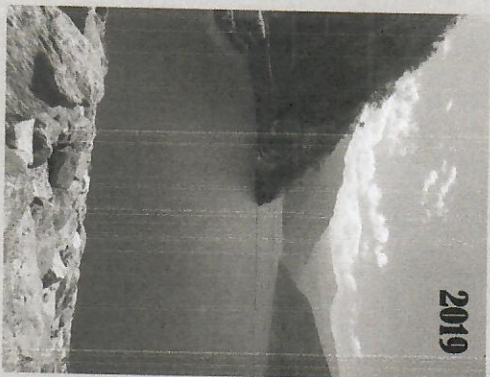
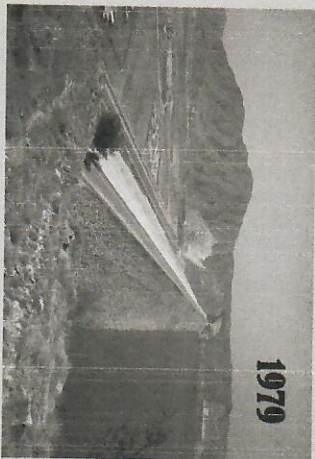


2019

Forty Years of Evolution in Specialty Geotechnical Construction Processes for Dams & Levees



1979



Dr. Donald A. Bruce, as Introduced by Dr. Brian H. Greene

"Legacy Lecture" Series Workshop
Sponsored by the Foundations Committee of USSD
Annual Meeting in Chicago, Illinois, April 8, 2019

USSD Legacy Lecture
April 8, 2019

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Dictionaries define "Legacy" as follows

1. *A gift by will, especially of money or personal property.*

- or -

2. *Something handed down or received from an ancestor or predecessor or from the past ancient philosophers.*

For clarification, this Lecture

- Will not involve gifts of money or property
- Will not be given by one of your ancestors
- Will not be given by an ancient philosopher
- Will be given by an old grey-haired guy with lots of photographs.

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AGENDA

Part 1: Technology Review

1. Prestressed Rock Anchors
2. Deep Mixing Methods
 - Break –
3. Drilling and Grouting
4. "Positive" Cutoff Walls
 - Break –

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Part 2: Miscellaneous Issues

1. Dam Portfolio Risk Management
2. Comments on the PFMA Process
3. Site Safety
4. Boards of Consultants
5. Mentorship
6. Question & Answer Session (Dr. Greene)

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PART 1: TECHNOLOGY REVIEW

1. Prestressed Rock Anchors



Agenda

1. History of Anchor Usage in North American Dams
2. Evolution of Best Practices:
 - 2.1 Design
 - 2.2 Construction
 - 2.3 Stressing and Testing
3. Notable Influential Case Histories
4. Long Term Performance Assessment and Portfolio Risk Assessment of "Legacy Anchors"



1. History of Anchor Usage in North American Dams

Histogram of US Dam Construction (1800-2004)

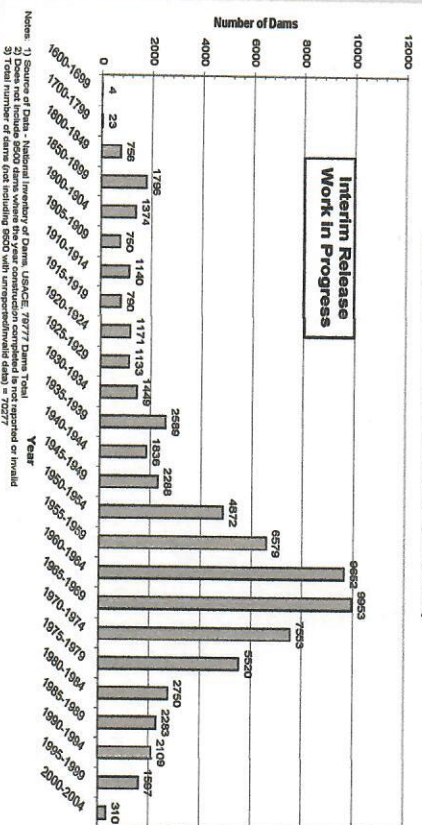


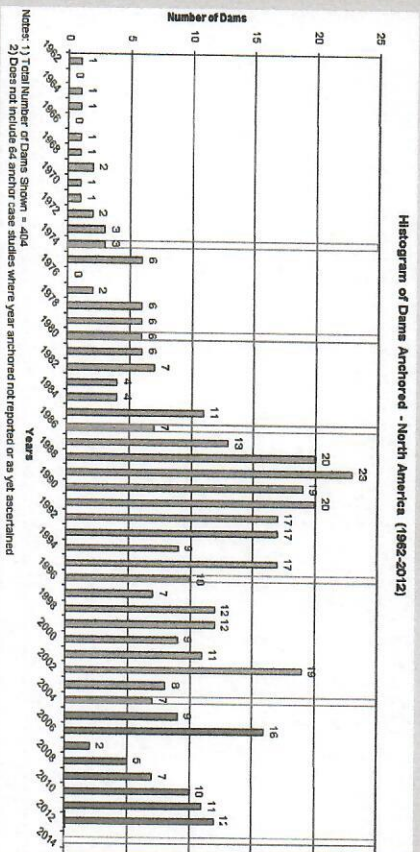
Table 1. Number and affiliations of Post-Tensioning Institute's Anchor Committee members.

ASPECT	1974	1980	1986	1996	2004	2014
Post-Tensioning Suppliers	6*	4*	4*	2*	3*	4
Anchor Contractors	2	2	3	3	3	3*
Consultants	2	None	1	2	2	2
Owners/Regulators	1	2	0	3	3	3
Sponsor Organizations	1	None	0	1	1	2
TOTAL	12	8	9	11	12	14

* Including the same Chairman from DSI (Post-Tensioning Supplier).
* Chairman from VSL (Post-Tensioning Supplier).
* Chairman from Schnabel Foundations (Specialty Contractor).

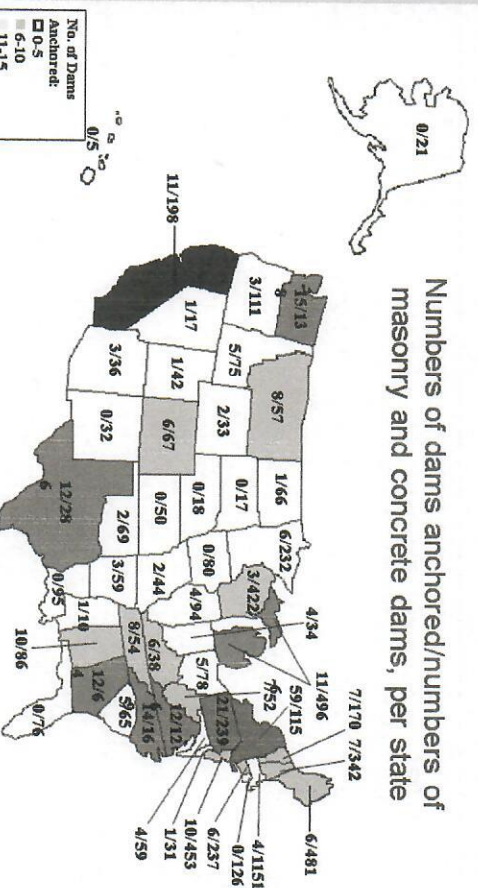
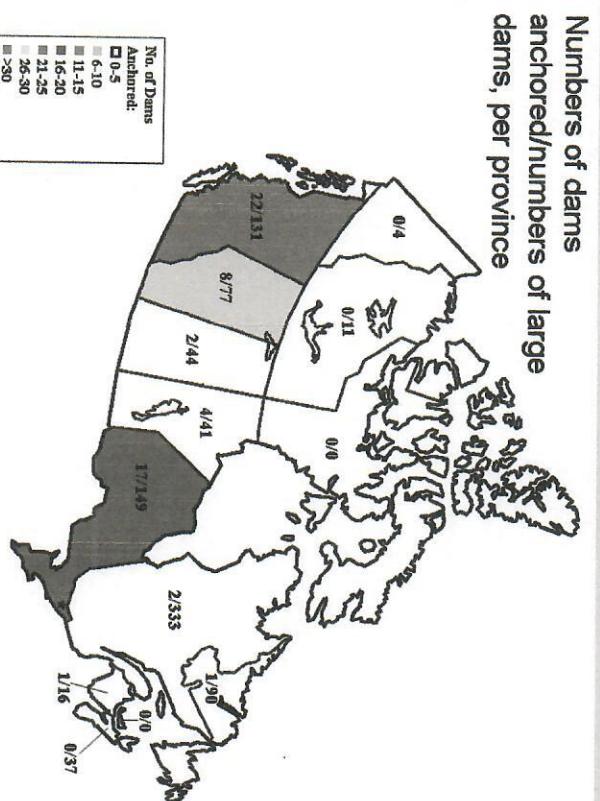
Table 2. Number of pages of major sections of the Recommendations.

ASPECT	1974	1980	1986	1996	2004	2014
Materials	1	2	2	8	10	10
Site Investigation	0	1	1	1	2	2
Design	2	6 1/2	6 1/2	12*	13	13
Construction Protection	1	4	5	10	14	15
Construction	7	9	9	10	15	17
Stressing and Tending	1	6	8	17	18	19
Application/References	16	18	1	10 1/2	5	8
Recordkeeping	0	1	1	1 1/2	1 1/2	2
Specifications	0	1	1 1/2	2	2	2
Responsibilities and Submittals	0	1	1 1/2	2	2	2
Epoxy-Coated Strand	0	0	Very minor reference.	Frequent reference but not section	10 (Separate sections)	10
TOTAL PAGES	32	57	41	70	98	109



Histogram of dam anchoring projects by year (Bruce et al., 2013), also showing dates of publication of PTI Guidelines.

The first post-tensioned dam was Cheurfa's, Algeria in 1934. Anchors have been installed in every other continent since, principally to compensate for original design deficiencies, war damage, structural foundation deterioration and/or revisions to current standards of safety.



2. Evolution of Best Practices

2.1 Design

General Note: All aspects, except overall stability and system design, are covered best in the Recommendations of the Post Tensioning Institute (2014), and are little changed from Littlejohn & Bruce (1977).

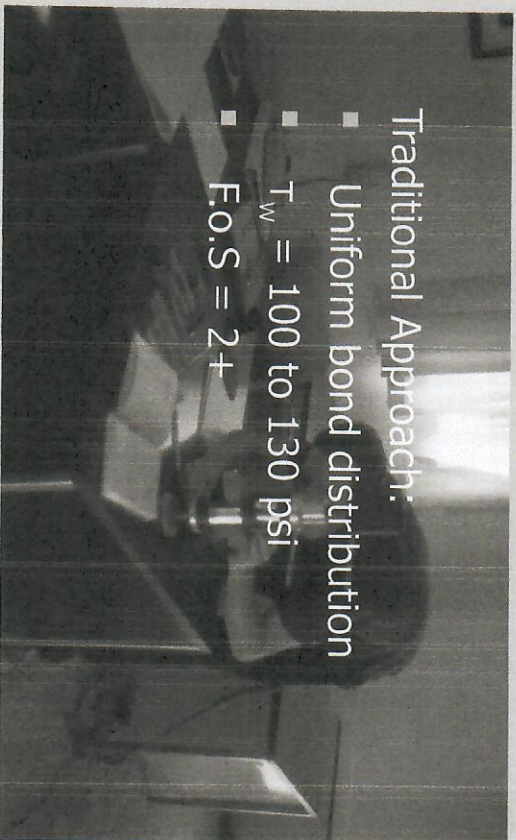
2.1.1 Overall Stability (i.e., Resistance to pull out)

- Conventional - and very conservative - to assume submerged "weight of rock" in a cone. The apex of the cone is typically assumed to be at the mid point of the bond length, with a 90° included angle. Individual cones transform into slabs in closely spaced anchors.
- Few designs consider the rock mass structure in dictating failure volumes, or friction across the assumed surface.
- See Hobst & Zajic (1977): no one else has!

2.1.2 Bond Length

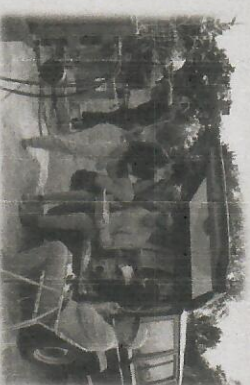
Traditional Approach:

- Uniform bond distribution
- $T_w = 100$ to 130 psi
- $F.o.S = 2+$



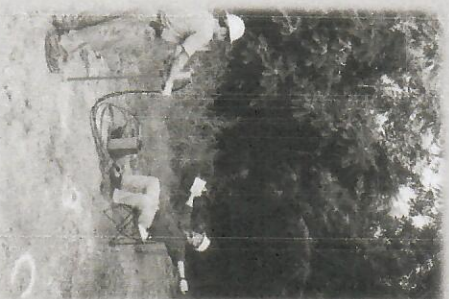
- Permissible geotechnical bond values are selected from
 - PTI, and other published sources
 - Prior experience
 - Site specific testing

- Geotechnical bond invariably governs design of bond length (not grout/tendon bond for clean steel)
- Bond lengths over about 35' are progressively less load efficient (bond is not uniformly distributed in all except the strongest rock masses: controlled by E rock to E grout ratio)



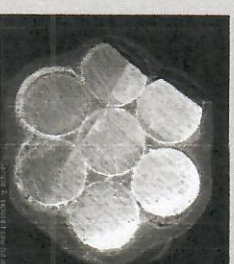
2.1.3 Tendon Design

- Stress at Test Load must never exceed 80% GUTS.
- Stress at Working Load typically 50 – 66% GUTS, thereby allowing test factors of safety of ≥ 1.33 .
- Lock-off Loads are typically 60 – 70% GUTS but can be much lower in certain conditions (e.g., AAR structures).
- Bar v strand selection depends on site logistics, load, and length. Typically multistrand tendons are required for dam anchors.
- Details provided in PTI (2014).



2.1.4 Corrosion Protection Design

- For permanent anchors (i.e., service life over 2 years), Class I Protection is required, per PTI (2014).
- Components may include corrugated ducting, greasing and sheathing and/or epoxy coating/epoxy filling.
- Design must always be the task of the Engineer of Record.
- Historically ineffective/unreliable corrosion protection has given rise to the “legacy anchor” problem, discussed in Part 3 of this Webinar.



Courtesy of N.C.C.

2.2 Construction Processes

2.2.1 Drilling

1970's:

- Diamond drilling in concrete and occasionally in rock
- Rotary or rotary percussive in rock
- Deviation monitoring (< 1 in 100)
- Pressure grouting and redrilling if watertest failed
- Maintain full manual logs

Now:

- Diamond drilling only used for reinforced concrete or very weak structures
- Use of down-the-hole hammer prevalent
 - Deviation control
 - Speed
 - Vibrations/pneumatic fracture
- MWD common

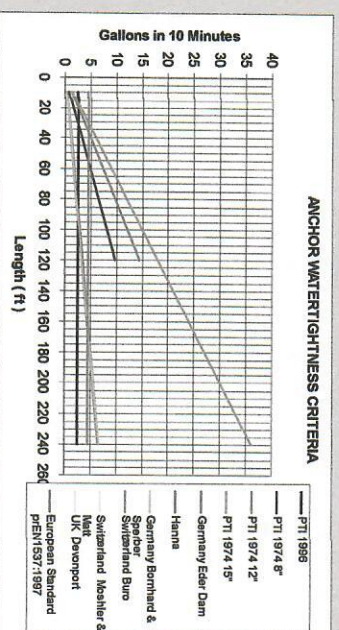
2.2.2 Water Pressure Testing

1970's:

- Full length test
- 0.5 gpm at 60 psi (more typical 0.001 gal/inch diameter/ft/min at 5 psi)
- Very conservative criterion: most holes had multiple regrouths and redrills

Now:

- Knowledge of fissure control on permeability
- 2.5 gal at 5 psi excess pressure criterion prior to and after placement
- Testing of corrugated protection also



2.2.3 Tendon Placement

- Method is project-specific.
- Goal is to install in a controlled and safe fashion to minimize potential for damage to the tendon and its corrosion protection.
- The following slides were provided by Mr. Paul Krumm of Nicholson Construction Company.

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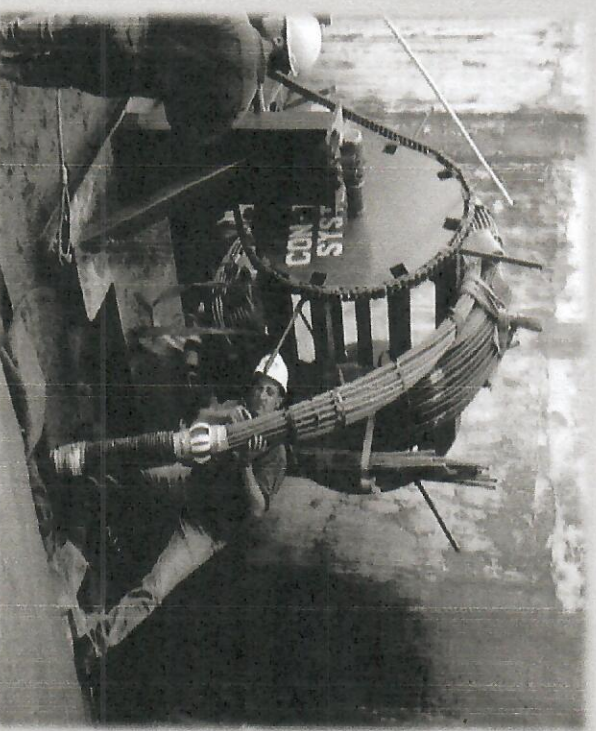
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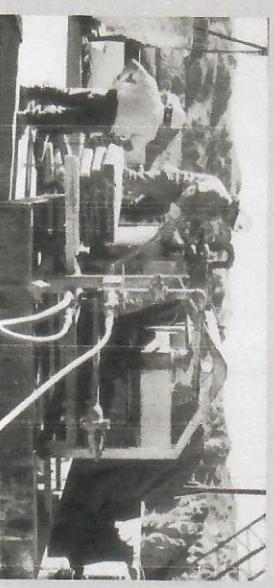
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2.2.4 Grouting

1970's:

- Proprietary non-shrink grout for first stage
- Water:cement ratio ≤ 0.45
- Pre-construction testing of mixes
- High speed, high shear mixer
- Tremie grout



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Now: Same except:

- No use of preblend cements
- Focus on fluid property testing, as opposed to cubes
- Often single stage grouting
- Preproduction testing



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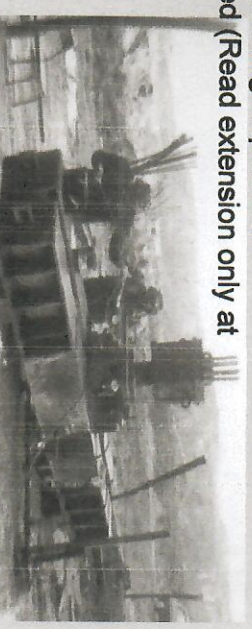
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2.3 Stressing and Testing

1970's:

- Progressive simple loading to 115% Design Working Load (to maximum 80% GUTS)
- Alignment Load of 10% Test Load
- No cycling
- Very little data recording required or analysis described (Read extension only at Test Load)
- Lock off at 50 to 70% GUTS
- Lift off test
- No creep test



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- **Proof and Performance Tests**
- **Analysis of elastic movement data**
- **Creep testing: short and extended**
- **Lift off testing**
- **Lock off $\geq 60\%$ GUTS**
- **Special provisions for epoxy coated strand**
- **Clear acceptance criteria and “rework” guidance**

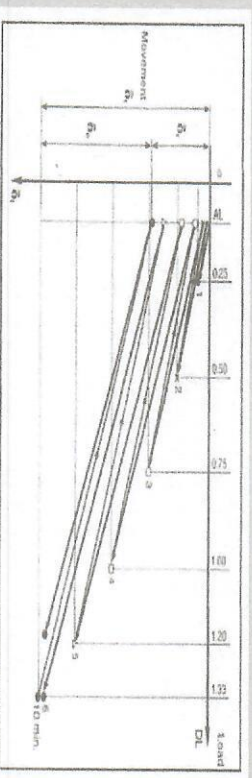
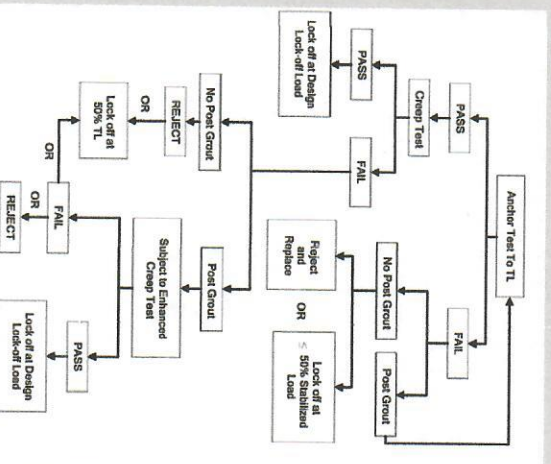


Fig. 8.1a Plotting of performance test data (PTT 2014)

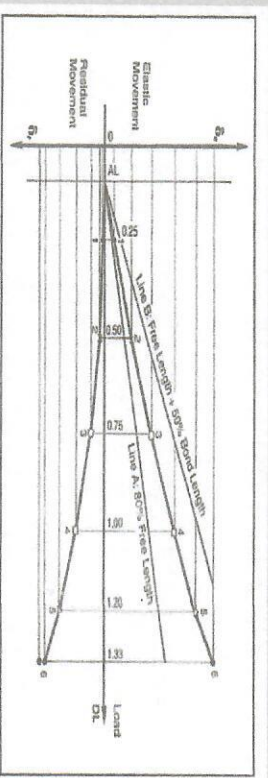
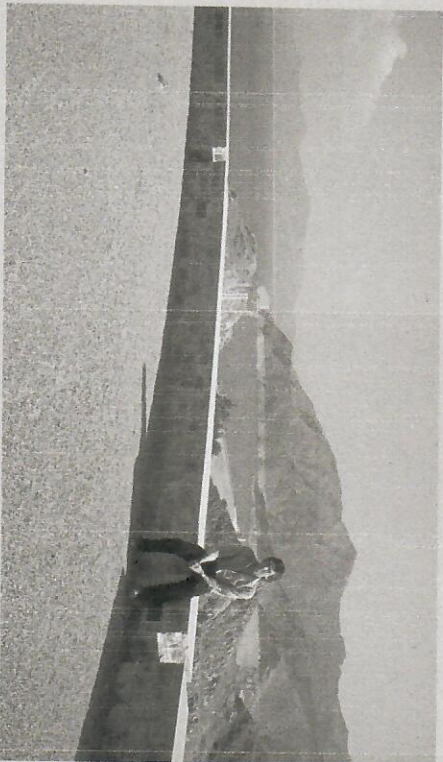


Fig. 8.1b-Plotting (PTJ 2014)

3.1 PhD Thesis (1973 – 1976)



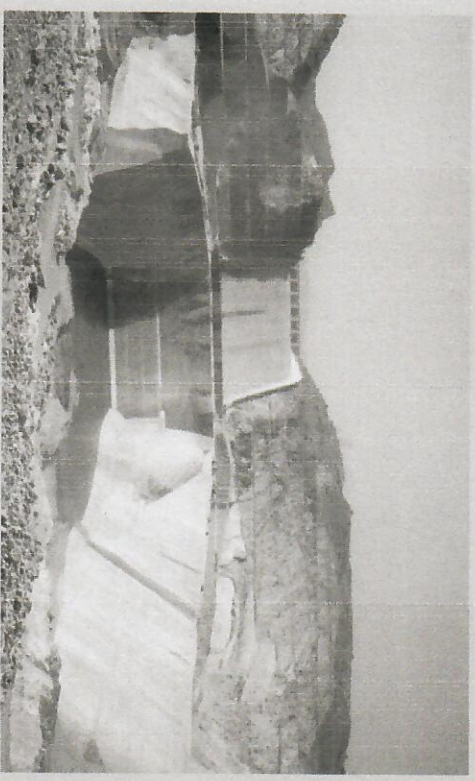
3.2 Tarbela Dam, Pakistan (1979 – 1980)



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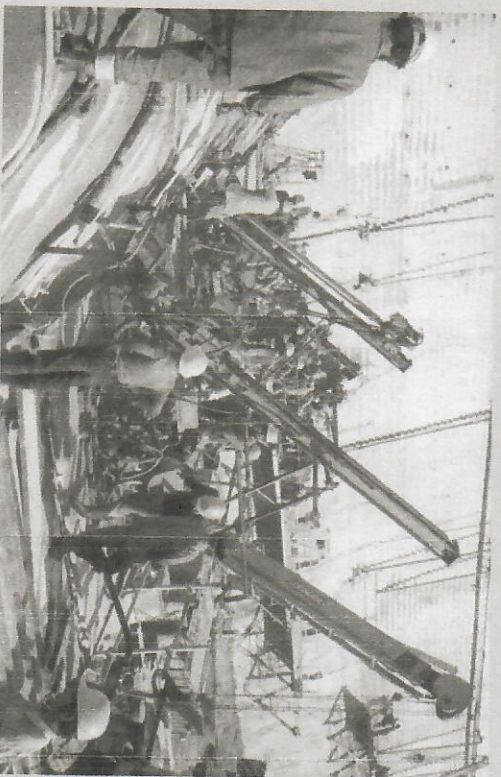


Service Spillway, protected by RCC and 1200 (invisible) high capacity anchors.

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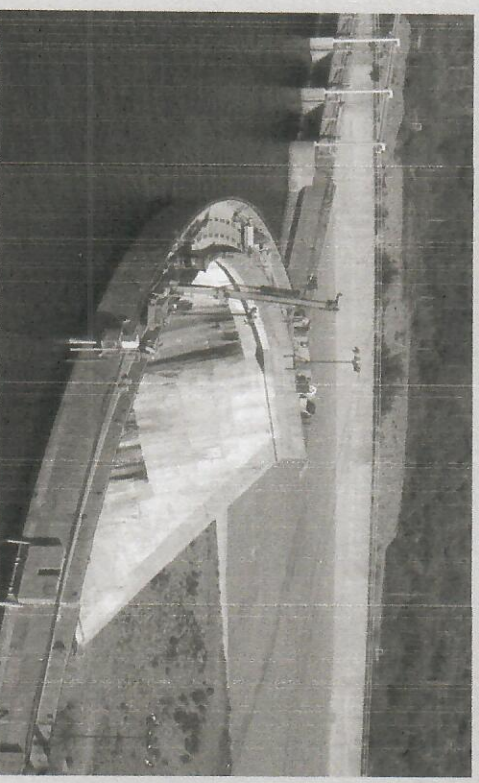


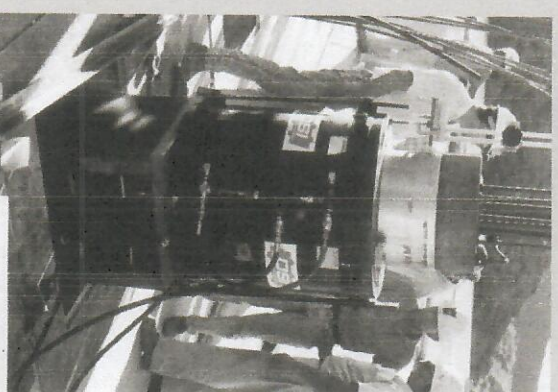
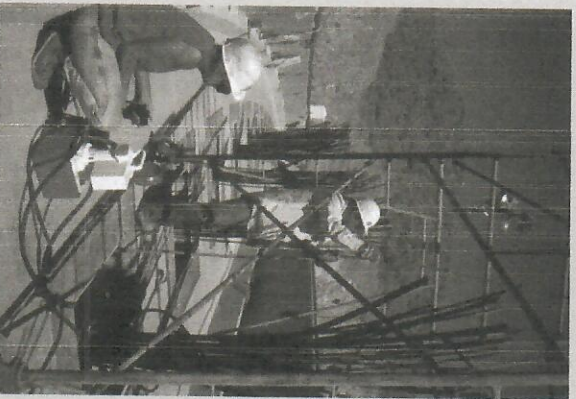
my car



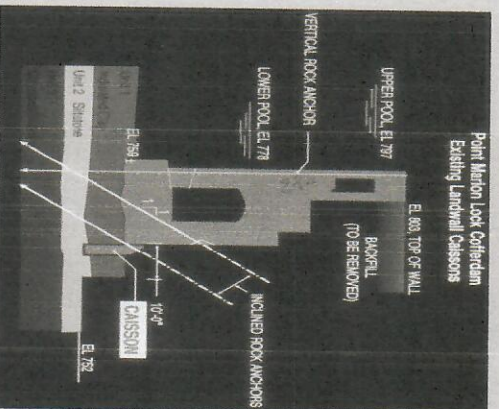
Strategic planning session on the Auxiliary Spillway Apron.

3.3 Stewart Mountain Dam, AZ (1991)





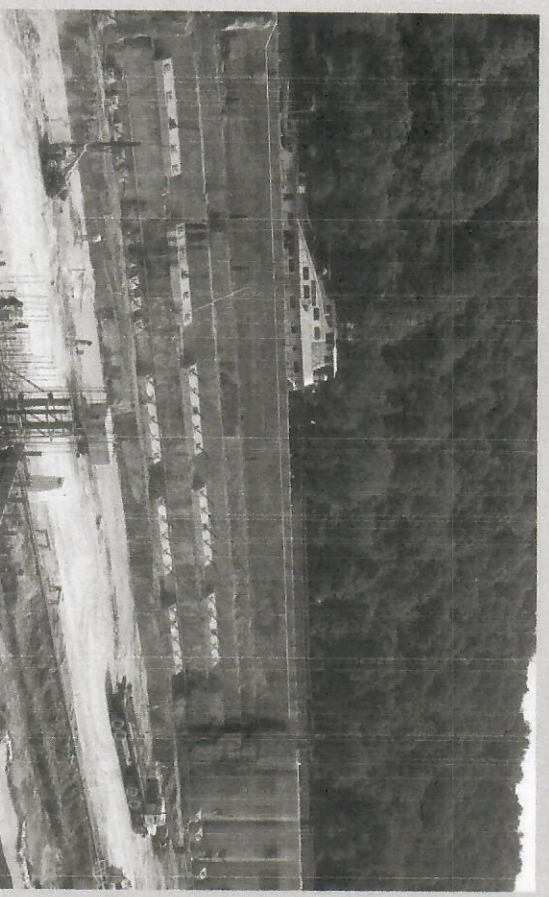
3.4 Point Marion, PA (1990 - 1991)



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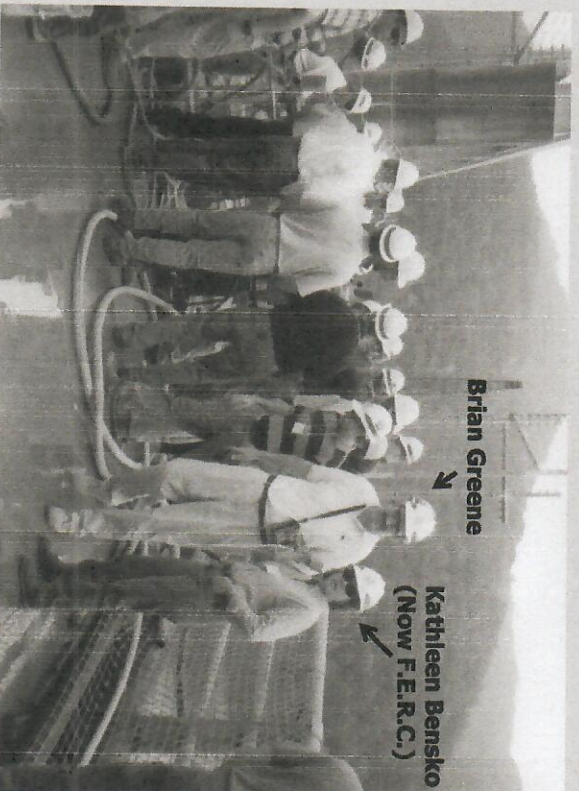
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Brian Greene
Kathleen Bensko
(Now F.E.R.C.)

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3.5 Tom Miller, TX and Wanapum, WA (Installation and Pregrouting of Corrugated Duct prior to tendon placement: Courtesy of Nicholson Construction)



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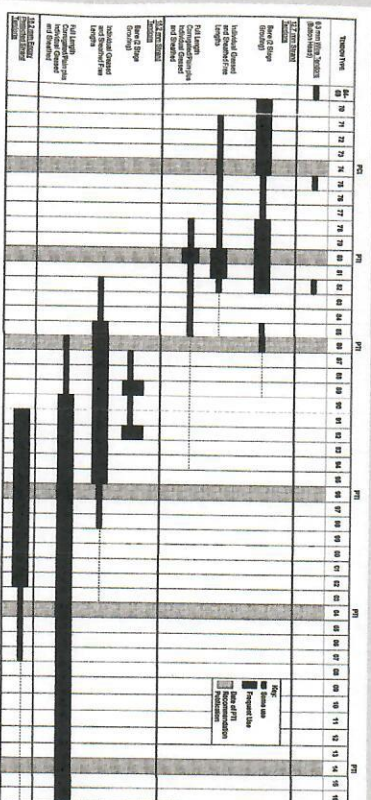
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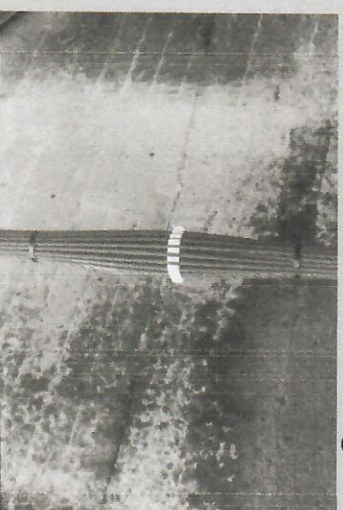


4. Long Term Performance Testing and Portfolio Risk Assessment of "Legacy Anchors"

4.1 Evolution of Corrosion Protection Concepts



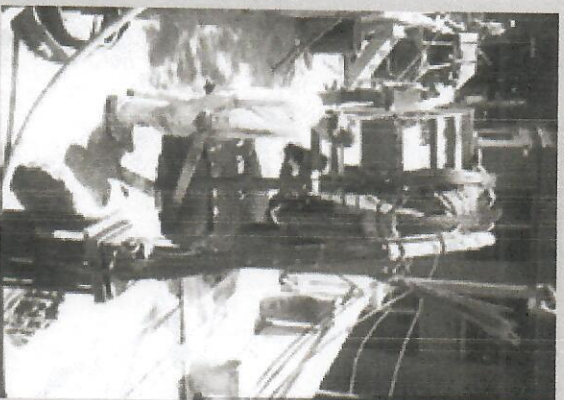
1960s – 1970s



- Tendon proposed/selected by Contractor/PT Supplier (wire, strand, bar).
- Grout conceived to be the only protection: 2 stages essential.
- Fully bonded, and so no long-term load monitoring capability.

1970s – 1980s

Greased and sheathed
free lengths, bare
strand on bond length.



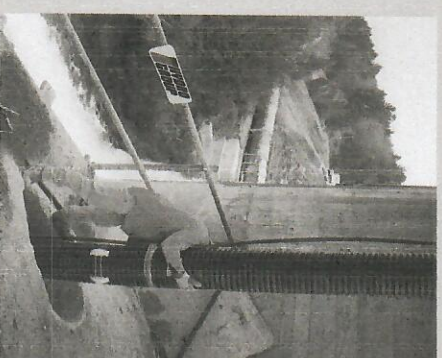
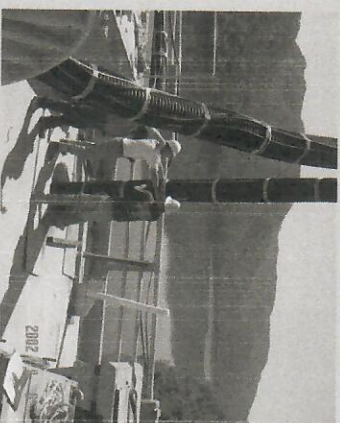
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1980's Onwards

Corrugated Sheathing on Bond Length (1980s).
Extending to Full Length
Protection by 1990s



Greased and sheathed protection on individual strands,
permitting single stage grouting.

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1990's Onwards

Epoxy-coated and filled
strand with or without grease
sheathed free length.
Typically require special
handling and installation
methods.



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Corrosion Protection Requirements

CLASS	PROTECTION REQUIREMENTS		
	ANCHORAGE	UNBONDED LENGTH	TENDON BOND LENGTH
I ENCAPSULATED TENDON	1. TRUMPET 2. COVER IF EXPOSED	1. GREASE-FILLED SHEATH, OR 2. GROUT-FILLED SHEATH, OR 3. EPOXY FOR FULLY BONDED ANCHORS	1. GROUT-FILLED ENCAPSULATION, OR 2. EPOXY
II GROUT PROTECTED TENDON	1. TRUMPET 2. COVER IF EXPOSED	1. GREASE-FILLED SHEATH, OR 2. HEAT SHRINK SLEEVE	GROUT

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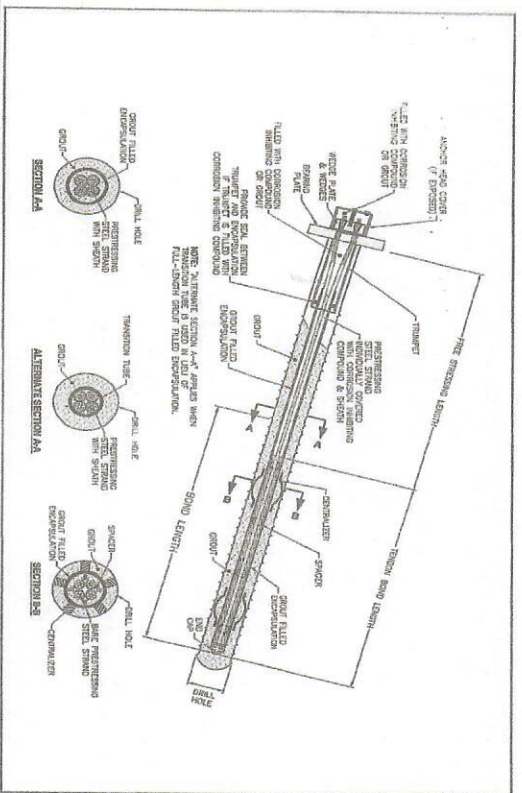


Figure 5.2a – Class I protection: encapsulated strand anchor (PTI 2014)

Based on the results of our database of dam anchor projects, we conclude:

- About 60% of the existing anchors in N. American dams were installed prior to Class I protection becoming mandatory in 1996. This defines “legacy” anchors.
- Early anchor technology was driven by post-tensioning suppliers and specialists, and not geotechnical contractors, as now.
- The problem is worldwide.
- There is no single, easy, technical answer, and different owners have different risk tolerance levels. Therefore owner attitudes range from total replacement to “turn a blind eye.”

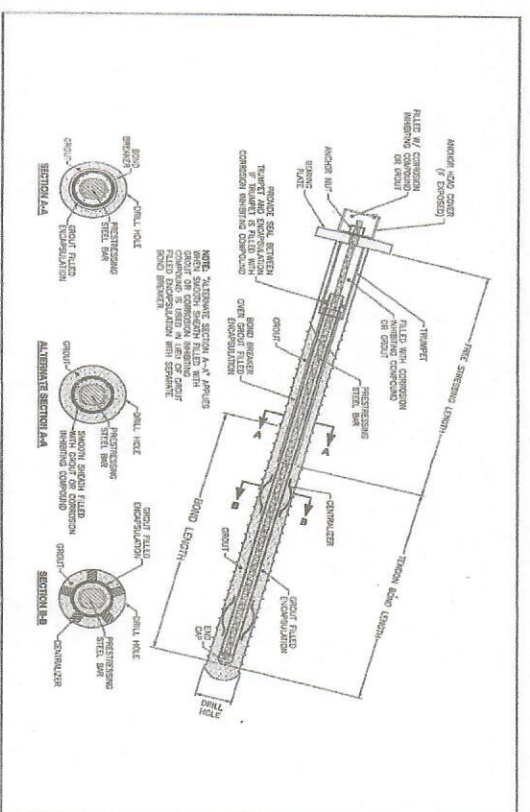


Figure 5.2b – Class I protection: encapsulated bar anchor (PTI 2014)

4.2 Challenges to Evaluating Legacy Anchors

1. Most owners and consultants simply did not contemplate at time of design and installation that long-term monitoring would be advantageous, let alone fundamental. Therefore, no provisions for installing restreassable or retestable anchor heads.



2. Fully grouted tendons without a sheath around the free length cannot be lift-off tested to measure residual load.

4.4 Ongoing & Future Study Research

- Current CEATI Study (2017 – 2019) with John Wolfhope
 - Review of past case histories
 - Review of past research projects
 - Interviews with key owners
 - Update database of projects
 - Development of “path forward” / “best practice” guidelines
- Future Research Opportunities
 - Exhumation upon dam decommissioning
 - Overcoring and extraction
 - Optimization of NDT testing potentials
 - Sharing of national and international concepts and information
- Challenge
 - Finding a platform to fund and publish new findings

What's Wrong with this Picture?



2. The Deep Mixing Methods



Agenda

- 2.1 In the Beginning
- 2.2 Some Landmark Projects and Events
- 2.3 New Arrivals



2.1 IN THE BEGINNING

1954	Original MIP System (Inrusion Prepakt)
1986	SMW Seiko arrive in U.S.
Late 1980's	Jackson Lake Dam, WY (Seiko/GeoCon)
Late 1980's	Start of Environmental Applications (GeoCon)
Early 1990's	Start of Levee (Cutoffs) and Dam (Seismic) Remediations
1992-1994	First major Earth Retaining Structure (Boston, MA)
1995	Visit by U.S. engineers to Japan
1996	First Lime-Cement Column project (New York)
1997-1998	Largest wet DMM project to that time (Boston, MA)
1997-2000	FHWA State of Practice Studies are published
Early 2000's	Technical Exchanges with Japan

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IN THE BEGINNING (continued)

2000-2003	Desk, Bench and Field Tests, New Orleans
2001-2005	National Deep Mixing Research Program (States Funded)
2003	International Conference in New Orleans
2005	Katrina and Rita
2006	Task Force Guardian
2006	CSM brought to Canada and TRD brought to U.S.
2006-2007	Deep Mixing at Tuttle Creek Dam, KS
2007-Present	National Deep Mixing Project Revised
2008-Present	Cutoff Walls at Lake Okeechobee
2010-2011	LPV 111, New Orleans, LA
2012	International Conference in New Orleans
2012-2013	Kitimat, BC
2013	Increasing DFI support for DMM
2015	USACE, Reclamation and DFI Manuals

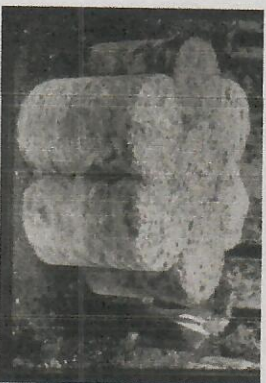
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Conditions Favoring DMM

- 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



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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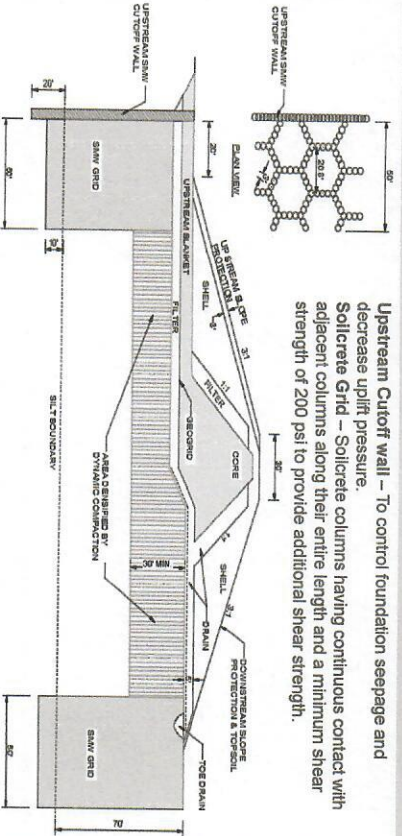
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Foundation stabilization of Jackson Lake Dam



Typical Cross-Section Configuration

Sources: 1. Foundation Stabilization of Jackson Lake Dam, A. Pujol-Rius, P. Gargay, J. Neal and O. Teki, 12th 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. Wirtusz & J. McClain, USCOOLD

Courtesy
of JAFEC
USA, Inc.

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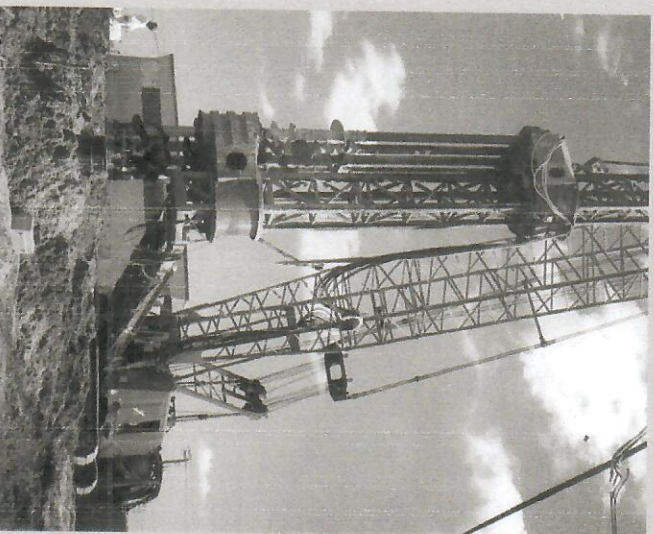
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Upstream Cutoff wall – To control foundation seepage and decrease uplift pressure.

Solcrete Grid – Solcrete columns having continuous contact with adjacent columns along their entire length and a minimum shear strength of 200 psi to provide additional shear strength.

**First Multiple Auger Drill
Manufactured in U.S.
Hialeah, FL (~1988)**

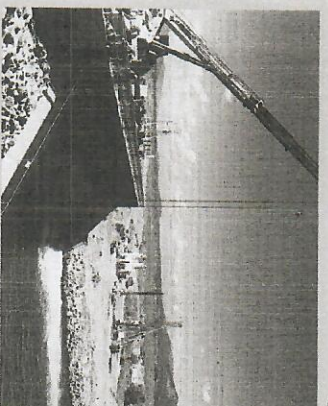


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DM design concept



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

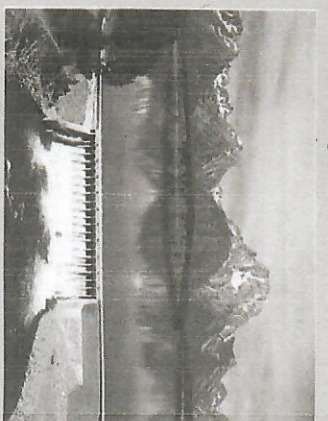
Source: Jackson Lake Dam project boasts unusual soil-improvement method, Intermountain Contractor, Oct 1987

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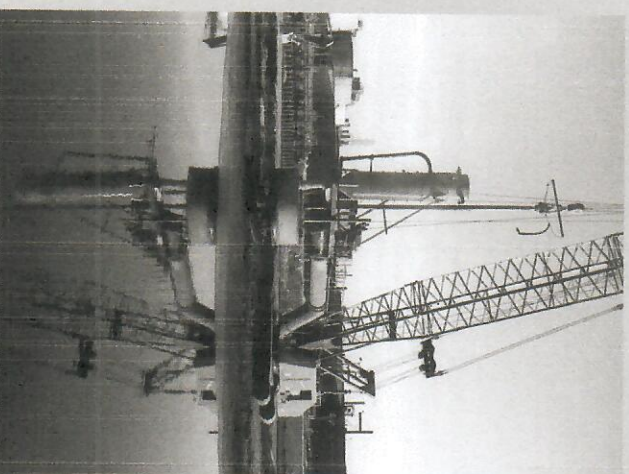
74



".... To the right of station 29+00 the SMW structure designed o 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

First Large-Scale SSM Project
(~1989)



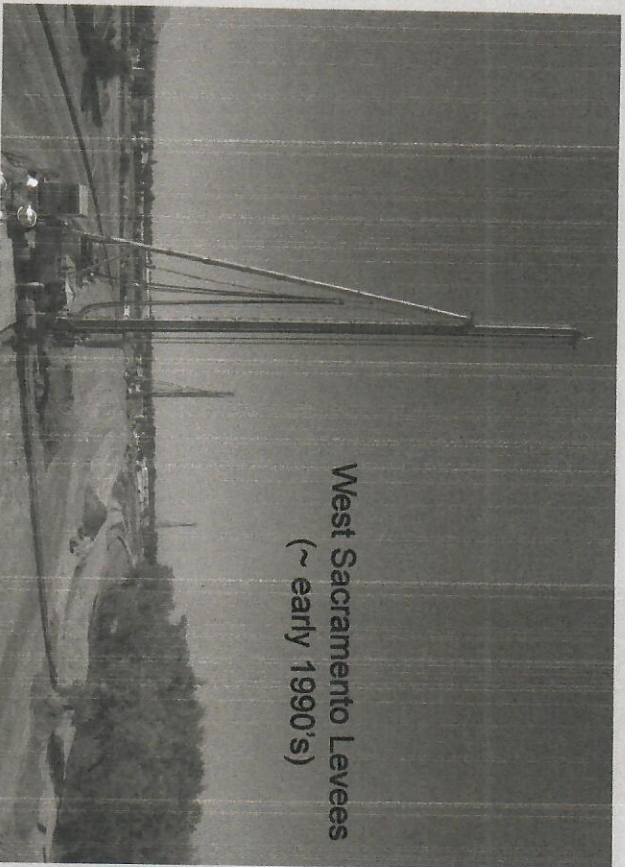
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West Sacramento Levees
(~ early 1990's)

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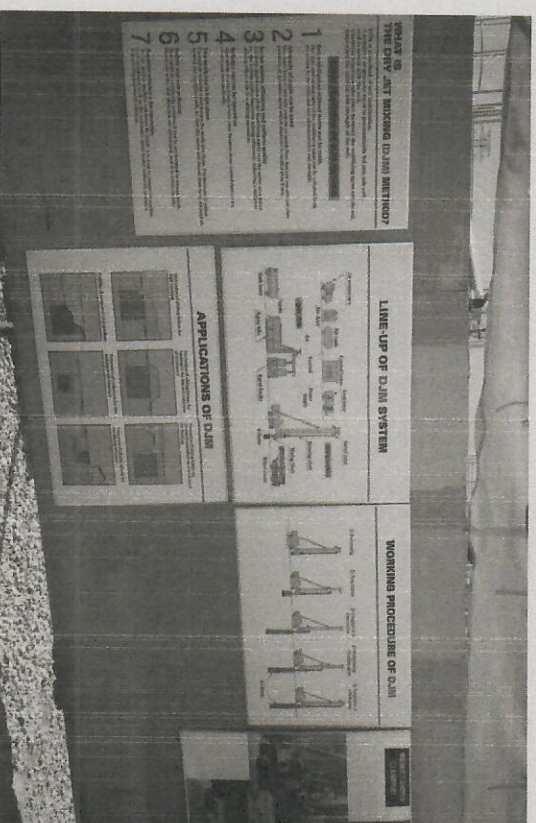
79



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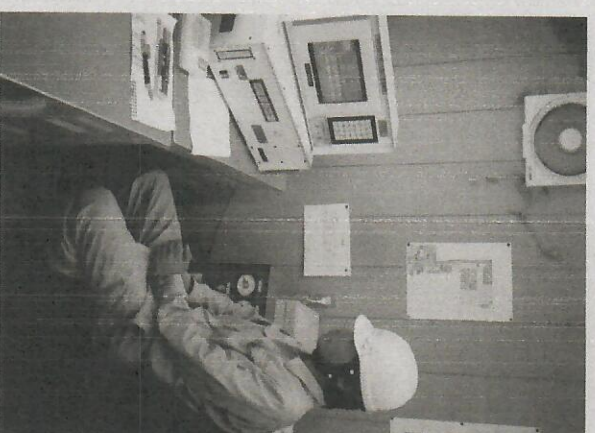
81



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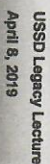
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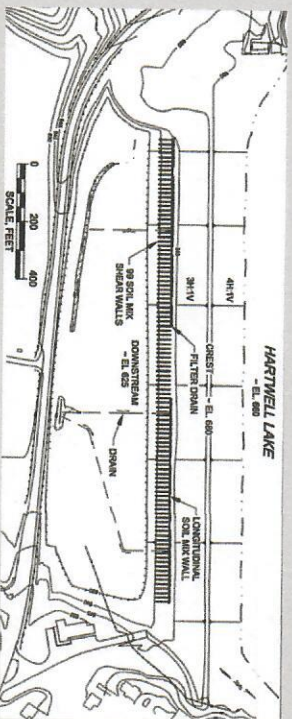
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2.2.2.1 Clemson Upper & Lower Diversion Dams South Carolina



- 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 Clemons Upper and Lower Diversion Dams," Wooden, 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 Clemons Upper and Lower Diversion Dams," Wooden, R. L., and Foreman, B., Proceedings of the 25th Annual United States Society on Dams Conference, 2005.

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2.2 FOUR LANDMARK PROJECTS

Caveats and Apologies

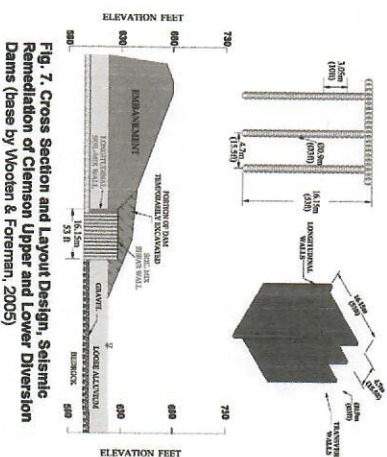
- Incomplete (e.g., important DMM projects conducted in Bay Area, the Pacific Northwest, and on California Dams and Levees)
- No contractor preference implied, but:
- Thanks for all the contractors who sent images – including: Bauer Foundations; DeWind, Fudo, GeoSolutions/GeoCon, Golder Construction,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



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Clemson Upper & Lower Diversion Dam South Carolina



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

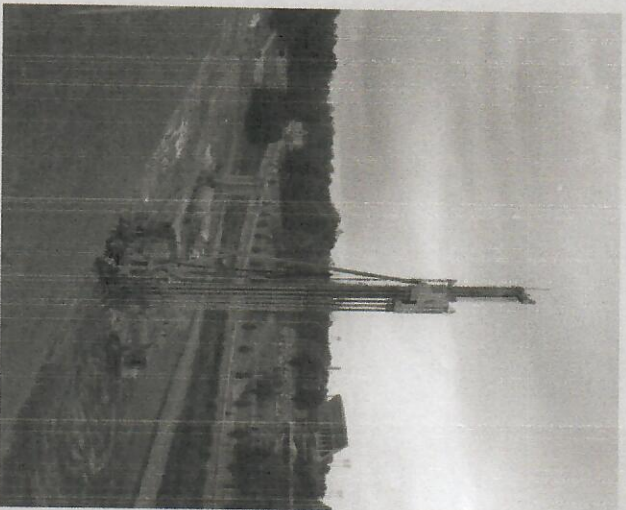
DM longitudinal wall – To prevent softened alluvium from squeezing or flowing between the transverse walls.

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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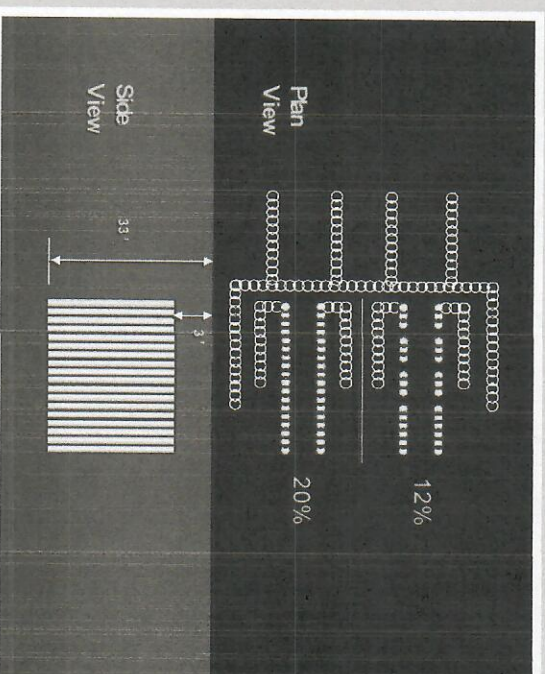
Phase 1: First Demonstration Program (2001)

- No prior history of DMM in the area despite very poor soils and huge levee infrastructure.
- Usual reasons can be cited:
 - Reliance on "traditional" solutions.
 - Lack of funds.
 - "There must be a problem before there is a solution."
- USACE raised funds for a classic "3 step" research program:
 - Desk study (feasibility in local soils).
 - Lab study (properties of mixed soils).
 - Full-scale field test (performance of columns at different replacement ratios).



2.2.2 Deep Mixing in New Orleans

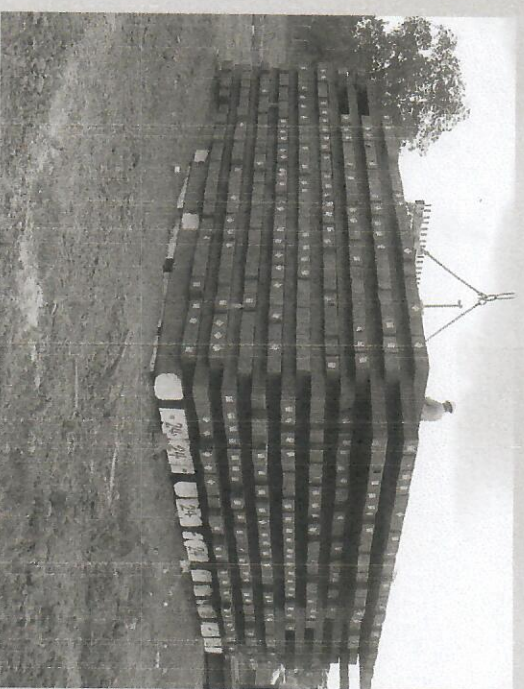
1. Phase 1: First Demonstration Program (2001)
2. Phase 2: Task Force Guardian and Beyond (2006-2010)
3. Phase 3: LPV 111 and others (2009 onwards)



As-built cell configuration with 12% and 20% replacement ratios.



Extraction of Top of Column



Cell A fully loaded with 1100 tons of steel

Outcome of Test Program

Invaluable information was gained on designing and constructing Deep Mixing in the local soils. However, there remained some doubts (misunderstandings) in certain quarters about its technical and commercial viability in Louisiana and so it was decided to keep DMM "on ice."



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).



Four Task Force Guardian Projects (2006)

Orleans Avenue Interim Closure Structure
17th Street Canal Interim Closure Structure
Homeplace Levee Enlargement
Gainard Woods Pump Station



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Phase 2: Wet Mixing at Orleans Avenue

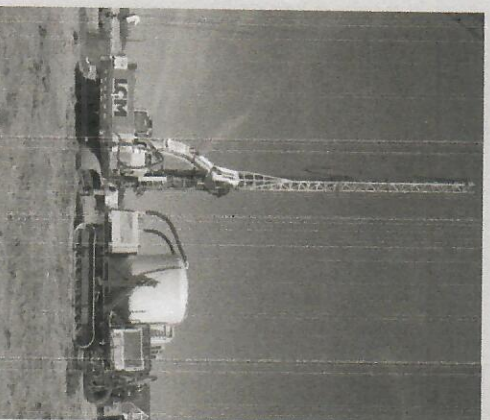


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Phase 2: Dry Mixing at 17th Street Canal and Homeplace Levee



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Phase 2 Projects (Task Force Guardian to 2010)

PROJECT NAME	START DATE	APPLICATION	DETAILS	CONTRACTOR
17th Street Canal	2006	Overwater mixing for interim canal closure structure in cellular grid pattern.	2,200 DRE columns, 800 mm diameter, 18 m deep Triple axis WRE in rows and square grid. About 6,000 cubic meters of treated soils.	Hayward Baker, Inc.
Orleans Avenue Canal	2006	Overwater mixing for interim canal closure in cubic meters of treated soils.	Triple axis WRE.	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 Pump Station	2008	Flood wall replacement.	Triple axis WRE.	Raito, Inc.
Westwego Pump Station Phase 2	2009	Ground improvement for new structure in cellular grid.	DRE columns, 800 mm diameter	Hayward Baker, Inc.
IHNC Reach III	2010	Soil improvement under I-wall levee section in panels.	DRE columns, 800 mm diameter	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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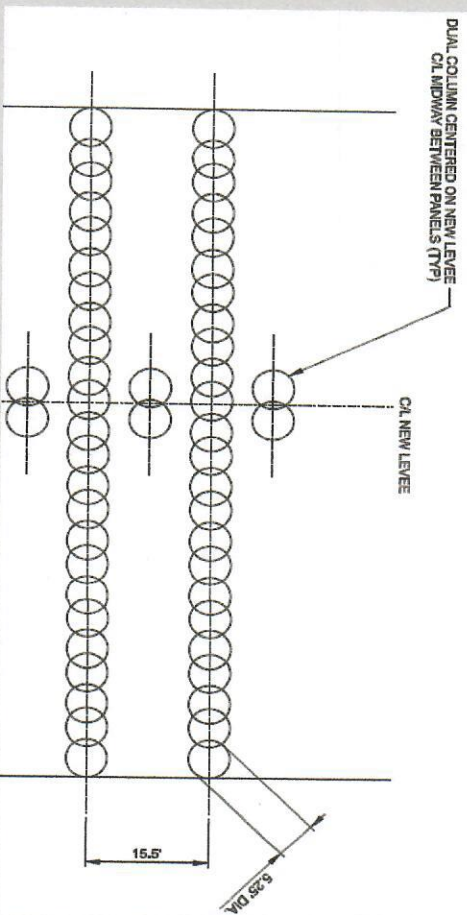
100

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.



LPV III Production

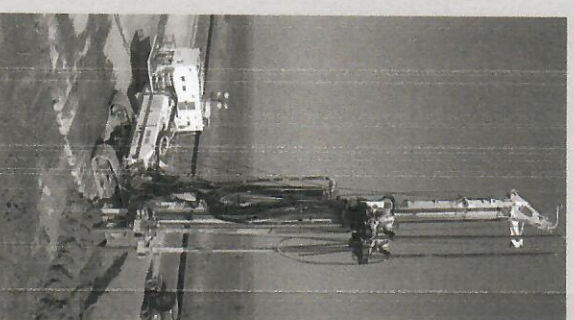
PRODUCTION START DATE	1/14/2010
PRODUCTION COMPLETION DATE	3/18/2011
TOTAL CALENDAR DAYS	439.00
TOTAL MONTHS	14.43
TOTAL SHIFTS WORKED (as of 3/18/2011)	3,309
TOTAL MANHOURS (as of 3/18/2011)	502,817
TOTAL DMM ELEMENT INSTALLED	18,028
TOTAL VOLUME TREATED	1,681,579
TOTAL CEMENT USED	457,693
TOTAL TRUCK-LOADS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

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.



Observations

The Phase 1 USACE Test Program was, in retrospect, an extraordinarily timely and valuable undertaking on different levels, given what was to follow in August 2005.

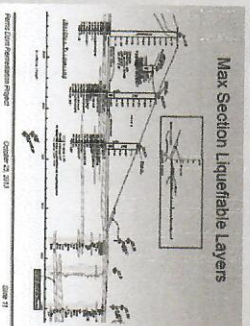
The Phase 2 projects completely validated the technical and economic viability of DMM in Louisiana on a number of medium-scale jobs.

Confidence and experience gained in Phase 2 directly influenced the decision to use DMM in LPV 111 – the largest DMM project undertaken in North America. This project has set new standards in technology, quality and procurement practices.

Throughout the New Orleans Experience, there has been unprecedented cooperation between the Government, the consultants, the contractors, and the suppliers.



Seismic Remediation of Perris Dam CDSM cells for embankment stabilization

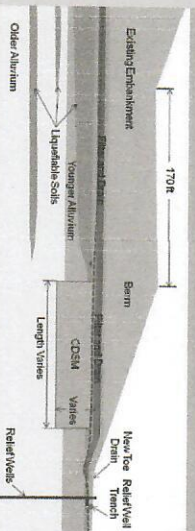


Cross section of Perris Dam

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.

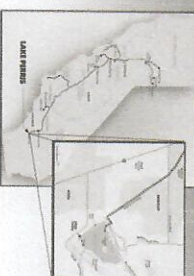
Typical Repair Section (Sta. 73+00 to Sta. 114+00)



2.2.3 Seismic Remediation of Perris Dam

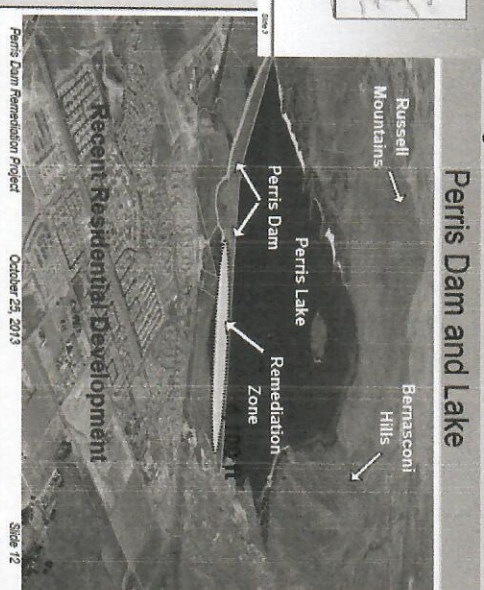
CDSM cells at embankment toe for liquefaction mitigation

Location of Perris Dam and Lake



Length of remediation toe = 4,100 ft.

Perris Dam and Lake

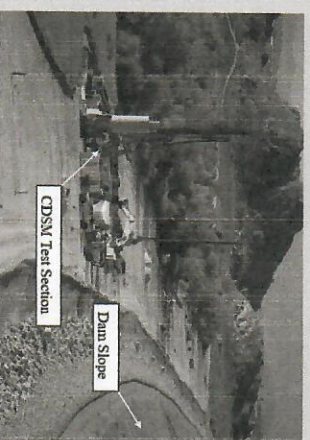


Site is located 5 miles from San Jacinto fault zone, Magnitude Mw 7.5

Dam height: 126 ft
Construction: 1970 to 1972

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

DWR study and test section

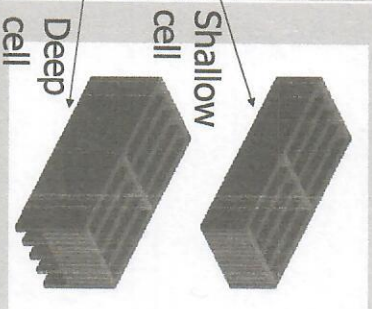
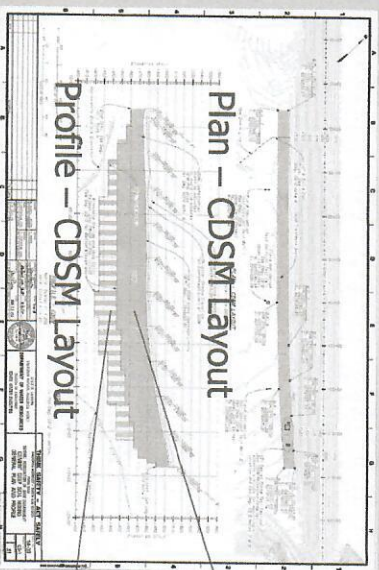


Sources: 1. Results of a Cement Deep Soil Mixing Test Section at Perris Dam, W.Y. Chen and M. Driller
2. DWR reports and papers

- 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.

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.

Full production of CDSM cells



Courtesy of JAFEC USA, Inc.

Perris Lake Dam Foundation treatment



Top of CDSM cells exposed for placement of filter and drain

Photo from site camera

Buckeye Lake Dam, OH



Courtesy of Gannett Fleming, Inc.

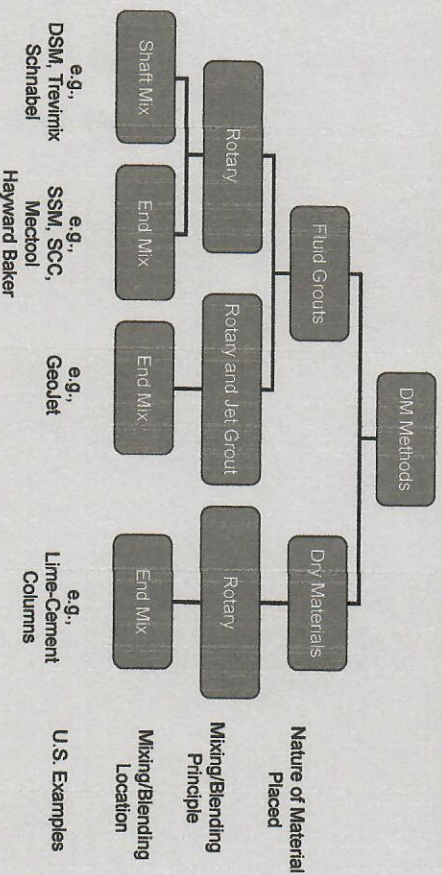


Portage Lakes Dam, OH

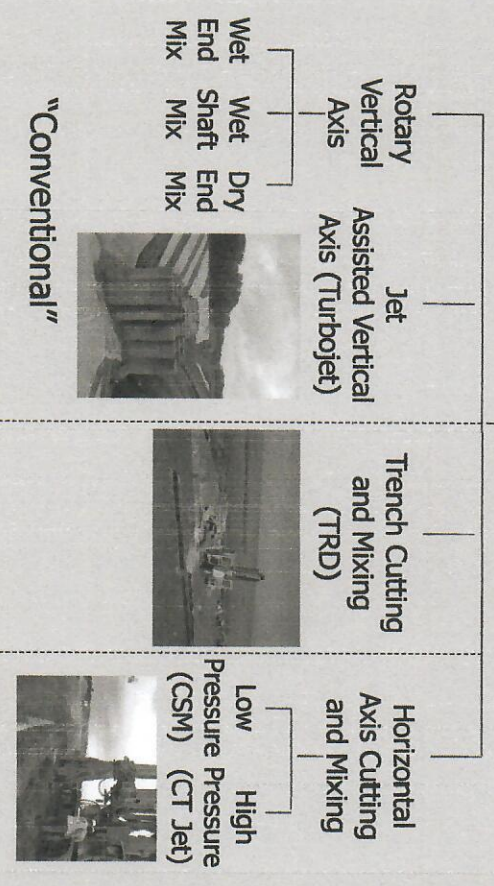
Courtesy of Tetra Tech, Inc.

2.3 NEW ARRIVALS

Original Classification of Deep Mixing Methods (FHWA 2000)



Updated DMM Classification (Bruce, 2010)



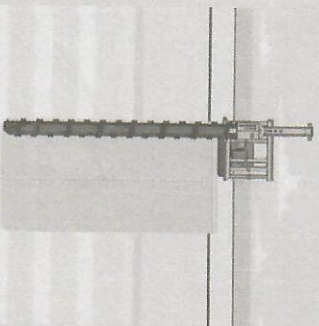
Herbert Hoover Dike, FL

USACE managed 4 different risk elements as follows:

1. Technology Risk: Prequalification of 3 different methods (out of 8 proposed), each with very detailed statements of prior experience.
2. Schedule Risk: Breaking down whole project into numerous smaller sections, permitting simultaneous work in several sections.
3. Project-Specific Risk: Each section predicated by a 500-foot-long Demonstration Section. Production only permitted after USACE acceptance of Demonstration Section Report. USACE also employed an external consulting group as continuity/oversight over all individual contracts. For in-situ homogeneity, extensive reliance placed on Optical Televiewer (Robertson Geologger).

Continuous Trench Cutting

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

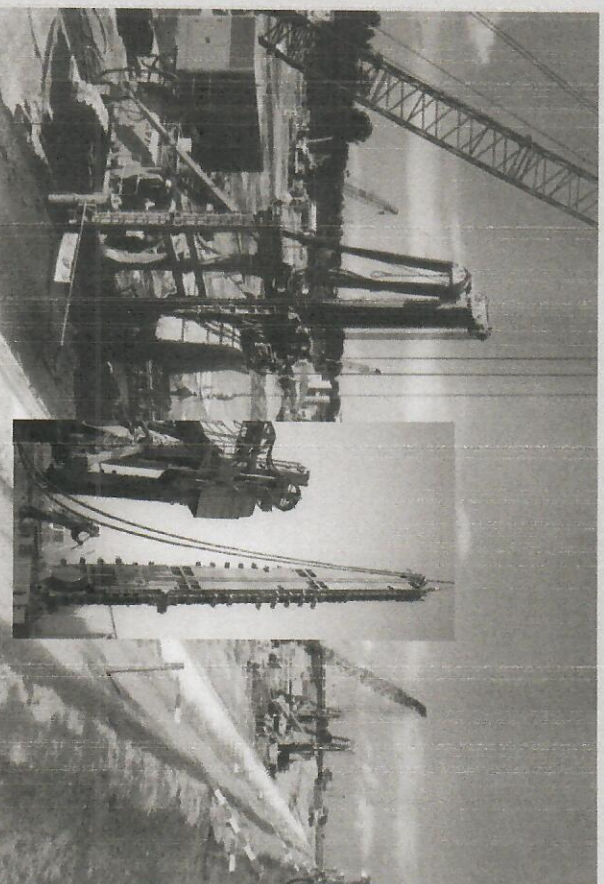


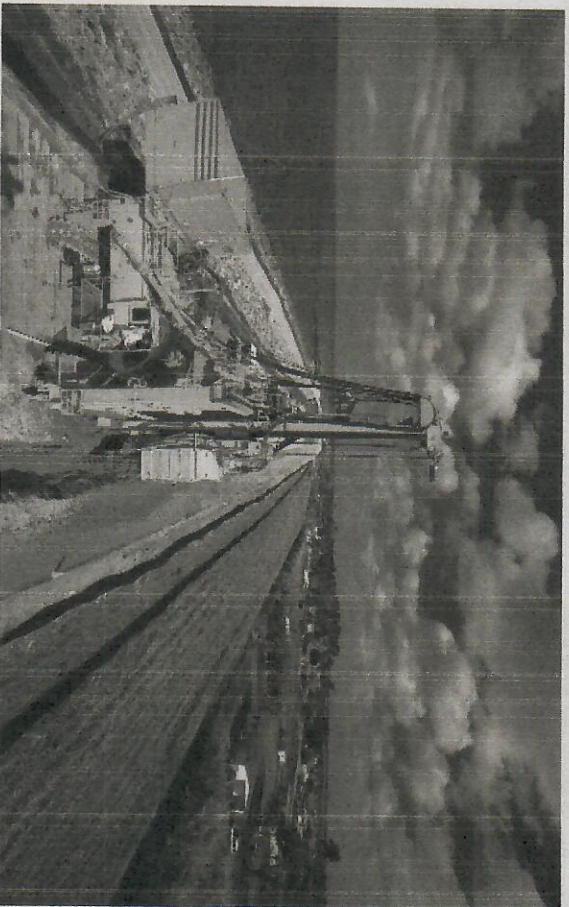
- Conceived in 1993 in Japan.
- First used in U.S. in 2005.
- 170 ft. depth capability, 18-34 inches wide.
- Continuous wall created by lateral motion of vertical "chain saw," installed in a predrilled hole.

4. Performance Risk: Use of Performance Specification, but very clear QA/QC and Verification criteria defining:

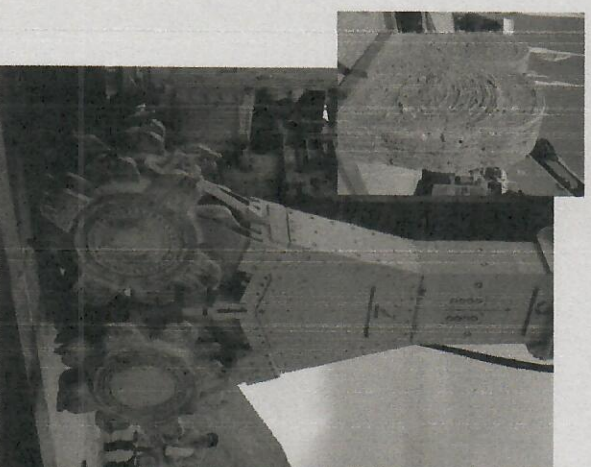


- Continuity, homogeneity, verticality;
 - 18- to 36-inch width;
 - In-situ permeability $\leq 1 \times 10^{-6}$ cm/s (in coreholes at 200-foot centers);
 - UCS 100 to 500 psi from cores, at 28 days;
 - Chemical compatibility with groundwater and soil.
- Phase 1 featured over 21 miles of cut off with 3 different construction methods. Phase 2 (over 30 miles) now underway.



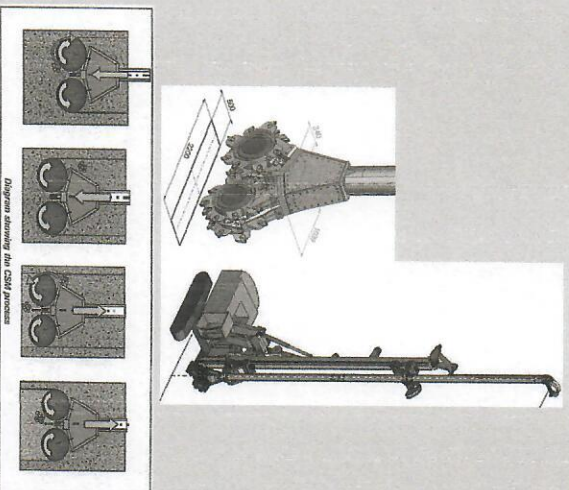


"One Pass" System (DeWind)



CSM (Cutter Soil Mix) Method

- Joint Bauer Maschinen/Bachy Solafranche 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.

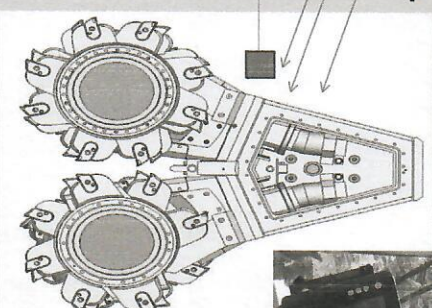


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CSM Quality Control Systems

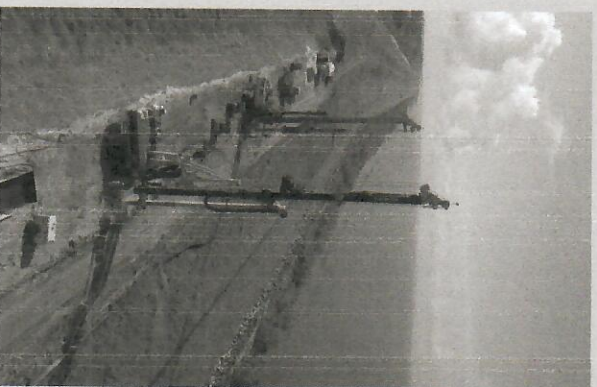
The CM machine is fitted with a set of instruments that convey to the operator, in real time all the information that is needed to monitor and control quality of the work.

- External pressure sensor
- Instruments that read:
 - Vertically on "X" and "Y" axes
- Torque on cutting wheels
- Wheel speeds



BAUER B-Tronic system

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

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

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



3. Drilling and Grouting



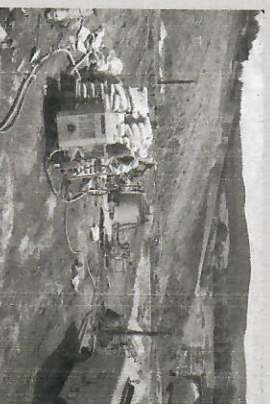
- 3.1 Historical Context
- 3.2 Drilling Methodologies
- 3.3 Grout Mixes and Equipment
- 3.4 QA/QC & Monitoring
- 3.5 Overview



3.1 Historical Context

Traditional Practices

- Highly prescriptive specifications.
- Almost complete absence of rational design and acceptance processes and widespread use of "rules of thumb" for design and execution.
- Use of:
 - vertical holes to a predetermined depth
 - single row grout curtains
 - long downstages of predetermined length
 - rotary drilling (percussion = air flush)
 - low and conservative grout pressures
 - "thin" grouts
 - "dipstick, gage and stopwatch" methods for injection control
 - termination of work based on grout takes (and/or cost)

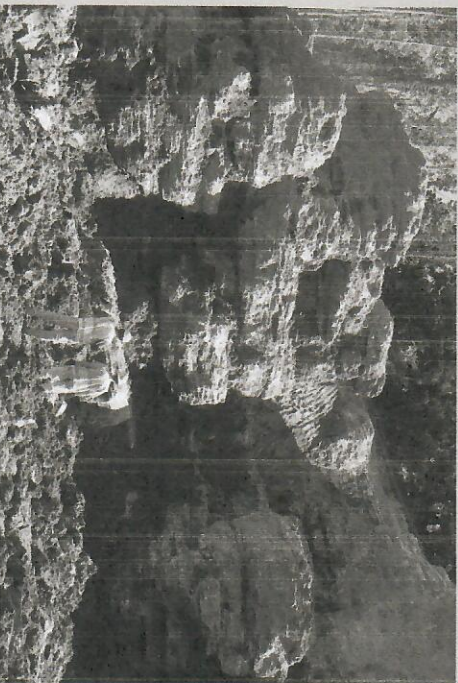


To further illustrate this "traditional" mentality, one may consider the opinion of James Polatty, formerly of the USACE, and a prominent grouting engineer of the period. In an invited lecture on U.S. dam grouting practices in 1974, he gave the following synopsis:

"In preparing this paper, I requested copies of current specifications for foundation grouting from several Corps of Engineers districts, the TVA and Bureau of Reclamation. In comparing these current specifications with copies of specifications that I had in my files that are 30 years old, plus my observations and experience, I concluded that we in the United States have not, in general, changed any of our approaches on grouting. AND THIS IS GOOD" (emphasis added).

Interestingly, he then went on to cite "difficulty in having sufficient flexibility in the field to make necessary changes to ensure a good grouting job" as a problem on certain of his projects, while "communications and training" was also listed as a challenge.

- These archaic practices were totally unsuited to the post-1990 remedial grouting demands with respect to logistics, geology, performance and dam safety.



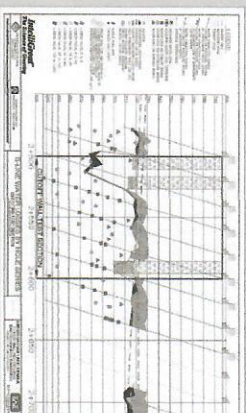
Contemporary Practices

- Market conditions/industry inertia up until mid-1990's were generally against new technologies. Notable exceptions were USACE/Reclamation at Ridgway Dam, CO, and Upper Stillwater Dam, UT, and the initial promotion of GIN Theory.
- Technology was totally changed after the association of Advanced Construction Techniques, Toronto, ON (Contractor) and Gannett Fleming, Inc., Harrisburg, PA (Consultant).
- They simultaneously introduced numerous technical developments – as an integrated package – and design concepts (e.g., Quantitatively Engineered Grout Curtains) at a time when the USACE was moving towards "Best Value," as opposed to "Low Bid," and more Performance-based Specifications.

However,

Since late 1990's, there has been a "technological revolution" in rock mass grouting in North America due to:

- Demand/challenges of market (especially remedial curtains in karst).
- Advances in technology, driven by a limited number of contractors and consultants.
- More appropriate, project-specific specifications ("performance based"), not recycled "boiler plate."



- The associated design improvements have included:

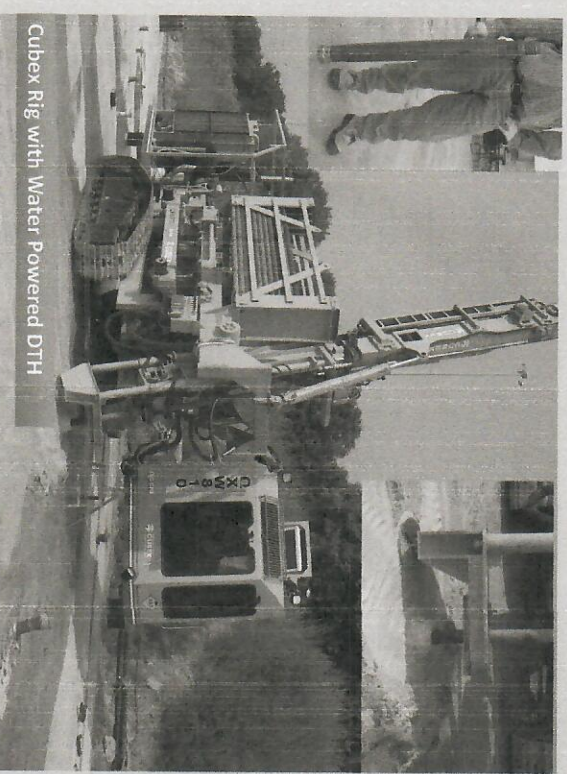
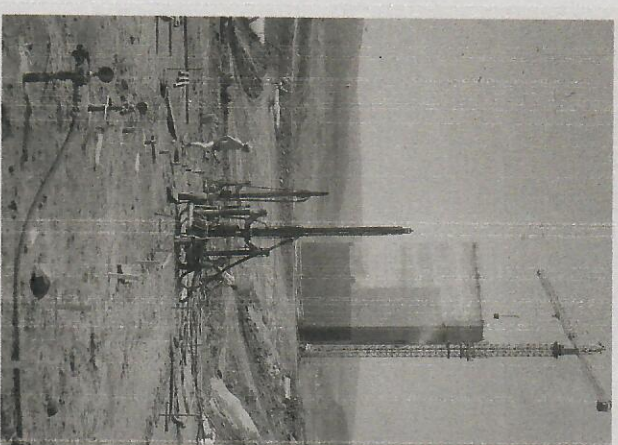
- multirow curtains
- inclined holes in each row
- depth of curtain determined by geology and/or by rigorous seepage analyses
- stage lengths commensurate with the structural geology
- use of the highest safe grouting pressures
- verification of proper stage refusals
- verification of residual in-situ permeability upon closure

- Fundamental developments have been made in the construction techniques

3.2 Drilling Methodologies

3.2.1 Developments in Rock Drilling Methods

- Rotary
 - High rpm, low torque, low thrust (blind or core)
 - Low rpm, high torque, high thrust
- Rotary Percussive
 - Top Hammer
 - Down-the-Hole Hammer
 - Direct circulation
 - Reverse circulation
 - Dual fluid drilling
 - Water hammers
- Rotary Vibratory (Sonic)

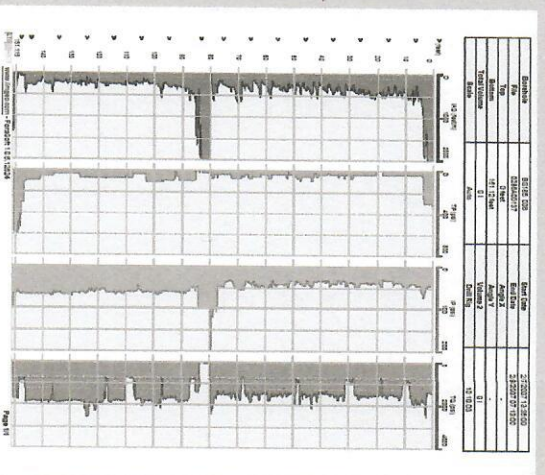


Drilling Rock with Water-Powered Down-the-Hole Hammers

- Traditionally, it was the case that percussion = air flush, and rotary = water flush.
- Most specialists agree air flush for fissure grouting is unacceptable.
- "Misting" is even worse than "clean" air itself.
- Water DTHH combines advantages of DTHH drilling (speed, straightness, etc.) with necessity for water flush. Water, unlike air, is a non-compressible medium, and UHV's are much lower for water. This causes less damage to borehole walls.
- Transient piezometric "spikes" may occur during drilling, but no credible Dam Safety incidents have been recorded. Excellent record since first use at the McCook Reservoir project in 2001.
- Use of automated MWD commonplace.

Monitoring While Drilling (MWD)

("Every hole is a site investigation")



Observations from the McCook Reservoir Test Site (2001)

- Test Section Successfully Grouted to 0.1 Lugeon and proved that grouting was an effective means of meeting project objectives
- Provided information to optimize the design and construction of the project:
 - Established optimum hole spacings, hole depth, sequencing, and optimum grout mixes to be used; determined that microfine did not improve results.
 - Determined that water powered down the hole hammer drills were much faster and provided quality holes.
 - Determined best methods of treating slurry wall / top of rock interface zone.
- Determined that the future contract should be based on Best Value and that automated drilling and grouting control and data collection were invaluable tools.

Automated Monitoring While Drilling



Calculation of Specific Energy (e):

$$e = \frac{F}{A} + \frac{2\pi NT}{AR}$$

where

e = specific energy (kJ/m³)

F = thrust (kN)

A = cross sectional area of hole (m²)

N = rotational speed (revolutions/second)

T = torque (kN-m)

R = penetration rate (m/sec)

Benefits to Owner and Contractor

Provided these data are studied and analyzed in real time, then the following benefits are realized:

For the Owner:

- Provides additional data upon which to responsively design the remediation principles.
- Provides data upon which to instruct interim variations and changes.
- Provides data upon the progressive effectiveness of the work.
- Transforms every production grout hole into an investigation hole also.



For the Contractor:

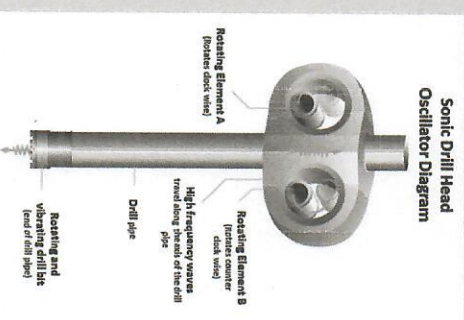
- Provides data to modify construction parameters.
- Enhances perceived "competency" of contractor ("black box" syndrome).
- Provides excellent data in event of claim preparation (i.e., contractual risk management).

3.2.2. Drilling in Overburden

- Governed by USACE Engineering Regulation - ER 1110-1-1807 (1997). Use of air or water disallowed.
- Rise of rotary sonic drilling and dry, double head duplex.
- In any method, use of cleaning water must be carefully regulated and the flush conveyed away from the hole.



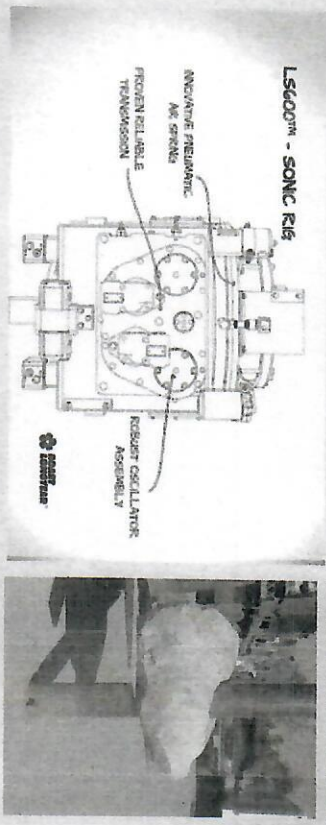
Increasing Popularity of Sonic Drilling for Embankment Penetration



- Sonic uses high frequency (50-150 Hertz) mechanical vibration combined with rotation and down-pressure.
- Vibrations generated by eccentric counter-rotating rollers in drill head.
- Vibrations coincide with the natural resonate frequency of drill pipe.
- Drill string produces spring-action and delivers energy to bit face.
- Sonic advancement occurs by shearing and minor displacement.

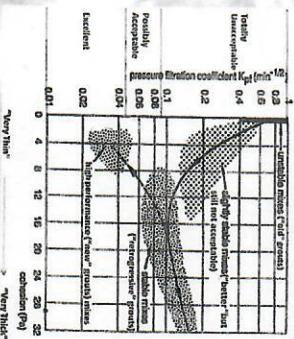
Advantages of Sonic Drilling

- Can provide continuous, relatively undisturbed cores in soil (3 to 10-ft diameter) & rock
- Very high penetration rates
- Readily penetrates obstructions
- Depths to 500 feet
- Can easily convert to other types of drilling
- No flush in overburden, minor amounts in rock

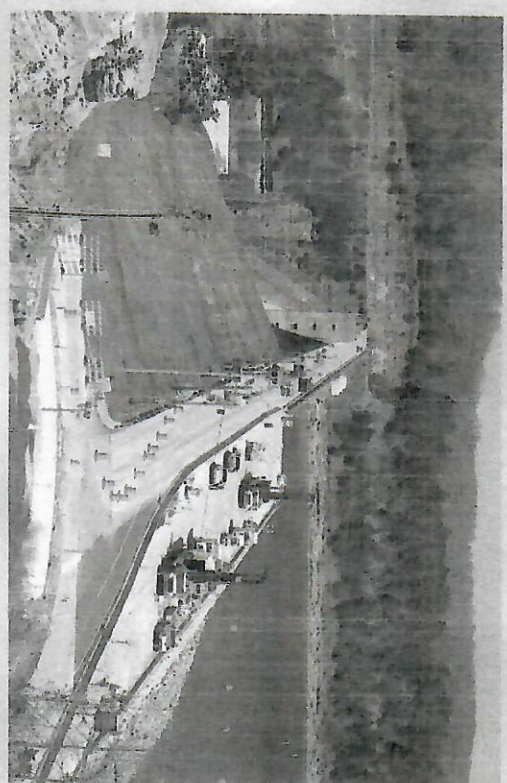


3.3 Grout Mixes and Equipment

- Penetrability controlled by cement grain size, and grout apparent cohesion, but especially by pressure filtration coefficient.



- The required properties can only be achieved by multi-component grouts ("stable, balanced") incorporating water, cement, bentonite, superplasticizer and stabilizer et al.
- Stable grouts allow "Apparent Lugeon Theory" for automated injection control to be used.

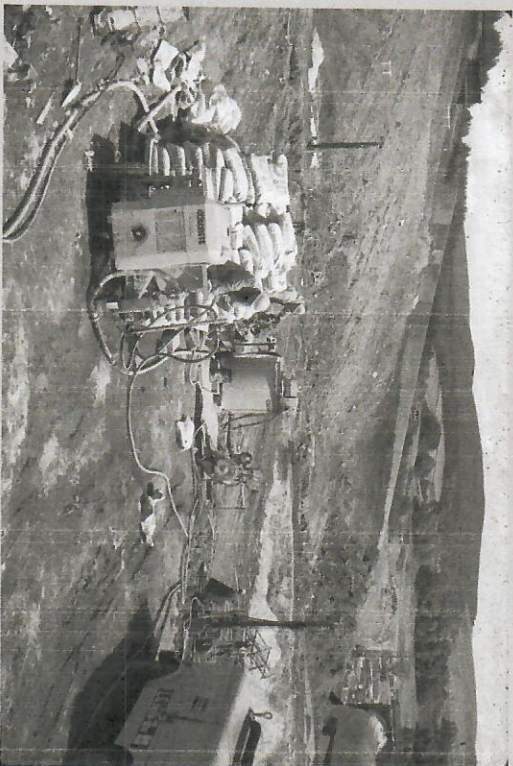


"the only true innovation to come to the drilling industry since the Chinese invented cable tool drilling some 3,000 years ago" (Roussy, 2002)

Typical Fluid for HMG Properties ("High Performance" Grouts)

CATEGORY	TEST	REALISTIC LIMITS
Routine Field QA/QC	Marsh Funnel (Fluidity)	Mix A 30-35 s Mix B 40-45 s Mix C 55-60 s Mix D > 60 s
	Baroid Mud Balance (s.g. and so WCR)	+ 0.02
	Bleed (static stability)	≤ 2%
	Pressure Filtration (stability during injection)	0.04 to 0.08 min ^{-1/2}
Classification/Design Requirement	Initial and Final Set Times	4-12 hours
	Cube Strengths	Practically useless

Traditional Mixing Plant

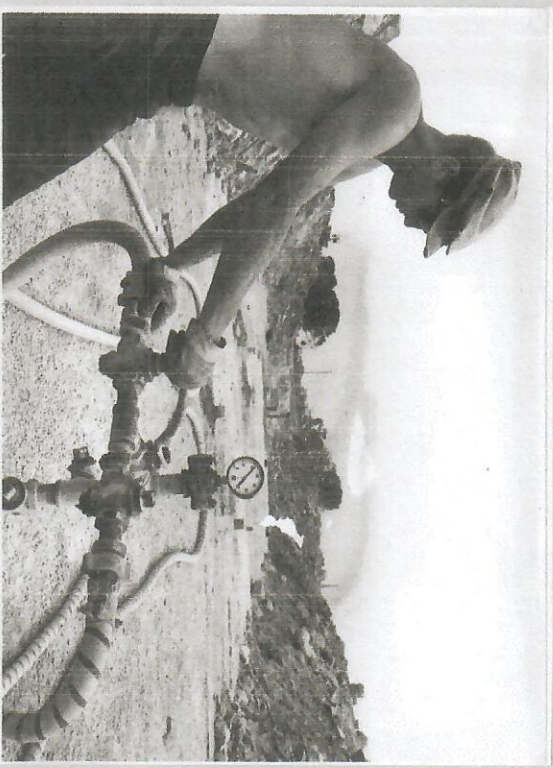


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Traditional Injection Control

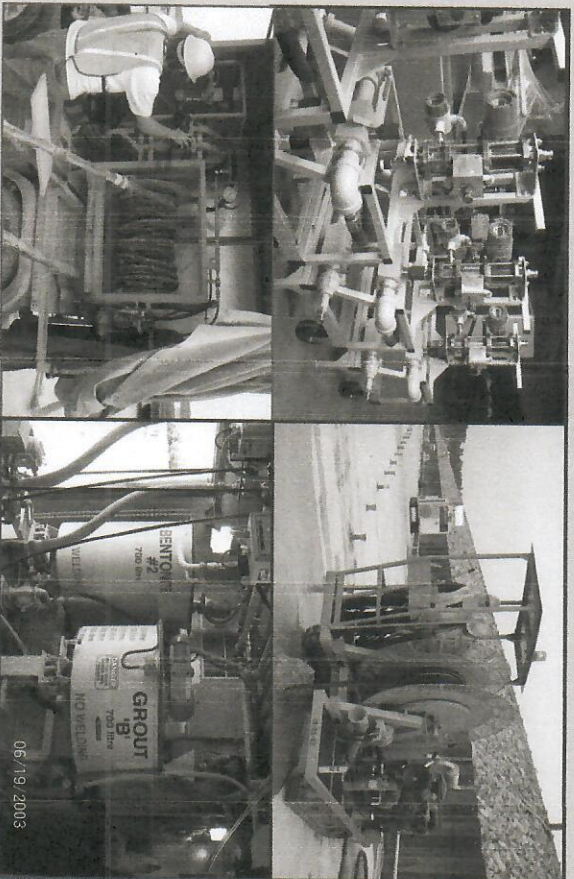


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Contemporary Injection Control



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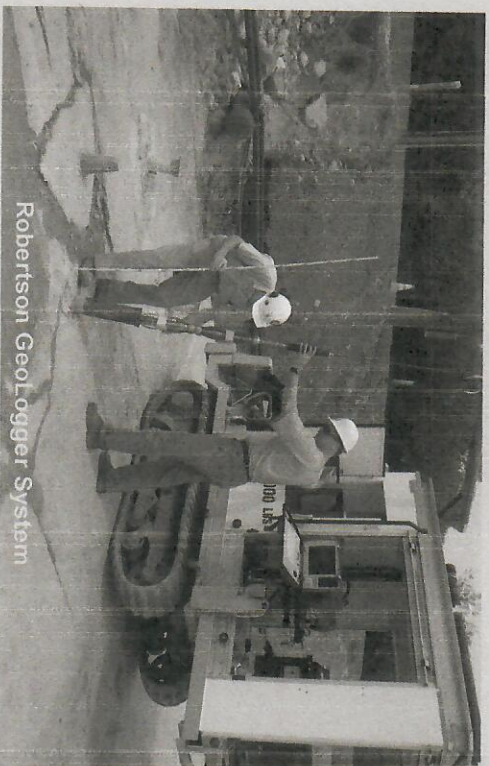


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3.4 Developments in QA/QC and Monitoring



Robertson Geologger System

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Routine Use of High Resolution Borehole Imaging

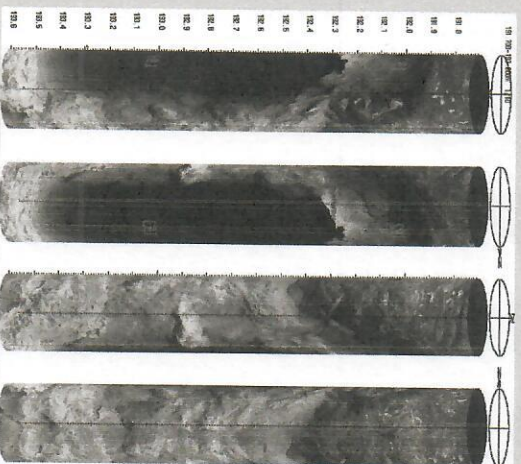
- Description: A high resolution down-the-hole camera that is able to create detailed images of the borehole walls as it traverses the length of the hole.
- Output
 - Inclination and Azimuth
 - X, Y, Z Coordinates (Deviation Survey)
 - Image Log (wrapped, unwrapped, multiple orientations)
 - Strike and Dip of fracture sets
 - Aperture Thickness
 - Stereonet Plots of discontinuity data
- Benefits to Grouting Program
 - Every hole can be treated as an "Exploration" hole
 - Accurate observation of in-situ rock conditions
 - Ability to "see" fractures, infilling, cavities and solution features
 - Densifies broken zones and core losses (observed in core holes samples)
 - Ability to determine appropriate grouting method
 - Verification of grouting effectiveness

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High Resolution Borehole Imaging



S36.70U
192.3' - 193.4':
Solution feature in Leipers
Fm.

Wrapped image suggests
feature trends NW-SE,
normal to dam.

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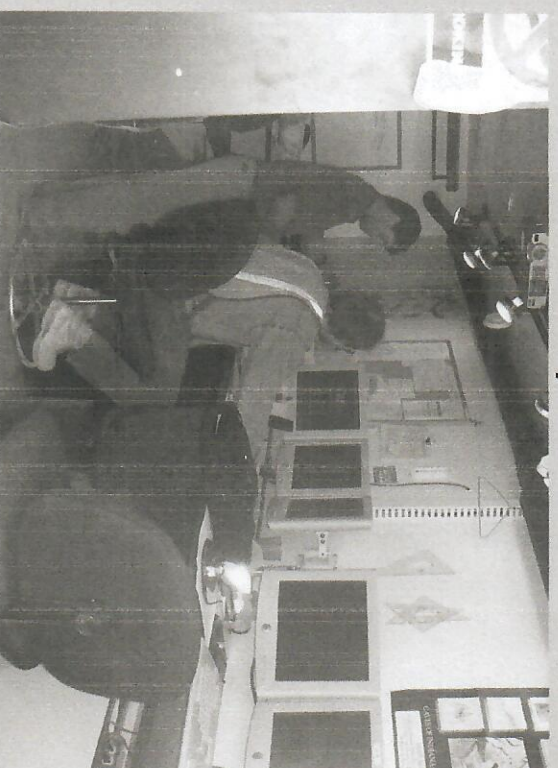
"Dipstick and Gage" Monitoring (early 1970's)



Current State of Best Practice



Early 2000's



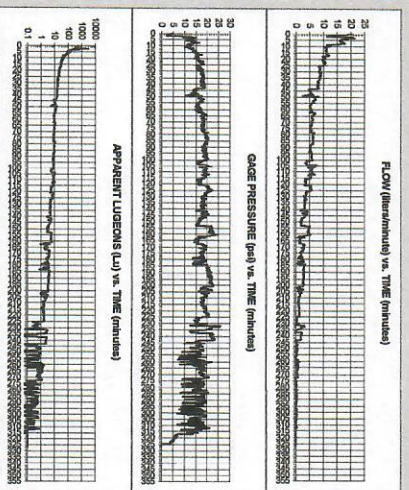
Refusal vs. Closure Resolution

- Refusal
 - Every Grout Stage should be brought to proper Refusal: otherwise the (expensive) drill hole has not been efficiently exploited
 - Example: 0.25 gpm (~1 lpm) held for 5 minutes: some specs are now relaxing to 0.75 or 1.0 gpm
 - Achieved on an Individual Stage Basis
 - "Refusal" Does Not Mean "Closure"
- Closure
 - Permeability of the Rock Mass Attained to a Degree of Certainty
 - Compared to Target Permeability
 - Holistic Analysis of Achieved Results at Each Hole Series and Each Line
 - Statistical Methods
- Apparent Lugeon Theory
 - For rheologically stable grouts, then the grouting operation can be analyzed and controlled as if water were being injected.

- Apparent Lugeon value (Lu_g) is calculated (and displayed in real time) as for water Lugeon value, i.e.,

$$Lu_w = \frac{\text{water flow rate}}{\text{pressure} \times \text{stage length}}$$

$$Lu_g = \frac{\text{grout flow rate}}{\text{pressure} \times \text{stage length}} \times \frac{\text{marsh grout}}{\text{marsh water}}$$



- Goal during stage grouting is to gradually and naturally reduce initial Lu_g towards zero (i.e., Q is minimal). This is true refusal.

Lessons Learned: JIMP

- **System Should be Up & Running Before Production Work Begins**
 - Important to Establish a Baseline of Instrument Readings
 - Historical Data and Peak Readings
- **Implement Joint Instrumentation Monitoring Plan (JIMP)**
 - Pre-defined Threshold Levels
 - Established Guidelines for Course of Action when Thresholds Reached
 - Continually Re-Evaluate and Adjust Threshold Levels and Actions as Needed
- **Data Viewed at a Joint "Mission Control" Facility**
- **Monitor and Collect Instrumentation Data Well After the Work is Complete**
 - Was the Project Successful?
 - Evaluate Long-Term Benefits
 - Monitor Changing Conditions
 - Monitor Potential Issues

Note. The Owner is in the best position to conduct, evaluate and publish long-term monitoring data.

Joint Instrumentation Monitoring Plan (JIMP) and Long-Term Monitoring

- A JIMP has become absolutely essential.
- Identifies who reads what and how frequently.
- Identifies threshold/action levels for each instrument, and courses of action arising.
- Continual evaluation and reevaluation is necessary during the works.
- All instrumentation data (including the WPT and grouting information) should be reviewable in real time in a proper, joint "Mission Control" facility.

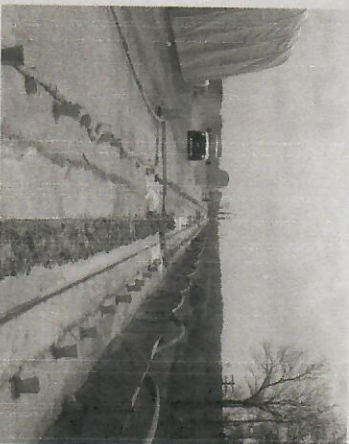
Data Management System (DMS)

- DMS must be functional before Production Work is allowed to start.
- Contractors are typically underprepared and overwhelmed.
- DMS must be controlled by a suitably qualified grouting engineer, not an IT Specialist. Must be "opposite number" on Owner's side.
- All parties must be able to view (one set of) data, transcending "proprietary" objections.
- Historical information (geology, construction, dam performance, etc.) should be preloaded into the DMS prior to Production Work commencing.



3.5 Overview

- Grout curtains are being systematically engineered to satisfy the in-situ residual permeabilities required by the design (1-5 Lugeons).
- Every major project has provided compliant results using "new technologies"
- Curtains are being used as integral part of the "Composite Wall" concept to explore and improve the rock before construction of a concrete diaphragm wall between the outer rows.
- Every such project has been successfully and safely completed.
- Several contractors are now skilled in the use of the "new technologies".
- USACE's Engineering Manual on Grouting Technology (July 2014).



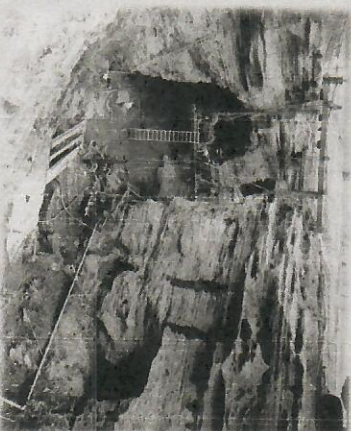
4. Cut Off Walls

- 4.1 Wolf Creek Dam, KY (1975 – 1979)
- 4.2 Subsequent developments in Equipment and Techniques
- 4.3 Wolf Creek Dam, KY (2008 – 2011)



4.1 Wolf Creek Dam, KY (1975 – 1979)

Wolf Creek Dam, KY – a 3,940-foot-long homogeneous fill and contiguous 1,796-foot-long gated overflow section. Founded on Ordovician carbonates with major kaskification. Retains Lake Cumberland and protects Tennessee.



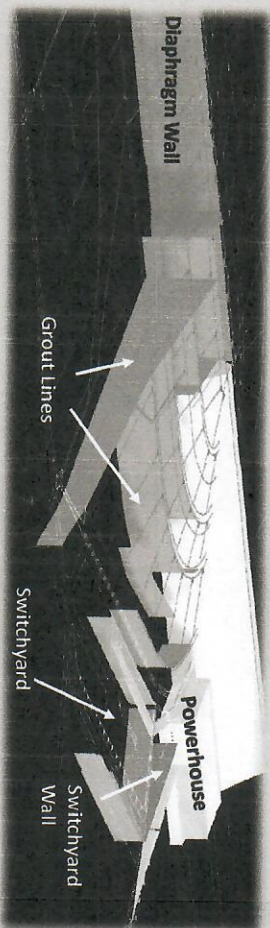
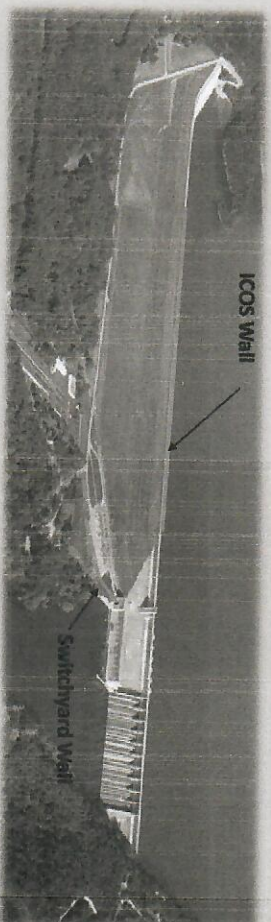
- Designed in the 1930's, built from 1941-1943 and 1945-1952.
- Severe hydraulic distress observed after impoundment leading to emergency grouting by USACE in 1968-1970 and 1973-1975.



- Primary Failure Modes related to erosion and piping of natural soft karstic infill materials and clay backfill in the core trench.
- Need for "definitive solution" led to international competition, won by ICOS Corporation of America in 1975. This successful solution for an existing dam featured a concrete diaphragm wall built by a unique combination of rotary drilling and clamshell excavation, both by then well established techniques.
- Remediation was described frequently in the international technical press.

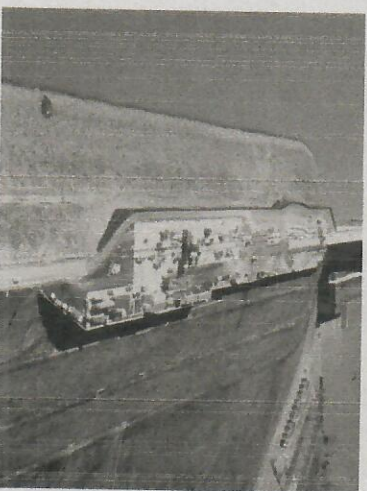
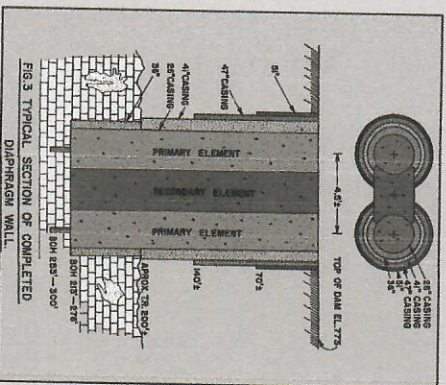


First Solution – Cutoff Wall and Extensive Grouting Campaigns



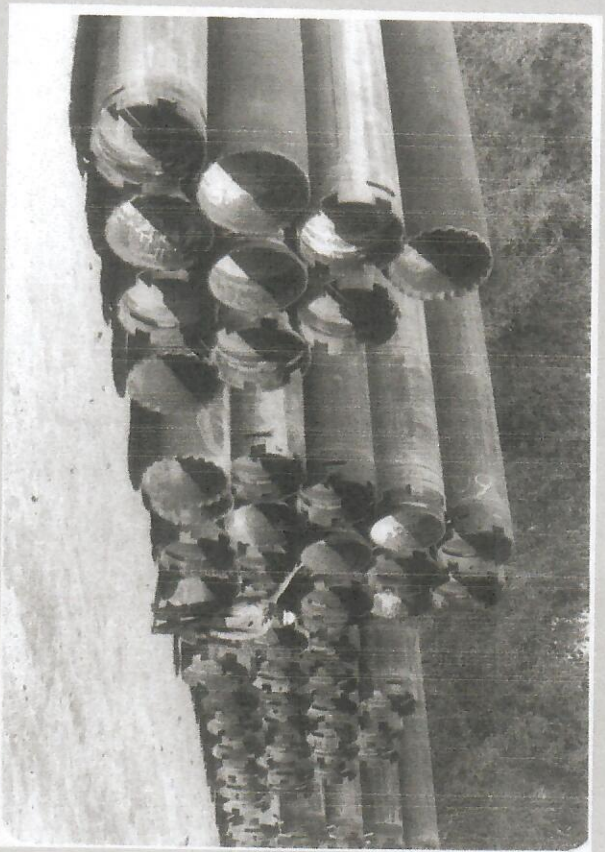
First Solution – Cutoff Wall and Extensive Grouting Campaigns

ICOS' barrier wall was installed along the centerline of the Embankment



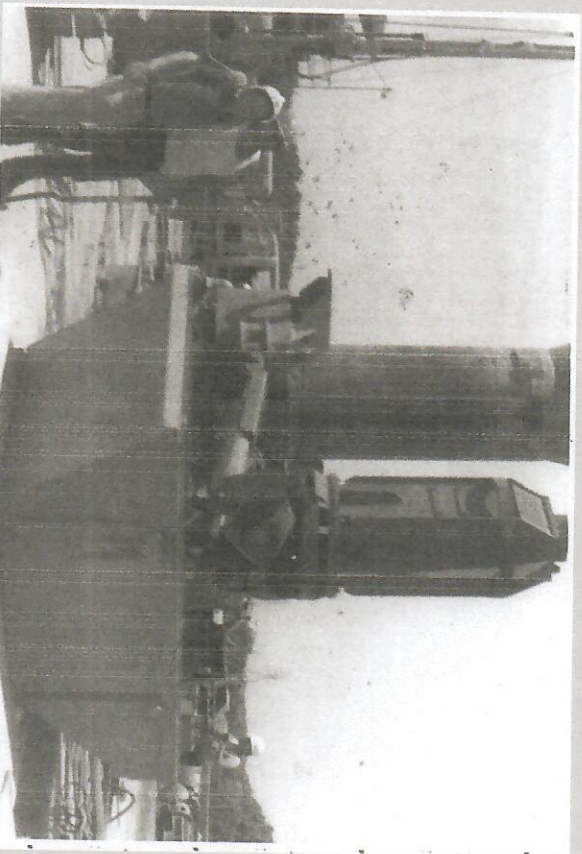
Approximately 990 Concrete to Steel Joints





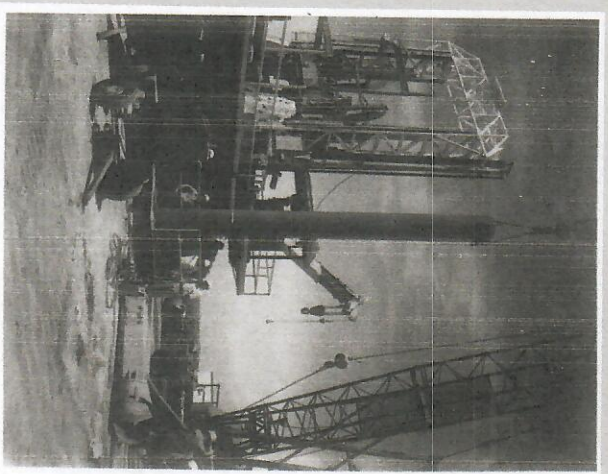
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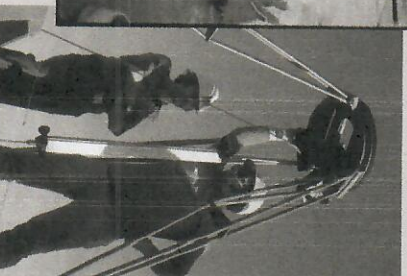
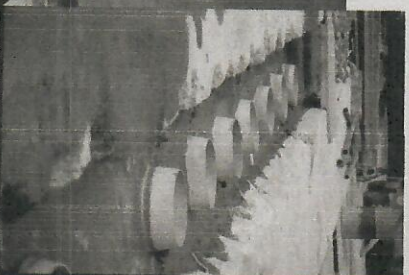
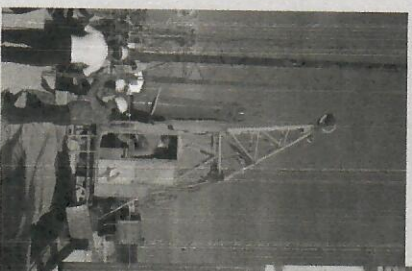
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- The main wall was 24 inches thick, 2,237 feet long, and a maximum of 280 feet deep. A secondary wall was built in the downstream switchyard.
- Built from 1975-1979 at a cost of 97 million dollars.



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4.2 Subsequent Developments in Equipment & Techniques



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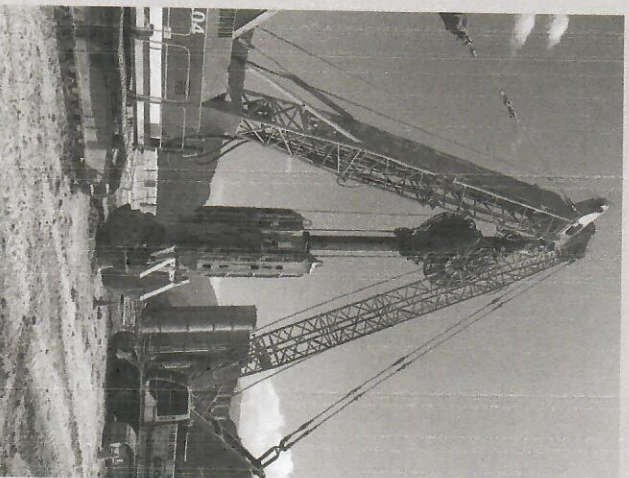
Clamshells (cable or hydraulic)



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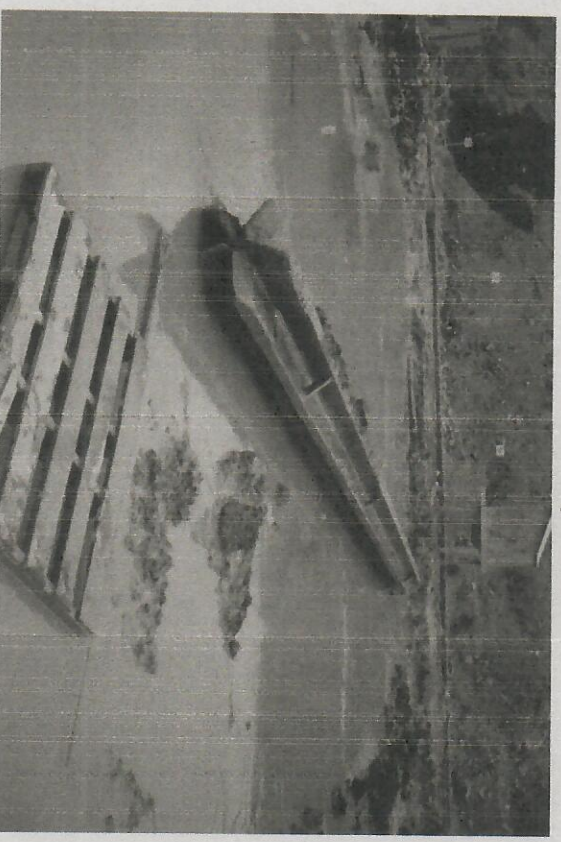


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Vancouver Island, 1989

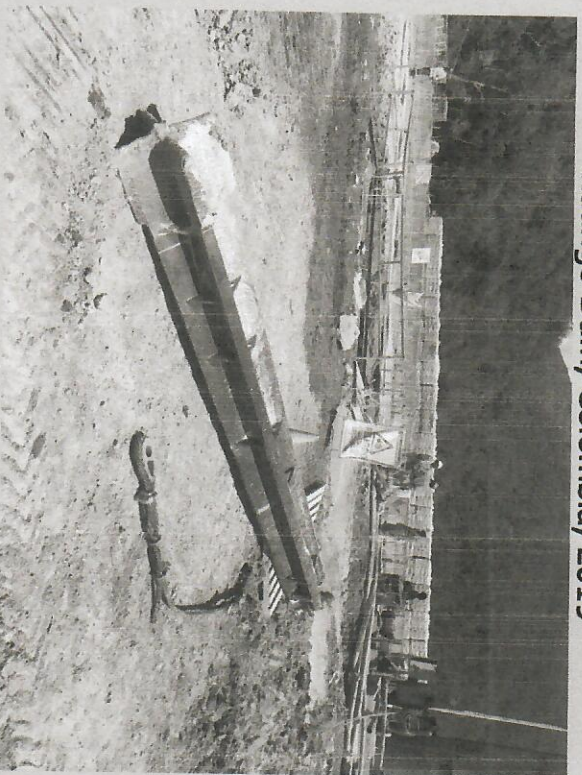


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Ituango Dam, Colombia, 2019

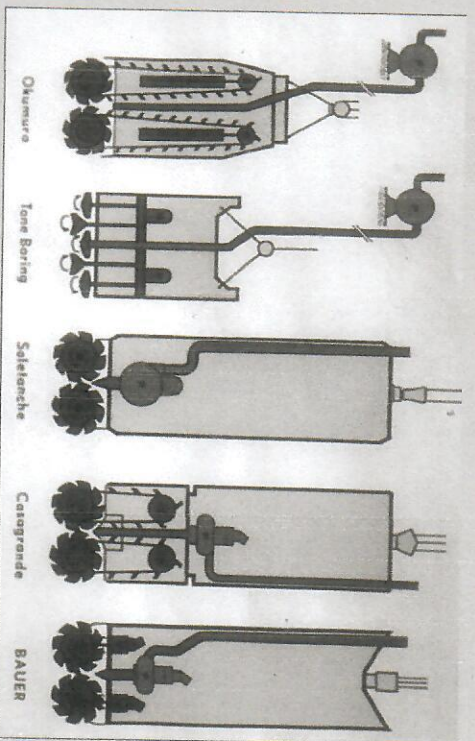


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Cutters/Mills

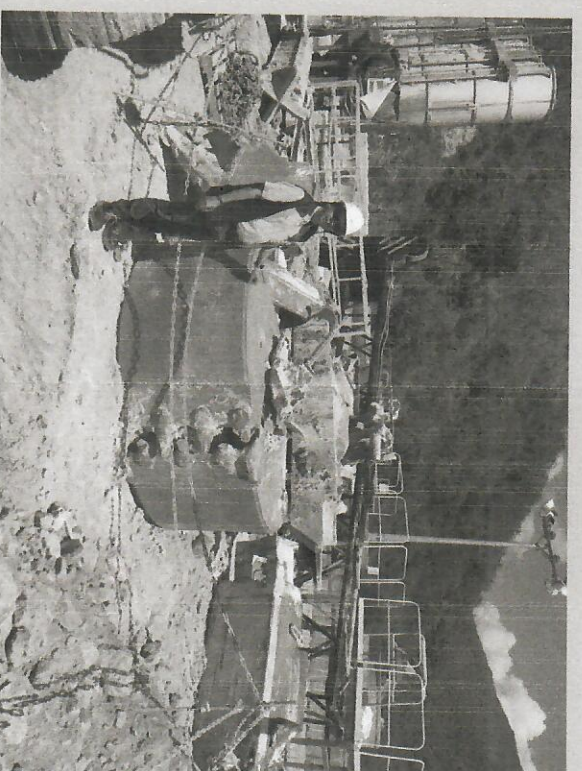


Development of Trench Cutters

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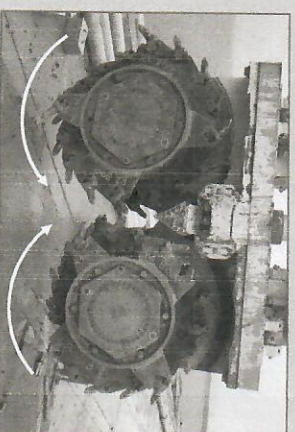
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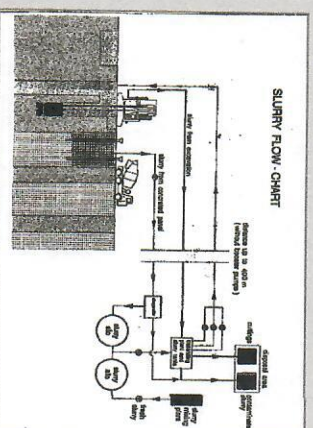
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■ Panel Excavation

The cutters continuously remove the soil from the bottom of the trench, breaks it up and mixes it with a bentonite slurry in the trench.



The slurry charged with soil particles is pumped through a pipe to the de-sanding plant where it is cleaned and returned into the trench.



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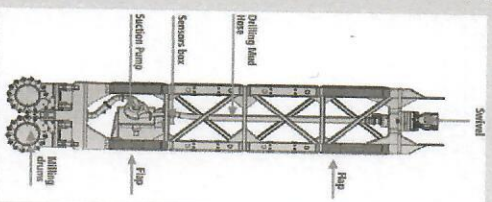
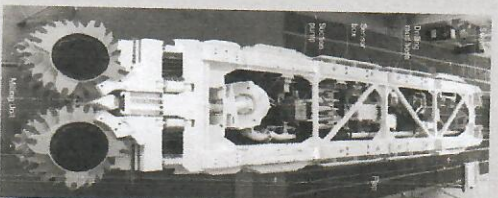
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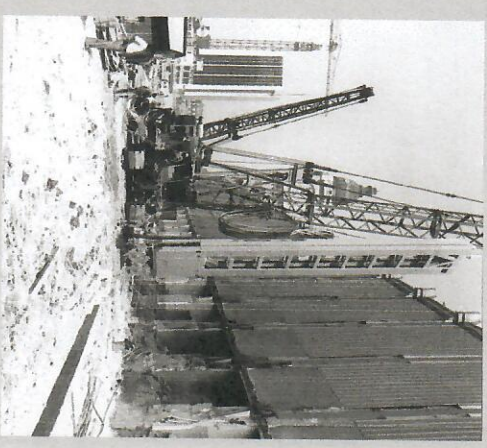
HYDROMILL TECHNOLOGY

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.

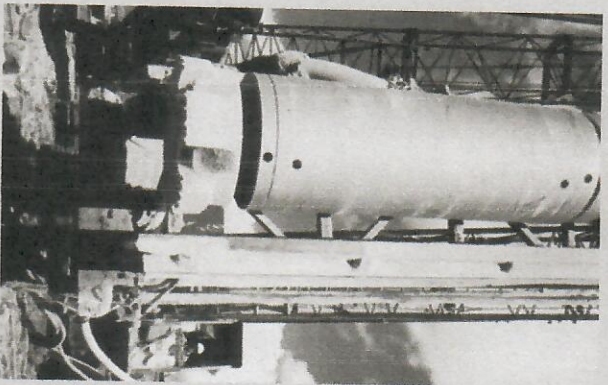


- Initially deployed in Paris in 1973, a hydrofraise was first used for a dam remediation by Soletanche, Inc. at St. Stephen Dam, SC, in 1984 (110,000 square feet).
- Thereafter, it has been used (by other contractors also) on 8 other major dam remediations in the U.S. prior to 2008, totaling about 2.4 million square feet, and several other dams since.



A hydrofraise was used in remedial works to a maximum depth of over 400 feet (Mud Mountain Dam, WA) and have recently been tested to over 800 feet in a test by Trevi at Gualdo, Italy, to within 0.13% vertically





Conventional Secant Pile Method

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Beaver Major Rehabilitation

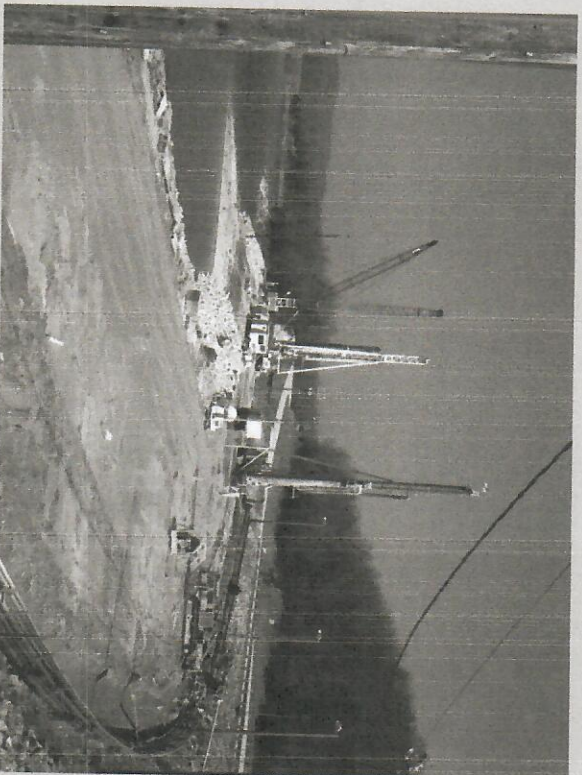


Dike 1
Cutoff Wall Construction Area

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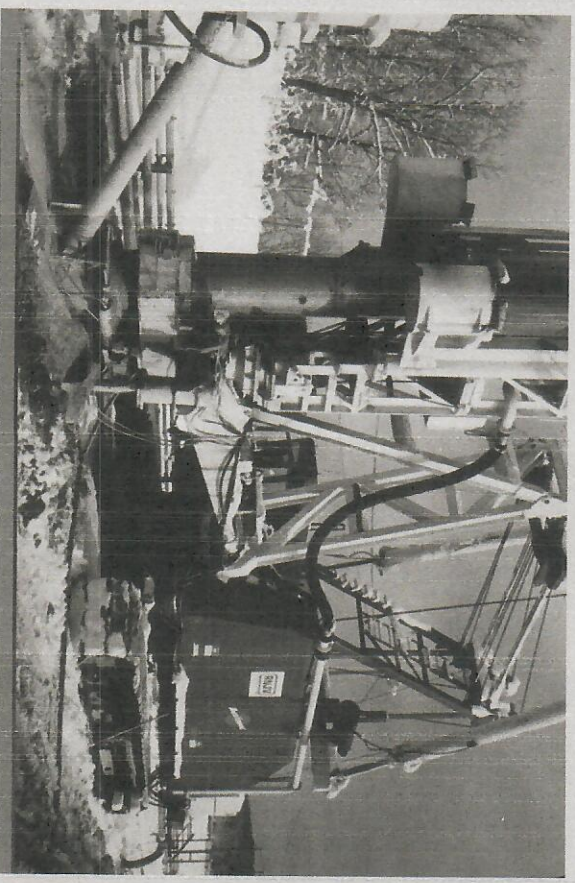
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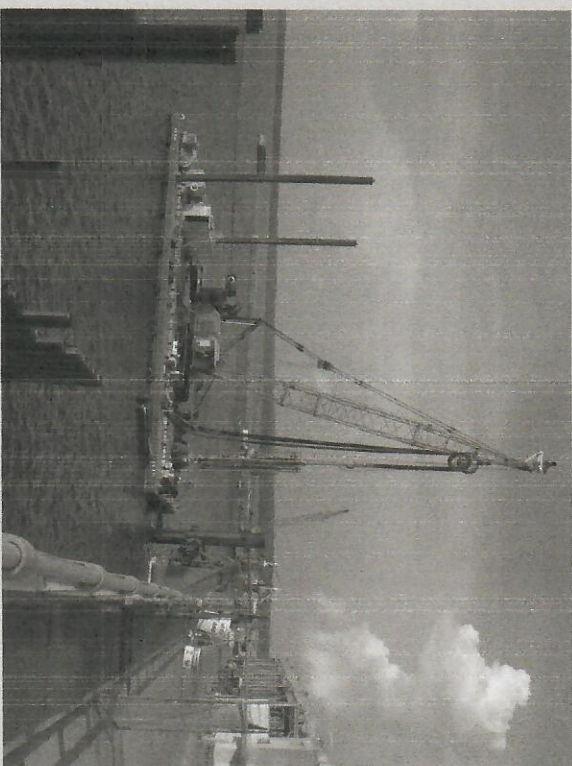
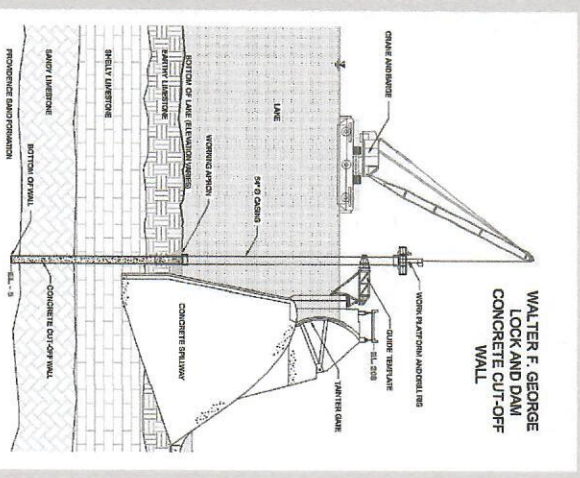
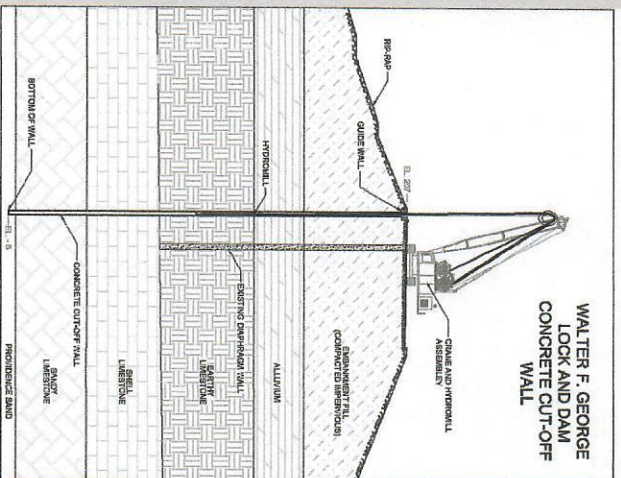
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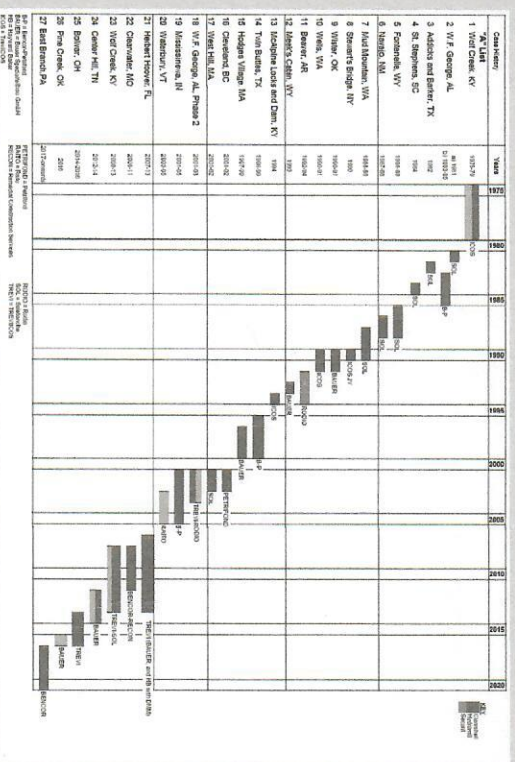
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Project Listing Showing Chronology Type of Cut-Off and Specialty Contractor to 2019



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U.S. Case Histories – 1975-2016

DATE OF CONSTRUCTION AND REMEDIATION	CONTRACTOR	TYPE OF WALL	COMPOSITION OF WALL	GROUND CONDITIONS	PURPOSE OF WALL	SCORE OF PRODUCT			REFERENCES
						AREA	MIN. WIDTH	DEPTH	LENGTH
1. WOLF CREED, 1976-1978	ICOS	24-inch diaphragm piles joined by 24-inch wide steel plates. Two phases of work.	Concrete.	Deep fill, and over significant alluvial deposits with cavities, often city-type.	To provide a concrete cut-off dam and tie into bedrock progressively developing in the west.	273,000 sf (Phase 1) 261,000 sf (Phase 2)	24 in	Max. 280 ft 1,560 ft	• ICOS brochure (undated) • "Pile" (1988)
2. W.F. GEORGE, AL		26-inch rock Satelectra piles using cables and delay-cured cement.	Plastic concrete	Random. FILL with silty clay over 50' ALLUVIUM.	To provide a temporary cut-off through the dam and alluvium.	130,000 sf (Phase 1) plus 961,000 sf (Phase 2)	26 in	Max. 139 ft 1,500 ft	• Satelectra (undated) • "Barron" (undated)
1981	Barron	24-inch piles 16-27 ft long	3,000 psi Concrete	LIMESTONE	To prevent seepage and piping through con.	462,000 sf (Phase 1) plus 773,000 sf (Phase 2)	36 in	Max. 65 ft Typical 55 to 92 ft	• Barron (undated)
1983-1985	3. ADORCKS AND BARRON, LTD. 1982	36-inch rock Satelectra* using G.C.P.	G.C.P.	Deep FILL over CLAY.					• Satelectra western.
4. ST. JOSEPH'S, SC. 1954	Satelectra	concrete panel wall, installed by hydraulic pile protection by soil.	Concrete	Deep FILL over silty clay. STABLE.	To provide a cut-off through dam.	73,620 sf (Phase 1) 53,000 sf (Phase 2)	24 in	Max. 120 ft Including 3 ft slope	• USACE (1954) • Satelectra (undated) • "Pile" (1988) • Price et al. (1989)

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

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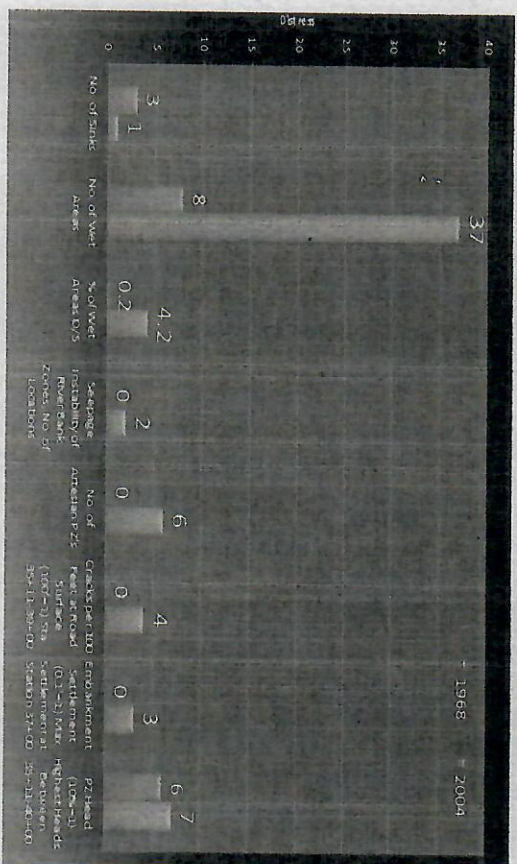
4.3 Wolf Creek Dam, KY (2008 – 2011)

- During the 1975-79 project, at least one member of the Board of Consultants (Dr. Peck) opined that the wall was neither deep enough nor long enough.
- ...and of course he was correct.
- By January, 2007, Wolf Creek Dam was judged to merit a DSAC-1 rating – therefore requiring urgent and compelling action. The justification was a return of the classic distress symptoms.



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Increasing Distress Indicators



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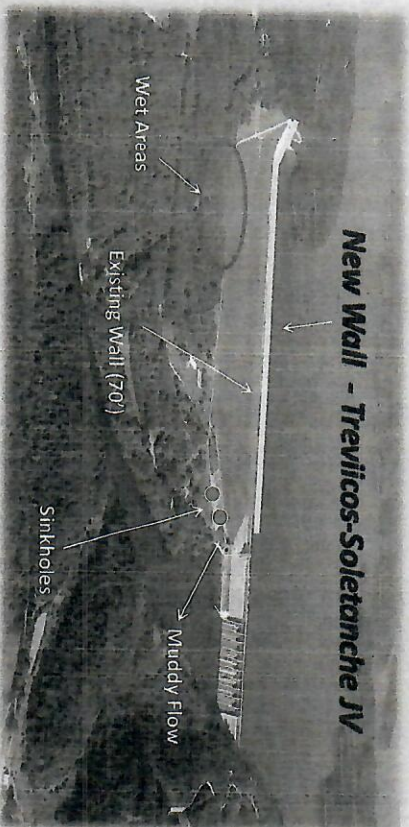
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The Solution by the USACE

- 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 → TSV is awarded the main remediation contract for \$341 M
- In the meantime → USACE maintains the pool elevation 80 ft below its maximum capacity



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- An emergency grouting operation was conducted as Phase 1 of the remediation in 2007-2008 by Advanced and Gannett Fleming as Phase 1 of a "Composite Wall" solution.
- Phase 2 involved the construction of a new cutoff upstream of the original, and longer and deeper, for an area of about 980,000 square feet – almost twice the original.
- Bid documents and specifications were Performance-based and emphasized Dam Safety in every process of the work, and urgency.
- It was obvious to all bidders that the technology of the 1970's could not safely, reliably, or competitively satisfy the requirements of the 2008 project.
- The size, complexity and profile of the job attracted international attention from major prospective bidders.

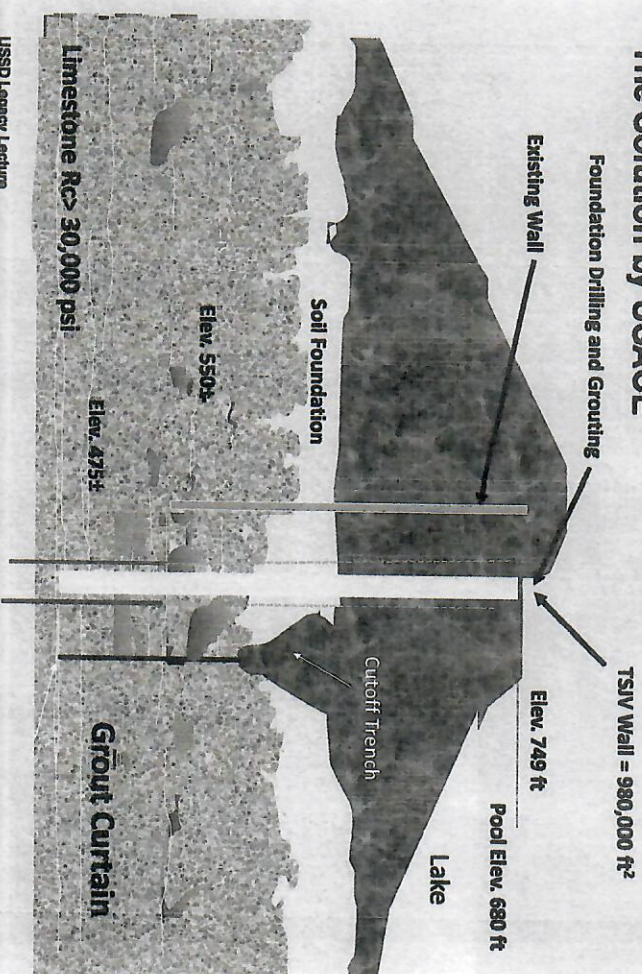
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The Solution by USACE



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The diagram illustrates a TSVJ retaining wall system. The wall itself is 3 ft thick and has a centerline (C/L) indicated. It is supported by secant piles, which are shown as two overlapping layers of concrete. The distance between the centerlines of the secant piles is 8 ft. The wall is constructed from concrete and is embedded into the ground. The ground consists of alluvium and weathered rock. The wall is topped with a protective concrete embankment wall. The wall is drilled into the ground at a depth of 12 ft. The wall is labeled with 'HMG' (Heavy Metal Guard) and 'LMG' (Light Metal Guard). The wall is also labeled with 'Directional Drilling'.

The Solution by TSVJ

- Protective Concrete Embankment Wall
- Secant Pile
- Wall C/L
- 3 ft
- 8 ft
- 12 ft
- HMG
- LMG
- Alluvium & Weathered Rock
- Rock
- Strength between 10,000 and 36,000 psi
- Features up to 40 ft in height
- Mixed rock/soil conditions
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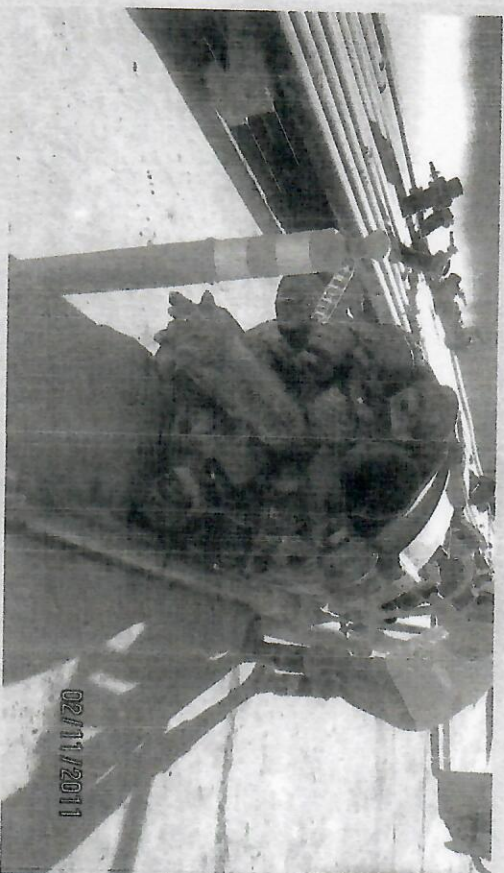
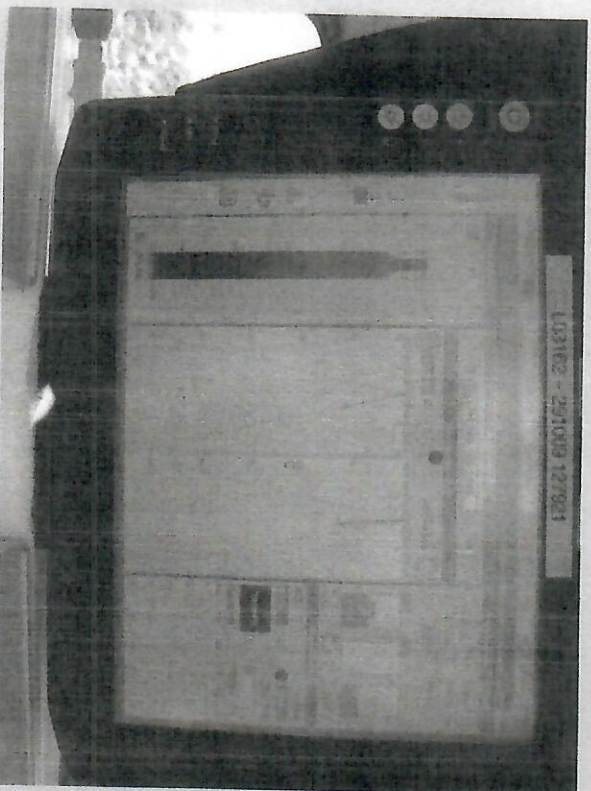
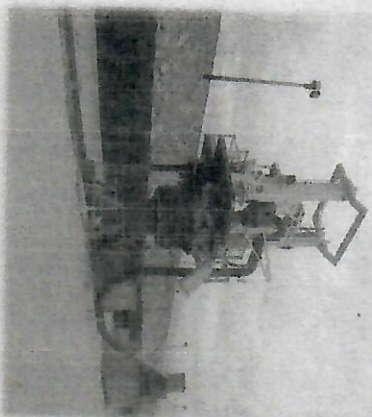
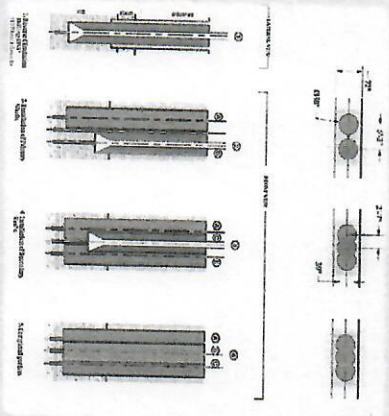
A black and white aerial photograph of a large industrial complex, possibly a shipyard or a steel mill. The facility features several large, rectangular industrial buildings, numerous cranes, and extensive piping. The complex is situated in a flat, open area, with a body of water visible in the lower right corner. The image is oriented horizontally on the page.

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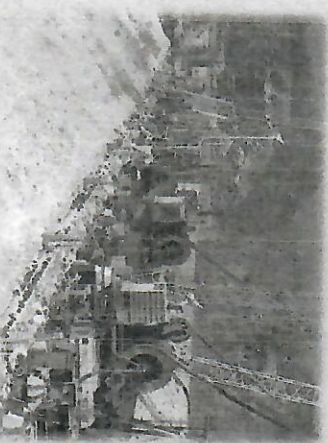
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Secant Piles

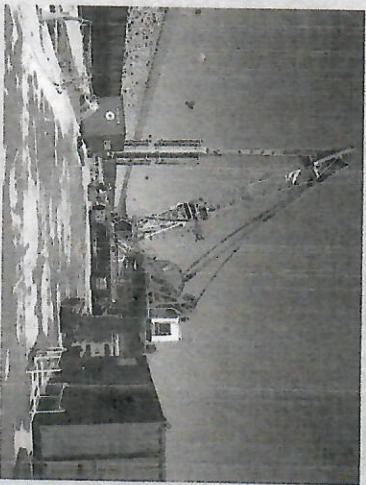
- Following the directional drilling pilot hole, 50" piles installed at 31.5" or 35" centers
- Ensuring the required overlap and minimum thickness – Max target depth 277-ft



- 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.



- 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. These specifications have therefore become more Prescriptive.



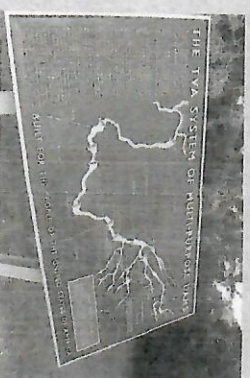
- USACE and the original Board of Consultants made an extraordinarily courageous decision to accept ICOS' proposal in 1975, which in effect bought 30 years of dam safety.
- USACE and the 2007 Board of Consultants were no less courageous in designing the second wall, given their superior insight about the fragility of the system.
- Risk mitigation measures were embraced by the USACE:
 - "Best Value" award basis, with a focus on the Technical Proposal.
 - Successful execution of "Technique Demonstration Areas."
 - Very high levels of QA/QC and Verification.
 - Implementation of an intense Instrument Monitoring Plan.
 - Effective and efficient Partnering, and use of Board of Consultants, (USACE) and Internal Advisory Panel (TSJV).

PART 2. MISCELLANEOUS ISSUES

1. Dam Safety Assurance Programs
2. Comments on the PFMA Process
3. Safety
4. Boards of Consultants
5. Mentorship
6. Questions & Answer Session (Dr. Greene)

1. Dam Safety Assurance Programs

- All dam owners now have such programs
- Rise is in no small way due to Owners' responses to specific project drivers, e.g., Teton Dam, Hurricanes Rita and Katrina, Kingston Power Station.
- Classic examples are the DSAP of TVA (who are credited with providing the following slides), the RMC, and many other Federal and non-Federal Agencies.



- TVA's Dam Safety Assurance Program (DSAP) was established in 2010 as a long-range plan to more fully understand issues which may potentially affect the safety of river dams, the potential impact to TVA assets, and reduce the risk of a dam safety event.
 - Drivers to establish DSAP: Kingston Ash Spill, TVA adopts FERC-based Dam Safety requirements, and nuclear commitments.
 - "ROR (river) dams, while having many years of good performance, require some re-evaluations and rehabilitation. This included updating the design basis to modern industry standards, evaluating dams for potential failure modes, performing risk screenings and analysis, and correcting any identified issues." – River Operations & Renewables Dam Safety Assurance Program: A Program to Reduce Risk of a Dam Safety Event, May 31, 2013.
- DSAP is comprised of 3 parts
 - Operational Improvement Program – "get well"
 - Assessment Program – "we don't know what we don't know"
 - Rehabilitation Projects
- DSAP was initially established as a 30-year program
- Funding is Strategic O&M and Capital

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121 TVA Dams

Dam Safety Executive Oversight Committee

Dam Safety Officer

Dam Safety Governance & Oversight Group

Dam Safety Risk Program

Dam Safety Steering Committee

Dam Safety, Independent Review Board

Interdepartmental Programmatic Review (e.g., ASRSO)

River System Dam Safety Group (River Dams Oversight)

Power Operations
12 Fossil Dams

Natural Resources
6 Dams/Reviews

Engineering

Inspections

River Dam Assets
87 River Dams
4 Pumping Stations
530 Spillway/Sluice Gates
9 Spillway Gates
39 Emergency Generators
14 Navigation Locks

Roving Maint Crews

Maint & Ops

Governance & Oversight

- RDS Execution & Support
- Risk
- Contract Labor
- Oversight & Execution

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- **Protect lives and property by enhancing safety and reducing dam risk by ensuring these dams are designed, constructed, operated, and maintained as safely and as reliably as is practicable.**
- **Accomplished by inspecting, monitoring, and performing and documenting the design, construction, operation, maintenance, modification, and emergency preparedness for each impoundment and dam to TVA's Dam Safety standards**



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- Routine inspections are performed to ensure operational and structural integrity of water barriers.
- Special inspections are conducted after earthquakes, heavy rain, flooding, etc.
- This is in addition to a vast array of Automated and Manual Instruments.

Formal
Intermediate
Monthly
Special

Routine



Rope Access Inspection

ROV Inspection

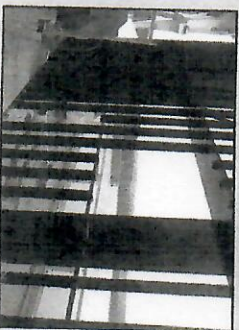
Diving Inspection

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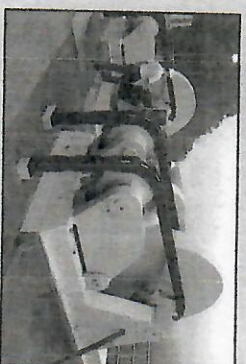
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Dam Safety Maintenance Program

- Preventative maintenance
- Corrective maintenance
- Dedicated roving maintenance crews



Nickajack Dam Trash Rack Damage



Gate Chains at Boone Dam



Placing riprap at Pickwick Dam

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Updating the Dam Safety Program

- Re-analyzing extreme events
- Re-analyzing stability of dams
- Sometimes required to perform a major modification



Temporary Sand Baskets at Valtia Bar Dam

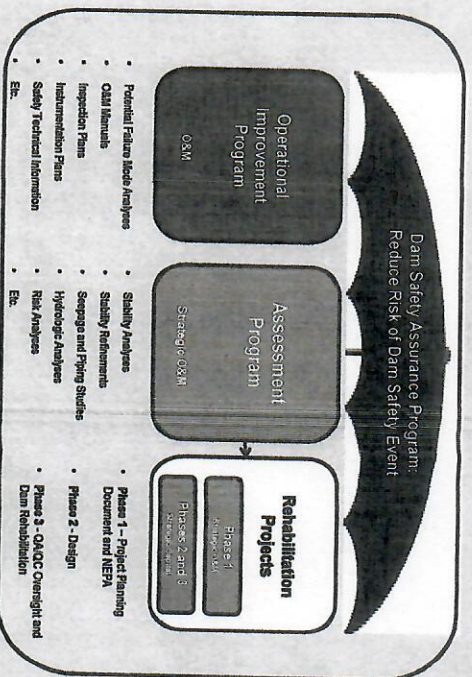


Foundation Treatment at Bear Creek Dam

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Program Initiated:
FY10

Program Completion
Scheduled for:
FY40+

- All these actions and programs inform the Portfolio Risk Management Framework, and Dam Safety Oversight.

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2. Comments on the PFMA Process

1. It's a great ideal
2. Oroville has – correctly – highlighted areas of improvement, and especially the need to guard against complacency / over-familiarity.
3. How about a silent vote when allocating PFM Class?
4. SQRA's & QRA's are clearly very valuable tools, but the process is to a large extent still driven by strong personalities and facilitators / participants very familiar with the generic processes. We must guard against unintentional but systematic bias.
5. Common sense is also a good ideal! (when applied to the development of any particular PFM – and especially those relating to internal erosion and piping).
6. It is essential to consider how the dam was built: there is a world of difference between a "conventional" compacted fill dam, and an "unconventional" puddle core embankment. In this regard, comprehensive STID's are highly influential.
7. "If everyone is thinking alike, then somebody isn't thinking" General George S. Patton.

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3. Safety

1. Remarkable changes in attitudes and processes over the last 40 years.

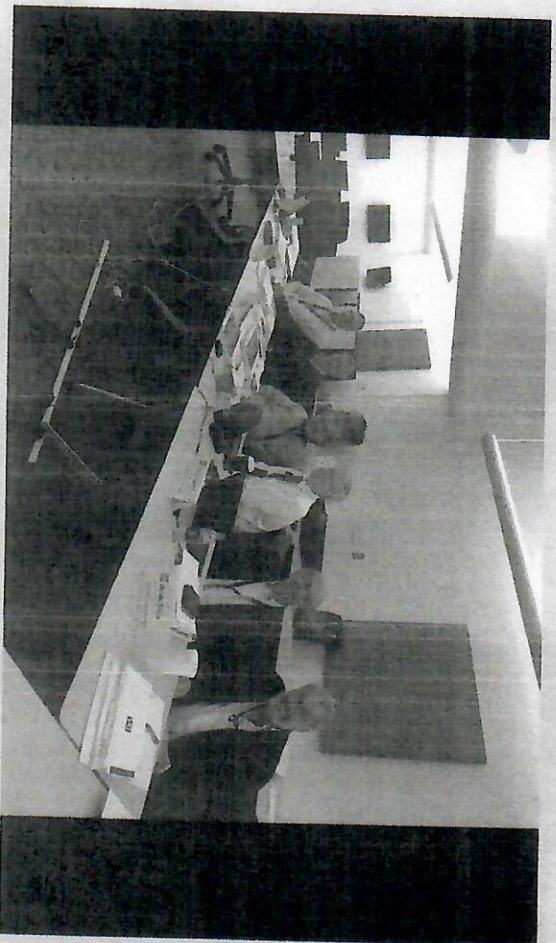


2. "Safety" is no longer lip service: it is the most important aspect of any construction activity.
3. It is often a prime determinant of acceptability of a contractor's bid.
4. Specific examples of enhanced safety concepts:
 - "stretch and flex" before work
 - tailgate meetings
 - introductory and weekly safety meetings
 - maintenance of meaningful safety statistics
 - zero tolerance stance on PPE, drugs, alcohol, etc.
 - parking/driving/phoneing restrictions
 - "safety moment" before office meetings
 - "buddy" system during site walks for BOC members
 - Monetary rewards for achieving safety standards
5. Assurance of safe working conditions is vitally important in attracting people into our workforce and keeping them content and productive.



4. Boards of Consultants

1. Every major project should have one (BOC, IRB, CRB, TRT, etc.)
2. Ideal number of members for a project is 2 - 4: larger numbers are advisable on long-term "standing" Boards.
3. Not all Boards function equally effectively: the most effective Boards have
 - strong subject matter experts with contemporary knowledge
 - they should be an Independent Board of Consultants, not a Board of Independent Consultants
 - respect for the other members areas of expertise
 - minimal egos, maximum personalities
 - are "learning" boards, not "pontificating" boards
4. Boards should be used frequently, and be engaged in interim conference calls to keep them updated.
5. Boards should not be involved in Contractor or Consultant procurement except to:
 - help establish the pre-Qualification requirements
 - help review submittals and Reports, upon requests
6. Boards must be allowed frequent site visits - and access to the contractor as appropriate.



6. Question & Answer Session (Dr. Greene)

1. Career inspirations and challenges
2. Key developmental projects
3. Paradigm shifts
4. Advice on Publishing
5. Advice to the next generation of engineers/geologists

5. Mentorship

- Mentorship is essential in developing good habits and common sense in younger engineers.
- Mentoring is something that most of us do, often without realizing it.
- However, with the growing reliance being placed on ever advancing computer capabilities and skills, it is even more important that our younger engineers are mentored in a dedicated and systematic way. This is especially so when integrating employees from different countries and cultures.
- Despite formal "mentorship programs" being emplaced in the larger corporations, these may not be as effective as the "one on one" arrangements found in smaller offices.
- Mentorship should be included as a true "core value" in corporations' business plans, and promotional activities.