THE EVOLUTION OF SPECIALTY GEOTECHNICAL CONSTRUCTION TECHNIQUES: THE "GREAT LEAP" THEORY

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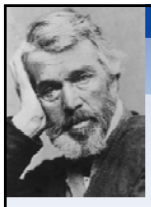
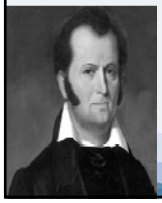
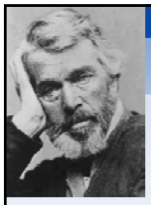
Terzaghi Lecture
March 17, 2015



1. DEVELOPMENT OF THE BASIC THESIS

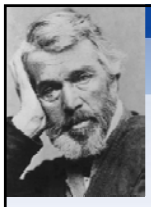
- Carlyle's "Great Man" Theory of History
- "Great Men" in Geotechnical Engineering Practice: The Terzaghi-Goodman-Peck Triangle, and Others
- "Great Leap" Theory Applies for Geotechnical Construction Techniques






- "Great Leap" Theory demands the satisfaction of six successive criteria:

1. The project or group of projects must be of exceptional and/or unprecedented scope, complexity, and construction risk.
2. A Specialty Contractor with ingenuity, resolve, and resources, and an equipment manufacturer must both exist.
3. A responsible individual/agency for the Owner must be prepared to take the perceived risk of deploying a new technology or technique.
4. The project(s) must be successful!
5. Details must have been published widely in the scientific press.
6. Within a few years of completion, there must be some type of codification/standards document, permitting wider use by industry.


- The theory can be demonstrated by analyzing progress in 3 processes in particular:
  - Grout curtains in rock
  - Cutoff walls for dams
  - Deep Mixing Methods
- Other processes could be used for illustration (e.g., rock anchors, micropiles, large diameter piling, soil treatment).


2. GROUT CURTAINS IN ROCK

2.1 The Exceptional Nature of the Project

- It is more appropriate to consider a *group* of projects 1997-2007 involving deep remedial curtains in karstic limestone.

- Pre-Leap 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).

- Pre-Leap Practices (continued)
  - These archaic practices were totally unsuited to the 1997-2007 demands with respect to logistics, performance and dam safety.

(Courtesy of California Department of Water Resources)

To illustrate this 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.

2.2 Availability of the Technology

- 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.

– Notes:

1. The associated design improvements included:
   - o multirow curtains;
   - o inclined holes in each row;
   - o depth of curtain determined by geology and/or by rigorous seepage analyses;
   - o stage lengths commensurate with the structural geology;
   - o use of the highest safe grouting pressures;
   - o verification of proper stage refusals;
   - o verification of residual in-situ permeability upon closure.

- Major technological developments were incorporated into all the important processes:
  - Drilling
    - Design and construction of new generation drilling rigs (Cubex).
    - Use of sonic drilling and double-head dry duplex for overburden drilling (Boart Longyear/Advanced).
    - Use of water-powered down-the-hole hammer (Wassara) for rock drilling.
    - Routine use of automated “Measurement While Drilling” instrumentation (Lutz and others).
    - Routine use of hole deviation monitoring (Robertson Geologger and others).

Photo No. 30. Drilling curtain holes through concrete at Elevation 188 in monolith 19. View downstream.
Neg. No. CD 6186 2-4-65

(Courtesy of California Department of Water Resources)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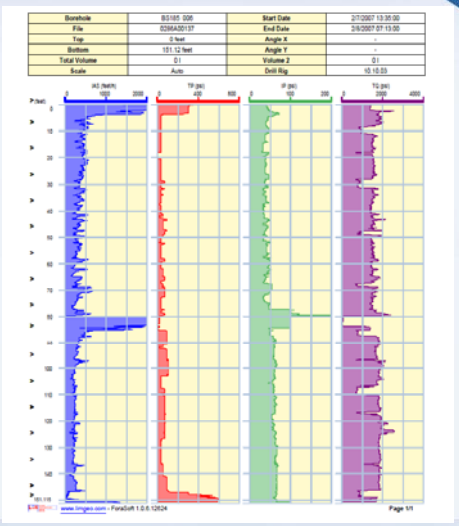
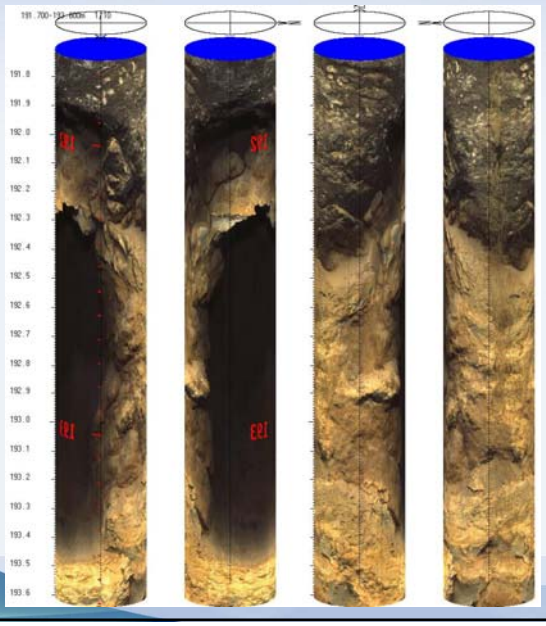
QXW810
Water Powered DTH

Monitoring While Drilling (MWD)



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.

- Injection Systems
  - Grout “buggies.”
  - Automated grout batching and mixing in weatherproofed enclosures.
- Grout Mixes
  - Development of balanced, stable multicomponent grouts giving superior rheological properties (Naudts, Master Builders, Sherrill).
  - In particular, exploiting a full understanding of the importance of the pressure filtration coefficient (DePaoli et al.)

Photo No. 31. Grouting equipment. High speed, double drum grout mixer is on right; agitator is on left. Grout pump is behind agitator. View towards left abutment.
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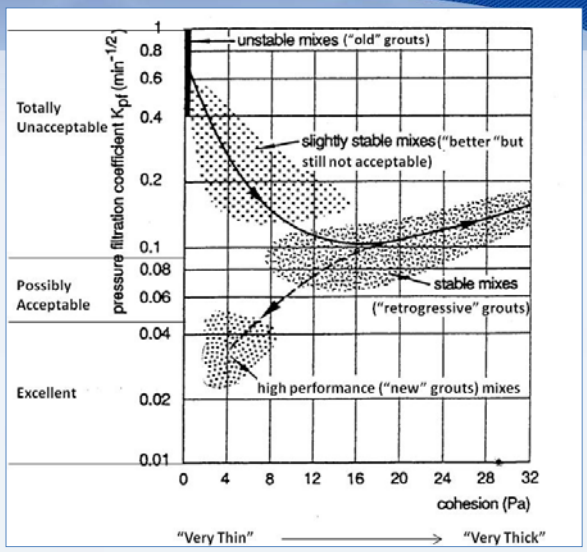
(Courtesy of California Department of Water Resources)

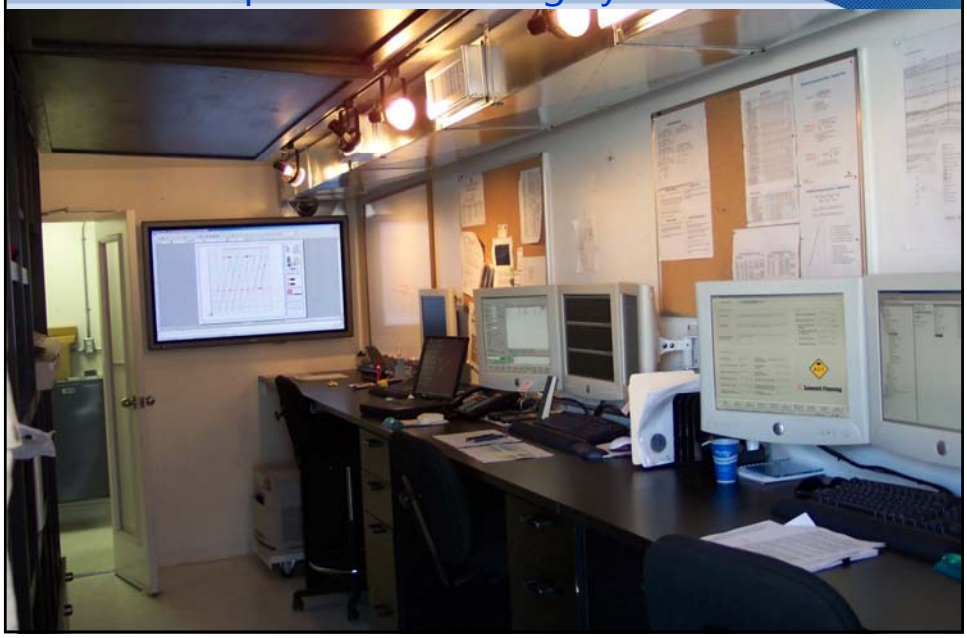
Monitoring Equipment

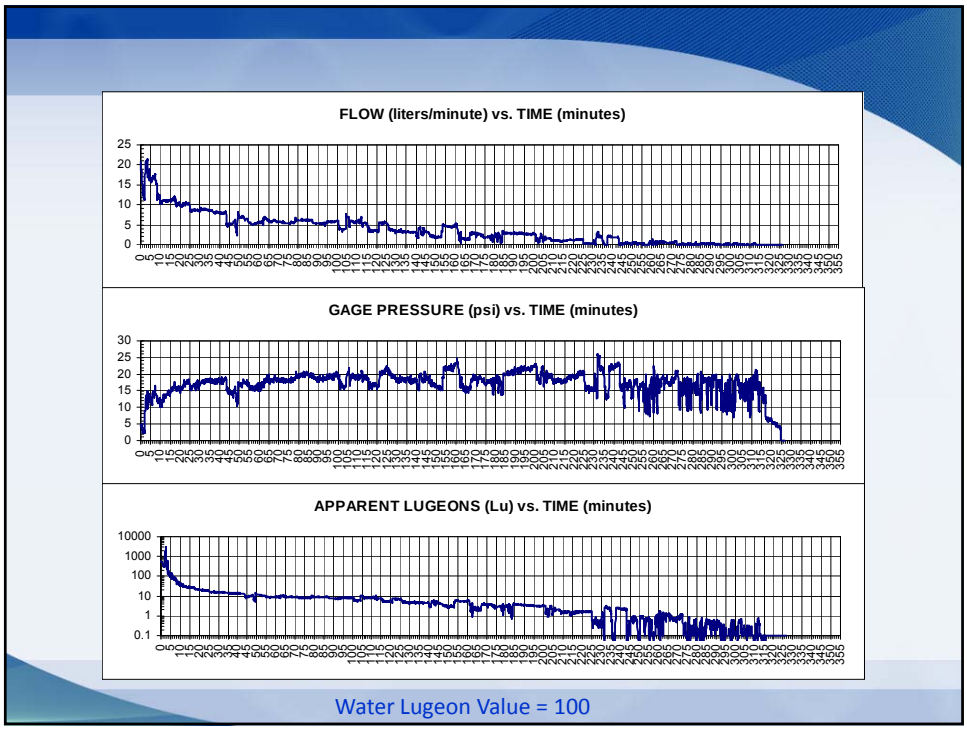


Historical path of development from unstable mixes to contemporary balanced multicomponent mixes (modified after DePaoli et al., 1992).

- Computer Control and Analysis
  - First CAGES (ECO Grouting), soon modified to "Intelligrout," to record, analyze, control and display all injection parameters in real time.
  - Use of Apparent Lugeon Theory (Naudts) predicated on development of stable mixes.
- Verification
  - Use of "Intelligrout" in real time (Advanced/Gannett Fleming).
  - Systematic use of multipressure Lugeon testing in Investigation and Verification Holes (Houlsby).
  - Systematic use of Optical Televiewer to show in-situ rock conditions without actually coring (Robertson).

Level 3 Computer Monitoring System



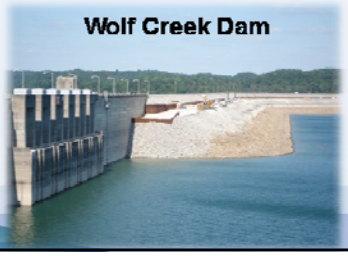


Water Lugeon Value = 100

2.3 Owner Risk Acceptance

Post-Leap

- First two projects had non-Federal clients (City of Bethlehem for Penn Forest Dam, PA, and County of Spotsylvania for Hunting Run Dam, VA). They and the Engineer-of-Record (Gannett Fleming, Inc.) accepted and shared the "novelty risk."
- For the later projects, the USACE accepted the "novelty risk," especially the Louisville, Little Rock, Nashville, and Chicago Districts, and Headquarters.

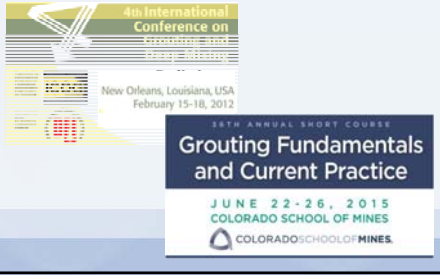


2.4 Success of the Project

- Curtains were systematically engineered to satisfy the in-situ residual permeabilities required by the design (1-5 Lugeons).
- Every project has provided compliant results.
- Curtains 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.

2.5 Technical Publications

- Proc. International Conferences on Grouting and Deep Mixing (Geo-Institute), New Orleans, 2003 and 2012.
- Proc. Annual Conferences ASDSO and USSD.
- Textbooks (Weaver and Bruce, 2007; Bruce, 2012).
- Annual Short Course on Grouting at Colorado School of Mines.
- Presentations at USACE's Infrastructure Conferences.
- Several other Contractors have been regularly using the "new methods" over the last 10 years with excellent results.



2.6 Codification

- Complete revision, by Gannett Fleming, under contract of the USACE's Grouting Technology Manual (EM-1110–2-3506) of 1984.
- Issued by USACE on July 31, 2014.

3. CUTOFF WALLS FOR DAMS

3.1 The Exceptional Nature of the Project

- 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 kastification. Retains Lake Cumberland and protects Tennessee.

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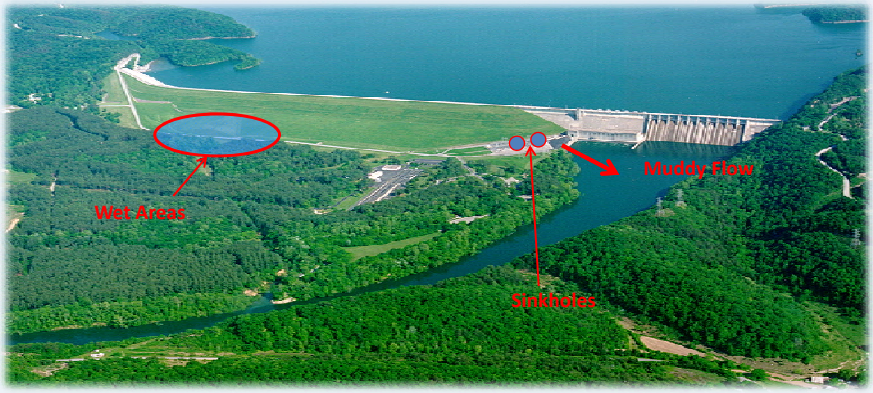
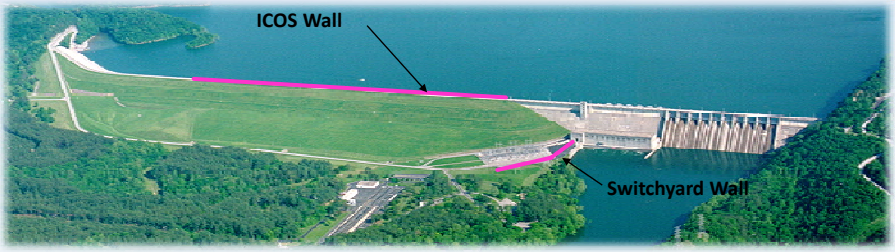
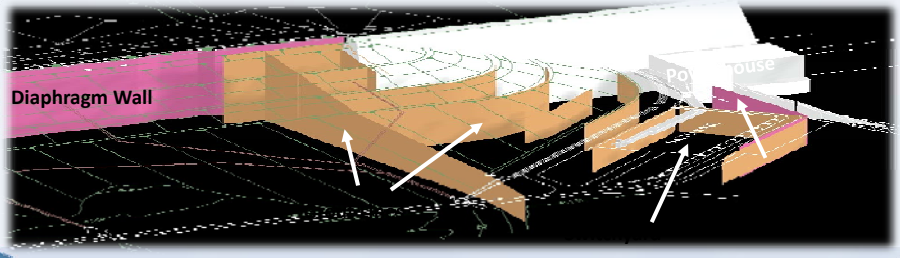
- Designed in the 1930's, built from 1941-1943 and 1945-1952.
- Severe hydraulic distress observed after impoundment leading to emergency grouting by USACE in 1968-1970 and 1973-1975.



- Primary Failure Mode 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.

First Solution – Cutoff Wall and Extensive Grouting Campaigns





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First Solution – Cutoff Wall and Extensive Grouting Campaigns

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

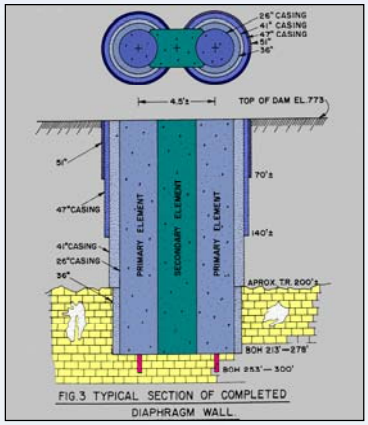

FIG.3 TYPICAL SECTION OF COMPLETED DIAPHRAGM WALL

Approximately 990 Concrete to Steel Joints

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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.

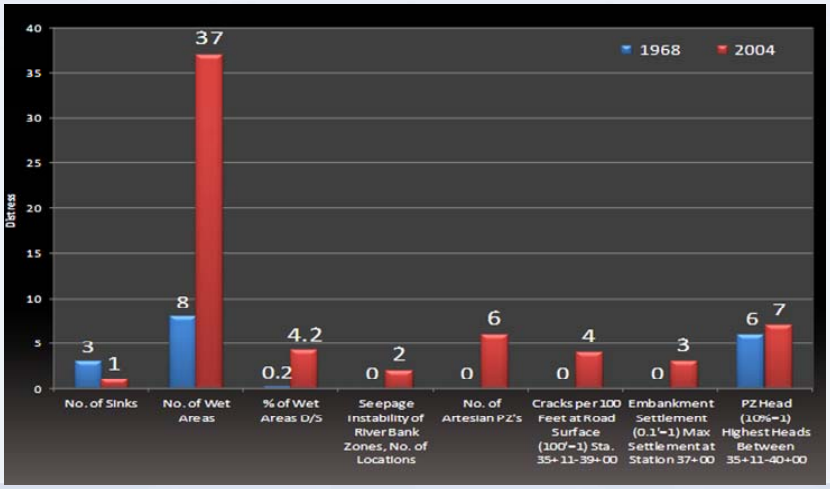
HOWEVER…

- During this original 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.

Increasing Distress Indicators



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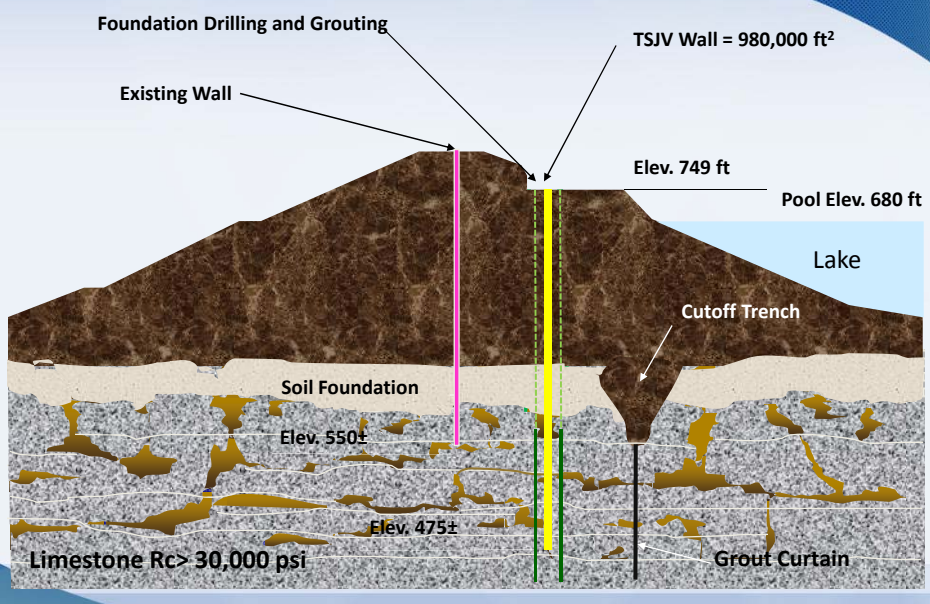
- Emergency grouting operation conducted as Phase 1 of the remediation in 2007-2008 by Advanced and Gannett Fleming as Phase 1 of a “Composite Wall” solution.
- Phase 2 involved the construction of a new cutoff upstream of the original, and longer and deeper, for an area of about 980,000 square feet – 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.

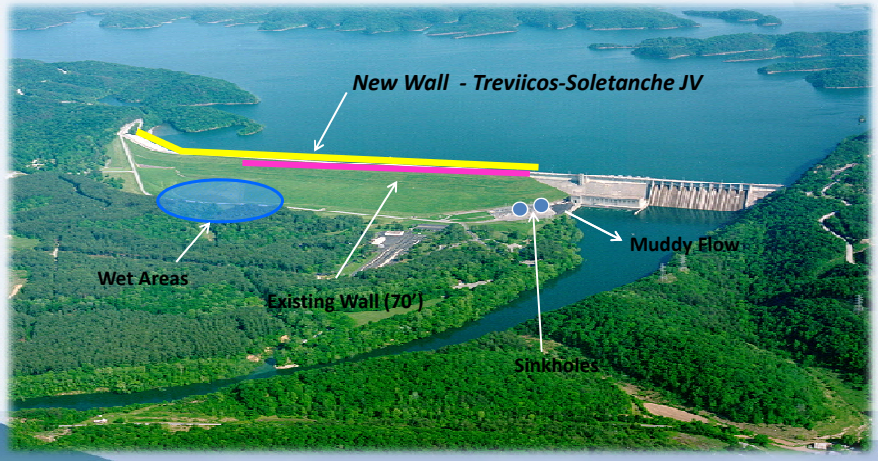
The Solution by USACE



3.2 Availability of the Technology

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 80 ft below its maximum capacity



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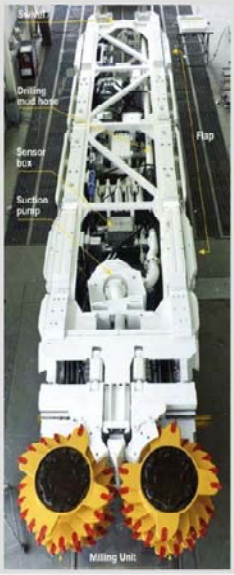
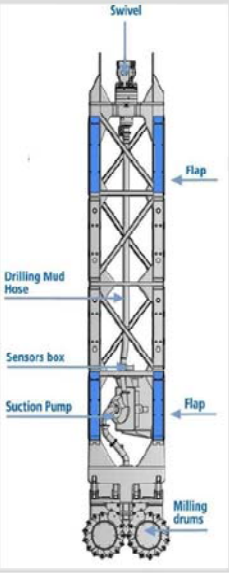
- The Trevi Group had acquired the ICOS Corporation of America in 1997, and had merged these assets with RODIO.
- TreviICOS had successfully conducted the cutoff at Walter F. George Dam, AL, from 2001-2003, principally leveraging expertise in large diameter secant pile technology (also used at Beaver Dam, AR, in 1992-1994).
- The Trevi Group also had particular expertise in directional drilling – essential for creating pilot holes with the specified 0.25% tolerance – and in Water-Powered, Down-the-Hole Hammer (Wassara).
- Soletanche – a pre-war French subsidiary of RODIO – now part of the Soletanche-Bachy Group, had patented in 1972 the hydrofraise (also known as a cutter or mill, by subsequent competitors).

HYDROMILL TECHNOLOGY



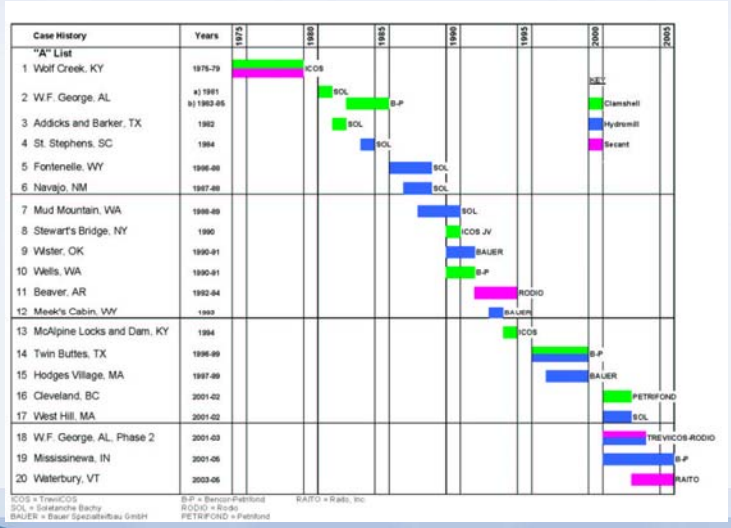
The core of any Hydromill is its trenching/cutting unit, that schematically consists of a heavy steel frame integrating the following components:

- 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 had 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.

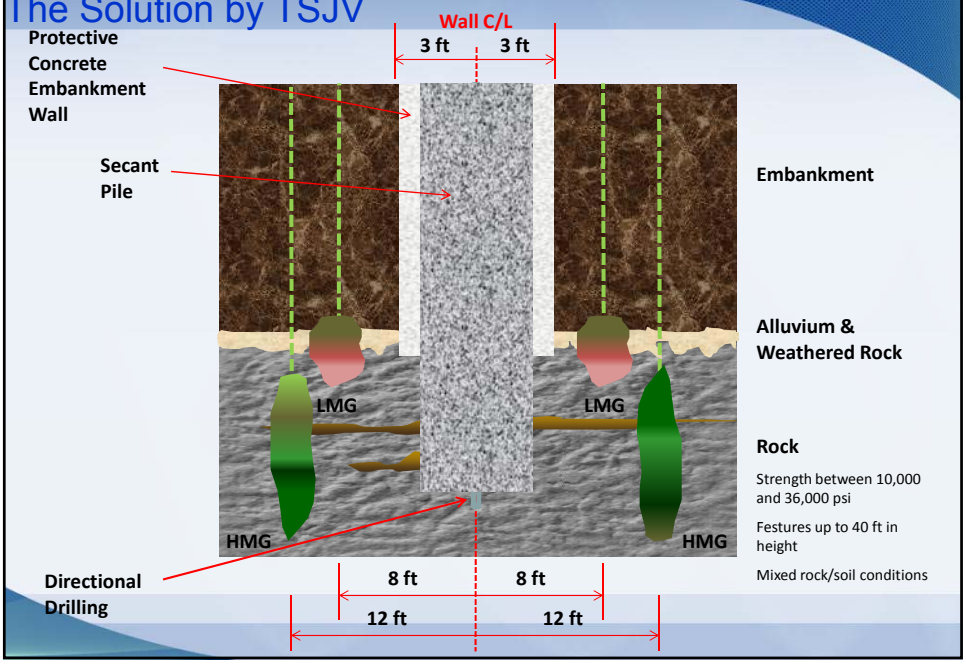
Project Listing Showing Chronology Type of Cut-Off and Specialty Contractor



- Hydrofraises had been 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 at Gualdo, Italy, to within 0.13% verticality.

- Recent technological developments have focused on reliability, productivity, and verticality monitoring and control.
- The experience of the partners in Wolf Creek 2 was combined to provide the successful solution:
  - A 6-foot-wide, 535,000 sf “disposable” diaphragm wall constructed by hydromill through the embankment and just into the bedrock: the “Protective Concrete Embankment Wall” (PCEW), and
  - The actual cutoff created in the underlying karst by drilling 1,197 guided 50-inch diameter secant elements through the PCEW.

The Solution by TSJV



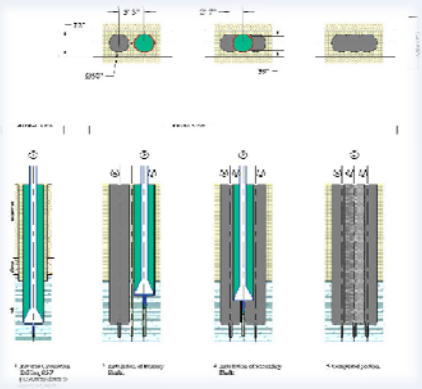
- Hayward Baker were engaged to explore and pretreat the potentially vulnerable embankment/rock contact with a LMG operation, and to thereafter extend the Advanced/Gannett Fleming grout curtain.

Protective Concrete Embankment Wall

Directional Drilling

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



3.3 Owner Risk Acceptance

- USACE and the original Board of Consultants made an extraordinarily courageous decision to accept ICOS' proposal in 1975, and 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 emplaced 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, and Internal Advisory Panel (Contractor).

3.4 The Success of the Project

- 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.

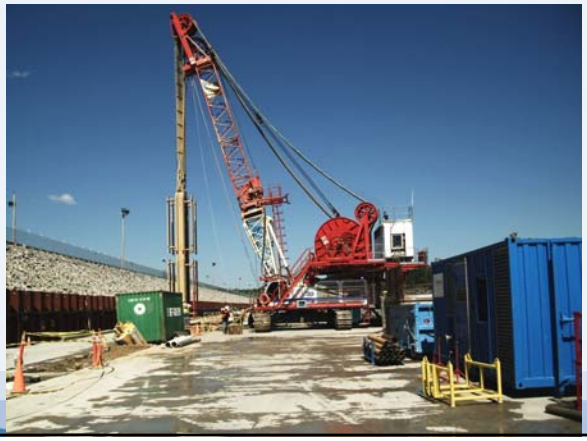
3.5 Technical Publications

- At least 12 technical publications from 2010 to May, 2014, in USSD, ASDSO and ICOLD Conferences.
- Further papers in international conferences in the U.S. and Europe.
- Numerous internal reports for the USACE and the Contractors.

3.6 Codification

- RMC of the USACE (David Paul) producing an Engineering Manual on cutoff walls for dams and levees, to enhance EM 1110-2-1901. To be published September, 2015.
- Bureau of Reclamation (Mark Bliss) finalizing new Design Standard on cutoff walls. To be published in August, 2015.
- DFI Slurry Walls Committee (Gianfranco DiCicco) developing a similar guideline on the application of specialty techniques for dam and levee remediation. Scheduled for 2016.
- All of these will provide “new blood” for the existing ICOLD Bulletin 150, and the European Standard EN1538.

- 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.



4. DEEP MIXING

4.1 The Exceptional Nature of the Project

- Deep Mixing Methods developed in Japan and Sweden in 1967 and introduced to the U.S. in 1986.
- Many large projects executed in the U.S. 1986-2008 for highways, dams, bridges, tunnels, ports and environmental applications. Major but erratic market in terms of annual volume.
- Many well-resourced contractors from U.S., Japan or European origins. Very keen price competition. "Always one very low."
- All applications used vertical axis mixing equipment (1-6 shafts), but relied on traditional concepts, methods and monitoring.

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- Some project outcomes were not totally satisfactory, especially in plastic, organic soils and in very heterogeneous deposits.

- Hurricanes Katrina and Rita in August and September, 2005, led directly to the need for massive DM applications in New Orleans, and indirectly, via the USACE's Portfolio Risk Assessment initiative, to the remediation of Herbert Hoover Dike, FL (inter al.).
- Technical, logistical, schedule and environmental challenges on each project were unprecedented.
  - New Orleans, Contract LPV 111: almost 1.7 million cubic yards of Deep Mixing in 100 rig months (double shifts). Levee to be completed by June 1, 2011.
  - Herbert Hoover Dike: 21 miles of cutoff to 90-foot depth in 4 years.

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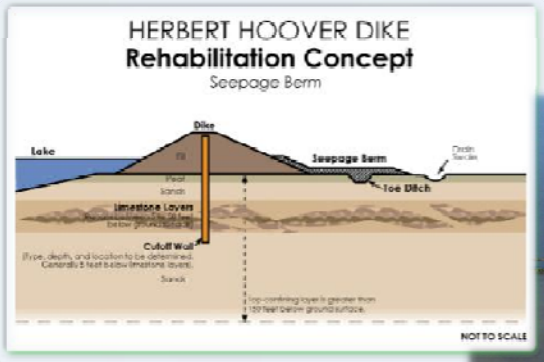
- The traditional DM Methods and resources would not suffice, and innovative procurement processes would be essential.



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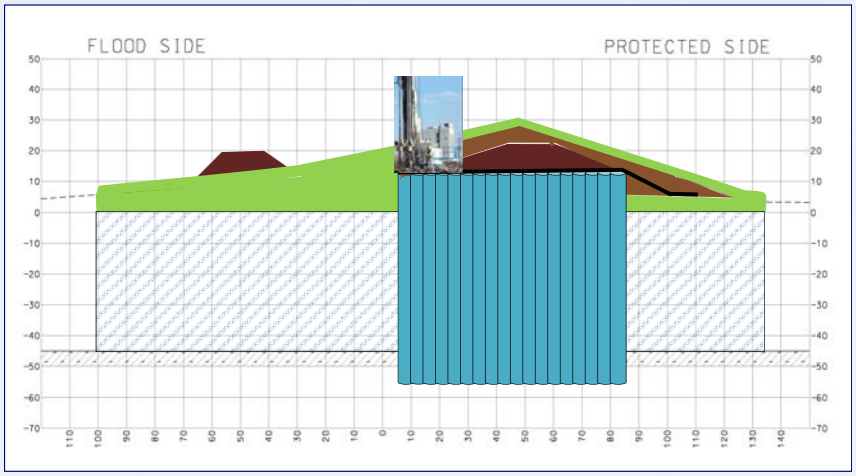
4.2 Availability of the Technology
4.2.1 *New Orleans LPV 111*

- Parent group of successful Deep Mixing Contractor owns Soilmec (manufacturer) who:
  1. had developed a jet-assisted DM method (Turbomix);
  2. could supply most of the 8 DM rigs themselves (FUDO Tetra Corporation provided 2);
  3. could supply the 8 automated mixing and pumping plants required to be positioned at equal intervals along the 5.5-mile-long project;
  4. had developed advanced mixing parameter, display, control and recording systems (essential for homogeneous mixing of variable strata);
  5. could supply the specialized coring equipment and expertise (3% of all elements were to be cored: no reliance on wet grab sampling).

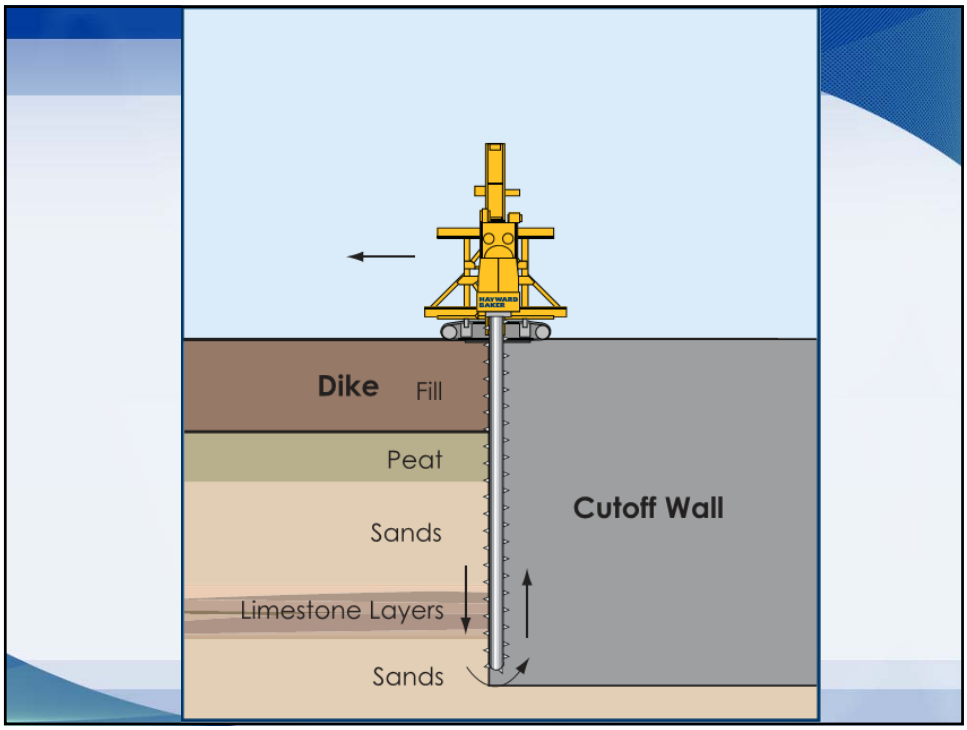

Sequence of Operations



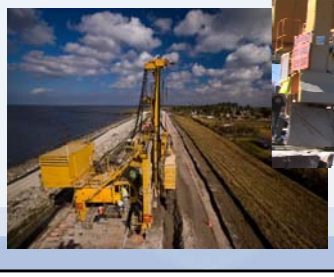
4.2 Availability of the Technology

4.2.2 *Herbert Hoover Dike*

- Three different technologies/companies prequalified by USACE to bid competitively on each contract segment:
  - cement-bentonite panel wall with grab and hydromill (TreviICOS);
  - Cutter Soil Mix (CSM) panel wall (Bauer Construction);
  - TRD (Trench Remixing Deep) continuous wall (Hayward Baker).
- TRD conceived in Japan and by 2008 had been used in over 300 projects in Japan.
- Vertical "chainsaw" cutting and mixing method can produce continuous walls up to 170 feet deep and 18 to 34 inches wide.



- Technology imported to the U.S. in 2006 by Hayward Baker and proved in the Alamitos Gap project in California soon after.
- Downwards/upwards ripping action provides very effective vertical homogenization of the soilcrete – a particular advantage in the very variable conditions at Herbert Hoover Dike.
- Extremely productive in appropriate soils conditions.



Classification of Deep Mixing Methods as at 2008

- Rotary Vertical Axis
  - Wet End Mix
  - Wet Shaft Mix
  - Dry End Mix
- Jet Assisted Vertical Axis (Turbojet)
- Trench Cutting and Mixing (TRD)
- Horizontal Axis Cutting and Mixing
  - Low Pressure (CSM)
  - High Pressure (CT Jet)

"Conventional"

4.3 Owner Risk Acceptance

4.3.1 *Herbert Hoover Dike*

- Technology Risk: Prequalification of 3 different methods (out of 8 proposed), each with very detailed statements of prior experience.
- Schedule Risk: Breaking down whole project into numerous smaller sections, permitting simultaneous work in several sections.
- 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 external consulting group as continuity/oversight over all individual contracts. For in-situ homogeneity, extensive reliance placed on Optical Televiewer (Robertson Geologger).

- 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 ≤ $1x10^{-6}$ cm/s (in coreholes at 200-foot centers);
  - UCS 100 to 500 psi from cores, at 28 days;
  - Chemical compatibility with groundwater and soil.

4.3 Owner Risk Acceptance
4.3.2 *New Orleans LPV 111*

- Technology Risk: First full-scale field demonstration program for DM conducted by USACE (Pete Cali) in 2001, and several medium-scale DM projects 2006-2008. "Industry Day" briefing in 2007.
- Schedule Risk: Use of Early Contractor Involvement (ECI): project bid at 10% Plans and Specs, and awarded at 35% Plans and Specs. Design specifications were finalized together with the Contractor, as mobilization was actually underway.

4.3 Owner Risk Acceptance
4.3.2 *New Orleans LPV 111*

- Project-Specific Risk: Classic developmental progression required by USACE and Engineer of Record:
  - desk studies (for feasibility);
  - bench-scale tests (for mix design, in 4 phases);
  - full-scale Validation Tests (for process optimization, in 5 phases);
  - intense monitoring of Production Works.
- Performance Risk: Use of Performance Specification, but very clear QA/QC and Verification criteria focusing on strength and homogeneity.

4.4 Success of the Project

- In every aspect, the Deep Mixing conducted at LPV 111 was successful:
  - completed within 14 months, on schedule;
  - 18,022 individual elements installed, using over 460,000 tons of slag cement;
  - over 500 coreholes, with average Recovery of 99% (compared to 80% criterion);
  - average UCS of 292 psi, compared to 100 psi criterion;
  - no inclusion in cores greater than 12 inches in maximum dimension;
  - most of the 500,000 cubic yards of spoils were used by the General Contractor for levee reconstruction ("Recycled Embankment Material");
  - very effective use of Contractor's Internal Advisory Panel.

- Similarly, at Herbert Hoover Dike, the 20,000 lineal feet of TRD wall satisfied the project specifications and requirements (as did the balance of the work conducted by the other methods). Valuable lessons were learned on all sections regarding mix designs (management of heat of hydration and pressure filtration especially) and on coring techniques. All 21.3 miles of cutoff were completed on schedule in early 2012.

4.5 Technical Publications

- One complete session (6 papers) of the 2012 International Conference in New Orleans was devoted to LPV 111. Several TRD papers were presented in the same Conference.
- Numerous papers in Annual Conferences of ASDSO and USSD.
- Publications at international conferences in Belgium and Italy, and in the ISSMGE Bulletin.
- Chapter in textbook “Specialty Construction Techniques for Dam and Levee Remediation “ (2012) on TRD (and on CSM and C-B Walls).

4.6 Codification

- TRD, CSM and C-B Walls described in current Manuals by USACE, Reclamation, and DFI (as detailed in Section 3.6, above).
- DMM details included in USACE design guide (Filz and Templeton, 2009).
- Details/lessons learned incorporated in 2013 FHWA Deep Mixing Manual (M.E. Bruce, et al.).
- Other “One Pass Trenching” systems now developed/more widely accepted.

5. FINAL REMARKS

- For each of the three techniques/applications presented, satisfaction of each of the six defining criteria is proved:
  - For Drilling and Grouting: The "Great Leap" comprised a group of major developments in processes, materials, technology platforms and design concepts. Implemented under the vision of one contractor/consultant team in response to a major market need.

  - For Concrete Cutoffs: The "Great Leap" had 3 steps:
    - the initial acceptance that a diaphragm wall was a safe and feasible solution for dam remediation (Wolf Creek 1);
    - the development of the hydromill; and
    - the technological advances made in response to extraordinary technical and dam safety challenges (Wolf Creek 2).

- For Deep Mixing: The "Great Leap" of 2008 comprised two parallel strides:
  - The implementation of a newly imported technology (TRD); and
  - A group of major enhancements to a traditional technology (TTM).

- Each "Great Leap" was engineered to satisfy the demands of a specific project (or group of related projects) of unprecedented scale and urgency, and each was facilitated by the use of innovative procurement vehicles by the Federal Government.

- Each "Great Leap" has been widely published and the outcome incorporated in new Design and Practice Manuals and Guidelines, and has been adopted (as far as Patents permit) by industry at large.

This image is taken from the seminal textbook “Foundation Engineering” by Peck, Hanson and Thornburn (1974).

“Karl Terzaghi (1883-1963)

Founder and guiding spirit of soil mechanics, outstanding engineering geologist, and preeminent foundation engineer. He was the first to make a comprehensive investigation of the engineering properties of soils: he created or adapted most of the theoretical concepts needed for understanding and predicting the behavior of masses of soil, and he devised the principal techniques for applying scientific methods to the design and construction of foundations and earth structures.”

- The image was not taken by Mrs. Metz from the textbook, but was sent at my request by Rick Robertson of CH2M Hill International – Panama (Leader of Locks Dispute Team for the Third Locks Project).
- He sent this photo of a photo of a drawing he had tacked to his office wall under the following cover:

  “Pinned up, watching over us in our day-to-day activities and reminding us of the observational method. Bringing a smile to my face.”

- So, the real legacy of Prof. Terzaghi?
  - An educator, but more an inspiration.
  - A scientist, but equally a communicator.
  - A genius, but in reality the ultimate role model for all, despite – or because of! – his well-documented love of wine, women and song.

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- The time to prepare this presentation was donated by my family.
- My thanks to all of you who chose to attend this presentation, and to the Geo-Institute for extending the invitation to give it.

Thank You!