FOCUS ON GEOENVIRONMENTAL ENGINEERING

PILE WALL CUTS OFF SEEPAGE

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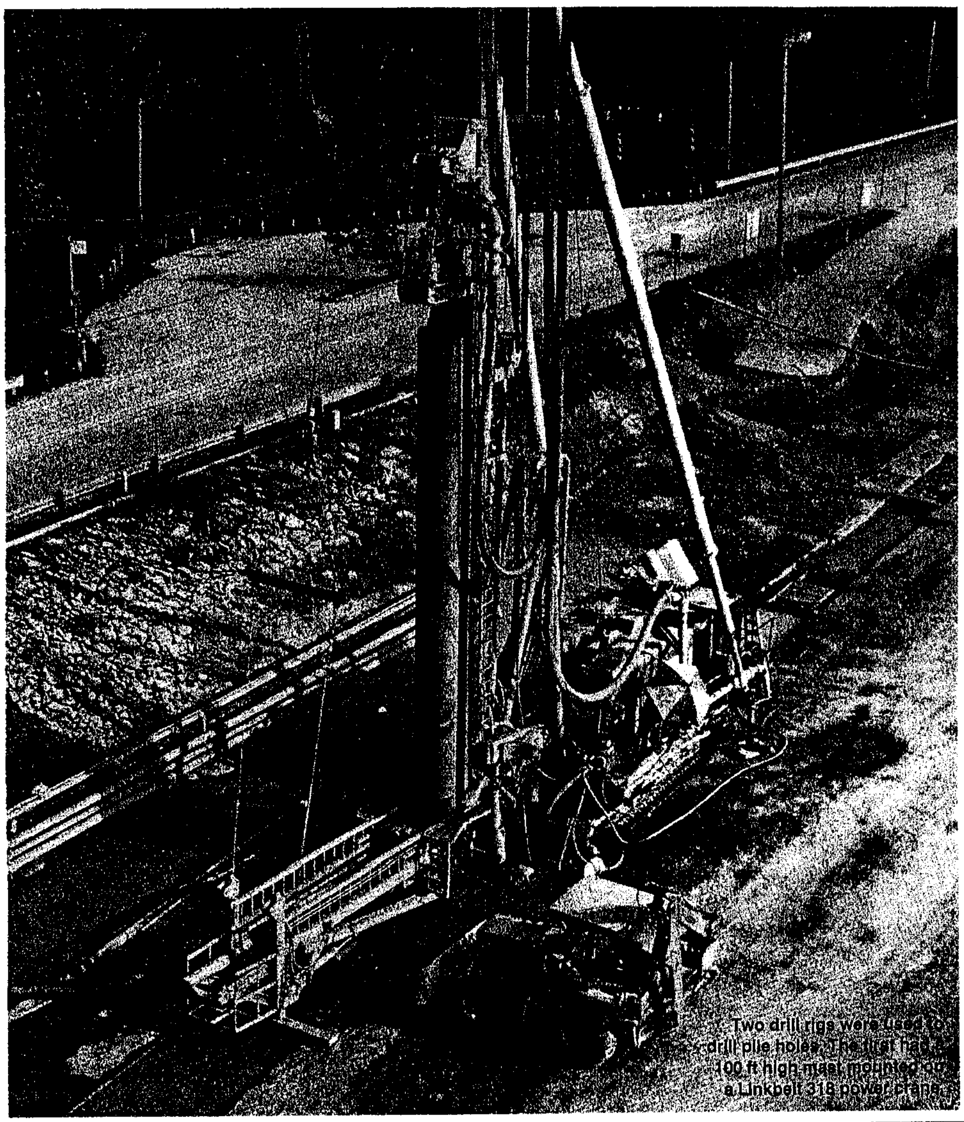
An unusual cutoff wall, constructed by the secant pile method, succeeded in drying up seepage through the permeable strata below a saddle dam in Arkansas.

A new cutoff wall design has stopped leakage below an Arkansas dam where other methods have failed since the dam's completion in 1966. The problem has not been in the main dam, a 228 ft high concrete gravity structure, but under a saddle dike separated from the dam by a 1,242 ft long zoned embankment.

Beaver Dam, which is located on the White River in northwestern Arkansas, is owned by the U.S. Army Corps of Engineers. It is flanked on the north by the main embankment and three dikes. The Corps installed a grout curtain along the centerline of dike 1 during the original construction, when its engineers identified an underlying Boone formation graben (depressed area) that was very permeable. Soon after the reservoir was filled, however, some 800 gal./min flowed from several points downstream of dike 1. Remedial grouting during 1968 to 1971 reduced the flow to some 500 gal./min; lowering the flood-control pool did not affect seepage, but only curtailed flood-management capacity.



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By February 1988 the Corps had designed a "positive" concrete cutoff wall to be installed in the bedrock upstream of the cove of dike 1. The first attempt to construct a slurry-trench wall, using the rock-milling technology of the French-built "12000 Hydrofraise," failed. Apparently, in-situ strength of the fresh rock was higher than anticipated and could not be excavated economically.

In August 1990, the Rodio Nicholson Joint Venture won a contract, based on the concept of forming the wall by secant large-diameter concrete piles. This method had been developed for a similar cutoff wall at Khao Laem Dam in Thailand in the early 1980s. We proposed drilling the bedrock with down-the-hole hammers with drill bits 34 in. in diameter. Construction of the wall began in October 1992 and lasted 22 months.

CONSTRUCTION CHALLENGES

This massive and critical dam-rehabilitation project involved major geological, logistical and quality assurance/quality control (QA/QC) challenges that were eased by the benefits of a formal partnering

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process by the owner and contractor throughout. This was important during evaluations of construction techniques that were changed in response to unforeseen site and/or geotechnical problems.

Geological conditions required the wall to be 80–185 ft deep along a length of 1,475 ft for a total area of 107,700 sq ft. The graben below dike 1 extends below 200 ft of the main embankment and is downfaulted about 200 ft, with some planes infilled by competent breccias or solution deposits. Between the relatively impermeable overburden (15–40 ft deep) and bedrock lies the weathered siliceous and cherty Boone infilled with soft clay and rock fragments. The sound rock contains a network of interconnecting cavities that locally extend down to elevation 974 ft (the top of the dike is at elevation 1,142 ft).

Considerable work had to be done before drilling began. From a work platform about 65–75 ft wide benched into the upstream face of dike 1, embankment and overburden materials were excavated by slurry-wall techniques to the top of the weathered rock and replaced by concrete. The replacement excavation comprised 4,713 sq yd and consumed 7,011 cu yd of 3,000 psi concrete. This created a competent, in-situ 4 ft thick "casing" for the piles that would be drilled through.

Several operational rules were enforced. Drilling was permitted only more than 30 ft from an adjacent open pile not entirely in rock. At least 48 hr had to elapse after concreting a primary pile before drilling the next primary pile, and secondary piles were drilled only when the concrete of the two adjacent primaries had reached at least 2,000 psi, unconfined compressive strength.

EQUIPMENT

Two drill rigs were used for drilling the pile holes. The first, originally used at Khao Laem Dam, had a 100 ft high mast mounted on a Link Belt 318 crawler crane. It carried a 200 hp hydraulic-power pack, powering a rotary head and drill-rod loader. The second machine, designed and built on site, was generally a more powerful version of the original, comprising a Manitowoc 4100 crane, a power pack, Watson rotary head and two lateral-rod changers.

The 30 ft long drill rods had a 32 in. outside diameter with an inner air passage of $11\frac{7}{8}$ in. Each rig could drill 70 ft in a single pass. Depending on ground conditions, rod rotational speed varied from 2 to 10 rpm. We used different models of air-powered, down-the-hole hammers, some only on trial. The main types, each equipped with a 34in. diameter bit, were the Ingersoll Rand DHD130A and the Sandvik XL24.

A second drill rig, designed and built on site, was composed of a Manitowoc 4100 crane, a power pack, a Watson rotary head and two lateral rod changers.

Each hammer was equipped with an internal check valve to allow underwater operation. In one successful experiment, an Ingersoll Rand CD24-5 cluster drill penetrated a zone of very abrasive cemented (Sylamore) sandstone. This equipment comprised a 24 in. diameter shell, housing five conventional down-the-hole hammers, each 8 in. in diameter. All drilling tools were maintained and serviced on site by a major subcontractor, Keystone Drilling Services, Inc. of Eureka Springs, Ark.

Compressed air at 150 psi came from a bank of nine static electric-powered compressors, each with a volume capacity of 960 cu ft/min at 300 psi maximum pressure. They were arranged in two groups of four each, with one spare or supplemental, depending on rig requirements. Drill penetration rates for primary piles ranged from 8 to 21 ft/hr; for secondaries, rates ranged from 13.5 to 23 ft/hr. The rates varied considerably from area to area and from rig to rig.

In addition to the material testing equipment, several QA/QC instruments included survey and laser systems for setting up the drill rigs and controlling drill-string alignment, plus a device for controlling hole verticality. Work done by subcontractors included providing concrete from a batching plant, concrete coring and testing, preliminary site surveying, electrical installations and site restoration.

CONSTRUCTION

Most piles were constructed by a standard sequence that began with setting up the drill rig using theodolites and lasers. Following that were (1) drilling, varying the air pressure to meet local geological conditions and monitoring the mast verticality after each rod change; (2) rod extraction and hole-depth sounding; (3) debris removal, by airlift, bucket or grab, from the pile toe; (4) verification of hole verticality by a "submersible reverse plumb bob" device; and (5) concrete placement via 10 in. diameter tremie tubes fed by a 1.5 cu yd hopper with screen. These tubes were progressively withdrawn during filling, with the toe always embedded 10–20 ft in the concrete.

As work progressed and these standard construction details were reviewed by the Corps and contractor, several other tasks were necessitated, including:

• Downstaging. We had foreseen potential problems of drilling through the unstable weathered rock lying between the overburden replacement and bedrock. When these prevented continuous drilling to full depth, we extracted the rods and sounded the pile depth. If more than 2 ft of loose material was removed, we backfilled the hole with concrete from the surface. After at least 24 hr, the hole was redrilled through the unstable zone. Some of the 71 holes completed this way required three successive treatments that involved 6,087 ft of redrilling and 2,111 cu yd of concrete.

- Pretreating the ground by pressure grouting. To overcome a layer of coarse gravel, we test-grouted a 120 ft section through two rows of holes drilled 4 ft apart, one row 1 ft upstream and the other 1 ft downstream of the cutoff. Cementitious mixes were injected during withdrawal of steel casings 7 in. in diameter, drilled to the level of "recoverable rock." This work totaled 3,483 ft of drilling and 282 cu yd of grout, allowing 14 piles to be installed in this grouted zone without the need for downstaging. The trial showed that the principles of grouting could be used to fill voids and permeate loose, cohesionless materials in the weathered area.
- Grouting to stabilize holes. Instability of the weathered rock posed severe problems in areas B and D, where the work platform settled and sinkholes appeared. We suspended work on nearby piles and excavated the sinkholes, then backfilled them with lean-mix concrete. From a number of alternatives, we selected a modified grout-based method for treating the work platform, embankment, overburden, weathered rock and top 3–5 ft of sound rock. Basically, the percussive drilling was suspended when stable depth had been reached. The rods were then reintroduced, but with a 32 in. diameter rock-roller bit at their tips. Grout was pumped through the rods and bit while the drill string was rotated and advanced through the unstable materials or voided zones. With repetition until stable bedrock was reached, this process achieved efficient stabilization and permitted use of standard construction methods for hole completion.

We used this method on 51 piles in area D, some of which required up to six treatments. Those piles required more than 1,470 cu yd of grout plus, in some of the piles, 132 cu yd of concrete. We used the same method for all holes in area B, where the weathered rock was even more unstable. On one occasion there were 10 repetitions, due to efforts to recover a stuck excavating bucket. Total grout for this area was 4,971 cu yd, and 2,553 cu yd of downstage concrete was used, far more than the volume of neat drilled holes because of the cavities encountered.

MONITORING THE SEEPAGE

In addition to the existing instrumentation, the Corps installed several devices to measure the seepage through dike 1. These included Parshall flumes, a V-notch weir, a French drain weir and an artesian well. Where seepage had been recorded at several hundred gallons per minute (varying with the lake level) prior to construction, all devices showed sharp decreases with successive completions in the different areas. By August 1994, all five seepage areas had dried up, and the total underseepage was barely 4 gal./min. Flows of less than 1 gal./min have been noted during dry spells. ▼

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