Seepage Cutoffs for Dams: Reassertion of the "Composite Wall" Concept

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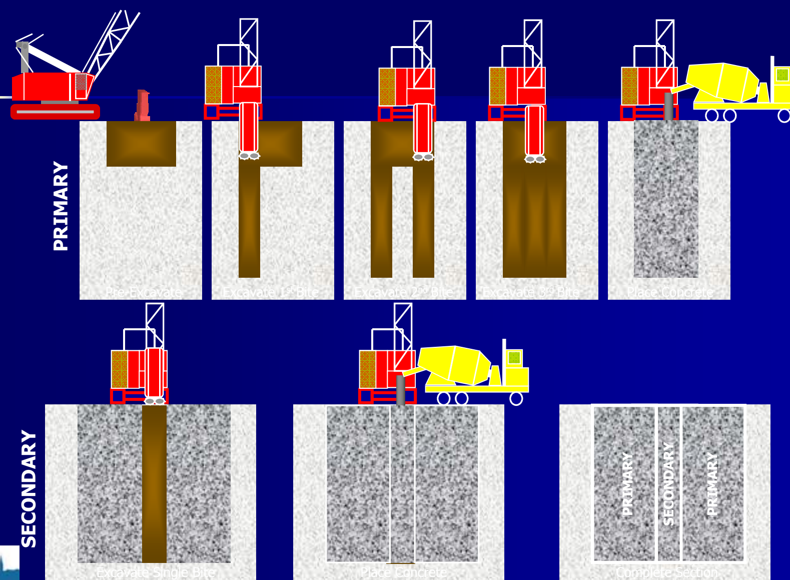
1. Review of Concrete Cut-Off Wall Construction
2. Review of Contemporary Grout Curtain Technology (Quantitatively Engineered Grout Curtains)
3. "Composite" Cut-Off Solutions for Carbonate Foundations
4. Final Remarks

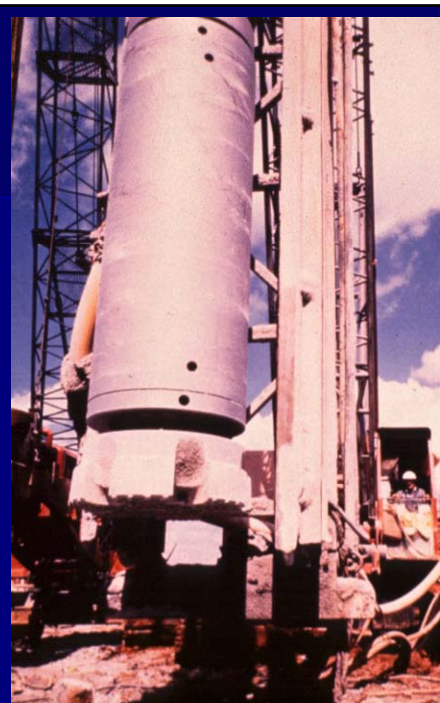
1. Concrete Cut-Off Walls Using the Panel Method



Clamshells
(cable or hydraulic)

Hydromill
("Cutter")

1. Concrete Cutoff Wall Using the Conventional Secant Pile Method



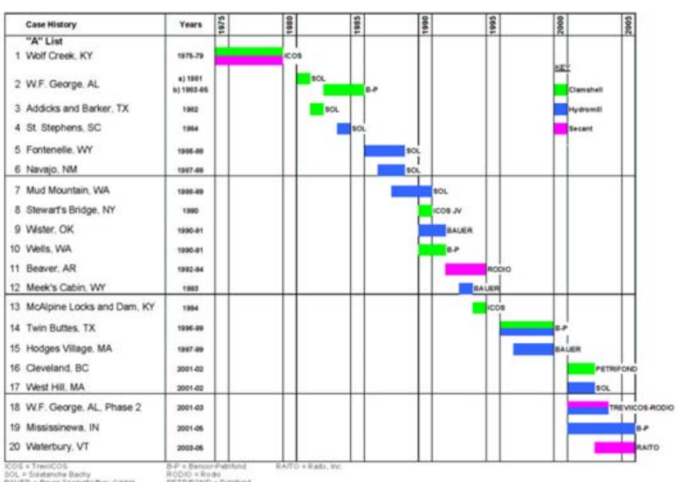
W.F. George, AL

U.S. Case Histories to Date

Dam Name and Year of Remediation	Contractor	Type of Wall	Composition of Wall	Ground Conditions	Purpose of Wall	Scope of Project: Area	Scope of Project: Min. Width	Scope of Project: Depth	Scope of Project: Length	References
1. WOLF CREEK, KY. 1975-1979	ICOS	24-inch diameter Primary Piles, joined by 24-inch wide clamshell panels. Two phases of work.	Concrete.	Dam FILL, and ALLUVIUM over argillaceous and karstic LIMESTONE with cavities, often clay-filled.	To provide a "Positive concrete cut-off" through dam and into bedrock to stop seepage, progressively developing in the karst.	270,000 sf (Phase 1) plus 261,000 sf (Phase 2)	24 in	Max. 280 ft	2,000 ft plus 1,250 ft	• ICOS brochures (undated) • Fetzer (1988)
2. W.F. GEORGE, AL 1981 1983-1985	Soletanche (Phase 1) Bencor-Petrifond (Phase 2)	26-inch thick panels using cable and kelly-mounted clamshell 24-inch panels 15-27 ft long	Plastic concrete 3,000 psi Concrete	Random, impervious FILL with silty core over 25-30 ft ALLUVIUM over chalky LIMESTONE	To provide a "positive concrete cut-off" through the dam and alluvials.	130,000 sf (Phase 1) plus 951,000 sf (Phase 2)	26 in 24 in	Max 138 ft 110-190 ft	Approx. 1,000 ft 8,000 ft	• Soletanche Brochure (undated) • Bencor Brochure (undated)
3. ADDICKS AND BARKER, TX. Completed in 1982 (Phase 1 took 5 months)	Soletanche*	36-inch thick panel wall with clamshell excavation using Kelly.	Soil-Bentonite.	Dam FILL over CLAY.	To prevent seepage and piping through core.	450,000 sf (Phase 1) plus 730,000 sf (Phase 2)	36 in	Max 66 ft typically 35 to 52 ft	8,330 ft plus 12,900 ft	• Soletanche website.
4. ST. STEPHENS, SC. 1984	Soletanche	24-inch-thick concrete panel wall, installed by Hydromill. Plus upstream joint protection by soil-bentonite panels.	Concrete and soil-bentonite.	Dam FILL, over sandy marly SHALE.	To provide a cut-off through dam.	78,600 sf (concrete) plus 28,000 sf (soil-bentonite)	24 in	Max. 120 ft including 3 ft into shale	695 ft	• USACE Report (1984) • Soletanche (various) • Parkinson (1986) • Bruce et al. (1989)

* Soletanche have operated in the U.S. under different business identities over the years. "Soletanche" is used herein as the general term.

Project Listing Showing Chronology Type of Cut-Off and Specialty Contractor



Concrete Cut-Offs for Existing Embankment Dams

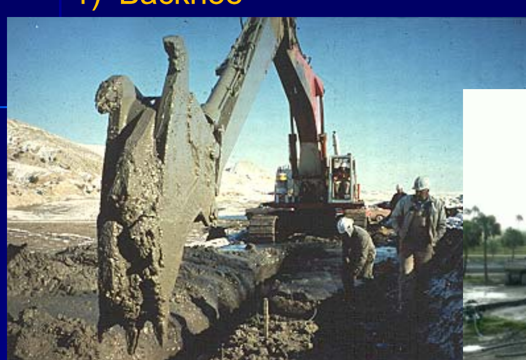
Type of Construction	Number of Projects	Square Footage		
		Smallest	Largest	Total
Mainly Clamshell	7	51,000	1,400,000	3,986,320
Mainly Hydromill	9	104,600	850,000	2,389,415
Mainly Secant Piles	4	12,000	531,000	1,050,700
Total	**20**			**7,426,435**

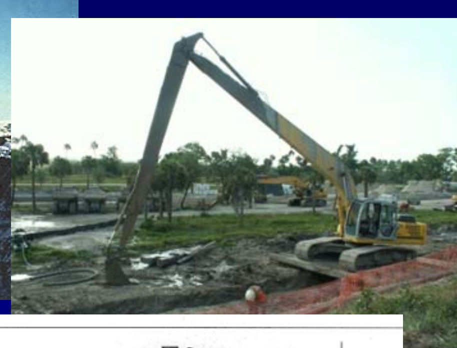
Note:

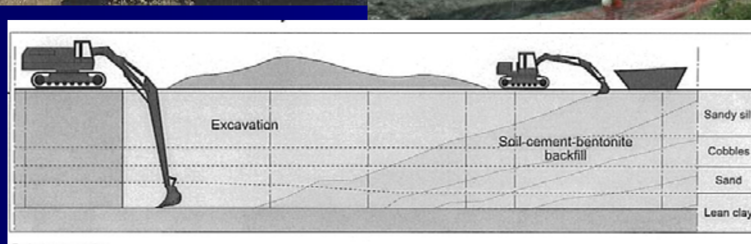
1. This is the cumulative result of 32 years of activity to date. During the next 5 years, USACE alone will likely conduct a similar dollar value again, on 3 dams.

Technologies Not Included in this Presentation

1) Backhoe

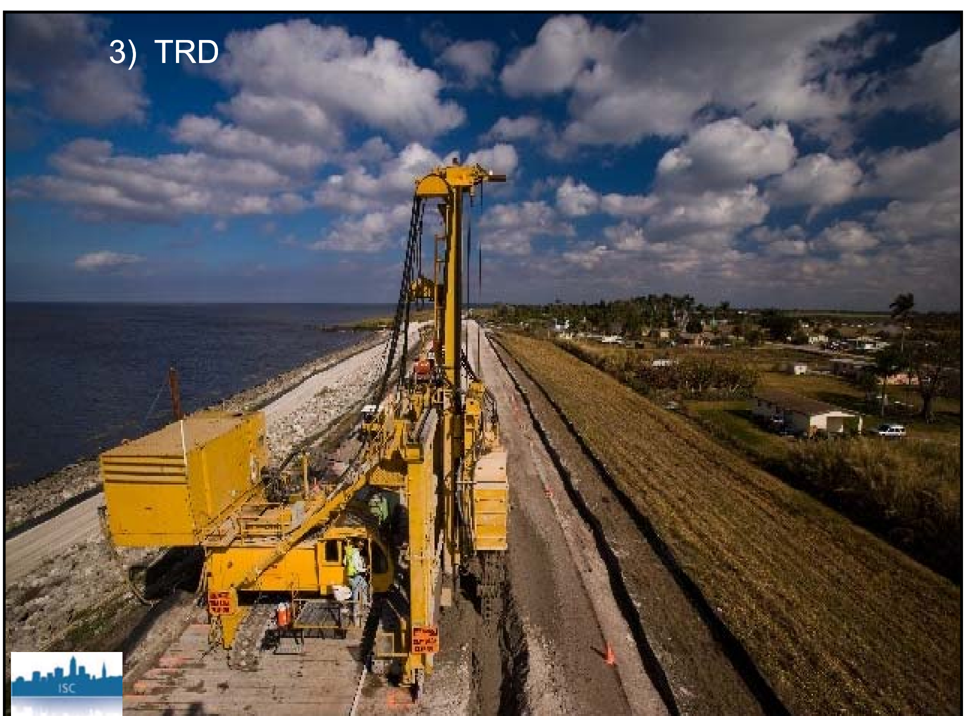






2) Conventional Deep Mixing

3) TRD



4) CSM

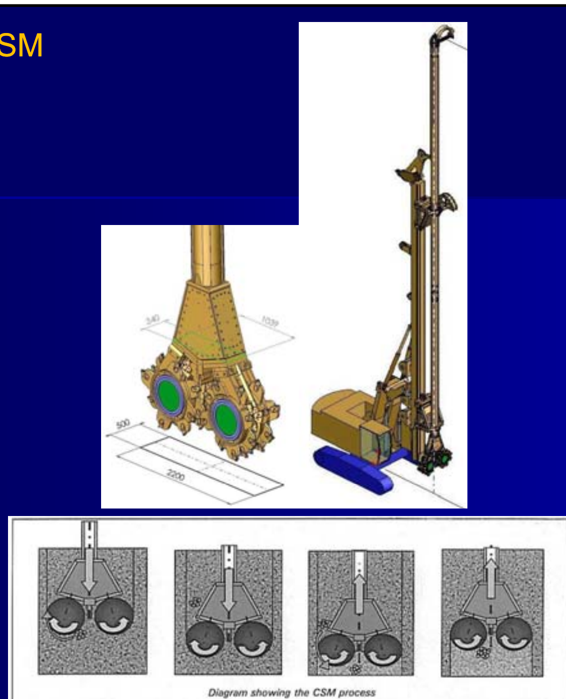
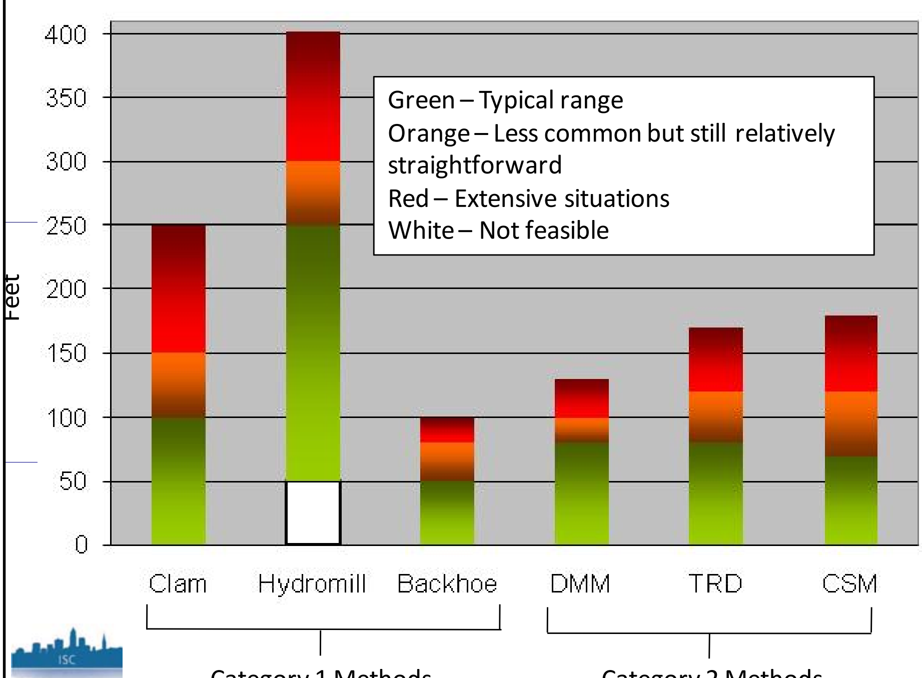


Diagram showing the CSM process


400
350
300
250
200
150
100
50
0
Feet
Green – Typical range
Orange – Less common but still relatively straightforward
Red – Extensive situations
White – Not feasible
Clam
Hydromill
Backhoe
DMM
TRD
CSM
Category 1 Methods
Category 2 Methods

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

Revolutionary Elements 1996-Present

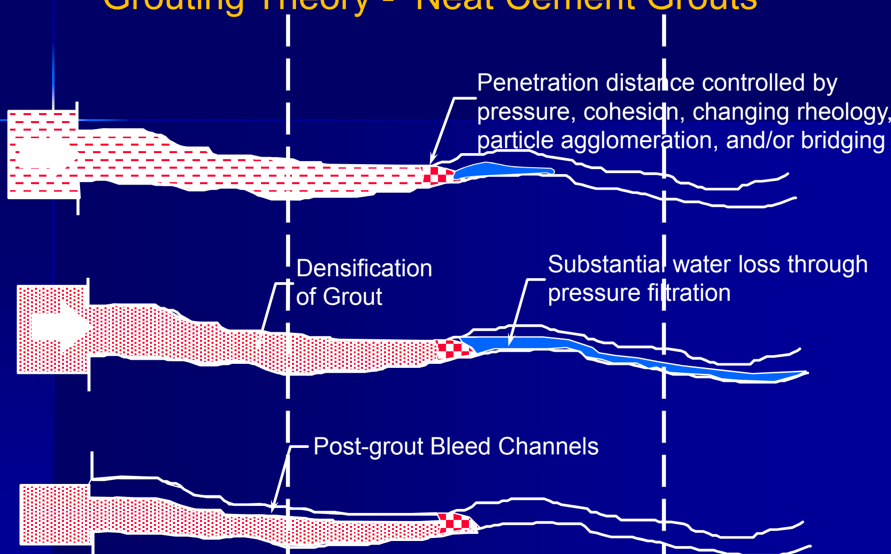
- Quantitative Design
  - Intensity of Grouting consistent with design assumptions and requirements
- Hole Orientation and Depth selected consistent with site geology
- Stable Grouts with multiple admixtures
- Pressures – Maximum safe pressure utilized
- Data Acquisition – Flowmeters and Pressure Transducers
- 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

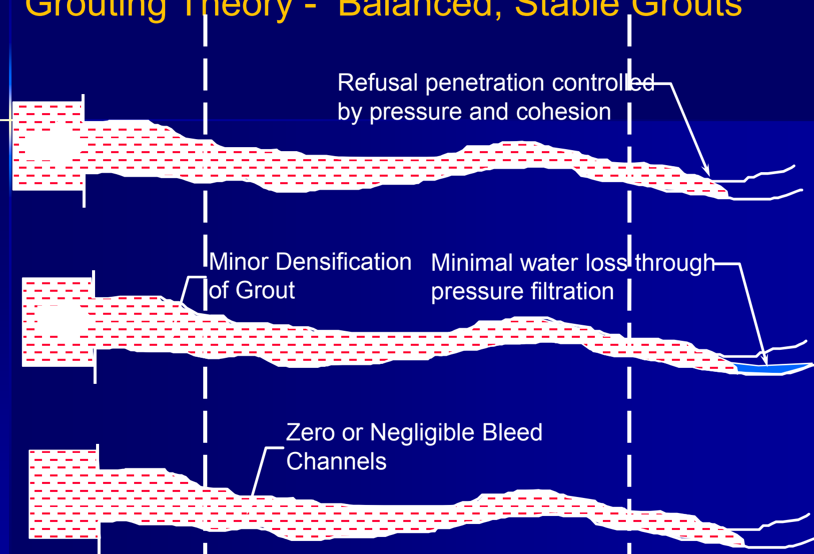


Result: high residual permeability and poor durability.

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

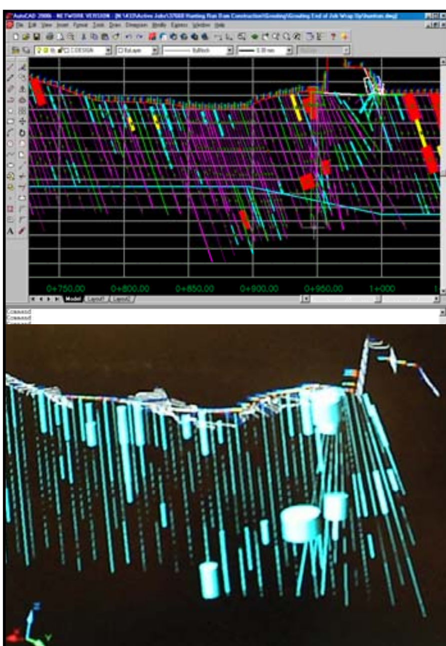
Grouting Theory - Balanced, Stable Grouts

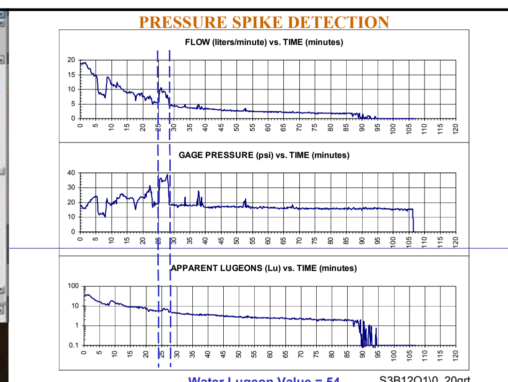


Result: low residual permeability and excellent durability.

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)





Gannett Fleming
ENGINEERS AND PLANNERS

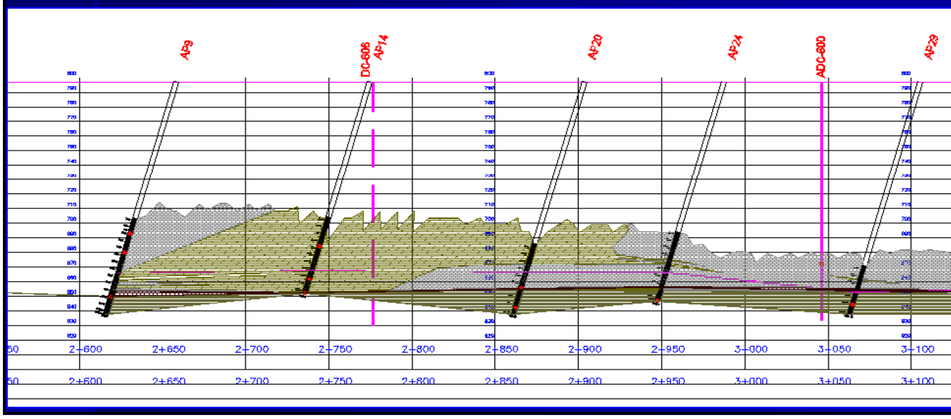
Example 2: Computer Monitoring of Grouting

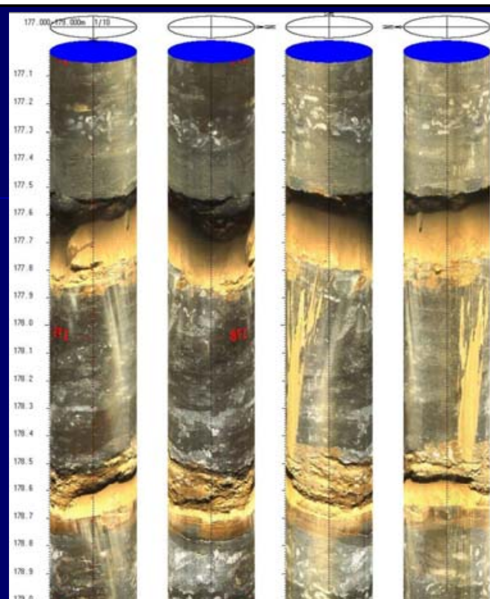
Advantages: Grouting

- 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

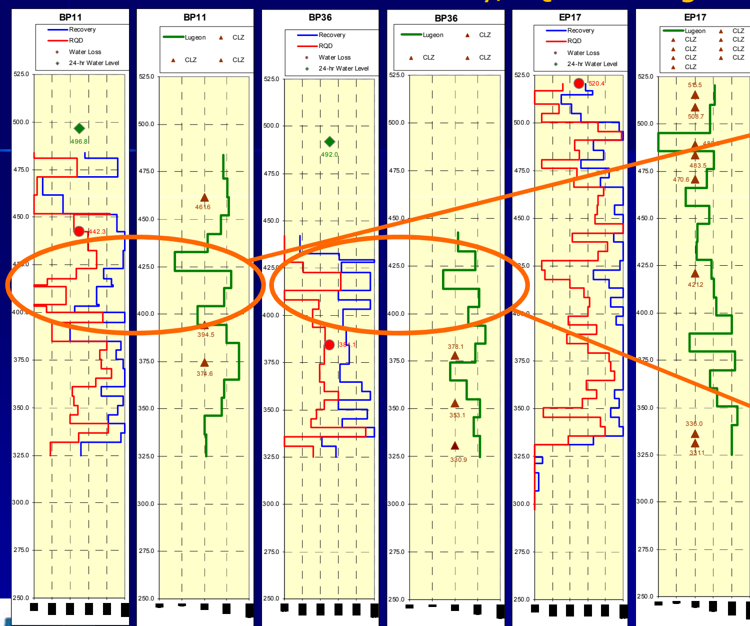
- Logical organization of Geotechnical and Geological Data
- Electronic link between data
- Eliminates sorting through paper logs, photographs, lab test results, etc. to interpret conditions





"Virtual Rock Core" Showing Weathered Partially Clay Filled Joints in Limestone Formation

Correlation between Recovery/RQD and Lugeon Value



Recovery/RQD Reduction and Lugeon Value Increase

Recovery/RQD Increase and Lugeon Value Decrease

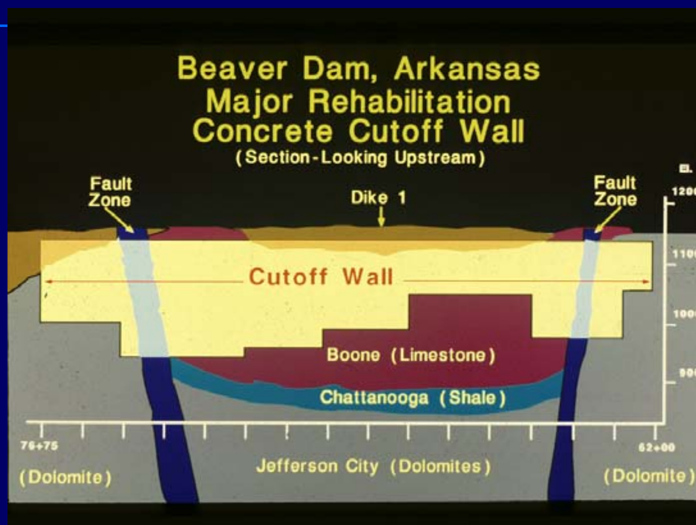
BP11 **BP36** **EP17**

3. "Composite" Cut-Off Solution for Carbonate Foundations

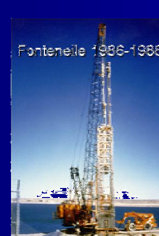
Basic Principles

- 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!

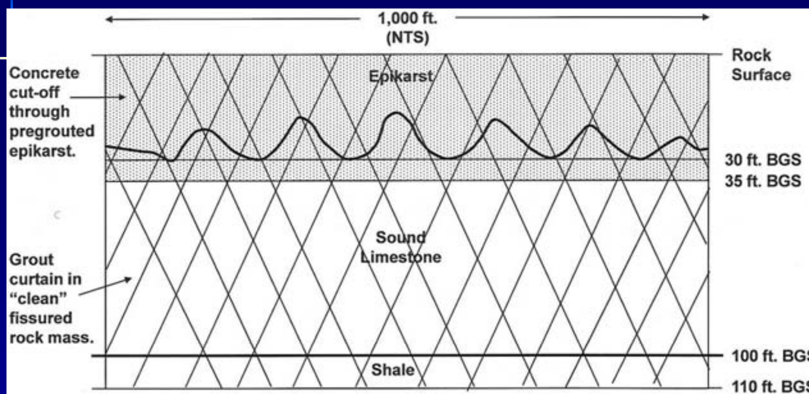
Basic Premise

- 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.

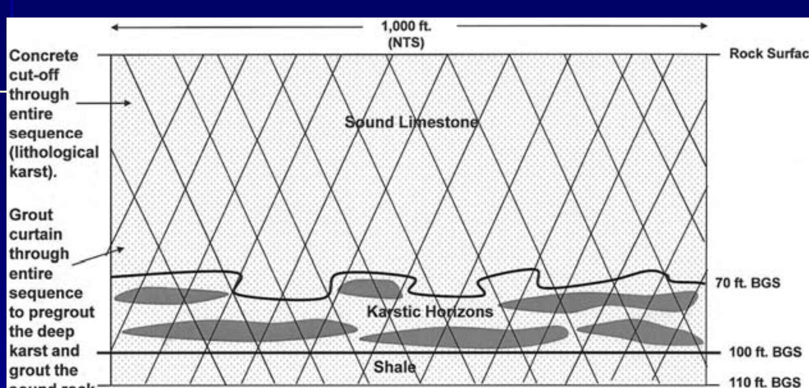
Illustrative Examples: "Clearwater" Case



- Area of Grout Curtain (including pretreatment of epikarst) = 1,000 ft. x 110 ft. = 110,000 sft.
- Area of Subsequent Concrete Wall = 1,000 ft. x 35 ft. = 35,000 sft.

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.

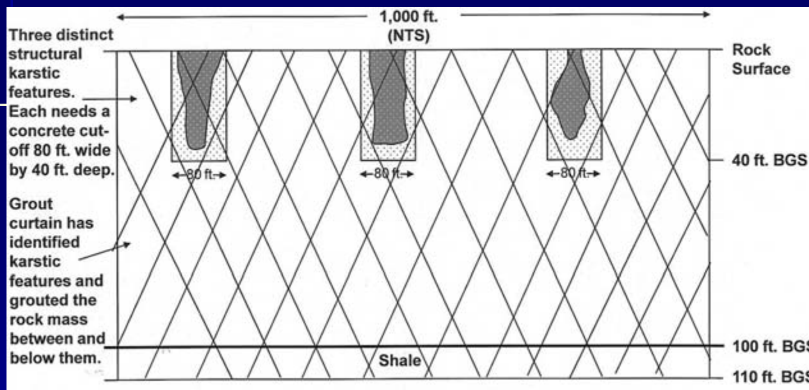
"Wolf Creek" Case



- Area of Grout Curtain = 1,000 ft. x 110 ft. = 110,000 sft.
- Area of Subsequent Concrete Wall = 1,000 ft. x 110 ft. = 110,000 sft.

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.

“Bear Creek” Case



- Area of Grout Curtain = 1,000 ft. x 110 ft. = 110,000 sft.
- Area of Subsequent Concrete Walls = 3 x 40 ft. x 80 ft. = 9,600 sft.

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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