Seepage Cutoffs for Dams: Reassertion of the “Composite Wall” Concept

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Contents of Today’s Presentation

1. Review of Concrete Cut-Off Wall Construction

2. Review of Contemporary Grout Curtain Technology (Quantitatively Engineered Grout Curtains)


4. Final Remarks
1. Concrete Cut-Off Walls Using the Panel Method

Clamshells (cable or hydraulic)
1. Concrete Cutoff Wall Using the Conventional Secant Pile Method

Beaver Major Rehabilitation

Dike 1
Cutoff Wall Construction Area
### U.S. Case Histories to Date

<table>
<thead>
<tr>
<th>Project Name and Year of Recognition</th>
<th>Contractor</th>
<th>Type of Cut-Off</th>
<th>Type of Wall</th>
<th>Special Conditions</th>
<th>Purpose of Wall</th>
<th>Project Information</th>
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*Gostancho* denotes projects that were completed in the U.S. under different business identities over the years. "Gostancho" is used herein as the general term.

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### Project Listing Showing Chronology

Type of Cut-Off and Specialty Contractor

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Concrete Cut-Offs for Existing Embankment Dams

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<th>Type of Construction</th>
<th>Number of Projects</th>
<th>Square Footage</th>
<th>Total</th>
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<td>Mainly Clamshell</td>
<td>7</td>
<td>51,000</td>
<td>3,986,320</td>
</tr>
<tr>
<td>Mainly Hydromill</td>
<td>9</td>
<td>104,600</td>
<td>2,389,415</td>
</tr>
<tr>
<td>Mainly Secant Piles</td>
<td>4</td>
<td>12,000</td>
<td>1,050,700</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>20</strong></td>
<td><strong>531,000</strong></td>
<td><strong>7,426,435</strong></td>
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Note:
1. This is the cumulative result of 32 years of activity to date. During the next 5 years, USACE alone will likely conduct a similar dollar value again, on 3 dams.

Technologies Not Included in this Presentation
1) Backhoe
2) Conventional Deep Mixing

3) TRD
4) CSM

Green – Typical range
Orange – Less common but still relatively straightforward
Red – Extensive situations
White – Not feasible

Category 1 Methods
Category 2 Methods
2. Review of Contemporary Grout Curtain Technology: The Evolution of the Revolution

Revolutionary Elements 1996-Present

- Quantitative Design
  - Intensity of Grouting consistent with design assumptions and requirements
- Hole Orientation and Depth selected consistent with site geology
- Stable Grouts with multiple admixtures
- Pressures – Maximum safe pressure utilized
- Data Acquisition – Flowmeters and Pressure Transducers
- Data Recording – Computer Monitoring by experienced Engineer or Geologist
Example 1: Grout Design
Characteristics of Unstable Water Cement Grouts

- Cement + Water
- Considerable Bleed Potential
- Low Resistance to Pressure Filtration
- Unorganized Particles
- Unpredictable Behavior due to Changing Rheology During Injection
- Marginal Durability

Grouting Theory - Neat Cement Grouts

Penetration distance controlled by pressure, cohesion, changing rheology, particle agglomeration, and/or bridging

Densification of Grout

Substantial water loss through pressure filtration

Post-grout Bleed Channels

Result: high residual permeability and poor durability.
Characteristics of Balanced Stable Water Cement Grouts

- Cement + Water + Rheology Modifiers
- Zero Bleed
- Resistant to Pressure Filtration
- Organized Particles
- Minimal Change in Rheology During Injection

Grouting Theory - Balanced, Stable Grouts

- Refusal penetration controlled by pressure and cohesion
- Minor Densification of Grout
- Minimal water loss through pressure filtration
- Zero or Negligible Bleed Channels

Result: low residual permeability and excellent durability.
Common Additives to Balanced Stable Cement-Based Suspension Grouts

- Water
- Portland Cement (typically Type III)
- Bentonite
- Silica Fume
- Flyash (usually Type F)
- Welan Gum or other Viscosity Modifier
- Dispersant (SuperP)

Example 2: Computer Monitoring of Grouting
Advantages: Grouting

- Measurement Accuracy Significantly Improved
- Real Time Data is obtained (2-10 seconds vs. 5-15 min.)
- Allows one to use higher pressures with confidence; Dilation and Lifting easily picked up on screen
- Formation Responses to procedure changes (mix or pressure) are known immediately
- Accelerates the Work
- Reduces Inspection Manpower Requirements (~25% for Level 2 Technology and ~60% for Level 3)
- Permits reallocation of resources to analyze program results and recommend cost effective program modifications.
Advantages: Interactive Geology

- Logical organization of Geotechnical and Geological Data
- Electronic link between data
- Eliminates sorting through paper logs, photographs, lab test results, etc. to interpret conditions

"Virtual Rock Core" Showing Weathered Partially Clay
Filled Joints in Limestone Formation
3. “Composite” Cut-Off Solution for Carbonate Foundations

**Basic Principles**

- Modern grouting methodologies can be relied upon to provide durable, effective cut-offs, provided significant fine material (e.g., fine karstic ditritus) is not retained in the grout/rock structure comprising the cut-off.
- Concrete cut-off walls are essential to provide durable, effective cut-offs through rock masses found to contain significant amounts of karstic material which can be eroded under service conditions.

- However, the price of a concrete cut-off wall can be up to 10 times that of an equivalent grout curtain and the huge equipment required may be incompatible with site logistics. Furthermore, most of the cut-off will be in rock of high strength and/or minimal clay presence: why excavate 20,000 psi rock to replace with 3,000 psi concrete?

…and pay for the privilege!
Basic Premise

- Conduct high quality drilling and grouting operation along the whole alignment as the first, engineered step, not as an intermittent and/or emergency operation.

- This operation will:
  1. Provide a very high intensity of site investigation data upon which to optimize the depth and extent of the subsequent concrete cut-off wall.
  2. Pretreat the epikarst and other voided areas to prevent massive, sudden loss of bentonite slurry during the excavation for the concrete cut-off. (Potentially a dam safety issue.)
  3. Provide a cut-off in “clean” rock conditions, of an engineered residual permeability.

Build cut-off wall only where required.

Highlights of the Drilling and Grouting Program

- Minimum 2 rows of inclined holes, either side of the potential cut-off wall alignment.
- “Measurement While Drilling” all holes.
- Intense water pressure testing before, during and after grouting to quantify conditions.
- Use of Optical Televiewer in special features.
- Use of modified, stable HMG grout mixes, and LMG as appropriate. (Absolute refusal.)
- Build cut-off wall only where required.
Illustrative Examples: “Clearwater” Case

Epikarst is found during pregrouting to an average of 30 ft. b.g.s. The concrete cut-off needs only to be installed to 35 ft. b.g.s.

“Wolf Creek” Case

Heavily karstified horizons are found at depth. Therefore the concrete cut-off is required for the full extent. The grouting has pretreated the karstic horizons to permit safe concrete cut-off construction.
Discrete karstic features have been found, structurally driven. Thus, individual concrete cut-offs can be installed, after drilling and grouting has confirmed the extent of these features and has pretreated them to permit safe concrete cut-off construction.

5. Final Remarks

- The U.S. has now developed an excellent (but small) pool of experienced, well resourced, specialty contractors using state-of-practice means, methods, and materials.
- New technologies permit fast collection and processing of geotechnical data to produce very accurate geological models which can be updated “in real time.”
- Attempting to “shoe horn” one particular remedial technology or methodology into a specific site is misguided, and will result in:
  - ineffective seepage control performance;
  - construction claims;
  - dam safety issues;
  - the need for future remediation;
  - possible abandonment of the project.
5. Final Remarks (continued)

- The use of “composite” cut-offs has significant schedule and cost advantages. However, at a time when specialty construction companies are very busy, “sharing the load” (between two technologies) may help the ambitious rehabilitation program of the next 5 years to be accomplished within schedule and cost-effectively.

- For the good of the industry, it is essential that long-term performance information is published. (Federal Agencies and/or their A/E’s are best positioned to author these.)

- On each project, modifications to foreseen means and methods are inevitable, and prompt attention and resolution are essential.

- Improve performance associated with elimination of defects, e.g., clay in curtain, or defective juts in wall.

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