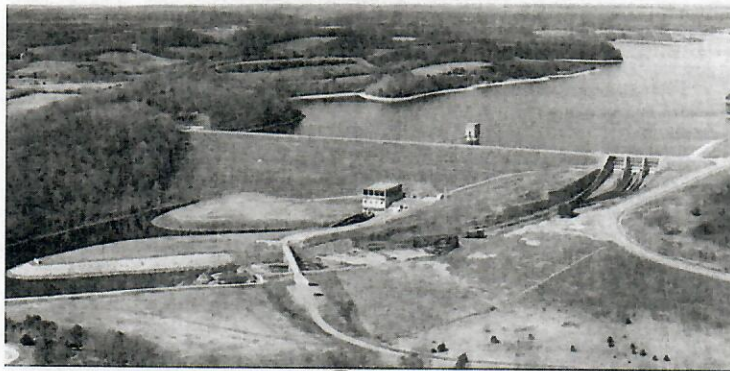




Association of State
Dam Safety Officials

**AN INTRODUCTION TO SOME SPECIALTY GEOTECHNICAL
CONSTRUCTION TECHNIQUES USED FOR FOUNDATION
TREATMENT AND SEEPAGE REDUCTION IN SOILS**

*Dr. Donald A. Bruce
President, Geosystems LP*

1

AGENDA

1. BACKGROUND (5 Minutes)
2. TECHNIQUES USED TO TREAT SOIL (100 Minutes)
 - 2.1. Terminology and Classification
 - 2.2. LMG ("Compaction Grouting")
 - 2.3. Jet Grouting
 - 2.4. Deep Mixing Methods (and Category 2 Cut-off Walls)
 - 2.5. Category 1 Cut-off Walls
3. FINAL REMARKS, QUESTIONS AND ANSWERS (15 Minutes)

2

2

1. BACKGROUND

- Wide range of techniques.
- Each technique has its own particular field of applicability especially in soil treatment and pros/cons.
- Each technique has its own particular set of logistical and practical requirements and challenges.
- Dam and levee safety during construction is always paramount. In this regard, a TCEAP and JIMP are essential elements.

3

3

- Insufficient time to discuss rock fissure and void grouting.
- This Webinar should be of particular value to engineers involved in feasibility level studies, regulators, and prospective facilitators and participants in PFMA sessions.
- Ground improvement techniques such as vibrodensification, deep dynamic compaction and stone columns are not described since they cannot be used under existing sites since full removal of the dam/levee must be first undertaken.

4

4

2. TECHNIQUES USED TO TREAT SOIL

2.1 TERMINOLOGIES AND CLASSIFICATION

- Permeation grouting: filling of preexisting, natural voids in the soil structure to reduce permeability and/or increase strength. Grout materials reflect soil pore sizes: cement based grouts in medium sands and coarser but colloidal solutions (e.g., sodium silicate) and true solutions ("chemicals") in finer soils. Maximum limit of permeable soils is 15% fines. NOT FURTHER DISCUSSED
- Compensation/Frac Grouting: deliberately sending lenses of cementitious grouts into the ground to compensate for structural movements at the surface, due to tunneling below. NOT FURTHER DISCUSSED
- Low Mobility Grouting: aka (wrongly) "Compaction Grouting". Use of low slump, highly frictional grouts to densify and/or displace soils, and fill karstic voids. Surprisingly common and effective from Tims Ford Dam onwards.

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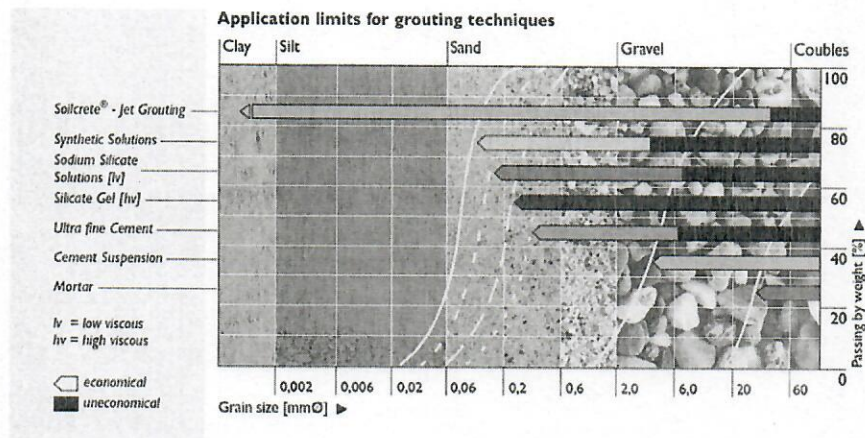
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- Jet Grouting: use of horizontal high pressure, high energy jets of grout + water and air to erode and mix soils to create "soilcrete" columns or panels. For dam safety reasons, quite rare as a remedial process in general, but some classic examples (e.g., Wickiup, Tuttle Creek, John Hart) and local levee markets (e.g., Sacramento, New Orleans, Florida).
- Deep Mixing Methods: insitu blending of the soil with low pressure grout ("binder") by mechanical means to also form "soilcrete". Massive projects in U.S. mainly for seismic retrofit and foundation improvement (e.g., LPVIII).
- Category 1 cut-offs: the soil/rock is completely removed and replaced with an engineered backfill material.

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GROUTING APPLICATIONS



7

2.2. LIMITED MOBILITY GROUTING (“Compaction Grouting”)

- LMG is the broad term now used for the methods and materials used for:
 - Soil densification (“compaction grouting”)
 - Lifting and levelling of structures
 - Soil displacement (e.g., soft residual clays in epikarst)
 - Void filling (karst, mine workings)

8

LMG Definition

“Grout injected with less than 1 in. (25 mm) slump. Normally a soil –cement with sufficient silt sizes to provide plasticity together with sufficient sand sizes to develop internal friction. The grout generally does not enter soil pores but remains in a homogeneous mass that gives controlled displacement to compact loose soils, gives controlled placement for lifting of structures or both.”

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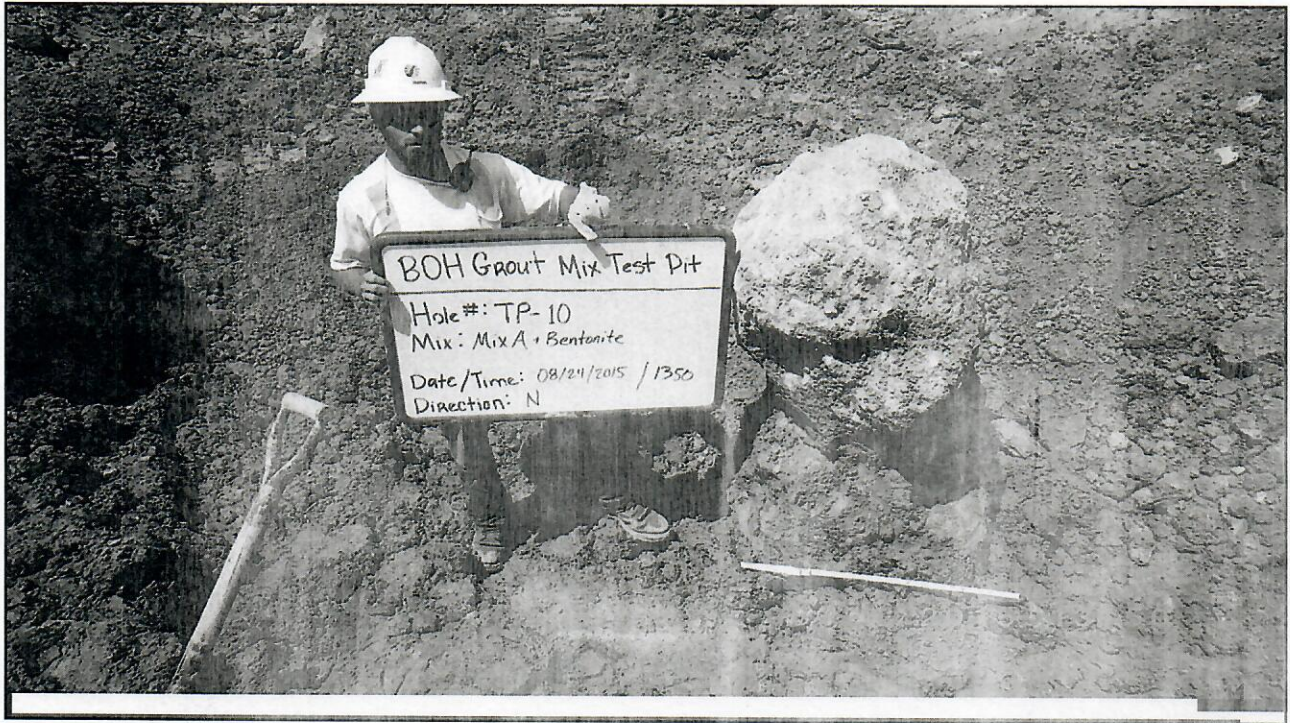
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San Diego - 1991



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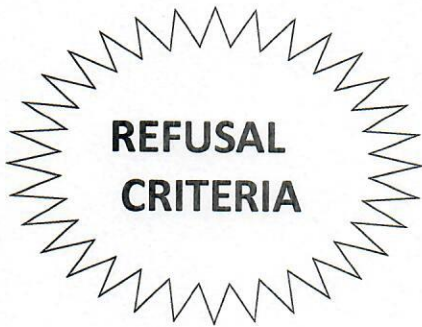
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- Primary
- Secondary
- Tertiary / Verification holes – if required
 - In extreme conditions, quaternary holes may be required
- Pre determined order in which you pump specified holes
- If the “team” is properly “disciplined” – quality information can be obtained for evaluation purposes, especially in situations where post grout drilling and testing is not practical
- Information obtained from drilling and grouting can be used as an extension of the Geotechnical report and can sometimes help identify root causes of settlement of structures.

14

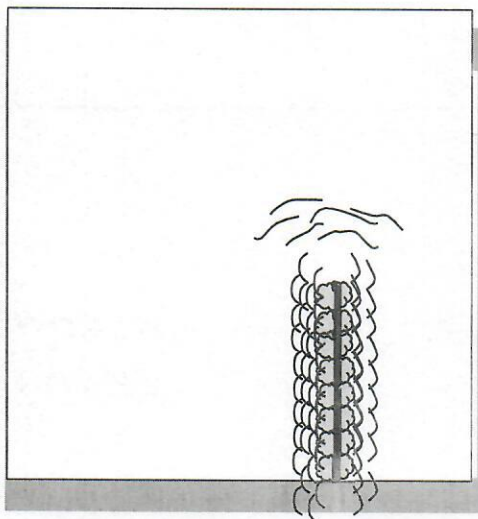


- Pre-established cutoff criteria for the grouting program at a given increment or stage
 - Pressure – when a certain maximum predetermined pressure is recorded at the injection header
 - Quantity- when a predetermined amount is injected at a given stage
 - Movement – when undesirable movement is detected
- Can be modified in the field based on actual in-situ conditions
- If one tweaks the program too frequently and prematurely, one loses the ability to compare valuable data

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¹⁶ Compaction Grouting Mechanics Summary



Grouting performed in "Stages", usually from the bottom-up.

Each stage is pumped until terminal criterion is met.

Casing is withdrawn in regular intervals as successive stages are pumped.

Result is a relatively uniform column of LMG.

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CASE HISTORY

TIMS FORD RIGHT RIM LEAKAGE

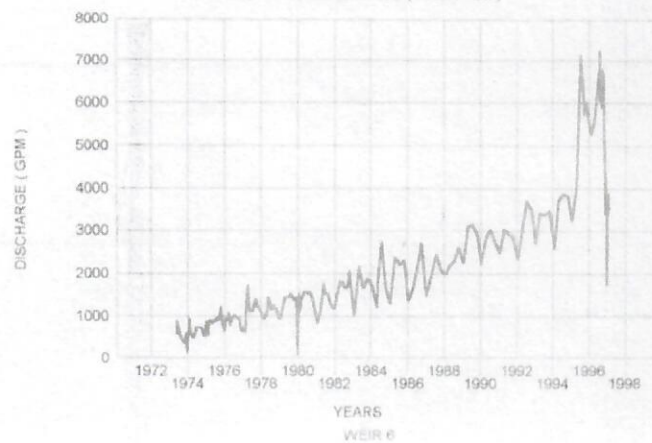
- Weirs utilized to monitor leakage through right rim
- Recorded flow vs. time
- Landslide on hillside observed
- Implemented grouting program to reduce leakage
- Monitoring leakage after grouting

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TIMS FORD DAM

RESERVOIR RIM LEAKAGE (RIGHT RIM)

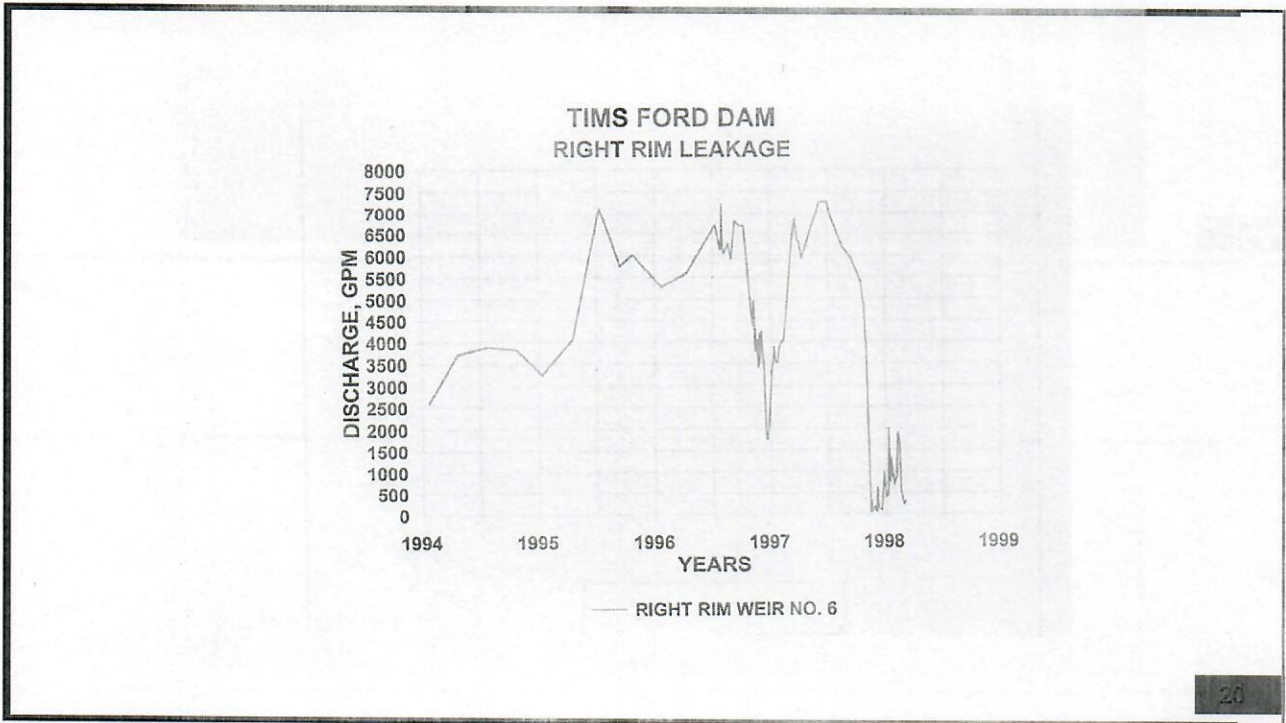


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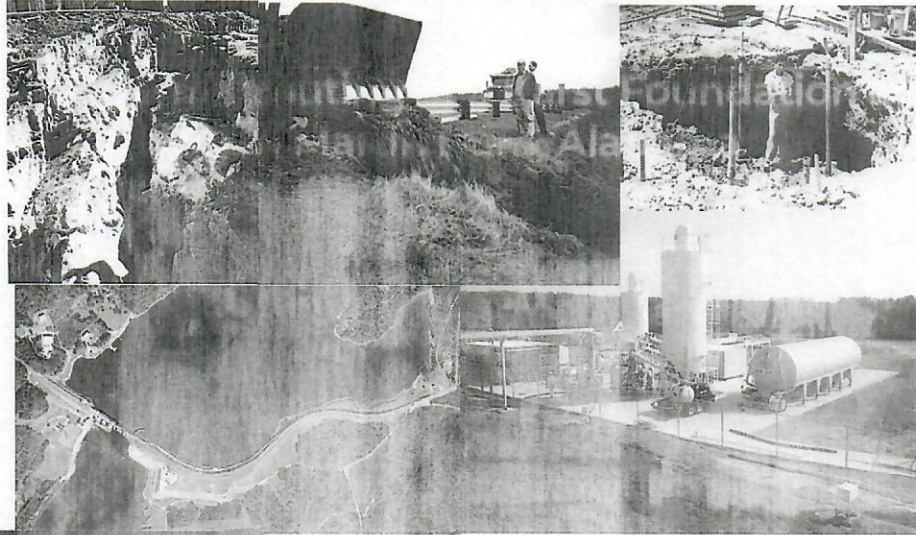


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Long-Term Grouting of a Karst Foundation at Logan Martin Dam, Alabama



G-I **GROUTING 2017**
HONOLULU, HAWAII | JULY 9-12, 2017
Grouting, Deep Mixing, and Diaphragm Walls

Donald A. Bruce, Brian H. Greene, R. Craig Findlay,
Bobby E. Williams, Johnny H. Williams, and Richard L. Mickwee

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Brief Introduction to Logan Martin Dam



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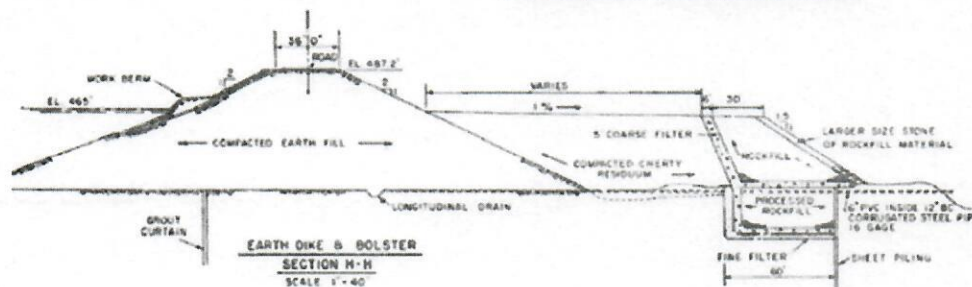
Phases of Grouting since Construction

- Phase 1 - Original Construction Grouting (1960, 1964)
- Phase 2 - Emergency Chimney Sink Grouting (1968)
- Phase 3 - Grouting Programs (1972-1990)
- Phase 4 - Deep Grouting Program (1991-2006)
- Phase 5 - Compaction Grouting Program (2005-2008)
- Phase 6 - West Side Grouting (2008-2011)
- Phase 7 - Deep Curtain Regrouting (2011-Present)
- Phase 8 - Downstream Shallow LMG Grouting (2013-2016)
- Phase 9 - Deep Rock Zone and Areas to the East (2016 - Present)

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Cross Section Through the Bolster

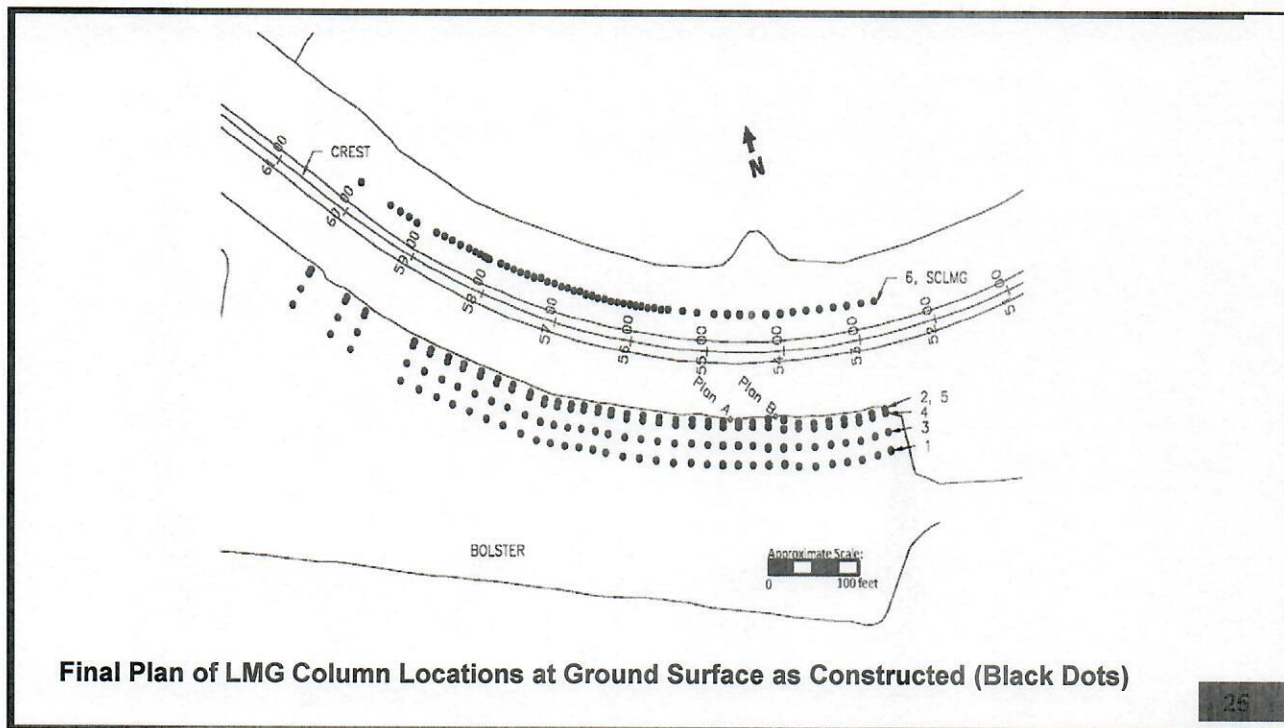


Additional deep into-rock piezometers on Bolster drilled as future grout monitoring instrumentation led to unsettling findings:

- Difficulties in setting casing, communications of pressure and drilling fluid between drill holes and instrumentation.
- Review of historic drill log data, framed in reference to the recent drilling data and the communication anomalies, led APC/SCS to conclude additional protection prudent to mitigate sinkholes.
- **Problem:** Untreated upper bedrock zone: 50 feet thick, consist of about 30% voids (filled and unfilled), underlying a relatively thin "roof" of competent rock.

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Piezometer Response

- Water elevations were influenced by drilling and grouting in all top-of-rock and into-rock piezometers relatively close to the grout holes.
- In many cases there was a rapid rise in water levels recorded by nearby piezometers, which returned to normal following cessation of drilling or pumping grout.
- Interestingly, 7 piezometers were lowered by 1 to 3 feet. 3 Piezometers appear to have been permanently raised slightly, but continue to show tailrace pressure influences and therefore the ability to drain.
- Two piezometers were inadvertently grouted up during the grouting process.

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Important to note: LMG has also been used at many other major dams, levees and quarries as part of an overall seepage reduction program, together with HMG, Category 1 cut-off walls and hot bitumen grouting.

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2.3. JET GROUTING

Jet Grouting is . . .

An erosion-based Ground Treatment technique used to create in situ geometries of soil cemented.

How does it work?

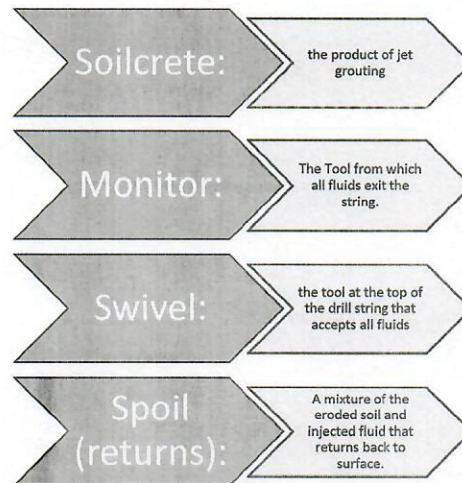
Soil is eroded by the collision of a high energy fluid with the soil. The energy of the fluid, the unit volume of fluid (and cement) injected per unit volume of soil-cement created, and the soil strength and type all play important roles.

Acknowledgement... George Burke, Formerly Hayward Baker

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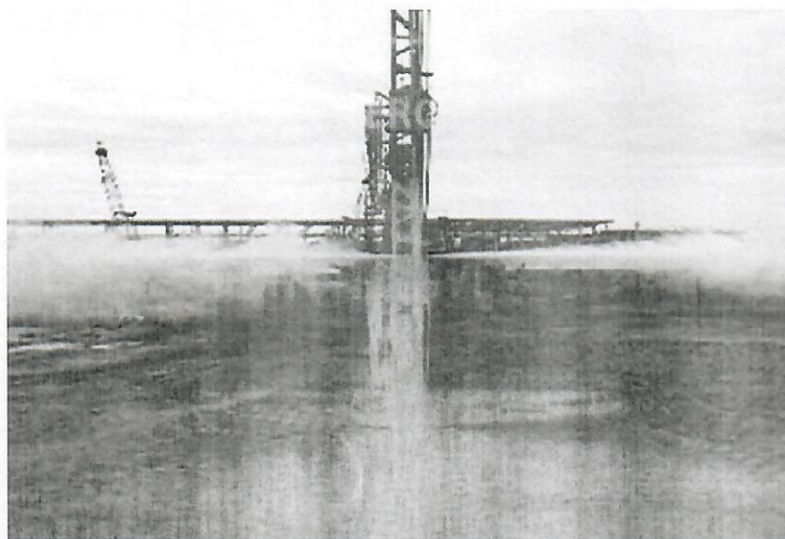
Some more definitions



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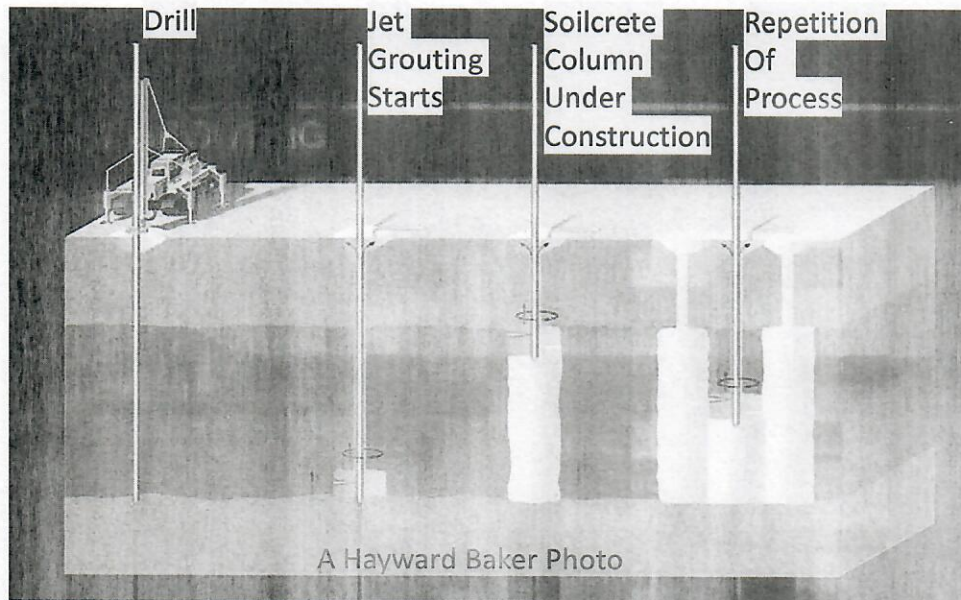
HIGH ENERGY!



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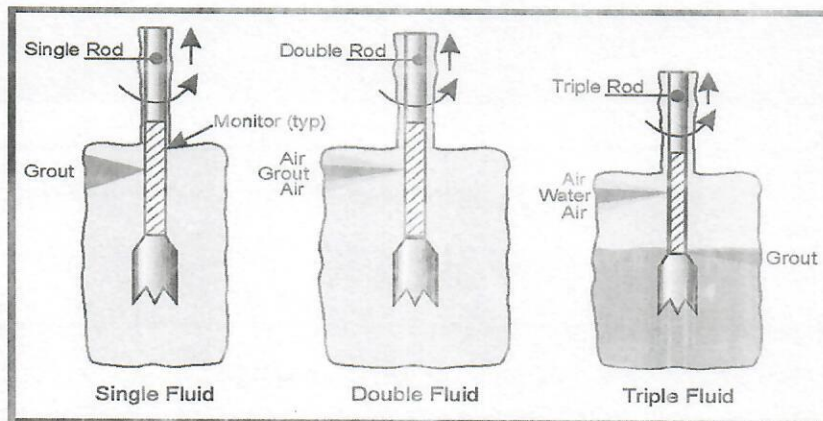
JET GROUTING



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Jet Grouting Systems



Soft and loose soils
Smaller diameter

Dense sands some CL
Larger diameter columns
Lower Unit Cost

All soil types except stiff
cohesive soil
Where control is essential
Adjacent to utilities and
structures

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Which System is Best?

- There is no single answer to this question.
- Usually more than 1 system can accomplish the project intent.
- Each specialist has experience suited to their specific equipment.

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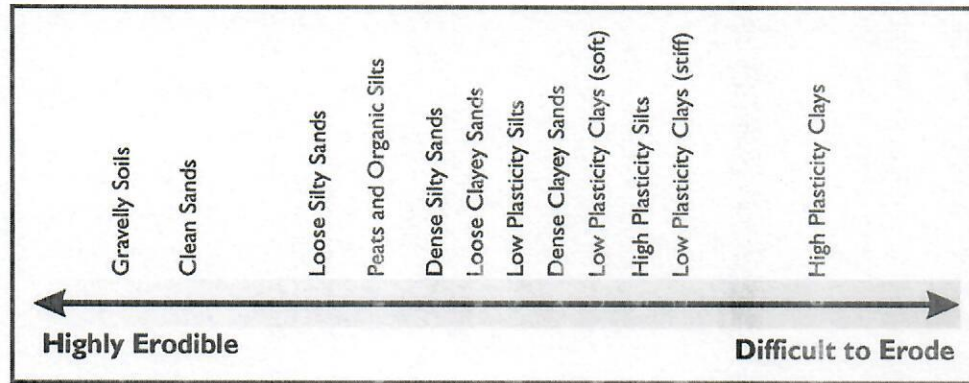
Geometry is a function of:

- Kinetic Energy
 - Velocity of the fluid
 - Air shroud (reduces attenuation)
 - Nozzle focus and condition
 - Injection volume rate
 - Erosion time
 - Rotation speed
 - Lift speed (step time and height)
- Soil strength and plasticity

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Soil Erodability Scale



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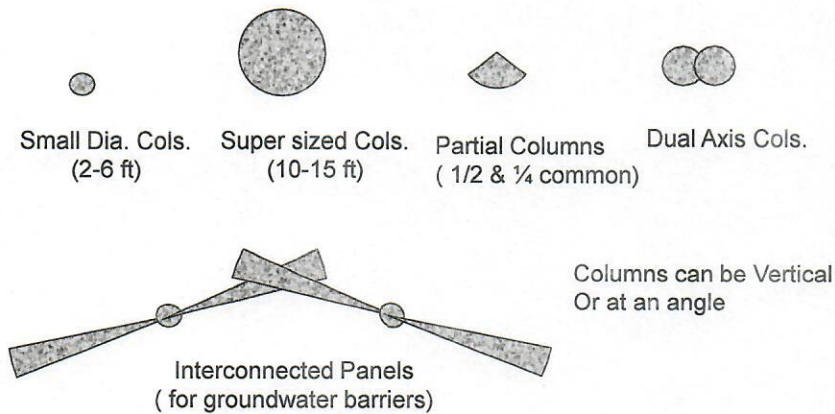
Soilcrete Column Diameter Expectations

Soil System	Soft Clays	Silts	Sands
Single	1.5-3.0 ft	2.0-3.5 ft	2.5-4.0 ft
	0.4-0.9 m	0.6-1.1 m	0.8-1.2 m
Double	3.0-6.0 ft	3.0-6.0 ft	4.0-7.0 ft
	0.9-1.8 m	0.9-1.8 m	1.2-2.1 m
Superjet	10.0-14.0 ft	11.0-15.0 ft	12.0-16.0 ft
	3.0-4.3 m	3.3-4.6 m	3.5-5.0 m
Triple	3.0-4.0 ft	3.0-4.5 ft	2.0-6.0 ft
	0.9-1.2 m	0.9-1.4 m	0.9-2.5 m

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Geometry - Shape

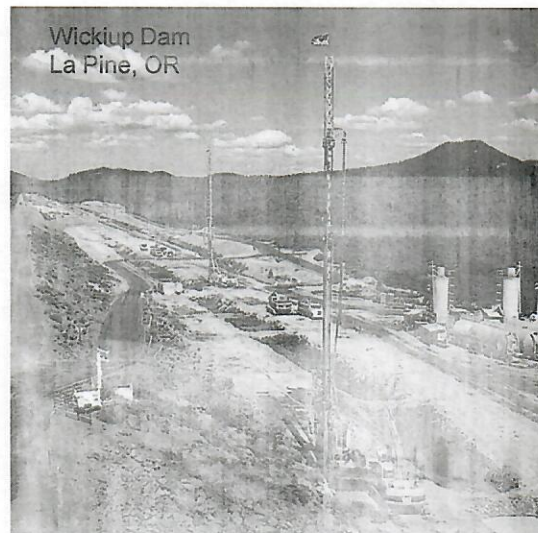


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Applications

- Underpinning Structures or Utilities
- Scour Protection
- Cross Bracing
- Base Seal against Groundwater
- Tunnel Break-ins, -outs, and cross passages
- Groundwater Barriers
- Excavation Support
- Ground Stabilization
- Wharf Restoration



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Aspects of Jet Grouting that require special attention

- Comprehensive knowledge of subsurface conditions
 - Stratigraphy and variation
 - Soil type, strength, density, moisture content, pH and atterberg limits (if applicable)
 - Groundwater conditions
 - Bedrock information if applicable
 - Subsurface utilities and potential obstructions

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Aspects of Jet Grouting that require special attention

- Work sequence is nearly always important for underpinning
 - Separation requirements
- For groundwater control
 - Fresh-in-fresh
- Working toward closure

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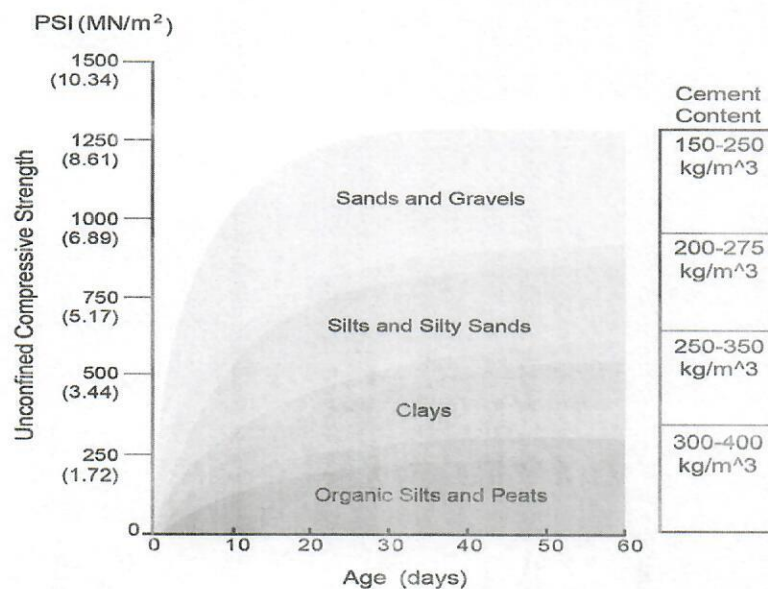
Aspects of Jet Grouting that require special attention

- Continuous spoil return is essential to control the insitu stress environment
 - Change grout viscosity
 - Use casing
 - Precutting measures
 - Auxiliary air lift
 - Change borehole size
 - Ream the borehole
 - Jetting during penetration
 - Change the air pressure and/or flow

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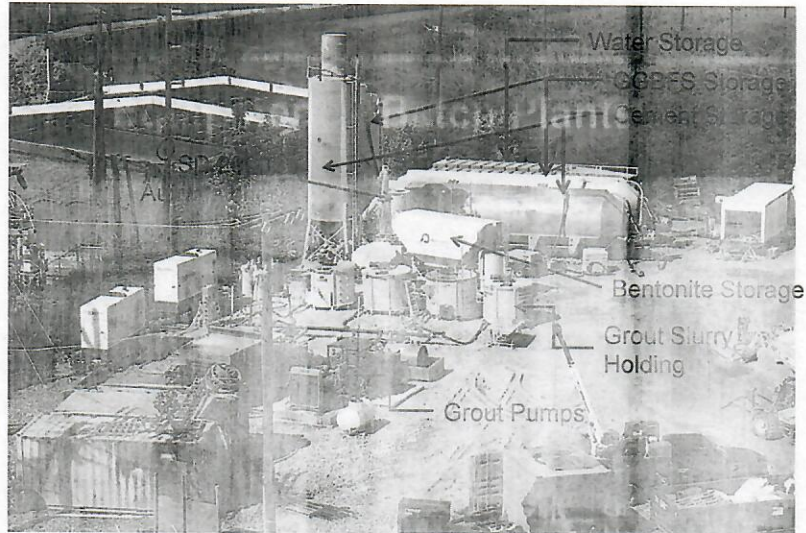
Typical Soilcrete Strengths



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Equipment – Batch Plants



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Spoils Handling

- The single biggest impact to daily production!
- Serious consideration is necessary prior to mobilization
- Understand how it will be handled

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SPOILS HANDLING

- What not to do:



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SPOILS HANDLING

- If you have room, this is great.



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SPOILS HANDLING

- Or a vacuum truck:



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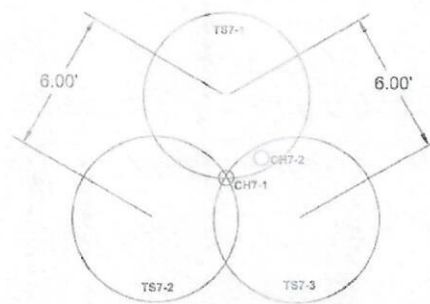
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Quality Control – Diameter Assessment



- Exhume if possible
- Core sample the interstice.

Ø7' Jet Grout Column Test Pattern



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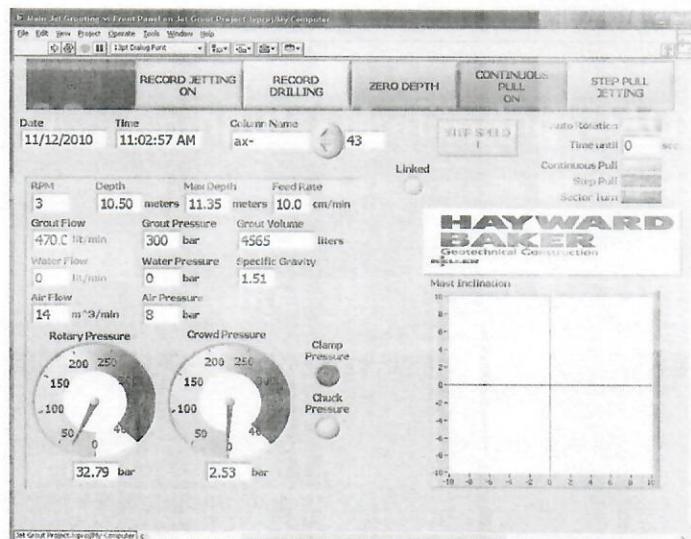
QC – Sampling for Strength and Permeability

- **Wet Grab Samples**
 - Using an insitu sampling devise
 - Advantages
 - Can take samples from any depth
 - Can use any size mold desirable
 - Relatively inexpensive
 - Disadvantages
 - Only a discrete sample
 - Influenced by inclusions to a much greater extent (scale effects)
 - Arguably much better or much worse than reality
 - Curing conditions different (but not better) than reality



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QC - Computer Monitoring (DAQ)



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QC – Sampling for Strength and Permeability

- Core Sampling
 - Advantages
 - Gives you a “visual”
 - Via “SQD” can offer information about homogeneity
 - Coring times can also provide info on uniformity
 - Can usually bring back testable samples
 - Disadvantages
 - Destructive means of sampling (particularly so when the matrix contains coarse grain sizes)
 - Should not expect perfection
 - Recovery ~ 60-90%
 - SQD ~ 25-75%
 - Not always suitable for permeability testing

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Specifications and Guidelines

- Jet Grouting Eurocode BS EN 12716: Revision 08 2016
- The Recently Revised ASCE Jet Grouting Committee guide has been posted to the GI website at the following location:
<http://grouting.geoinstitute.org/publications/>

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RECENT JET GROUTING CASE HISTORIES FOR DAMS AND LEVEES

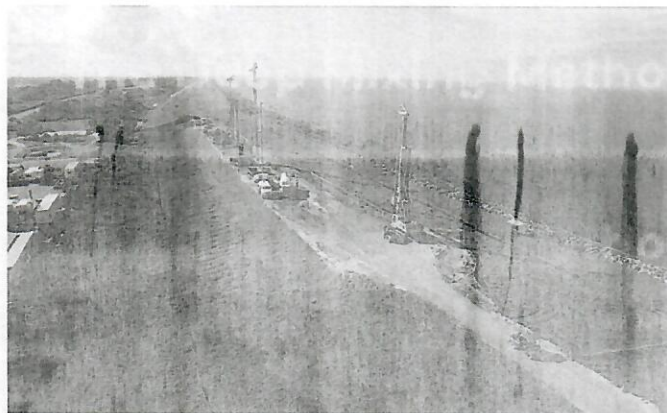


John Hart Dam, BC (Cut-off)
 Wickiup Dam, OR (Seismic retrofit of foundation)
 Tuttle Creek Dam, KS (Cut-off Test Section)
 Sacramento Levees, CA (Gap closure)
 Herbert Hoover Dike, FL (Gap closure)
 Ruskin Dam, BC (Insitu Training Wall)
 New Orleans Levees, LA (Underpinning and gap closure)

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2.4. The Deep Mixing Methods

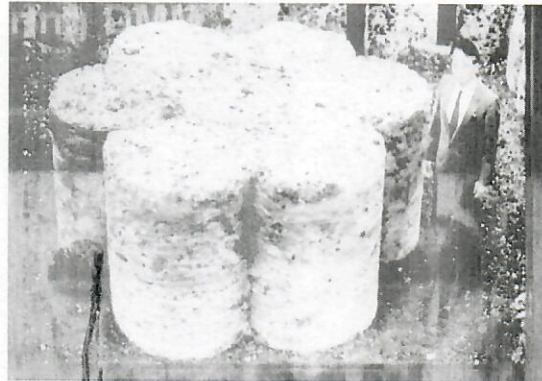


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Conditions Favoring DMM

- Ground is neither very stiff or very dense
- Ground has no boulders/obstructions
- Treatment < 40 m depth
- Unrestricted overhead clearance
- Good and constant binder source
- Large spoil volumes can be tolerated
- Vibrations are to be avoided
- Treated soil volumes are large
- "Performance Specifications" applicable
- Treated ground parameters well defined



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Jackson Lake Dam modification (1987 – 1988)



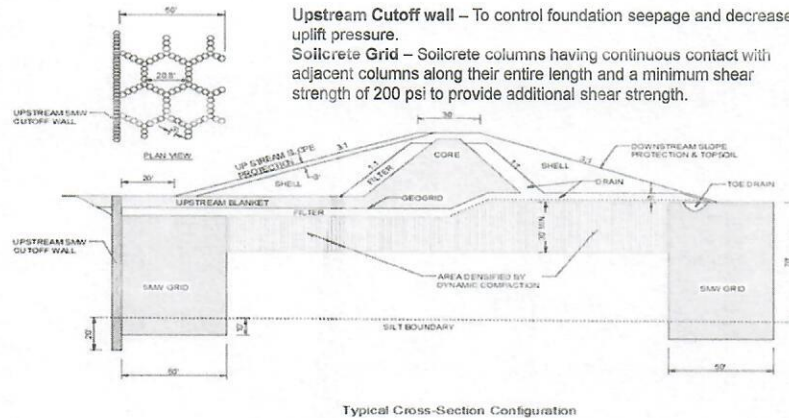
Source: Bureau of Reclamation web site
DM cells were installed using equipment of SMW Seiko, Inc. in 1987 and 1988.

- A 49-ft hydraulic fill dam; 4,300 ft long northern embankment founded on fluvial-lacustrine and lacustrine sediments
- Northern embankment and foundation were found to be susceptible to earthquake induced liquefaction by Seed & Lee in 1977.
- The primary objective of the construction program was to modify the structure and foundation to preclude failure due to the design earthquake
- Modifications to provide earthquake stability included:
 - Replacement of the Northern Embankment
 - Foundation treatment

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Foundation stabilization of Jackson Lake Dam



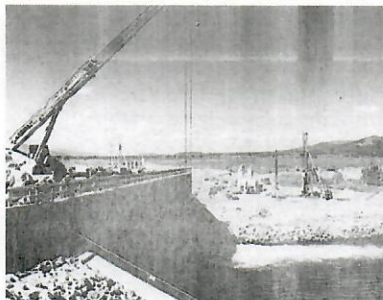
Sources: 1. Foundation Stabilization of Jackson Lake Dam, A. Pujol-Rius, P. Griggin, J. Neal and O. Taki, 12 International Conference on Soil Mechanics and Foundation Engineering, Rio de Janeiro, Brazil, August 1989; 2. Foundation Treatment Methods for Jackson Lake Dam Modification, J. Farrar, K. Wirkus & J. McClain, USCOLD

Courtesy
of JAFEC
USA, Inc.

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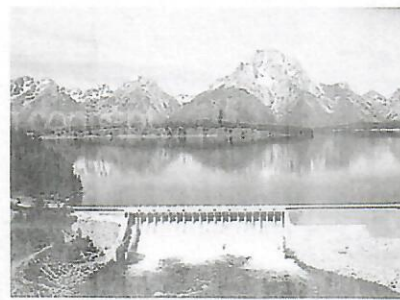
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DM design concept



"We are using soilcrete columns to increase the shear strength of the foundation." 1987

Source: Jackson Lake Dam project boasts unusual soil-improvement method, Intermountain Contractor, Oct 1987

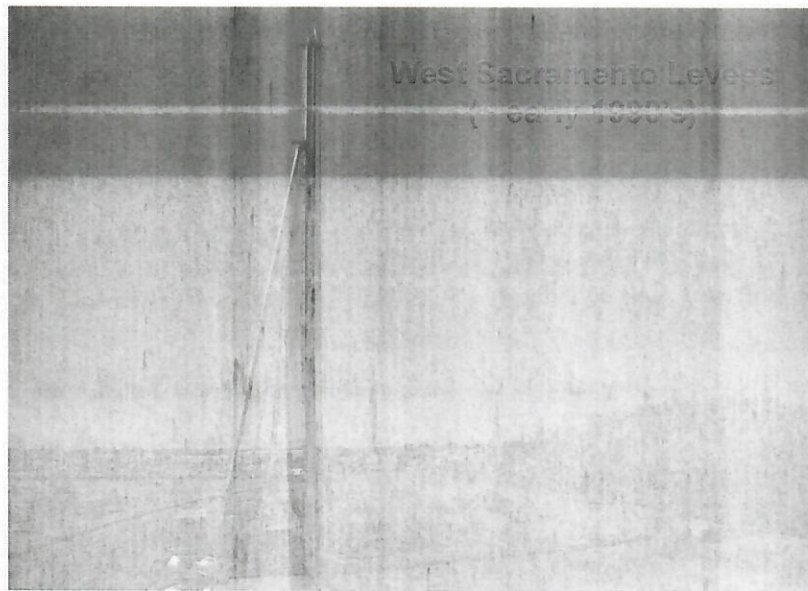


"....To the right of station 29+00 the SMW structure designed to prevent liquefaction of soils both the upstream and downstream outer shells of the embankment is in place." 2004

Source: Bureau of Reclamation Technical Memo. No. JL-8313-4 Issues Evaluation Report of Findings-Executive Summary Seismic Risk Analysis, 2004

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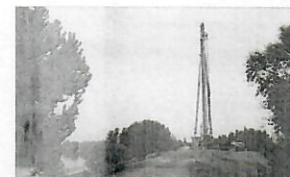
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FOUR LANDMARK PROJECTS

Caveats and Apologies

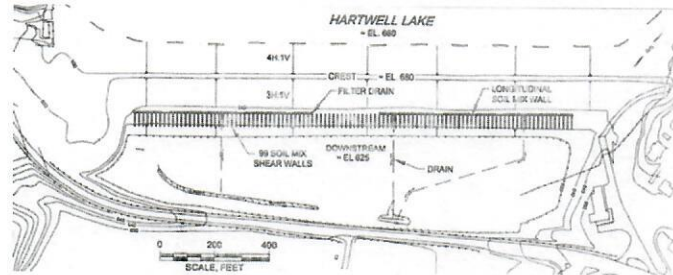
- Incomplete (e.g., important DMM projects conducted in Bay Area, the Pacific Northwest, and on California Dams and Levees)
- No contractor preference implied, but:
- Thanks for all the contractors who sent images – including: Bauer Foundations; DeWind, Fudo, GeoSolutions/GeoCon, Golder Construction, Hayward Baker, Jafec, Malcolm, Nicholson, Raito, Schnabel Foundations, TREVIICOS, Underpinning and Foundations
- Special thanks to Dr. David Yang formerly of Jafec USA Ltd., Gilbert Tallard, Dr. Pete Cali, and Prof. George Filz



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2.4.1. Clemson Upper & Lower Diversion Dams South Carolina



- The foundation soils of the 80-ft high dam consist of a loose silty sand / sandy silt alluvial deposit with thickness varying from 7 to 28 ft.
- Seismic investigation and evaluation concluded that there was a potential for a liquefaction-induced slide of the downstream slope during the design seismic event due to low estimated values of steady-state undrained strength at large strain in the foundation alluvial soils.

Sources: 1. "Evaluation and Design of Seismic Remediation for the Clemson Upper and Lower Diversion Dams," Wooten, R. L., Castro, G., Gregory, G., and Foreman, B., Proceedings of the 23rd Annual United States Society on Dams Conference, 2003.
2. "Deep Soil Mixing for Seismic Remediation of the Clemson Upper and Lower Diversion Dams," Wooten, R. L., and Foreman, B., Proceedings of the 25th Annual United States Society on Dams Conference, 2005

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Clemson Upper & Lower Diversion Dam South Carolina

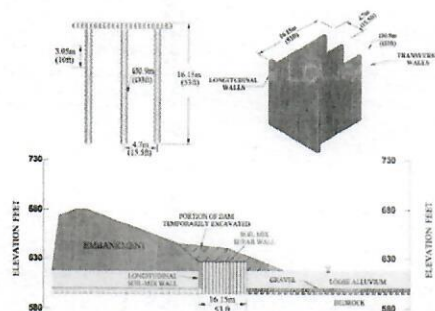


Fig. 7. Cross Section and Layout Design, Seismic Remediation of Clemson Upper and Lower Diversion Dams (base by Wooten & Foreman, 2005)

DM transverse shear walls - Oriented perpendicular to the dam axis to carry the seismic loads in lieu of the weak soil layers.

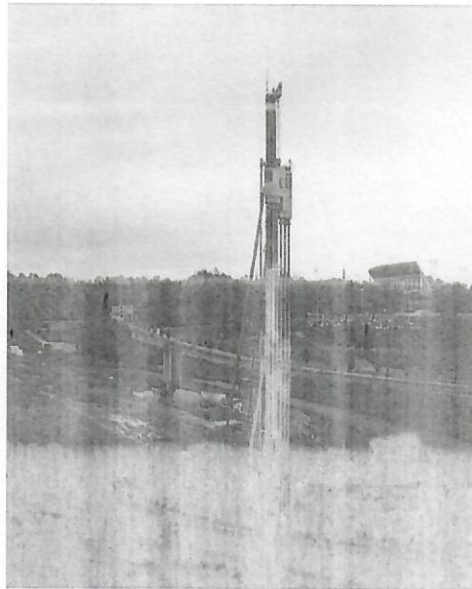
DM longitudinal wall - To prevent softened alluvium from squeezing or flowing between the transverse walls.

DM walls installed by Raito, Inc. in 2004 & 2005

Source: Application of Multi-shaft Deep Mixing in the U.S., David S. Yang, *National/Regional Reports, Deep Mixing 2009 Okinawa Symposium, Okinawa, Japan, May 2009*

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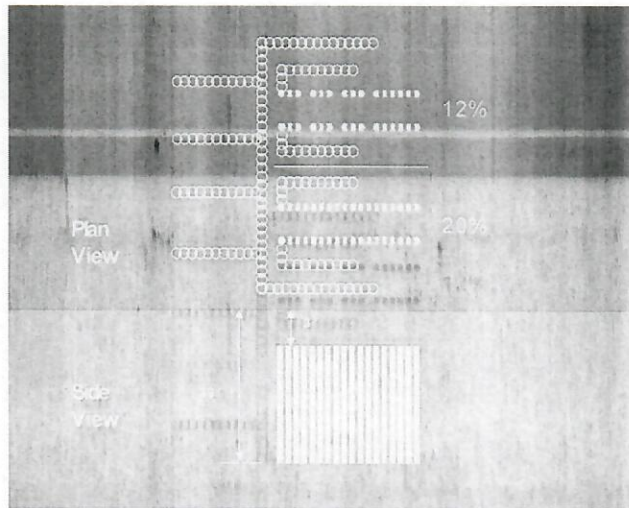
2.4.2 Deep Mixing in New Orleans

1. Phase 1: First Demonstration Program (2001)
2. Phase 2: Task Force Guardian and Beyond (2006-2010)
3. Phase 3: LPV 111 and others (2009 onwards)



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Phase 1: As-built cell configuration with 12% and 20% replacement ratios

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Phase 2: Task Force Guardian and Beyond (2006-2010)

- August 2005 Hurricanes Katrina and Rita force the "ice" to melt.
- Contents of an email from Dr. Pete Cali to a DMM colleague in Scandinavia, Friday, September 16, 2005:

"Dear ___, Thank you for your concern. We are OK. Lots of property damage, but all are well. When we get to the other side of this emergency, raising the height of the levees will be a priority, and hopefully deep mixing will play an integral role" (underline added).



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Phase 2 Projects (Task Force Guardian to 2010)

PROJECT NAME	START DATE	APPLICATION	DETAILS	CONTRACTOR
17 th Street Canal	2006	Overwater mixing for interim canal closure structure in cellular grid pattern.	2,200 DRE columns, 800 mm diameter, 18 m deep	Hayward Baker, Inc.
Orleans Avenue Canal	2006	Overwater mixing for interim canal closure in rows and "hammer heads."	Triple axis WRE in rows and square grid. About 6,000 cubic meters of treated soils.	Raito, Inc.
Gainard Woods Pump Station	2006	Emergency levee repair.	Triple axis WRE.	Raito, Inc.
P24 Plaquemines Parish	2006	Foundation stabilization with rows of columns for levee raising.	4,600 DRE columns, 800 mm diameter, 13 m deep	Hayward Baker, Inc.
Westwego Interim Phase 1	2008	Flood wall replacement.	Triple axis WRE.	Raito, Inc.
Westminster Pump Station	2008	Ground improvement for new structure in cellular grid.	DRE columns, 800 mm diameter	Hayward Baker, Inc.
Westwego Pump Station Phase 2	2009	T-wall foundation stabilization.	Triple axis WRE	Raito, Inc.
IIINC Reach III	2010	Soil improvement under I-wall levee section in panels.	DRE columns, 800 mm diameter 11.6 m deep	Hayward Baker, Inc.
LPV-109.02	2010	Levee raising.	Triple axis WRE	Raito, Inc.
WBV-09a	2010	First levee enlargement and pump station	Triple axis WRE	Raito, Inc.
WBV47.1	2010	Levee Raise	DRE Columns	Hayward Baker, Inc.

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Phase 3: LPV 111 (2010-2011)

- Lake Pontchartrain and Vicinity Hurricane Protection System Contract 111 extended over 6 miles along the north bank of the Gulf Intracoastal Waterway (GIWW).
- Bordered on both sides by the Bayou Sauvage National Wildlife Refuge.
- Levee raising therefore restricted to existing right of way and hence DMM was the cost effective solution for foundation soils.



68

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Construction

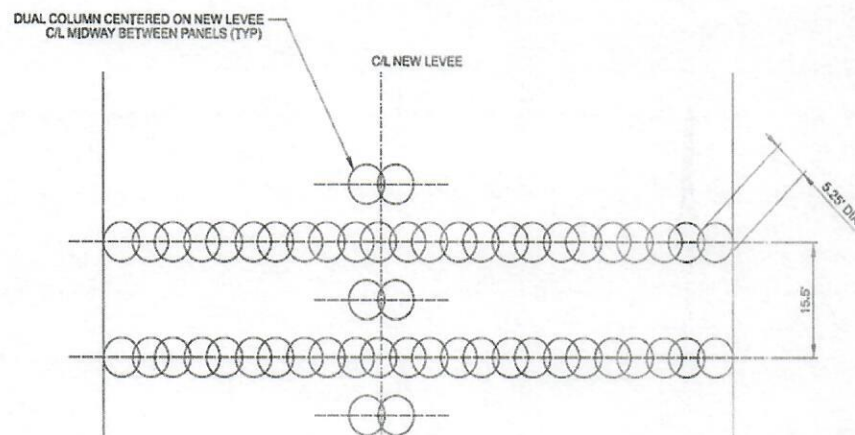
LPV111 CHALLENGES:

schedule – logistics – design – soil characteristics – size of the job

- 2x12 hrs/shifts, 5.5 days/week
- 6 dual auger + 2 single auger rigs
- 8 active batch plants producing ≈ 50 cy/hr of grout
- approximately 460,000 tons of cement used $\rightarrow$ 17,500 trucks
- 3 coring rigs
- over 500,000 man-hours in 14 months of production



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LPV III Production

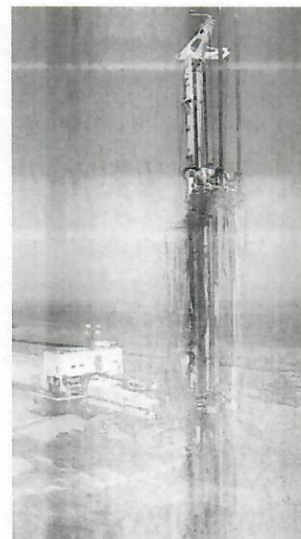
PRODUCTION START DATE		1/14/2010
PRODUCTION COMPLETION DATE		3/18/2011
TOTAL CALENDAR DAYS	N	439.00
TOTAL MONTHS	N	14.43
TOTAL SHIFTS WORKED (as of 3/18/2011)	N	3,309
TOTAL MANHOURS (as of 3/18/2011)	N	502,817
TOTAL DMM ELEMENT INSTALLED	N	18,028
TOTAL VOLUME TREATED	CY	1,681,579
TOTAL CEMENT USED	SHTON	457,693
TOTAL TRUCK-LOADS (approx.)	N	17,500
TOTAL WATER USED	GAL	136,832,094
TOTAL CORING	N	506
TOTAL UCS TESTS	N	5,082
OVERALL AVERAGE UCS (required = 100 psi)	PSI	292
TOTAL FAILING UCS TESTS (<100 psi)	N	66
TOTAL FAILING UCS TESTS (10% allowed)	%	1.30%

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71

Technology

- Over 60% of the ground improvement was accomplished with the Trevi Turbo Mix (TTM) technology, single and double axis.
- The TTM method was a recent development of the deep mixing technology. It combines the injection of cement slurry at high velocity into the ground with mechanical mixing of the rotating blades.
- The additional energy provided by the grout jets greatly improves the quality of the mixing of the soil with the grout and reduces the time required for the installation of the soil-mix columns.

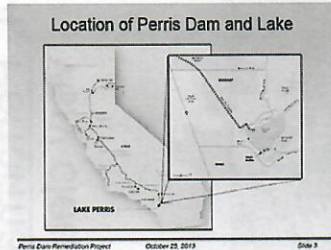


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2.4.3. Seismic Remediation of Perris Dam

CDSM cells at embankment toe for liquefaction mitigation

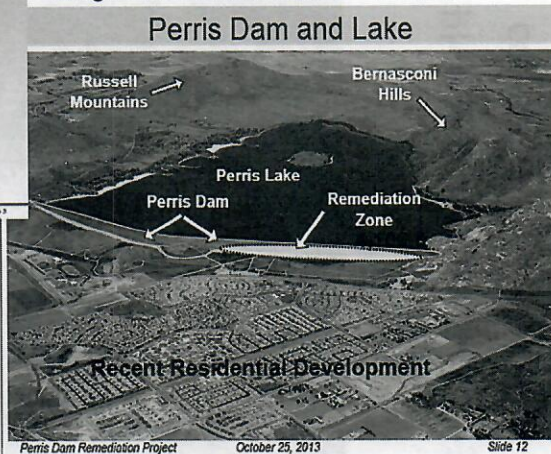


Site is located 5 miles from San Jacinto fault zone, Magnitude Mw 7.5

Dam height: 126 ft
Construction: 1970 to 1972

Base: 2013 DFI Presentation
by Mr. Mike Driller of
Dept. of Water Resources, CA

Length of remediation zone = 4,100 ft.

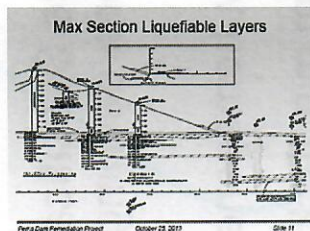


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Seismic Remediation of Perris Dam

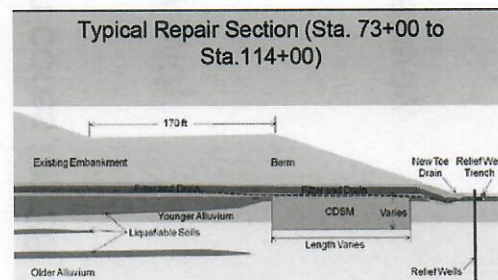
CDSM cells for embankment stabilization



Cross section of Perris Dam

Base: 2013 DFI Presentation by Mr. Mike Driller of
Dept. of Water Resources, CA & 2005 DWR Perris
Dam Foundation Study Report.

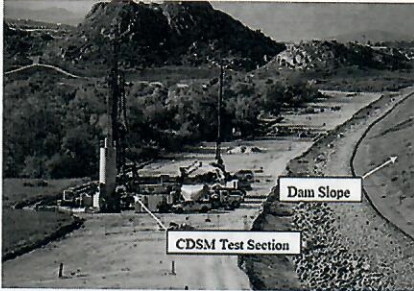
- DWR foundation study in 2005 indicated the thin sandy layers in dam foundation are liquefiable and may lose strength during a large seismic event.
- CDSM cells are designed to maintain the seismic stability. CDSM shear walls provide the resistance to the lateral force induced by the earthquake.



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DWR study and test section



Sources: 1. Results of a Cement Deep Soil Mixing Test Section at Perris Dam, W.Y. Chen and M. Driller
2. DWR reports and papers

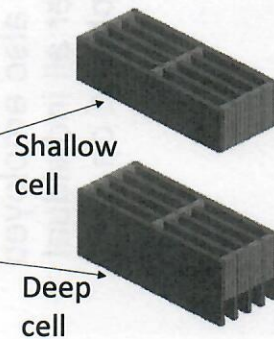
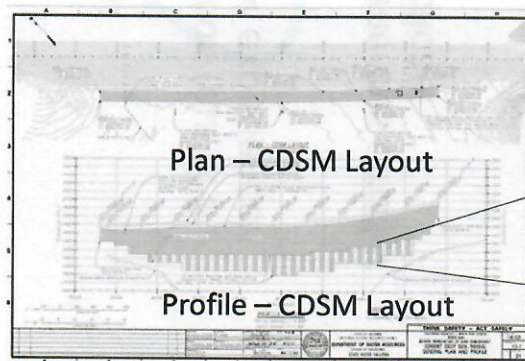
- A remedial alternative study in 2007 recommended removal and replacement of up to 25 feet of foundation soil at toe. CDSM was recommended to treat deeper portion of the foundation.
- Test sections were constructed in 2010 to evaluate CDSM and dewater & excavation construction method. It was found that water levels rebounded quickly after dewatering pumps were shut off.
- Based on the findings from test sections, DWR concluded that major excavation near the dam toe would be unsafe and both shallow and deep foundation soils need to be treated with CDSM.

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Plan & Profile - CDSM

- Shallow cells & longitudinal walls: 35 feet to intercept shallow liquefiable layers
- Transverse walls – 40 to 65 feet to intercept isolated deep liquefiable pockets

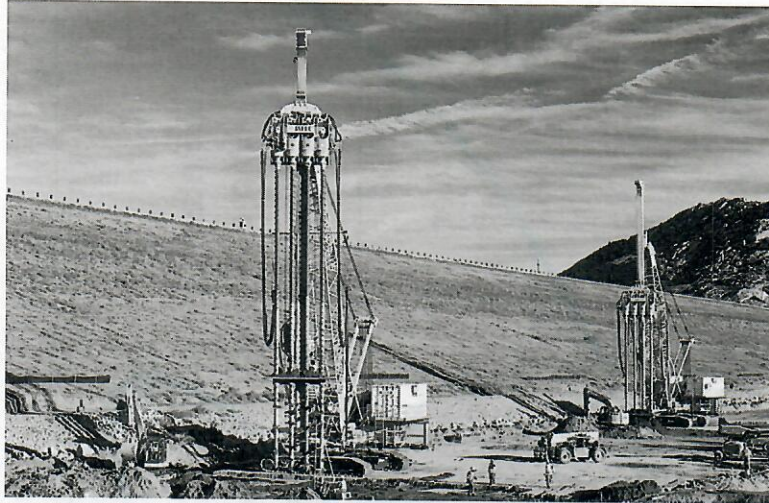


Courtesy of Jafec USA, Inc.

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Full production of CDSM cells

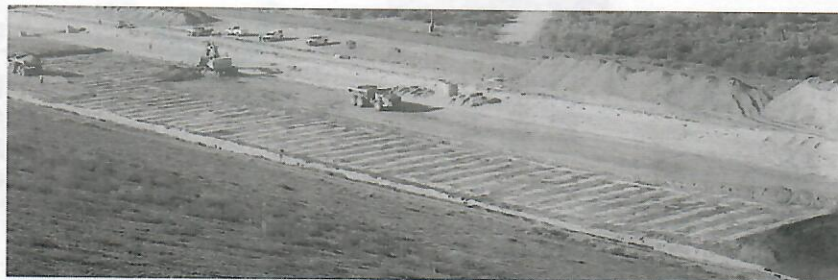


Courtesy of JAFEC, USA, Inc.

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Perris Lake Dam Foundation treatment



Top of CDSM cells exposed for placement of filter and drain

Photo from site camera

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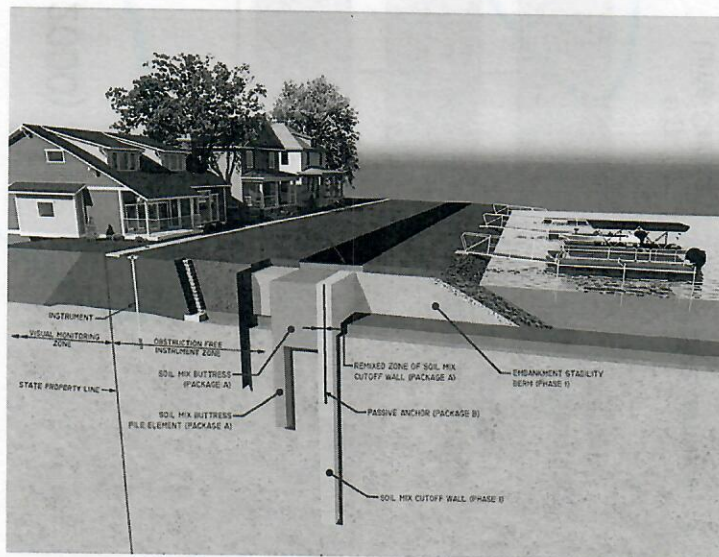
2.4.4. Buckeye Lake Dam, OH



Courtesy of Gannett Fleming, Inc.

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Rendering Courtesy of Gannett Fleming, Inc.

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Portage Lakes Dam, OH

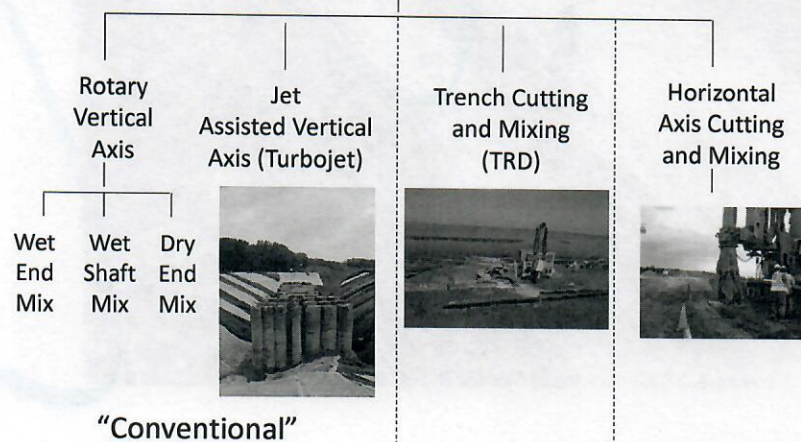


Courtesy of Tetra Tech, Inc.

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Updated DMM Classification (Bruce, 2010)

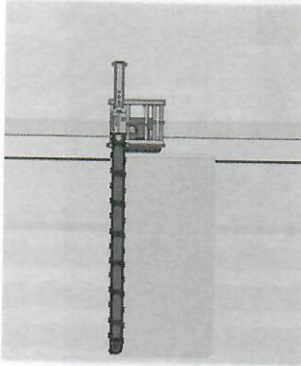


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Continuous Trench Cutting

TRD (Trench Re-Mixing and Cutting Deep Wall) Method



- Conceived in 1993 in Japan.
- First used in U.S. in 2005.
- 170 ft. depth capability, 18-34 inches wide.
- Continuous wall created by lateral motion of vertical "chain saw," installed in a predrilled hole.

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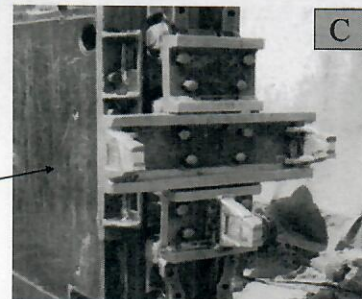
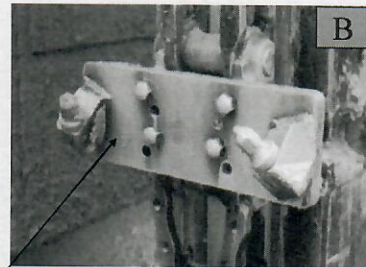
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Blades vary according to soil condition



- A) Standard blade
- B) Rounding blade for hard clay
- C) Long-nosed blade for boulder

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TRD

Particular Advantages

- Continuous, homogeneous, joint-free wall in all soil and many rock conditions.
- Productivities can be extremely high (instantaneous production > 400 sft/hour).



- High degree of real time QA/QC.
- Adjustability of cutting teeth.
- Can operate in low headroom (20 ft).
- Very quiet, modest size support equipment, "clean" operation.

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TRD

Potential Drawbacks

- ❖ Sharp alignment changes.
- ❖ Especially hard/massive/abrasive rock.
- ❖ Trapping of "post" in soilcrete or "refusal" on boulders/rock.
- ❖ Only one (excellent) contractor!



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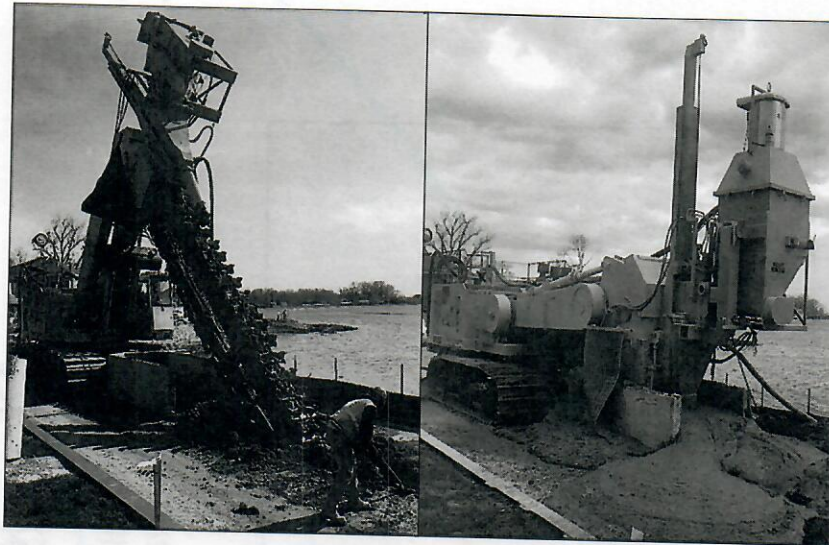
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"One Pass" System (DeWind)



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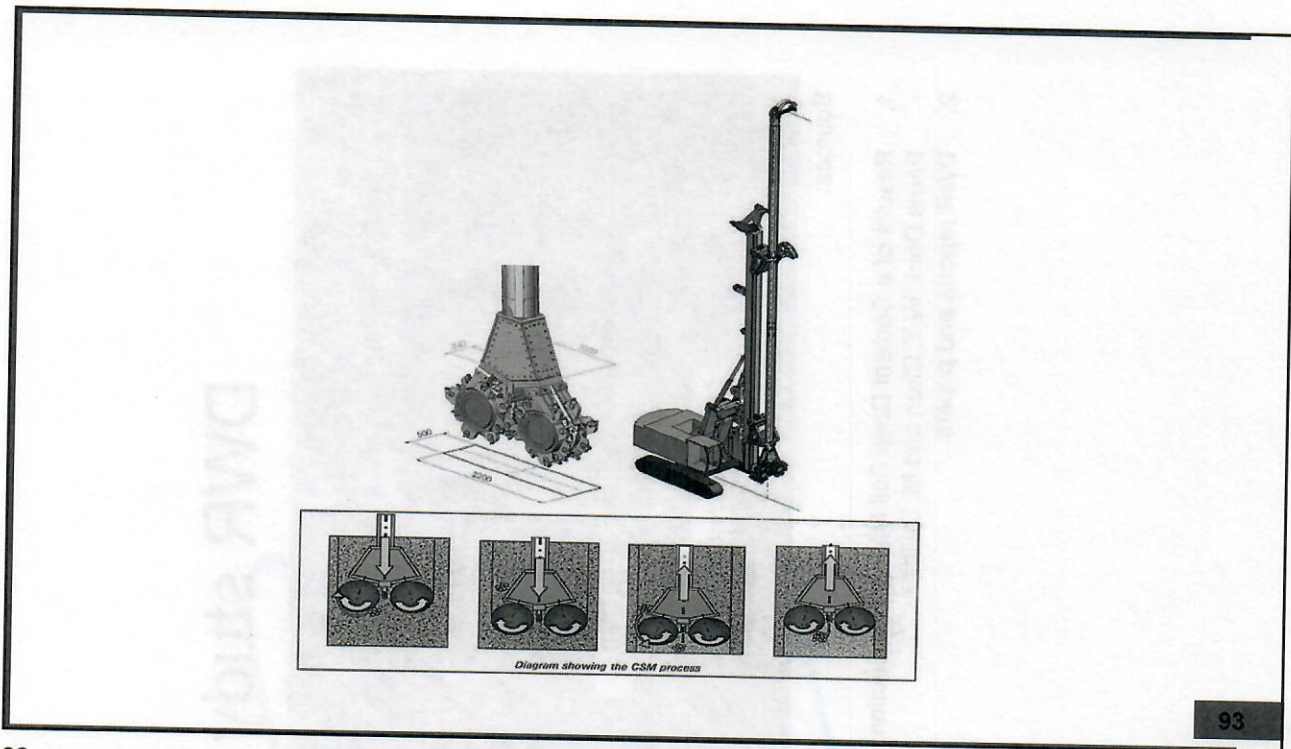


CSM (Cutter Soil Mix) Method

- Joint Bauer Maschinen/Bachy Soletanche development in 2003
- Combines expertise in hydromill and deep mixing.
- Rapidly increasing in popularity worldwide (over 40 units in service).
- Similar system developed by Trevi (CT Jet).
- Maximum depth 180 feet, 20-47 inches wide.

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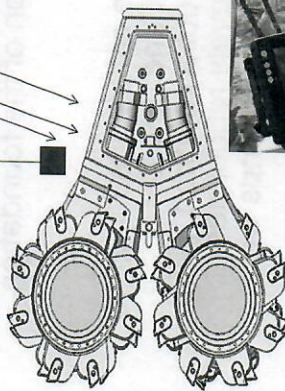
CSM Quality Control Systems

The CM machine is fitted with a set of instruments that convey to the operator, in real time all the information that is needed to monitor and control quality of the work.

External pressure sensor

Instruments that read:

- Verticality on "X" and "Y" axes
- Torque on cutting wheels
- Wheel speeds



BAUER B-Tronic system

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CSM

Particular Advantages

- Continuity assured by very strict verticality control.
- Very homogeneous product.
- Applicable in all soil conditions (peat should be removed).
- Adjustable teeth.
- CSM can be mounted on non-specialized carriers.
- Productivity can be very high.
- Can accommodate sharp alignment changes.
- Quiet and vibration free.



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CSM

Potential Drawbacks

- As for all DMM variants, rock, boulders and organics are challenges.
- Needs considerable headroom.
- Cost base (as for all DMM variants).



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At Herbert Hoover Dike, over 21 miles of cutoff were installed with 3 methods in Please 1:

- CSM (Bauer)
- TRD (Hayward Baker)
- SHS (Trevi ICOS)

A second phase of similar work has recently started totaling over 30 miles.



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Overview of Category 2 Walls

METHOD	PRINCIPLE	WALL DIMENSIONS		PROPERTIES OF BACKFILL		COSTS		RELATIVE BENEFITS/PROBLEMS	
		DEPTH	WIDTH	UCS	K	MOB/DEMOP	UNIT PROD.	PROS	CONS
Category 1 – Excavate and Replace (i.e., under bentonite slurry)									
Clamshell	Various types of clams can be used to remove soil in panels	Max 250' (typically < 150')	16-66" (typically 24-36")	Wide range of materials can be used for backfill depending on project requirements		Low-Moderate	Moderate-High	• Experience • Adaptability • Wide range of backfills • Considerable depth capability	• Spoils handling • Boulders • Rock • Verticality control • Loss of slurry • Access/headroom
Hydromill	Large frame with cutting wheels and reverse circulation mud pump to remove soil in panels	Max over 400'	24-60" (typically 33-39")	Wide range of materials can be used for backfill depending on project requirements		Moderate-Very High	High-Very High	• Greater depth capability • Can penetrate all conditions • Can be very fast • Verticality control	• Cost base • Loss of slurry during excavation • Spoils handling • Access/headroom
Backhoe	Modified long reach excavator to create continuous trench	Max 100' (typically < 80')	30-36"	Mainly used with SB backfill, but feasible with SCB and CB		Very Low	Very Low	• Very high productivity • Low cost • Experience • Many practitioners • Practical in tight access/low headroom conditions	• Depth limitation • QA/QC • Obstructions/dense or stiff soil/rock
Category 2 – Mix in Place									
Conventional DMM	Vertically mounted shafts are rotated into the soil creating panels of soilcrete	Maximum practical about 110'	20-40"	100-1,500 psi	5x10 ³ to 1x10 ⁴ cm/s	Moderate-High	Low to Moderate	• Speed • Experience • Several practitioners • High productivity	• Large equipment needs good access and virtually unlimited headroom • Depth limits • Very sensitive to obstructions • Variable homogeneity with depth • Cost base

(continues)

(continues)

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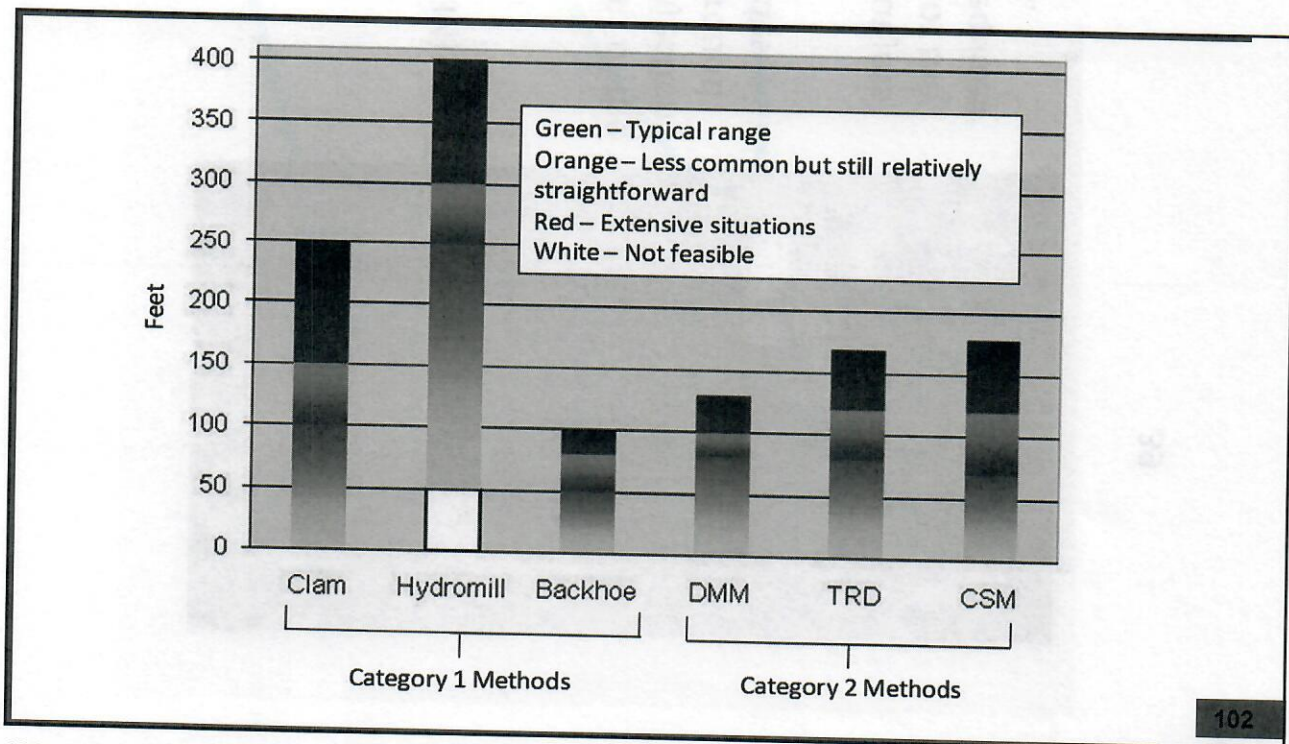
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METHOD	PRINCIPLE	WALL DIMENSIONS		PROPERTIES OF BACKFILL		COSTS		RELATIVE BENEFITS/PROBLEMS	
		DEPTH	WIDTH	UCS	K	MOB/DEMOL	UNIT PROD.	PROS	CONS
TRD	Vertical chainsaw providing simultaneous cutting and mixing of soil to produce continuous soilcrete wall	Maximum 170'	18-34"	100-3,000 psi	10^{-6} to 10^{-8} cm/s	Moderate-Very High	Moderate-High	- Continuity of cut-off is automatically assured - Homogeneity - Speed - Quality - Adaptability to wide range of ground conditions - Low noise and vibrations - Low headroom potential - Inclined diaphragms possible - Wide range in cut-off properties can be engineered	- Difficult wall geometries - Medium-hard rock, and boulder nests - Currently only one U.S. contractor - Requires very specialized equipment - Cost base
CSM	Cutting and mixing wheels mounted on horizontal axes create vertical soilcrete panels	Max 180'	20-47"	100-3,000 psi	10^{-6} to 10^{-8} cm/s	Low-Moderate	Moderate	- Panel continuity/verticality - Homogeneity - Speed - Adaptable to conventional carriers - Wide range in cut-off properties can be engineered - Can accommodate sharp geometry changes	- Rock, boulders and other obstructions - Cost base

Key to Costs

Mob/Demol		Unit Costs (i.e., cost per square foot of cut-off)	
< \$50,000	Very Low	< \$10	Very Low
\$50,000-\$150,000	Low	\$10-\$20	Low
\$150,000-\$300,000	Moderate	\$20-\$50	Moderate
\$300,000-\$500,000	High	\$50-\$100	High
> \$500,000	Very high	> \$100	Very High

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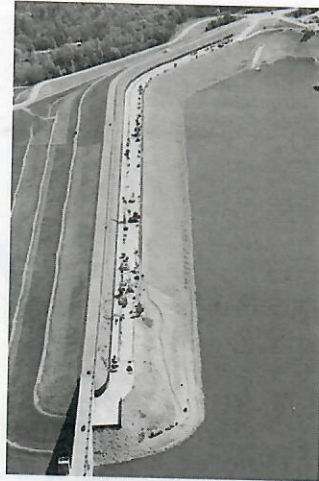


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2.5. Category 1 Cut-off Walls

Basic Classification

- Category 1 cut-offs created by backfilling a previously excavated trench, supported by bentonite (or polymer) slurry.
- Category 2 cut-offs created by mixing the levee and foundation soils insitu.



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Category 1 Cut-Offs (Excavate and Replace)

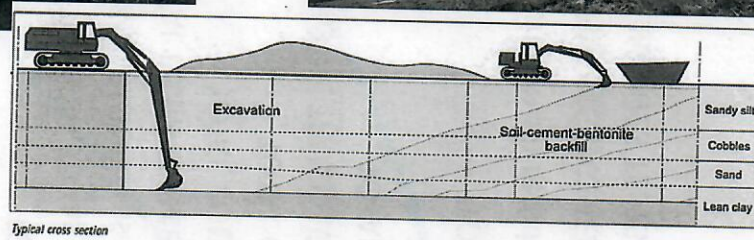
- Intrinsic advantage is that resultant "backfill" material can be engineered, on the surface, and is virtually independent of the native material through which the cut-off has been excavated.
- Wide range of possible backfill materials:
 - Conventional Concrete (rare for levees).
 - Plastic Concrete.
 - Cement Bentonite (typically SHS).
 - Soil Bentonite.
 - Soil-Cement-Bentonite



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- Excavation Principles
 - Continuous Wall (Backhoe)



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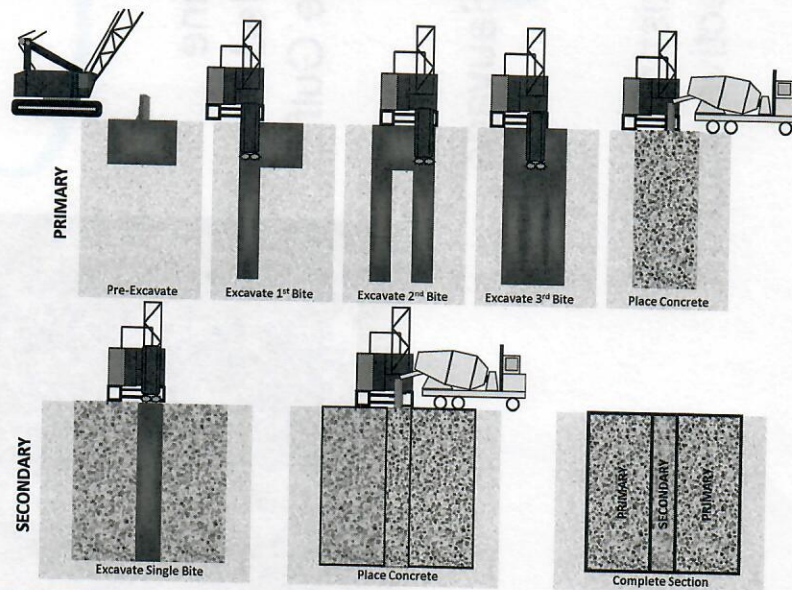
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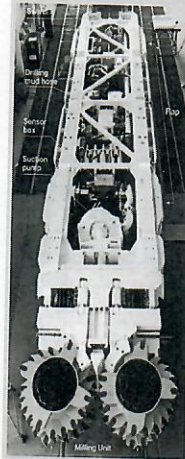
■ Excavation Principles
 — Panels (Clamshells or Hydromill)



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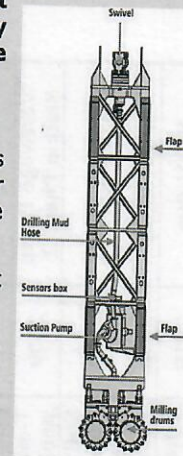
108

HYDROMILL TECHNOLOGY



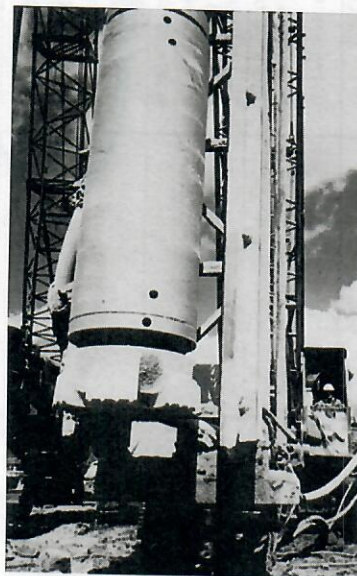
The core of any Hydromill is its trenching/cutting unit, that schematically consists of a heavy steel frame integrating the following components:

- swivel located on top of the frame
- two independent hydraulic engines which allows the rotation of a pair of milling drums located at the bottom of the frame;
- a mud suction pump placed just above the milling wheels;
- front and side hydraulically-operated "steering" flaps;
- a number of built-in sensors and inclinometers.



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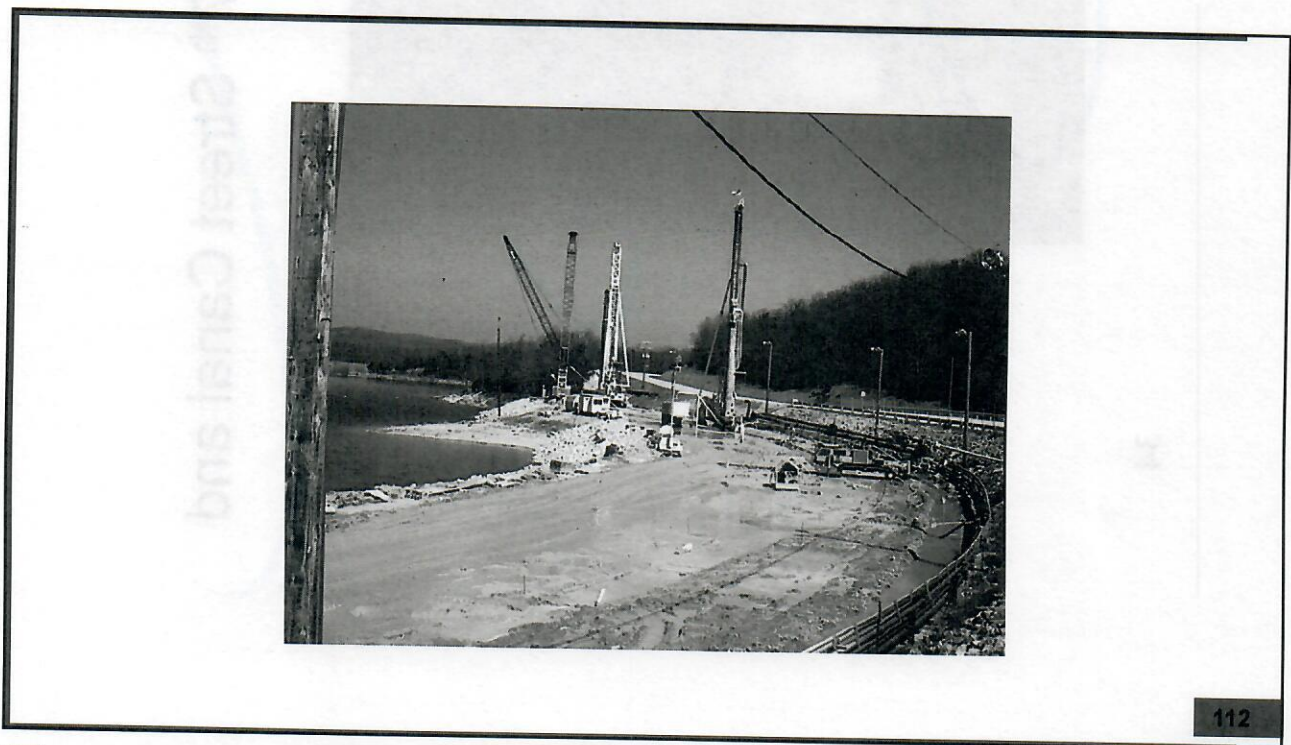
Conventional Secant Pile Method

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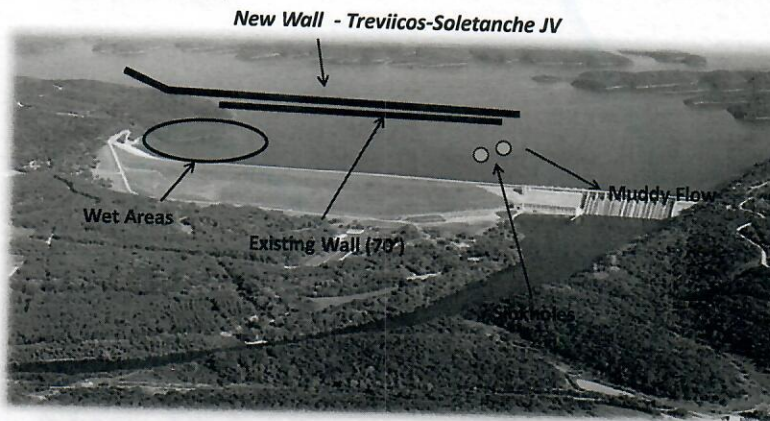
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Wolf Creek Dam, KY :The Solution by the USACE

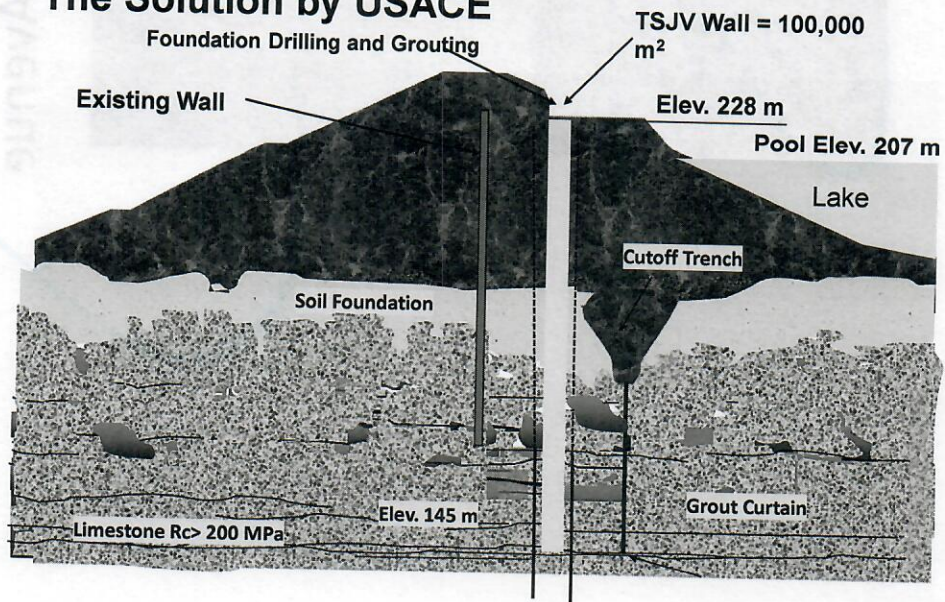
- Begins with 2-row grout curtain into rock (Advanced/Gannett Fleming)
- In late January 2007 → the USACE launches a \$584 M remediation program
- In late 2008 → TSJV is awarded the main remediation contract for \$341 M
- In the meantime → USACE maintains the pool elevation 25 m below its maximum capacity



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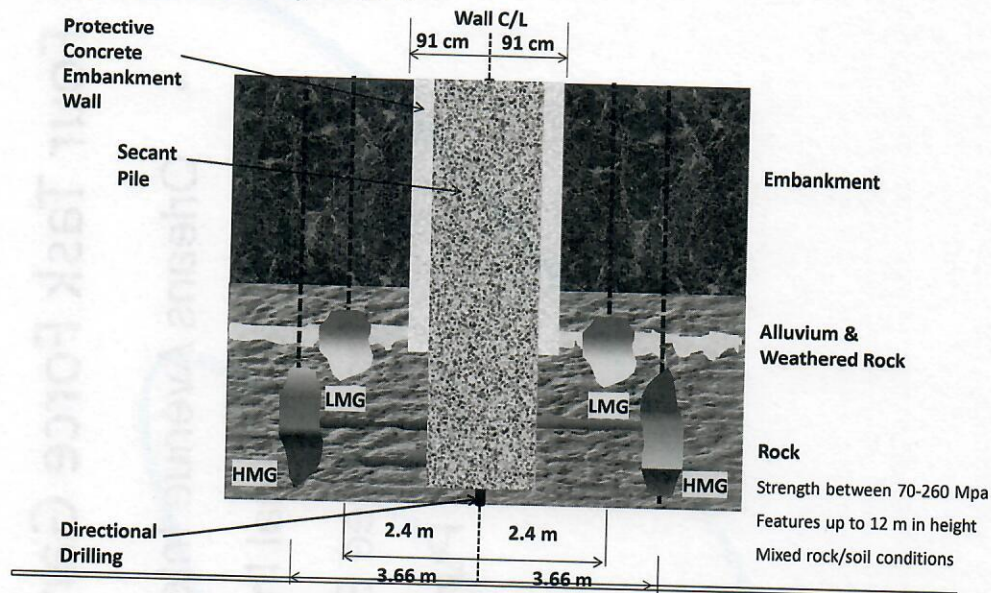
The Solution by USACE



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The Solution by TSJV



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- Hayward Baker were engaged to explore and pretreat the potentially vulnerable embankment/rock contact with a LMG operation, and to thereafter extend the Advanced/Gannett Fleming Phase 1 grout curtain.



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Protective Concrete Embankment Wall



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Directional Drilling Pilot Holes

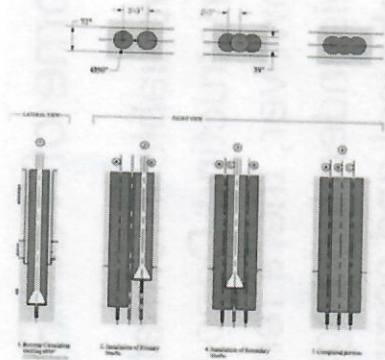


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Secant Piles

- Following the directional drilling pilot hole, 1.3 m diameter piles installed at 80 or 90 cm centers
- Ensuring the required overlap and minimum thickness. – Max target depth 85 m



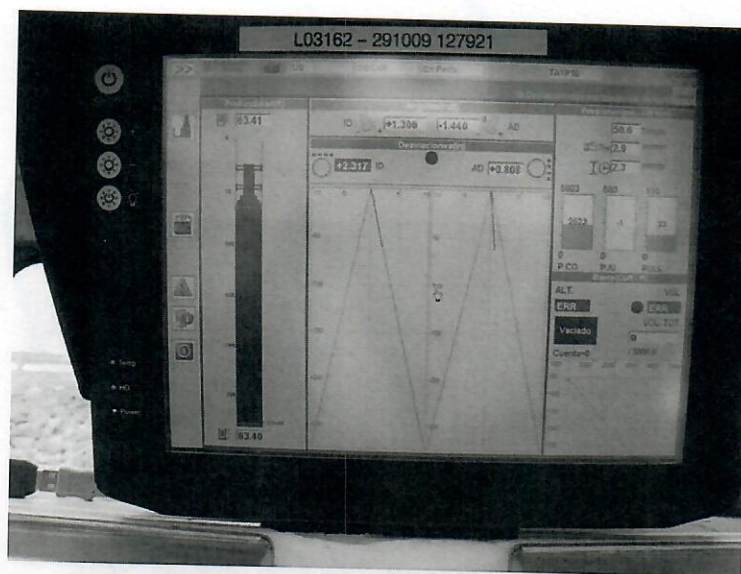
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- Only 1 of the 1,197 secant piles fell outside the verticality criterion (installed early in a Technique Demonstration Area).
- All other criteria (strength, permeability, continuity, homogeneity) were satisfied.
- Project completed 9.5 months ahead of the revised construction schedule.
- No dam safety incidents were recorded (although pressure “transients” were noted during predrilling).
- Dam and foundation are functioning efficiently, predictably and stably.



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Also noteworthy that the "lessons learned" from Wolf Creek 2 have been incorporated into subsequent USACE documents for cutoffs at Center Hill Dam, TN; East Branch Dam, PA; and Bolivar Dam, OH; and TVA's Boone Dam, TN. These specifications have therefore become more Prescriptive.

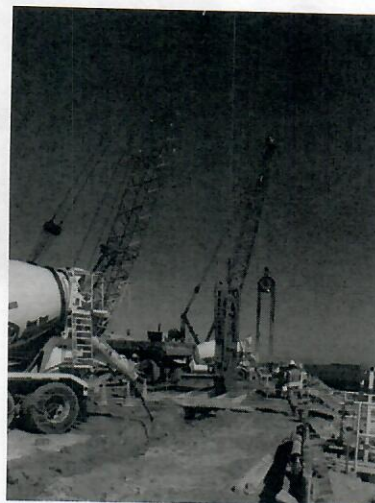


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Particular Advantages of Category 1 Cut-Offs

- Wide range of backfill properties.
- Can reach extreme depths:
 - 100 feet for backhoe
 - 250 feet for clamshell
 - 400 feet for hydromill
- Backhoe walls – where technically feasible – are very cost effective.
- All excavation methods and backfill types have long history of successful usage.
- In appropriate conditions, productivity can be high (> 3,000 sf/shift).
- Excellent pool of experienced contractors in the U.S.



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Particular Potential Drawbacks of Category 1 Cut-Offs

- More spoil is created and must be handled/stored/disposed of.
- Backhoe walls are somewhat of a commodity, and QA/QC is **always** a concern (e.g., placement of SCB).
- Lateral continuity of panel walls (deviation, contamination).
- Sudden loss of slurry into large voids.



- Clamshell and hydromill operations need substantial working platform, guidewalls, slurry plants, etc.
- Hydromill walls are typically non-competitive except where special conditions exist (e.g., very hard layers, boulders, etc.).

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U.S. Case Histories – 1976-2016

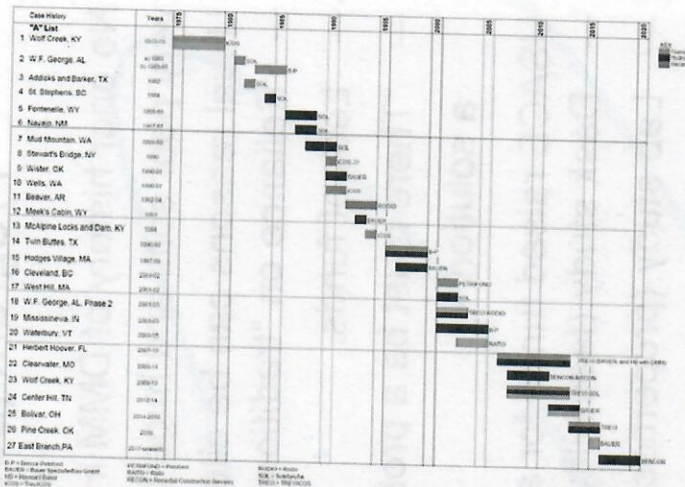
DAM NAME AND YEAR OF REMEDATION	CONTRACTOR	TYPE OF WALL	COMPOSITION OF WALL	GROUND CONDITIONS	PURPOSE OF WALL	SCOPE OF PROJECT				REFERENCES
						AREA	MIN. WIDTH	DEPTH	LENGTH	
1. WOLF CREEK, KY. 1975-1979	ICOS	24-inch diameter Primary Piles, joined by 24- inch wide clamshell panels. Two phases of work.	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) • Felzer (1988)
2. W.F. GEORGE, AL. 1981	Soletanche (Phase 1)	26-inch thick panels using cable and Kelly- mounted clamshell	Plastic concrete	Random, impervious FILL with silty core over 25- 30 ft	To provide a "positive concrete cut- off" through the dam and alluvials.	130,000 sf (Phase 1) plus	26 in	Max 138 ft	Approx. 1,000 ft	• Soletanche Brochure (undated)
1983-1985	Bancor, Patriford (Phase 2)	24-inch panels 15-27 ft long	3,000 psi Concrete	ALLUVIUM over chalky LIMESTONE		951,000 sf (Phase 2)	24 in	110-150 ft	8,000 ft	• Bancor 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 65 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) • Parsons (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.

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Project Listing Showing Chronology Type of Cut-Off and Specialty Contractor to 2019



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Category 1 Concrete Cut-Offs for Existing Embankment Dams (1975-2005)

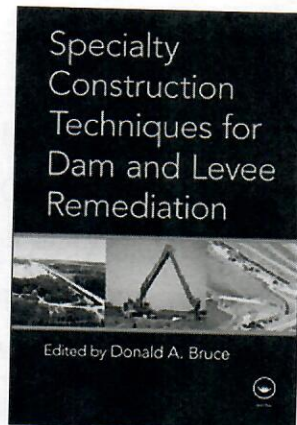
TYPE OF CONSTRUCTION	NUMBER OF PROJECTS	SQUARE FOOTAGE		
		SMALLEST	LARGEST	TOTAL
Mainly Clamshell	7	51,000	1,400,000	3,986,320
Mainly Hydromill	9	104,600	850,000	2,389,415
Mainly Secant Piles	4	12,000	531,000	1,050,700
Total	20			7,426,435

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.

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New Data Source



Chapters on:

- Drilling and Grouting Cutoffs
- Category 1 Cutoffs (Concrete)
- Category 2 Cutoffs (DMM)
- Composite Walls
- Anchors
- Instrumentation

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3. FINAL REMARKS, QUESTIONS AND ANSWERS

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THANK YOU

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34	038 10 020	14	100	340 10 020
33	038 10 020	13	100	340
32	038 10 020	12	100	340 10 020
31	038 10 020	11	100	340 10 020
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28	038 10 020	8	100	340 10 020
27	038 10 020	7	100	340 10 020
26	038 10 020	6	100	340 10 020
25	038 10 020	5	100	340 10 020
24	038 10 020	4	100	340 10 020
23	038 10 020	3	100	340 10 020
22	038 10 020	2	100	340 10 020
21	038 10 020	1	100	340 10 020