# Contemporary Grouting Practices In "Composite" Seepage Cutoff Construction

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Grout curtains have been used in the U.S. to control seepage in rock masses under and around dams of all types since the 1890s. For a variety of reasons, the long-term performance of many of these curtains has not been satisfactory, especially in lithologies containing soluble and/or erodible materials. Foundation remediation in such instances traditionally involved regrouting, often using the same means, methods, and materials whose defects were the underlying cause of the inadequacy in the first place.

Disillusionment with the apparent inability of these traditional grouting practices to provide a product of acceptable efficiency and durability led to the chorus of "grouting doesn't work" voices in the industry from the mid-1970's onwards. The fact that effective and durable grout curtains were being installed successfully elsewhere in the world, using different perspectives on design, construction, and contractor procurement processes, largely escaped the attention of the doubters.

Partly due to the anti-grouting lobby, equally in response to indisputable geological realities and challenges, and building on technical advances in "slurry wall" techniques, the concept and reality of "positive" cutoffs became the mantra for major embankment dam foundation rehabilitation in North America since 1975. Such walls, built through and under existing dams by either the panel wall technique (Figure 1), or secant large diameter piles, are constructed using high strength to plastic concrete. In contrast to grout curtains where well over 90 percent of the cutoff is in-situ rock, these "positive" cutoffs were, in theory, built of 100 percent pre-engineered material having well-defined properties.

Such "positive" walls are essential to provide long-term cutoff across karstic features which contain residual, potentially erodible material; such material simply cannot be grouted with a degree of uniformity and confidence to assure satisfactory long-term performance. To date, almost 7.5 million sf of concrete cutoff have been installed in 20 projects in the U.S.

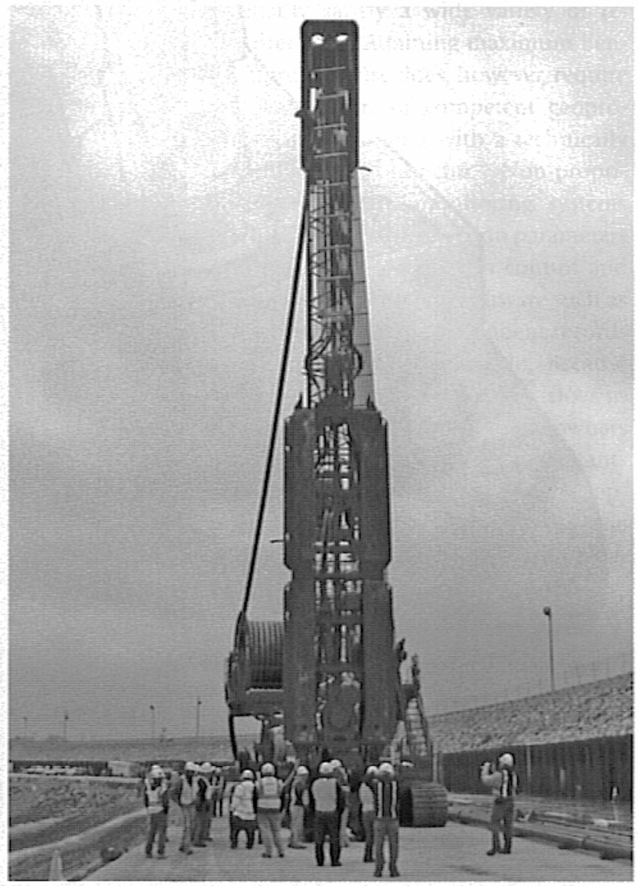

**Figure 1. Hydromill equipment for concrete cutoff wall excavation.**

From the mid-1980s, a new wave of dam grouting concepts began to emerge. So by the time of the seminal 2003 ASCE grouting conference in New Orleans, the revolution in North American practice for dam foundation grouting had been clearly demonstrated. The concept of a Quantitatively Engineered Grout Curtain was affirmed. Combining the best of both worlds — grout curtains and concrete cutoffs — has lead to the evolution of the "composite" cutoff concept.

## "Composite" Cutoffs: The Basic Premise

In recent years, a number of projects have featured the construction of a concrete cutoff wall installed through the dam and into karstified carbonate bedrock. The basic premise of such a "positive" cutoff is clear and logical: the presence of large, clay-filled solution features in the bedrock will defeat the ability of a grout curtain – even when designed and built using best contemporary practices – to provide a cutoff of acceptable efficiency and durability. This is particularly important when permanent "walk-away" solutions which must be robust, reliable, and durable are required.

Rock fissure grouting techniques are incompatible with satisfying a "walk-away" solution in the presence of substantial clayey infill materials. However, the benefits of a concrete cutoff come at a substantial premium over those provided by a grout curtain. A typical industry average cost for a grouted cutoff is about $25-$50/sf. The cost of a concrete cutoff can be 4 to 10 times this unit cost range, depending on the technique, ground conditions, depth of the cutoff, and nature of the site logistics. Furthermore, the construction of a concrete cutoff wall through the typical karstified limestone or dolomite rock mass will involve excavating the rock and backfilling with a material having a strength of 4,000 psi or less. In effect, great effort and expense is expended to provide a membrane (through the greater part of the project) which is of lower strength than the rock mass excavated to construct it.



Another practical factor that has often been overlooked is that construction of a concrete wall may simply not be feasible in ground conditions which permit the stabilizing medium (i.e., bentonite) or the drill flush (air or water) to be lost into the formation. In the extreme, either of these phenomena could create a dam safety threat as well as the loss of very expensive excavation or drilling equipment at depth. The solution in such situations has been to suspend the wall construction and to systematically and intensively pretreat the formation by grouting.

Pretreating involves drilling, water pressure testing, and grouting to improve the rock mass. It also generates a more detailed site investigation – at very close centers – along the whole extent of the anticipated concrete cutoff area. It would be reasonable, therefore, to propose that the data from these pretreatment programs be used to review the true required extent of the subsequent concrete wall, and thereby reduce overall project costs with sound engineering justification.

The concept may then be taken a stage further. Instead of drilling and grouting only as a remedial/facilitating operation under emergency conditions, specify it as an original design concept to:

- allow the location and extent of the major karstic features, which require cutoff with a concrete wall, to be well defined;

- pretreat the ground, especially the epikarst (upper most weathered zone of carbonate rocks), to an intensity that bentonite slurry or drill flush will not be lost during the concrete wall construction; and

- grout, to a verified engineered standard, the rock mass around and under the karstic features where it does not contain erodible material in its fissures.

Embracing these precepts leads to the concept of a "composite cutoff." Thus, a "composite cutoff" can be defined as a concrete wall surrounded by a contiguous and enveloping grout curtain. The concrete wall provides certitude of long-term performance in potentially erodible materials and the grout curtain provides acceptable levels of impermeability and durability in those portions of the rock mass with minimal erodible fissure infill material.

## Grouting for a "Composite Wall"

The essential features of successful "composite cutoff" wall construction include:

- preliminary assessment, investigation, and design;

- preparation of contract documents and choice of contractor procurement methods;

- technical considerations;

- cutoff wall construction requirements; and

- asessment of cutoff effectiveness.

*Preliminary Assessment, Investigation, and Performance Design.* The first step is to research and utilize all available historical data which may be useful in developing a tentative geo-structural model. Next, a site investigation must be conducted to test the geo-structural model and to provide prospective bidders with relevant information. The third step is to develop an initial estimate of the extent of the composite cutoff and its respective components. Then, the adequacy of the existing dam and foundation instrumentation must be assessed, new and replacement instrumentation must be designed and installed, and the monitoring frequency protocols adapted as needed to meet project requirements.

*Preparation of Contract Documents and Choice of Contractor Procurement Methods.* The features of the contract documents and contractor procurement methods can be as important to project success as the engineering evaluations and methods used for composite wall construction. Of key importance is the use of a performance rather than a prescriptive specification wherein performance goals and verification methods are defined and unacceptable methods and techniques are stated. In addition, specialty contractor services should be procured on the "Best Value" basis, and not "Low Bid."

*Technical Considerations.* If flush water is lost during investigatory drilling, slurry will be lost during wall excavation unless pretreatment is provided in these areas. The minimum treatment should include two rows of inclined holes, one on either side of the wall location (Figure 2). The rows may be 5-10 ft apart, and the holes in each row will typically be at 5- to 10-ft centers. The longitudinal inclination of the holes (typically 15° off vertical) will be different in each row.

**Figure 2. Contemporary drilling rig installing inclined holes.**

The grout curtain should be installed to at least 50 ft below the toe of the cutoff to assure adequate coverage and to search for unanticipated problems. The treatment can be regarded as equal parts an investigatory tool, a ground pretreatment operation, and a means to clean and seal rock fissures. Special attention must be paid to the epikarstic horizon, which will typically require special grouting methods such as Multiple Packer Sleeve Pipe descending stages and special grout mixes.

A test section at least 100 ft long should be constructed and verified to finalize the Method Statement for the remaining grouting work. A residual permeability of 10 Lugeons or less (approximately equal to $1 \times 10^{-4}$ cm/sec) should be achieved within the cutoff area, and a lower permeability at depths below the cutoff toe. Verification holes should be cored and observed in situ with a televiewer to demonstrate the thoroughness of the grouting.

Execution will involve stage water tests; balanced, modified, stable grouts; and computer collection, analysis, and display of injection data. During verification hole drilling, particular care must be taken to assure that no drill rods are abandoned within the alignment of the wall since the rods will interfere with the cutoff excavation techniques. Grouting pressures at refusal should be at least twice the foreseen maximum slurry pressure exerted during panel construction.

*Cutoff Wall Construction.* The test section should be established in a structurally and geologically non-critical area, which does not contain the deepest extent of the foreseen concrete wall. The test section can, however, be integrated into the final works if it is proved to have acceptable quality.

*Assessing Cutoff Effectiveness*. The protocols for instrument readings during remediation must be extended afterward, although usually at a somewhat reduced frequency. The data must be evaluated in real time to demonstrate that the remediation meets the performance criteria. The potential need for supplemental remediation should be recognized, but this may become clear only when the impact of the remediation of the dam/foundation system is fully understood. Finally, owners and designers should publish the results of these longer-term observations so that their peers are aware of these issues before engaging in their own programs of similar scope and complexity.

## What Does the Future Hold?

Between 1975 and 2006, almost 7.5 million square feet of cutoff wall were installed on 20 projects in the U.S. This trend will only increase as our nation's infrastructure ages. The lessons learned from these projects and from around the world will be invaluable as the geo-industry seeks to improve the effectiveness and variety of the methods available. In rock masses which contain significant amounts of erodible and/or solutionable material, "composite wall" construction concepts will become the industry standard.

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ONE ORGANIZATIONAL MEMBER'S PERSPECTIVE

# A Different Kind of Stimulus

*Kord Wissmann, Ph.D., P.E., M.ASCE*

**Kord Wissmann**

My friend Mike Cowell, president of GeoStructures, Inc., told me that he hired a new employee and asked her what she wanted to do.

"I want to change the world."

What!? Who turned the clocks back to 1969?

Funny thing though, she and a whole lot of other folks are out there rethinking this whole shooting match. Many are now saying, "I think I want to change the world too."

I want to serve people more. I want to help somebody. I want to make a difference in my community, my country, my profession. I want to build meaningful, beautiful structures that positively affect our society and our clients. I don't want to be a physician, a stock broker, a mergers-and-acquisitions specialist, a lawyer – don't value money quite like I used to. I want to be a Civil Engineer and I want to make a difference.

At a recent conference, I had the pleasure of meeting futurist Glenn Hiemstra. Glenn teaches that it's not just the future that's important, it's how we affect the present to achieve a preferred future. "The future is what we make it to be."

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