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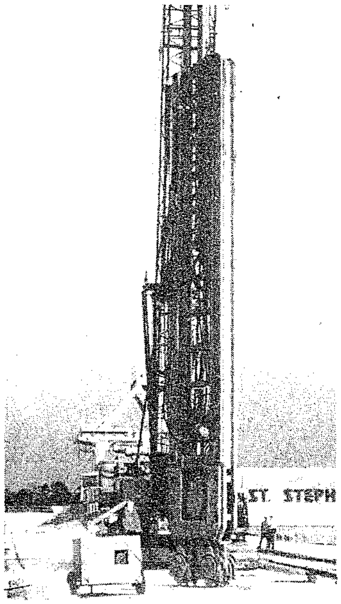

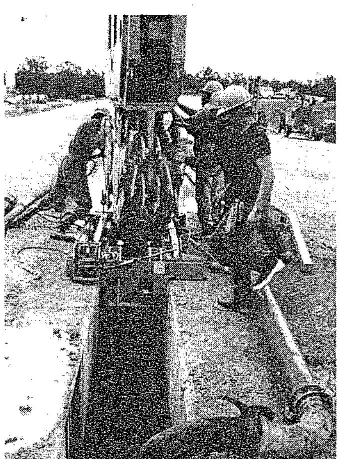

The REMR *Bulletin*

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

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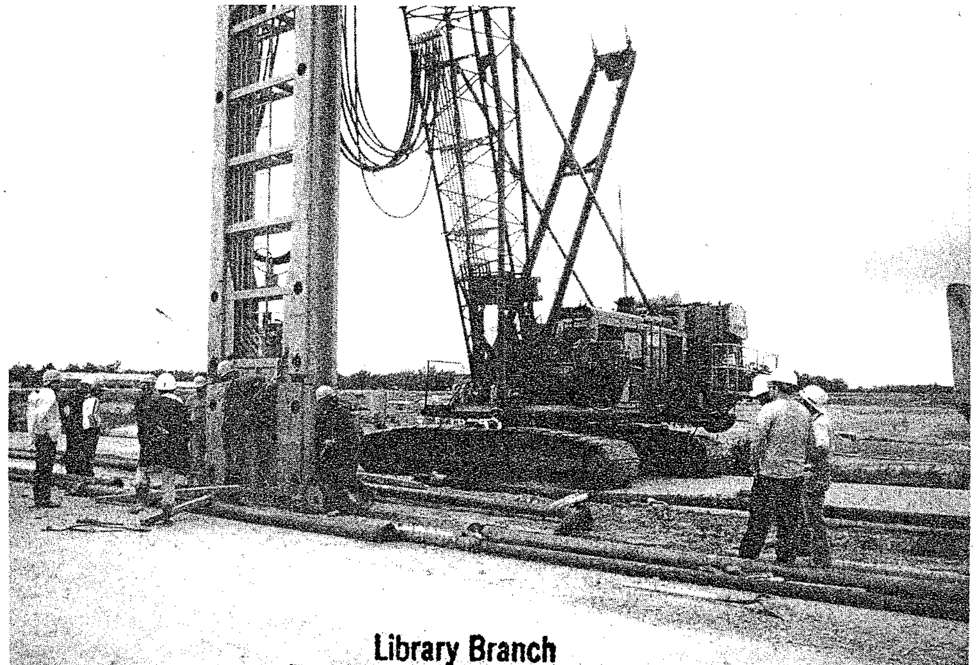


French Drilling Machine Shows Advantages in Excavating for Concrete Cutoff Wall

by Charles M. Hess
US Army Engineer District, Charleston

A French drilling machine known as the Hydrofraise has been successfully used in Charleston District in excavating for a concrete cutoff wall at the Cooper River Rediversion Project, South Carolina. This, the first application of the machine in the United States, was undertaken to control seepage both through and beneath the embankments adjacent to St. Stephen Powerhouse.

Prospective contractors for the cutoff wall were advised to expect considerable difficulty in excavating to the founding depths. Typically recorded standard penetration values of the in situ materials through which the contractor would be required to excavate were in excess of 100 blows per foot. In some areas, a sandstone cap up to 2 feet thick over the shale layer prevalent at the site proved to be an additional complication.

It was also noted that the contractor who had installed the soil-bentonite slurry trench for construction dewatering had considerable difficulty excavating the dense sands and shale at the site using a crane-operated, cable-suspended clamshell weighing approximately 12 tons. The trench contractor used both spiral and bucket augers to predrill the alignment of the trench prior to excavation with the clamshell. Blasting was prohibited.

Prospective slurry wall contractors were cautioned that predrilling or chiseling might be necessary to facilitate excavation of the interbedded sands and clays, zones of dense sand, sandstone cap above the shale, and shale into which the cutoff wall was to be founded. However, the cutoff wall specifications did not restrict the contractor to the use of clamshells for his excavating equipment.

In a sealed bid solicitation, Recosol, Inc. (formerly Soletanche and Rodio, Inc.), submitted the lowest proposal for installation of the concrete cutoff wall at $16.85 per square foot. The estimated quantity for the wall was 76,000 square feet. Site preparation, mobilization and demobilization, concrete coring for quality evaluation, and site restoration were all treated as separate pay items.

The proposed excavation and cutoff wall installation technique centered around use of the proprietary Hydrofraise, which had been developed by Recosol, Inc., over a 10-year period. The machine has been used extensively in Europe and also licensed to Ohbayashi-Gumi for exclusive use in Japan.

The Hydrofraise is powered by three down-the-hole motors with reverse mud circulation. A heavy metal frame serving as a guide is fitted at its base with two cutter drums carrying tungsten-carbide-tipped cutters which rotate in opposite directions and break up the soil (or rock). A pump located just above the drums excavates the loosened soil which is carried to the surface by drilling mud. The mud with cuttings is continuously filtered and poured back into the trench. The hydraulic cutting device is designed to give the cutter drums a high torque at low speeds of rotation.

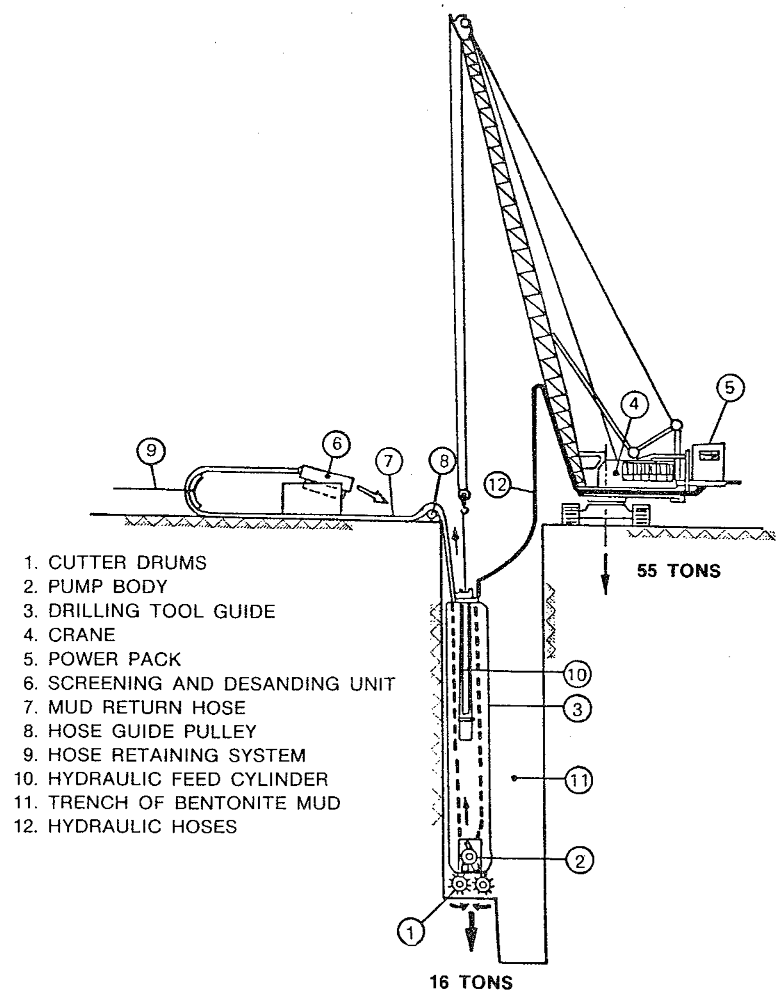
A heavy crawler crane supports and manipulates the machine. The guide frame is attached to the crane operating cable through a hydraulic feed cylinder which can be controlled to give a constant rate of advance or to maintain a constant weight on the cutter drums (the maximum being the weight of the machine, 16 to 20 tons).

Recosol claims that the Hydrofraise has the following capabilities:

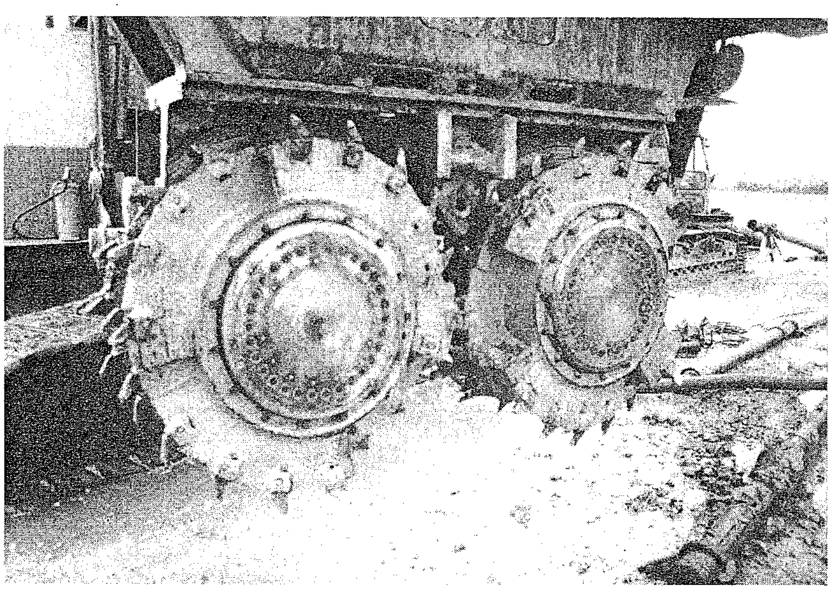
- The ability to drill strip piles or diaphragm wall elements in a very wide range of soils from cohesionless materials like silt, sand, and gravel to hard rock (up to 10,000 psi).
- Faster excavation due to a continuous digging action as compared to the cyclic action of conventional (clamshell) excavation. The average production rate published by Recosol is 110 square feet per hour.
- Elimination of the shoulder pipes for concrete placement in the primary panels. Shoulder pipes are not necessary because of the cutting action at the joints between panels.
- Cleaner, simpler, and safer excavation operation. All cuttings are contained within the pipelines and removed at the settling basin and desanders remote from the excavation. The need for hauling units at the excavation is eliminated. The work area remains relatively clean.
- The ability to carry out concreting as soon as the required depth has been reached. This is possible since the slurry is being constantly cleaned and desanded during the trenching operation. A separate desanding and cleaning operation is not required as with conventional clamshell excavating techniques.
- Elimination of the need for chiseling.
- Very suitable for use on urban sites due to the absence of vibration and shock. Overbreak is less than with conventional systems (less than 10 percent), and verticality is excellent and can be controlled and corrected to less than 0.2 percent if required.
- Easy adaptability of the machine to various wall thicknesses (from 2 to 5 feet) while maintaining the benefits of high-precision control and expeditious excavation. Thickness is adjusted by the addition of spacers mounted on the frame with associated wider cutter drums.

At St. Stephen, primary panels 30 feet long were excavated with three full bites (a bite being one pass of the machine) and two 3-foot wedge bites. A full bite was 2 feet wide, 8 feet long, and averaged 115 feet in depth. Secondary panels, between the primary panels, were sized so one full bite (8 feet long) excavated the panel, including 2 to 4 inches of concrete on each adjacent primary panel. This provided a well-keyed joint between the panels due to the groove cut pattern produced by the Hydrofraise. Excavation was not allowed adjacent to new concrete (primary panels) until a strength of 2000 psi had been attained (normally by the fourth day after placement).

The contractor's equipment setup consisted of a Link Belt LS 338 crane (100 ton) which



Hydrofraise and support equipment as set up at St. Stephen Powerhouse, Cooper River Rediversion Project, South Carolina



Close-up of cutter drums

carried the Hydrofraise and power unit, a Link Belt 318 crane (80 ton) for concrete placing, three Caviem desanders (130 cubic yards per hour), and the normal support of slurry mixing and pumping equipment. No air lifts or other cleaning equipment was used for cleaning the trench bottom or for final desanding since the Hydrofraise performed these functions as well as the excavation.

Based on the experience at the St. Stephen Powerhouse, all of Recosol's claimed advantages were realized to some extent. Detailed results actually achieved were as follows:

1. A wide range of materials was excavated including fat clays, dense sands, various types of shale and limestone, gravel, sandstone, and concrete. The dense sands contained lenses of sandstone and shale of various hardness, some in excess of 5000 psi in compressive strength. The lenses were usually less than 12 inches thick. Fat clays slowed production due to gumming of the cutter drum teeth and at times plugging of the intake suction ports to the pumps. These problems were usually handled with the Hydrofraise in the hole by shaking the unit, but occasionally the unit had to be withdrawn and cleaned manually. Harder rock seams reduced production significantly, at times to as little as 10 square feet per hour. Full-cut concrete excavation rates (concrete in excess of 3000 psi) ranged from 25 to 30 square feet per hour. The most difficult materials to excavate were floating cobbles and boulders (in excess of 2 inches) and any type of metal debris such as rebar. These items tended to lock the cutter drums or roll rather than being cut.
2. Comparison of the production rate of the Hydrofraise with that of conventional (clamshell with chisel or drill) excavation equipment, performing in the same vicinity during installation of the soil-bentonite slurry trench for construction dewatering, clearly reveals a higher production per unit of equipment, especially in the more difficult excavation areas. At times, Hydrofraise production more than doubled that of the clamshell.
3. Outstanding results were achieved in the quality of the panel joints. Cores taken at joints revealed an excellent keyed pattern across joints and a good bond between panels. Since the Hydrofraise excavates the outer edges of the primary panels, any irregularities or poor quality material is removed, exposing a clean face for the secondary panel concrete to bond with.
4. Very little damage to the existing embankments occurred due to slurry saturation, traffic, etc. No major safety problems were experienced during the wall construction, primarily due to the simplicity and cleanliness of the operation.
5. Although no separate desanding equipment was used at Cooper River, overall project production might have been increased if the Hydrofraise had been used solely for excavation while final desanding and cleaning were being performed with separate equipment. This increase could be especially significant in situations where excavation is completed at the end of the day and backfill does not occur until the next day.
6. No other excavation equipment was required. The Hydrofraise excavated all materials without additional assistance.
7. Verticality was better than specified for all panels without any corrective measures or special control efforts. The ability to accurately control this machine is one of its best features.
8. The hydraulic removal of the excavated materials allowed the excavation work to be performed in minimal work space with very little equipment movement at the site. Adding booster pumps to the slurry and discharge lines would permit placing the slurry ponds and desanding operation at any available location.

Additional information on use of the Hydrofraise at St. Stephens Powerhouse can be obtained by contacting the author, Charlie Hess, at FTS 677-4212 or 803-724-4212. Additional information on the Hydrofraise itself can be obtained by contacting Mr. Bernard Tarralle of Recosol, Inc., at 703-524-6503.

Charlie Hess is Chief, Construction-Operations Division, Charleston District. He received his B.S. in civil engineering from Rutgers and his M.S. in engineering administration from George Washington University. At Charleston District, he is responsible for projects such as the St. Stephen Powerhouse, dredging of Charleston Harbor, regulatory functions, and civil works construction.

Geophysical Methods Applied to Detect and Map Seepage Paths at Clearwater Dam

by Dwain K. Butler
US Army Engineer Waterways Experiment Station

Emergence of a seepage zone in the downstream left abutment of Clearwater Dam during high reservoir levels prompted Little Rock District to undertake a comprehensive seepage analysis of the dam. In support of this effort, the Waterways Experiment Station was requested to conduct a geophysical survey program which would include an investigation of areas of the abutment above possible seepage paths.

Earth dams like Clearwater are expected to seep, and dam designs include drainage systems to collect and discharge seepage water into the downstream channel. Sometimes, however, seepage occurs in an unplanned manner, exceeding the capacity of the drainage system or along a path not considered in the seepage design. Excessive unplanned seepage may be just unsightly, or it may threaten the integrity of the structure. In either case, geophysical surveys can be a powerful tool in a program to detect and map seepage paths.

GEOPHYSICAL METHODS

Geophysical methods applied to seepage problems generally attempt to detect and map either (1) an anomaly due to the path taken by the seepage or (2) an anomaly due to the seepage itself (or both). In the first case, the path will be an anomalous condition in the dam, the foundation, or the abutments of the dam, such as a fracture zone or solution channel. Although it is possible to have conditions such that seepage can occur over a broad zonal region, in most cases seepage occurs initially along a localized, linear-trending flow path which must cross the axis of the dam. In the second case, the seeping or streaming water must generate a detectable anomaly.

The geophysical methods commonly used in seepage studies are: (1) electrical resistivity sounding and profiling, (2) self (or spontaneous) potential (SP) surveys, and (3) seismic refraction surveys. Various types of resistivity profiling (including terrain electromagnetic surveys) and SP surveys are most generally applicable to seepage detection and mapping. Resistivity sounding and seismic refraction surveys are used primarily in a supporting role in seepage studies.

Standard horizontal resistivity profiling is used to detect and map potential seepage paths. How well anomalies can be delineated will vary depending on the nature of the path and whether or not seepage is occurring along the path. Fracture zones will generally produce low-resistivity anomalies due to serving as an active seepage conduit or to the presence of clays and other weathering products. The resistivity anomalies due to solution features can be negative or positive: water- or clay-filled features will produce negative anomalies, while air-filled features will produce positive anomalies. If multiple electrode spacings (or loop spacings for electromagnetic surveys) are used along a profile line, depth ranges can be specified for features causing the anomalies; however, the objective of horizontal resistivity profiling is generally to map anomalies in plan.

A modified pole-dipole resistivity surveying technique can be used for locating anomalies in three dimensions and for estimating sizes of features producing the anomalies. The modified pole-dipole technique is actually a combined sounding-profiling procedure.

SP surveys measure natural electrical potential field differences at the surface of the earth. Anomalies in the electrical field can be generated by the flow of fluids in the subsurface. SP surveys for geotechnical applications are typically fixed reference point surveys, where each measurement point along a survey line or grid is relative to a reference potential, which is generally the same for the entire survey. The reference electrode is usually located as far from suspected seepage zones as possible in an area which is "quiet" electrically. Other than metal electrodes and reference wire, a digital readout millivoltmeter with a 10-megaohm or greater input impedance is all that is needed for an SP survey. Seepage paths are commonly indicated by negative anomalies relative to the reference potential or to a no-seepage condition baseline value.

The geophysical methods necessary for a seepage analysis are not difficult to use. However, a geophysical survey program must be planned based, to the maximum extent possible, on knowledge of the (1) surface geometry of the dam and associated features, (2) design and construction details of the dam, and (3) geology of the foundation and abutments. Geophysical surveys also must be considered an integral part of the overall seepage analysis by both the geophysicist and the project engineer. The survey lines should be keyed to the existing or planned piezometer network, and borehole logs near resistivity sounding locations, near seismic refraction lines, and near horizontal resistivity profile lines should be used to constrain interpretation of the results.

CLEARWATER DAM

Built in the 1940s for flood control purposes, Clearwater Dam is located on the Black River 5 miles southwest of Piedmont, Missouri. Earthfill in construction, the dam is 154 feet high with a crest length of 4225 feet and has a maximum storage capacity of 391,000 acre-feet.

Rock below the floodplain and abutments of the dam is a dolomitic limestone which is cherty, intensely fractured, and highly weathered, particularly in the abutments. Top of the limestone is pinnacled, and air-, water-, and clay-filled cavities exist below the rock surface. Top of rock is typically about 50 feet below the surface of the smaller of the two left abutment ridges.

SURVEY RESULTS

Geophysical surveys were conducted along both the base and crest of the left abutment ridge (Figure 1). Pole-dipole survey results were interpreted to identify low-resistivity (L) and high-resistivity (H) anomalous zones beneath the profile line (Figure 2). A cluster of H and L anomalies at the water table below the 60- to 65-foot profile position was considered particularly significant. It was thought that the

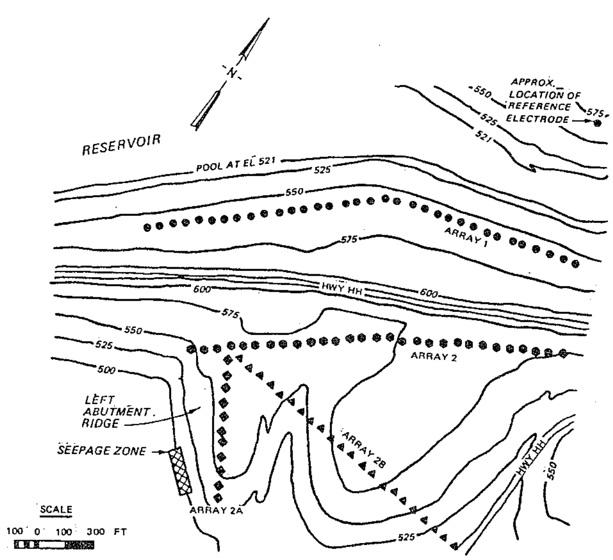


Figure 1. Clearwater Dam site map showing seepage zone and locations of SP arrays

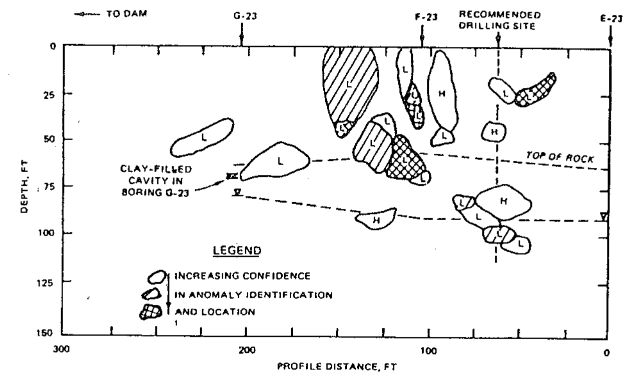


Figure 2. Pole-dipole resistivity survey results along the crest of the left abutment ridge

cluster might be a solution feature which was partially air-filled (H reading) and partially water- or clay-filled (L reading) or both. This interpretation was reinforced when a clay-filled cavity intercepted in boring G-23 coincided with the boundary of an L anomaly.

In the SP survey, the arrays were monitored as a function of time during both high and low reservoir levels. Typical results from array 2A are shown in Figure 3. The survey results for low pool conditions were very repeatable, mainly positive, and showed only small variation about a mean value of about 25 mV. Survey results for high pool conditions were less repeatable and showed considerably greater variability, and most of the SP readings were either negative or lower than their comparable low pool values.

The broad SP anomaly centered at electrodes 6 and 7 (Figure 3) coincided in location with the resistivity anomaly cluster (Figure 2), suggesting that the suspected air-filled portion of the cavity system may have become an active seepage path. The large-amplitude SP anomaly at electrode 9 was beyond the extent of the pole-dipole survey line.

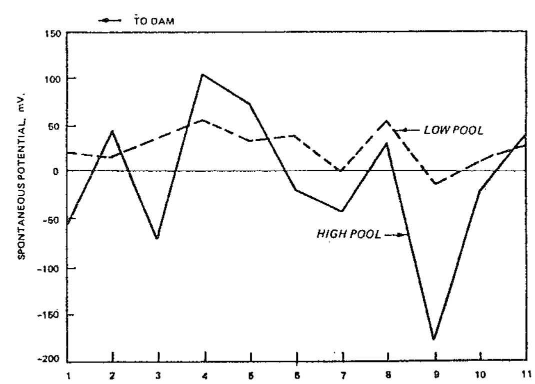


Figure 3. Results of SP survey (array 2A) for low and high pool conditions

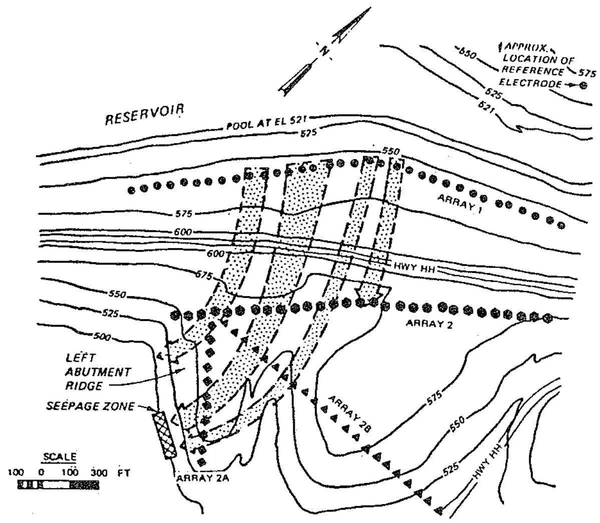


Figure 4. Site map showing seepage zone and probable seepage paths

Based on an analysis of all the geophysical surveys conducted at Clearwater, certain patterns and trends were apparent which were interpreted in terms of probable seepage paths (Figure 4). These trends were consistent with data from boring logs and with water level data collected from an extensive piezometer network at the damsite. It should be noted, however, that, given the extremely complex spatial and temporal variations of piezometer data commonly associated with seepage through carbonate rock with extensive solution features, it is doubtful that boring and piezometer data alone could be interpreted to this level of accuracy.

CONCLUSIONS

A geophysical survey program such as that conducted at Clearwater Dam can contribute significantly to a seepage analysis effort. Ideally, complementary surveys should be made and compared to existing borehole data. However, considerable experience, such as that described here, has shown that surveys can be used by themselves for seepage mapping and monitoring. Seepage paths are commonly indicated by negative anomalies relative to a reference electrode placed in a "stable" area away from seepage zones. The anomalies can also be determined relative to a no-seepage condition baseline SP survey. SP surveys are a very cost-effective way of delineating seepage paths in plan. They can be planned and interpreted by geophysicists, but the data can be collected by project personnel from in-place arrays as a function of time.

For more information on the geophysical work at Clearwater Dam, call Charlie Deaver, District Geologist, Little Rock District, at FTS 740-5665 or 501-378-5665. For more information on geophysical survey programs in general, call the author, Dwain Butler, at FTS 542-2127 or 601-634-2127.

Dwain Butler is a research geophysicist in the Earthquake Engineering and Geophysics Division, Geotechnical Laboratory, WES, and has been with the Corps of Engineers since 1971. He received his B.S. in physics from Texas Tech University, his M.S. in physics from the University of Maryland, and his Ph.D. in geophysics from Texas A&M University. He is principal investigator for REMR Work Unit 32315, "Geophysical Techniques for Assessment of Existing Structural Foundations."

Request for Articles

If you have experience in any of the areas being addressed by the REMR Research Program which might be of interest to our readers, we would appreciate your drafting an article describing your work or contacting us for assistance in doing so. Articles by persons outside the Corps are welcome and will be considered for publication so long as they are relevant to REMR activities of the Corps.

Write to: Commander and Director, US Army Engineer Waterways Experiment Station, ATTN: WESSC-A, PO Box 631, Vicksburg, MS 39180-0631. Or call Tim Ables at 601-634-2587 (FTS 542-2587).

News In Brief

Thomas Pfeffer, Operations Division, Missouri River Division, has been named to the REMR Field Review Group replacing Robert E. Pletka who is now Chief, Mechanical Facilities Section, Omaha District.

★★★★★

The 5th Field Review Group meeting for REMR was held in Portland, Oregon, on 3 and 4 April. Hosted by North Pacific Division, approximately 70 individuals attended, including 10 from other government agencies and 5 from private concerns.

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A revised list of key personnel for the REMR Research Program is included as an insert to this copy of *The REMR Bulletin*. Save it for a handy reference.

REMR Research Program

KEY PERSONNEL

	Office	*Office Symbol*	*Commercial No.*	*FTS No.*
DRD Coordinator, HQUSACE				
Jesse A. Pfeiffer, Jr.	Civil Works Programs	DAEN-RDC	202-272-0257	272-0257
Overview Committee, HQUSACE				
John R. Mikel (Chairman)	Operations Branch	DAEN-CWO-M	202-272-0242	272-0242
Tony C. Liu	Structures Branch	DAEN-ECE-D	202-272-8672	272-8672
Bruce L. McCartney	Hydraulic Design Branch	DAEN-CWH-D	202-272-0228	272-0228
Program Management				
William F. McCleese (Program Manager)	Structures Laboratory, WES	WESSC-A	601-634-2512	542-2512
CPT Wylie K. Bearup (Deputy Program Manager)	Structures Laboratory, WES	WESSC-A	601-634-3815	542-3815
Timothy D. Ables (Technology Transfer Specialist)	Structures Laboratory, WES	WESSC-A	601-634-2587	542-2587
Problem Area Leaders				
James E. McDonald (Concrete and Steel Structures)	Structures Laboratory, WES	WESSC-R	601-634-3230	542-3230
G. Britt Mitchell (Geotechnical—Soils)	Geotechnical Laboratory, WES	WESGE-E	601-634-2640	542-2640
Jerry S. Huie (Geotechnical—Rock)	Geotechnical Laboratory, WES	WESGR-M	601-634-2613	542-2613
Glenn A. Pickering (Hydraulics)	Hydraulics Laboratory, WES	WESHS-L	601-634-3344	542-3344
D. D. Davidson (Coastal)	Coastal Engineering Research Center, WES	WESCW-R	601-634-2722	542-2722
Jerome L. Mahloch (Environmental Impacts)	Environmental Laboratory, WES	WESEP-W	601-634-3635	542-3635
Paul A. Howdyshell (Electrical and Mechanical; and Operations Management)	Construction Engineering Research Laboratory	CERL-EM	217-352-7244	958-7244
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Thomas Pfeffer	Missouri River Division	MRDCO-O	402-221-7289	864-7289
James C. Wong	New England Division	NEDOD-P	617-647-8411	839-7411
Stanley R. Jacek	North Central Division	NCECO-O	313-226-6797	226-6797
John J. Sirak, Jr.	Ohio River Division	ORDCO-M	513-684-3418	684-3418
Carl F. Kress	South Pacific Division	SPDCO-O	415-556-8549	556-8549
Neal H. Godwin, Jr.	Southwest Division	SWDCO-O	214-767-2429	729-2429
ENGINEERING MEMBERS:				
William R. Hill	Lower Mississippi Valley Division	LMVED-T	601-634-5919	542-5919
Eugene Brickman	North Atlantic Division	NADEN-TF	212-264-7556	264-7556
John G. Oliver	North Pacific Division	NPDEN-T	503-221-3859	423-3859
John D. Parsons	Ohio River Division	ORDED-T	513-684-3006	684-3006
Howard S. Kobayashi	Pacific Ocean Division	PODEN-T	808-438-2837	
James W. Erwin	South Atlantic Division	SADEN-F	404-221-4256	242-4256

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Howard S. Kobayashi	Pacific Ocean Division	PODEN-T	808-438-2837	
James W. Erwin	South Atlantic Division	SADEN-F	404-221-4256	242-4256

REMR Videocassette Available

Copies of a videocassette giving a 17-minute overview of the REMR Research Program have been distributed to the Commanders of each District and Division having civil works responsibilities. The video is to be used in briefing Corps personnel about the objective of the program and to alert them to opportunities for sharing their expertise in REMR activities with others engaged in similar work. Additional copies of the videocassette are available and can be obtained by calling Tim Ables at FTS 542-2587 or 601-634-2587 or by writing Commander and Director, US Army Engineer Waterways Experiment Station, ATTN: WESSC-A, PO Box 631, Vicksburg, MS 39180-0631.

COVER PHOTOS

Overall view of Hydrofraise, a French drilling machine successfully used in Charleston District to excavate for a concrete cutoff wall at St. Stephen Powerhouse, Cooper River Rediversion Project, South Carolina.

Heavy metal guide box used to position the device along the guidewalls during excavation.

The REMR *Bulletin*

The REMR Bulletin is published in accordance with AR 310-2 as one of the information exchange functions of the Corps of Engineers. It is primarily intended to be a forum whereby information on repair, evaluation, maintenance, and rehabilitation work done or managed by Corps field offices can be rapidly and widely disseminated to other Corps offices, other US Government agencies, and the engineering community in general. Contributions of articles, news, reviews, notices, and other pertinent types of information are solicited from all sources and will be considered for publication so long as they are relevant to REMR activities. Special consideration will be given to reports of Corps field experience in repair and maintenance of civil works projects. In considering the application of technology described herein, the reader should note that the purpose of *The REMR Bulletin* is information exchange and not the promulgation of Corps policy; thus, guidance on recommended practice in any given area should be sought through appropriate channels or in other documents. The contents of this bulletin are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. *The REMR Bulletin* will be issued on an irregular basis as dictated by the quantity and importance of information available for dissemination. Communications are welcomed and should be made by writing the Commander and Director, US Army Engineer Waterways Experiment Station, ATTN: T. D. Ables (WESSC-A), PO Box 631, Vicksburg, MS 39180-0631, or calling 601-634-2587 (FTS 542-2587).

ROBERT C. LEE
Colonel, Corps of Engineers
Commander and Director
Waterways Experiment Station

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P O BOX 631
VICKSBURG, MISSISSIPPI 39180