systems, whereas other sources used various other rating systems. Most of the rating systems evaluated facilities by the following categories: yes/no, satisfactory/unsatisfactory, high/medium/low, excellent/good/fair/no change/bad/critical, etc. Five sources used a computer data bank, and eight required the use of photographs in technical evaluations. Sixteen sources required personnel conducting maintenance evaluations to have professional engineering and technical knowledge. Only four systems were found to be repeatable. Fifteen sources were found to inspect their facilities at specific time schedules.

No specific or uniform pattern was observed among the procedures studied that can be used as a general guideline for Civil Works maintenance. No appropriate rating system was found that applied directly to the periodic maintenance of Civil Works structures, and no system appeared to be easily usable and reliable when used by inexperienced raters. However, the Corps of Engineers' Pavement Maintenance Management System (PAVER) and the Federal Highway Bridge Inspection Program appear to offer approaches that, with modifications, could be applied to Civil works maintenance.

KEY WORDS: Bridges, Condition Rating Systems, Civil Works Structures, Flood Control, Highways, Irrigation Systems, Maintenance Management

REMR-OM-2

"REMR Management System." 1988 (Sep). By H. Thomas Yu and Anthony M. Kao, US Army Construction Engineering Research Laboratory, Champaign, IL. AD A200 728

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.

This report describes the REMR Management System, a computer-aided system for managing REMR Basic Functions module, Condition Evaluation and Rating module, and 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 Basic Functions module is described in detail in this report. The description of the Condition Evaluation and Rating module and the Consequence Modeling module is limited to the presentation of the concepts; the details of these modules will be reported separately.

KEY WORDS: Computer-Aided Systems, Condition Index, Project Management,

"User's Manual: Inspection and Rating of Steel Sheet Pile Structures." 1989 (Jun). Prepared by Lowell Greimann and James Stecker, Engineering Research Institute, Iowa State University, Ames, IA, for US Army Construction Engineering Research Laboratory, Champaign, IL. AD A210 411

A project team at Iowa State University undertook a research effort that focused on the evaluation and repair of the steel sheet-pile structures within the Corps' civilian projects. These structures do not require a great deal of maintenance, but failure of a steel sheet-pile wall can significantly affect operations--especially as part of a lock and dam facility. Steel sheet-pile structures provide an excellent vehicle around which a maintenance program can be developed, because the methodology developed for this relatively simple type of structure can be extended to more complex and critical structural systems. The specific objective of this initial work was to develop an inspection and rating system that uniformly and consistently describes the current condition of steel sheet-pile structures.

The project team at Iowa State University conducted several site visits and field investigations. Experts from the Corps of Engineers were asked to rate several walls, and the results were compared with a preliminary version of the rating system. Modifications were made to reflect more accurately the experts' opinions.

In this report, a general description of the current inspection and rating system, a definition of a condition index, and a brief description of sheet-pile distresses are given. The inspection requires simple hand tools such as a tape measure, level, weighted rope, and string. An inspection form has been developed upon which is recorded historical information (location, previous inspections, or repair history, etc.), structural information (wall type, SSP cross section, pile lengths, water depths, dredge line depth, surcharge loadings, etc.), and distress documentation (misalignment, corrosion, settlement interlock separation, etc.).

Once the inspection data have been gathered, they are entered onto a computer disk through a personal computer program. The condition index is a number scale from 0 to 100 that indicates the current state of the structure. Condition indexes below 40 indicate that immediate repair or possibly a more detailed inspection and re-analysis are required. The description provides sufficient detail for trial applications of the inspection process. The scope of this project has been specifically limited to steel sheet-pile structures associated with lock and dam facilities.

KEY WORDS: Condition Index, Inspection, Locks and Dam, Steel Sheet-Pile Structures

REMR-OM-4

"A Rating System for the Concrete in Navigation Lock Monoliths." 1989 (May). Prepared by Rupert E. Bullock, Engineering Consultant, Knoxville, TN, for US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A208 304

The purpose of this study was to develop a system for determining a condition index (CI) that numerically rates the condition of the concrete in a lock monolith on a scale of 0 to 100 by evaluating each concrete deficiency. The rating system described herein allows the CI to be determined by the use of a visual investigation with limited equipment. The rating is related primarily to structural integrity and secondarily to serviceability.

The CI procedure was developed by assigning specific deduct values to defects that include the following distress categories: alignment, cracking (checking, D-cracking, pattern, horizontal, vertical and transverse, vertical and longitudinal, diagonal, random, and longitudinal floor), volume loss (abrasion, cavitation, honeycomb, pop-outs, scaling, spalling, and disintegration), steel deterioration (corrosion stains, reinforcing, prestressing, and armor), and leakage and deposits. The deduct values are subtracted from 100 to establish the CI. Primary deduct values were determined with the intent of obtaining a CI of zero when deterioration of a concrete monolith caused the safety of that monolith to become critical. Nominal deduct values were assigned for defects in serviceability.

Deduct values for distress categories that tend to result in loss of concrete from the structure (volume), and thus effective weight and cross section, were assigned by making approximations concerning safety and assuming (a) all sections were cracked so that no tension or cohesion existed at the section and (b) the total force tending to produce sliding or total moment tending to produce overturning was constant.

The CI should be determined on all gate monoliths, on at least one of each of the remaining types of monoliths, and on the more distressed monoliths. It is recommended that a minimum of 10 percent of the monoliths be rated.

KEY WORDS: Concrete, Condition Index, Cracking, Navigation Locks, Rating System

REMR-OM-5

"Timber Dike Management System." 1989 (Sep). By H. Thomas Yu and Anthony M. Kao, US Army Construction Engineering Research Laboratory, Champaign, IL. AD A213 851

The Timber Dike Management System is a computer-aided management system for optimizing allocation of funds available for maintenance and repair (M&R) of timber dikes. The system employs a condition index (CI) for consistent, objective rating of the dike condition and provides easy access to

information critical for M&R management. For timber dikes, while maintenance options are limited, savings in maintenance cost can be realized by optimizing the timing and scope of maintenance work.

The Timber Dike Management System has three key features: a dike condition index (DCI) evaluation procedure, a data management system, and a consequence modeling procedure. A CI is an objective indicator of the "health" of a structure. Consequence modeling is an optimizing procedure that allows objective comparison of available alternatives.

This report focuses on the CI evaluation procedure of the Timber Dike Management System. The simple timber dike inspection and evaluation procedures described in this report proved capable of consistently producing reliable results. The DCI can be used for budget planning and prioritization of maintenance work. The data management system described in this report has been implemented and tested on an IBM-compatible personal computer as a program called TDIKE. Appendix A of this report describes the TDIKE program and the data manager. The consequence modeling procedure is currently under development.

The dike inspection and evaluation procedure, while simple, appears capable of consistently producing reliable results. Results of CI evaluation can be used for budget planning and prioritization of maintenance work.

KEY WORDS: Condition Index, Dikes, Rating System, Timber Dikes, Timber Dike Management System

REMR-OM-6

"Network Level REMR Management System for Civil Works Structures: Concept Demonstration on Inland Waterways Locks." 1989 (Dec). Prepared by Michael J. Markow, Sue McNeil, Dharma Acharya, and Mark Brown, Center for Construction Research and Education, Massachusetts Institute of Technology, Cambridge, MA, for US Army Construction Engineering Research Laboratory, Champaign, IL. AD A217 031

The objective of this project was to develop a Network Level Management System for the maintenance and rehabilitation of Corps Civil Works structures. This report focuses on locks on the inland waterways network. Once the management system has been demonstrated for locks, however, these concepts of maintenance management can be extended, adapted, and applied to other facilities within the REMR program.

The Management System is based on a life-cycle analysis of the performance and costs of facilities through some analysis period, as affected by REMR policy. The implementation of life-cycle analyses of facilities requires a new approach to looking at facility performance and the factors that influence costs throughout its service life. This approach is referred to as

"demand responsive," in that maintenance and rehabilitation are viewed as responses to the demand for repair or renewal of the facility. Treating REMR actions as demand-responsive activities requires that three additional elements be introduced within existing planning and management models:

— Estimates of future resource requirements and costs of managing facilities based on predictions of structural and operational deficiencies caused by use, environment, and age.

— Clear statements of REMR policies themselves, defining the types of preventive or corrective actions to be taken, and when and where they are to commence.

— Relationships between the as-maintained state of the civil facility and the impacts on both the Corps and the users of the facility (in terms of preservation of facility investment, the costs, time, and reliability of transportation service provided, safety, etc.), providing a measure of the benefits (or disbenefits) of each policy at the costs computed above.

This report explains the concepts involved in applying life-cycle costing to analyses of REMR policies. Considering locks specifically, it then develops example models of facility performance for lock gates, walls, and mechanical equipment, relates this performance to the costs and the impacts of different REMR policies, and builds these models within a prototype version of a microcomputer-based REMR Management System. The prototype system is then applied to several examples to demonstrate the application of demand-responsive maintenance concepts to realistic problems, to illustrate the system features and procedures, and to explain the results and their interpretation.

KEY WORDS: Life-Cycle Costs, Locks, Maintenance Management, Network Level Management System, Inland Waterways Locks, Rating Systems, Waterways

REMR-OM-7

"Inspection and Rating of Miter Lock Gates." 1990 (Aug). Prepared by Lowell Greimann, James Stecker, and Kevin Rens, Engineering Research Institute, Iowa State University, Ames, IA, for US Army Construction Engineering Research Laboratory, Champaign, IL. AD A227 198

The objective of this study was to develop an inspection and rating system that would uniformly and consistently describe the current condition of miter lock gate structures.

The project team at Iowa State University (ISU) performed research focusing on the evaluation and repair of miter lock gate structures. Inspection and rating procedures for miter lock gates were formulated, based on meetings with Corps personnel, site visits, and field investigations at lock and dam facilities. Field tests of the inspection form and rating process were conducted

at five gate sets, and the results of these tests were incorporated into the current version of the procedure.

The inspection process that was developed requires simple hand tools such as a tape measure, level, dial gage, and ruler. An inspection form was devised for recording historical information (location, previous inspections, repair history, etc.), structural information (cross sections, water depths, additional loadings, etc.), and distress documentation (offsets, elevation change, corrosion, etc.). Personal computer (PC) software was written for disk recording of inspection information.

A condition index (CI) can be computed directly from the inspection records. The CI is a number scale from 0 to 100 that indicates the current state of the structure. It is primarily a planning tool that indicates the relative need to perform REMR work. Condition indexes below 40 indicate that immediate repair is required or that a more detailed inspection and re-analysis may be necessary.

Two separate indexes make up the REMR condition index. The structural CI is a reasonably objective measure of the structural safety. It is related directly to the safety factor, which is calculated by the PC software. A functional CI, based on the subjective opinion of several experts from the Corps, is also calculated. It involves at least two considerations: (a) serviceability, or how the structure performs its function on a day-to-day basis, and (b) subjective safety, or how, in the judgment of expert engineers, the safety of the structure has been degraded by various distresses.

This report gives a general description of the current inspection and rating system. This includes the definition of a CI and a description of miter lock gate distresses. A detailed description of the inspection process is also given.

KEY WORDS: Condition Index, Inspection, Locks and Dams, Miter Lock Gate, Rating System, Safety

REMR-OM-8

"REMR Management Systems--Navigation Structures; Management System for Miter Lock Gates." 1990 (Dec). Prepared by Lowell Greimann, James Stecker, and Kevin Rens, Engineering Research Institute, Iowa State University, Ames, IA, for US Army Construction Engineering Research Laboratory, Champaign, IL. AD A231 469

Miter lock gates within Corps civilian projects are the focus of the research described in this report. The objectives of this work were (a) to develop an inspection and rating system that uniformly and consistently describes the current condition of miter lock gate structures and (b) to develop guidelines for the maintenance and repair of these structures.

After inspection data are gathered, they are filed on a computer disk through a microcomputer program. The program will then compute the structural and functional condition indexes (CIs) for miter lock gates. The program user can create a plot of CI versus time and formulate a number of maintenance and repair solutions from a set of alternatives. Consequences of the various solutions are quantified by re-evaluating the CI. When the initial costs, expected life, downtime costs, interest rates, and inflation rates are known, a preliminary life-cycle cost analysis can be performed. With this information, an experienced engineer can make a preliminary maintenance and repair plan for the structure.

The maintenance and repair analysis presented here represents a significant tool to be used by experienced engineers to help them arrive at maintenance and repair decisions. It should be considered as a preliminary version, as a step in an evolutionary process. As with all engineering analyses, numerical results should not be interpreted too literally, but considered in the light of "engineering judgment."

KEY WORDS: Condition Index, Inspection, Life-Cycle Cost Analyses, Miter Lock Gates, Preventive Maintenance, Preventive Maintenance Program, Rating System

REMR-OM-9

"Maintenance and Repair of Steel Sheet Pile Structures." 1990 (Dec). Prepared by Lowell Greimann and James Stecker, Engineering Research Institute, Iowa State University, Ames, IA, for US Army Construction Engineering Research Laboratory, Champaign, IL. AD A231 916

This research focuses on the evaluation and repair of the steel sheet-pile structures within the Corps' Civil Works projects. The objectives of this work were to (a) develop an inspection and rating system that uniformly and consistently describes the current condition of steel sheet-pile structures and (b) develop guidelines for the maintenance and repair of these structures.

This report discusses the current inspection and rating system and provides a definition of a condition index (CI) and a brief description of sheet-pile distresses. A detailed description of the inspection process is included. The inspection and rating procedure has been kept as simple as possible. The inspection requires simple hand tools such as a tape measure, level, weighted rope, and string. An inspection sheet has been developed for recording historical information (location, previous inspections, or repair history, etc.), structural information (wall type, cross section, pile lengths, water depths, dredge line depth, surcharge loadings, etc.), and distress documentation (misalignment, corrosion, settlement, interlock separation, etc.).

Inspection data are entered onto a computer disk through a personal computer (PC) program that summarizes the safety and serviceability problems associated with the structure. By supplying the initial costs,

expected life, downtime costs, interest rates, and inflation rates, an experienced engineer can make a preliminary maintenance and repair plan for the structure.

Two separate indexes make up the CI. The structural CI is a reasonably objective measure of the structural safety. It is related directly to the factor of safety, which is automatically calculated by the PC software. A functional CI, based on the opinion of several experts from the Corps, involves serviceability and subjective safety.

A maintenance and repair analysis phase of the program allows the user to make a preliminary assessment of various alternatives for repairing the structure. A list of problems in the structure is collected from the inspection data, and a list of maintenance and repair alternatives within the program can be updated and expanded. The user develops up to five maintenance and repair solutions, each of which consists of a set of maintenance and repair alternatives that solve the associated problems. The initial cost and expected life of each solution are entered. The consequences of each solution are quantified by re-evaluating the CI of the structure. Life-cycle costs of each solution are evaluated after the rates of interest and inflation and downtime costs are furnished.

KEY WORDS: Condition Index, Inspection, Life-Cycle Costs, Preventive Maintenance, Rating Systems, Safety, Steel Sheet-Pile Structures

REMR-OM-10

"Lockwall: A Microcomputer-Based Maintenance and Repair Management System for Concrete Navigation Lock Monoliths." 1990 (Sep). By David T. McKay and Anthony M. Kao, US Army Construction Engineering Research Laboratory, Champaign, IL. AD A228 625

This report describes LOCKWALL, a microcomputer-based maintenance and repair management system for concrete in navigation lock monoliths. The description includes an overall view of LOCKWALL's functions and operations and a brief description of the rating system for concrete navigation lock monoliths.

The LOCKWALL computer application was written as a menu-driven, user-friendly program. LOCKWALL's fundamental features include database management, an inventory of all lock structures within a given Division, concrete monolith condition assessment via a condition index (CI), a collection of text files on repair and maintenance alternatives for concrete in hydraulic structures, life-cycle costs analysis (consequence modeling), and report generation.

The concrete distress data, gathered by field inspection with a minimum of equipment, are used to calculate a CI for each monolith in the database. The CI indicates the condition of the concrete in each monolith. The CI thus

affords a means for the uniform and quantitative comparison of the condition of concrete in one lock structure to that of another.

In time, the collected data will yield curves showing deterioration rates of concrete in service. Such curves can be used to predict future concrete condition so that maintenance managers can optimally budget maintenance money. In addition to optimal budget planning, LOCKWALL will provide maintenance managers with justification for maintenance money and automated management reports, which will result in a better condition for dollars expended.

LOCKWALL can track data for any concrete monolith with the Corps. However, LOCKWALL was written to support only one Division at a time. Accordingly, nine modules were written, one for each of the nine Corps Divisions that manage concrete navigation lock monoliths. This report is not a user's manual for the LOCKWALL program. A user's manual will be published separately.

KEY WORDS: Concrete, Condition Index, Hydraulic Structures, Life Cycle Cost Anslysis, Lock Monoliths, Management Information Systems, Microcomputers, Navigation Locks, Rating Systems

REMR-OM-11

"REMR Management Systems--Coastal/Shore Protection Structures: Condition Rating Procedures for Rubble Breakwaters and Jetties, Initial Report." 1991 (May). By Donald E. Plotkin, US Army Construction Engineering Research Laboratory, Champaign, IL, and D. D. Davidson and Joan Pope, US Army Engineer Waterways Experiment Station, Vicksburg, MS. AD A237 042

This is an initial report on the development of a basic system for uniformly evaluating the condition of breakwaters and jetties of rubble construction with either rock or concrete armor. The intent of this system is to provide a consistent method of evaluation that supplies numerical condition descriptors that can be handled easily on a microcomputer. This numerical system aids in the maintenance planning process by permitting the condition to be monitored over time and by allowing a relative condition comparison between structures.

This system is based on visual inspection and uses numbers on a scale from 0 (worst) to 100 (best) to represent the relative condition of the structures. The process begins by assessing the crest (or cap), seaside, and leeside of each reach (section) of a structure according to a standard list of structural aspects. This assessment, in turn, leads to ratings for the seaside and leeside slopes and crest of the reach. Then, the reach ratings are combined to give a single, overall condition rating for the whole structure. The condition rating system considers both structural and functional aspects of each structure.

KEY WORDS: Armor, Breakwaters, Coastal, Concrete Armor, Condition Index, Condition Rating Evaluation, Rating Systems, Rock Armor, Jetties, Rubble Construction

REMR-OM-12

"REMR Management Systems--Navigation Structures; User's Manual for Concrete Navigation Lock Monoliths." 1992 (Mar). Prepared by the Automation Support Center, University of Illinois, Urbana, IL, and David T. McKay, US Army Construction Engineering Research Laboratory, Champaign, IL. AD A248 994

LOCKWALL is a microcomputer-based application that performs database administration, calculations, and generates reports. The LOCKWALL program houses an inventory of all waterway systems and navigation lock structures contained within any given Division. Data pertinent to each structure, such as owner/operator, construction date, lock width, lock length, lock lift, etc., are stored and are in place when LOCKWALL is delivered.

The first time condition inspection data are entered for a given structure, LOCKWALL prompts the user to characterize each lockwall and guidewall by providing lists of the monolith identification (ID) numbers that comprise each wall. Theses ID numbers are obtained from engineering drawings. This one-time process ensures that monolith ID numbers used by different inspection teams remain consistent.

The condition inspection data are gathered through visual observation and simple measurements. The inspection catalogs the location and extent of concrete cracking, loss of volume, and deterioration. Other forms of distress such as exposed steel, leaks, stains, deposits, and missing or damaged armor are noted. The data are accepted and stored by LOCKWALL , which uses an algorithm to produce a condition index (CI) for each monolith inspected. The CI is a numeric representation of the condition of the concrete in each monolith and ranges from 0 to 100, with 100 reflecting an "as-built" condition.

Additional information regarding maintenance and repair operations for concrete lockwalls is stored in the LOCKWALL program. These files do not interact with the CI database but are in place for informational purposes and serve as a library to help researchers determine proper maintenance strategies for a given set of distresses.

The LOCKWALL program has a Life Cycle Cost Analysis (LCCA) utility that can be directly tied into the CI inspection database. In terms of LCCA maintenance planning, all LCCAs require a standard input: inflation rate, interest rate, required life of overall maintenance, beginning year of maintenance plan, individual maintenance activity description, cost of individual maintenance activity, expected life of individual maintenance activity, and beginning year of individual maintenance activity. The standard output is a financial schedule showing the required real-time dollars and present worth

of such dollars to implement each individual maintenance activity. Total cost and total present worth for the overall plan are presented.

KEY WORDS: Concrete, Condition Index, Life-Cycle Cost Analysis, Locks (Waterways), Navigation Structures

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This bibliography presents abstracts of technical reports published through September 1992 under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. It contains seven sections relating to the problem areas addressed by the REMR Program: (a) Concrete and Steel Structures, (b) Geotechnical Applications, (c) Hydraulics Applications, (d) Coastal Applications, (d) Electrical and Mechanical Applications, (e) Operations Management, and (f) Environmental Impacts. Key words and an index of subject terms are also included.

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