

Foundation Cutoff Walls for Dams and Levees



Dr. Donald A. Bruce

GEOSYSTEMS, L.P.
724-942-0570
A Member
of:
Geo-Trust

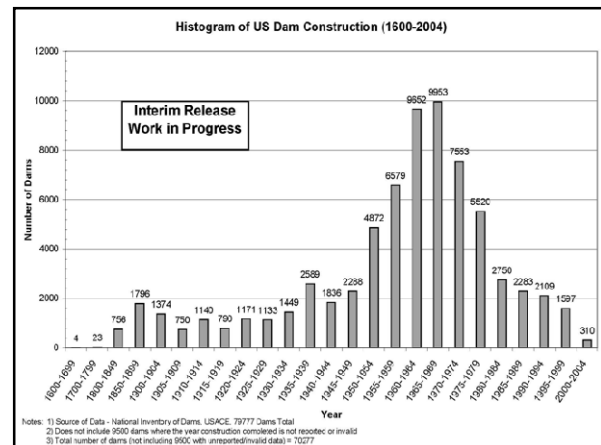
Scope of the Presentation

1. Introduction and General Background
2. Category 1 Cut-Offs (Excavate and Backfill)
3. Category 2 Cut-Offs (Mix in Place)
4. Overview
 - Focus on Pros/Cons/Limitations/Advantages
 - Research Needs Assessment



1. Introduction and General Background

- Over 84,000 dams in U.S.
- 14,000 meet "high hazard" criterion (loss of one or more human life)
- Median age 64 years
- 27,000 km end to end
- Perhaps around 180,000 km of levees, of which barely 15% are "Federal"



Fundamental challenges are posed to our dams and levees by:

- Geology: 40% of contiguous states underlain by evaporites/karst
- Seismicity: New Madrid, MO and Charleston, SC, as well as Western U.S.
- Aging/maintenance funding
- Natural disasters



Basic Classification of Cutoffs

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

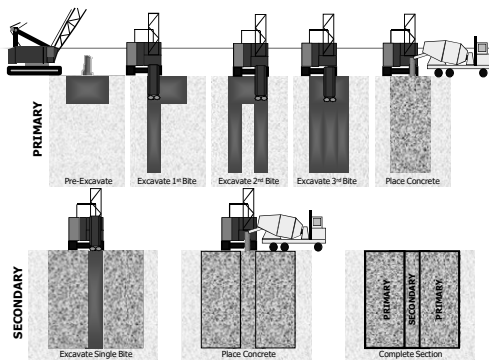


2. Category 1 Cut-Offs (Excavate and Replace)

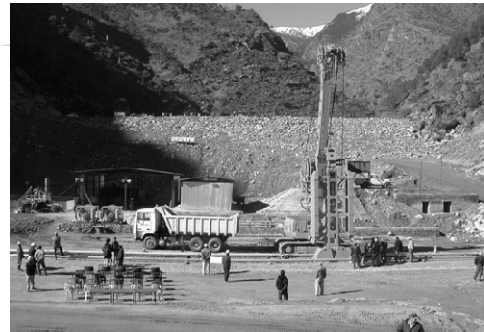
- Intrinsic advantage is that resultant “backfill” material can be engineered, on the surface, and is virtually independent of the native material through which the cut-off has been excavated.
- Wide range of possible backfill materials:
 - Conventional Concrete (rare for levees).
 - Plastic Concrete.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



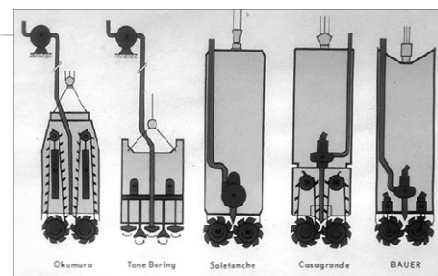
- Excavation Principles
 - Panels (Clamshells or Hydromill)



Clamshells
(cable or hydraulic)

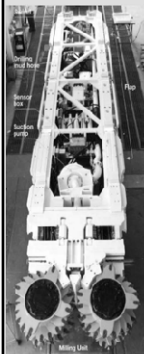


Cutters/Mills



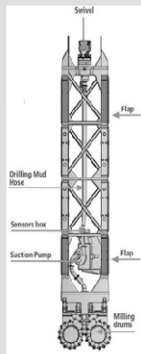
Development of Trench Cutters

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.



- Hydrofraises have 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.

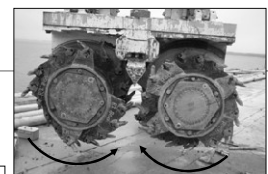
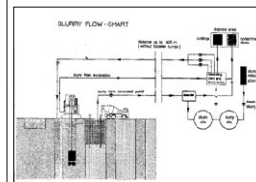


Protective Concrete Embankment Wall
Wolf Creek Dam, KY

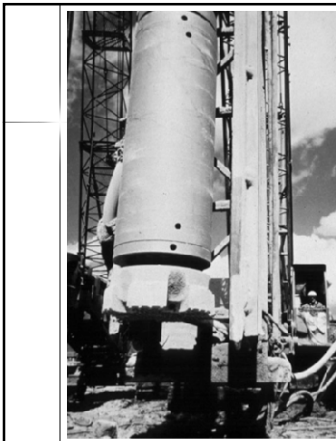


■ Panel Excavation

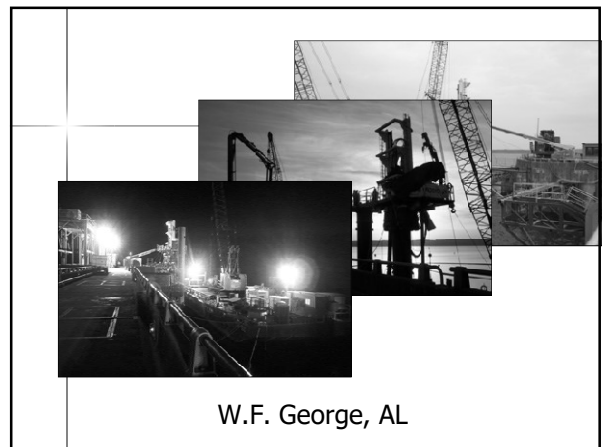
The cutters continuously remove the soil from the bottom of the trench, breaks it up and mixes it with a bentonite slurry in the trench.

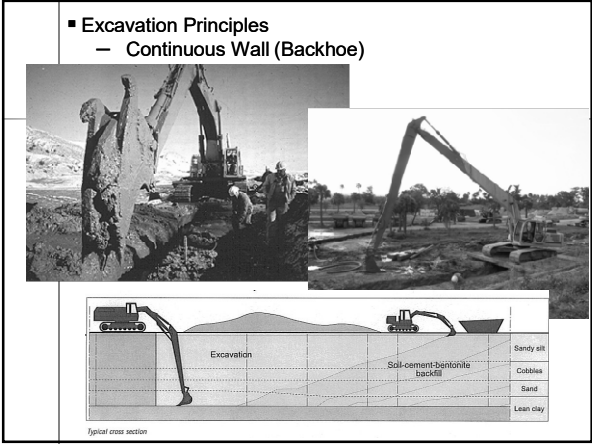
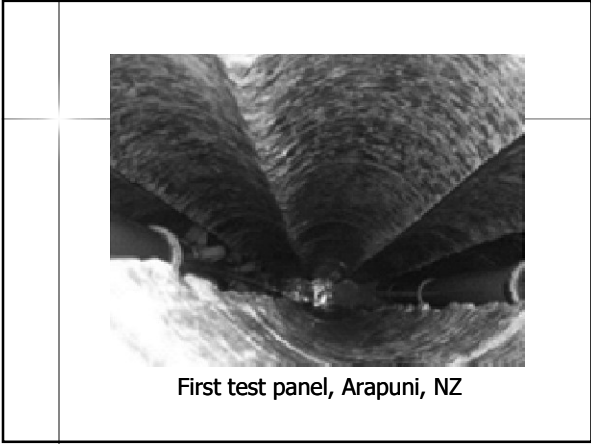
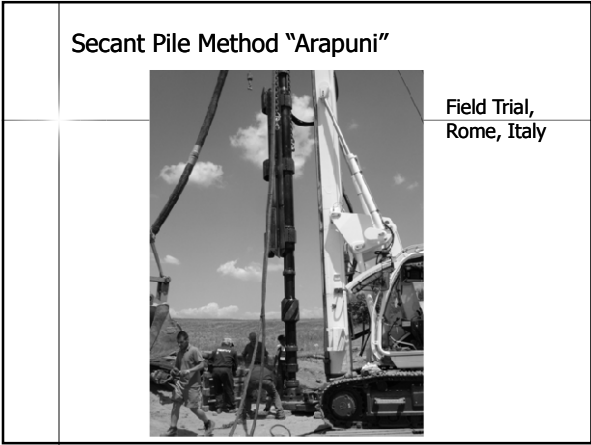
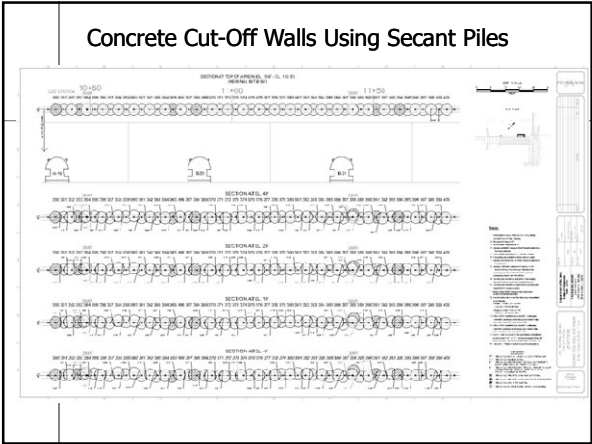


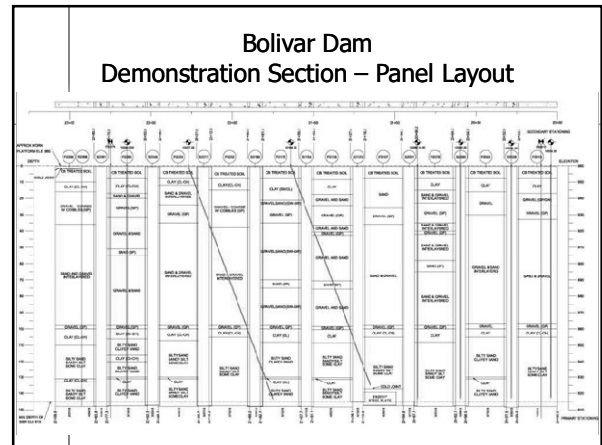
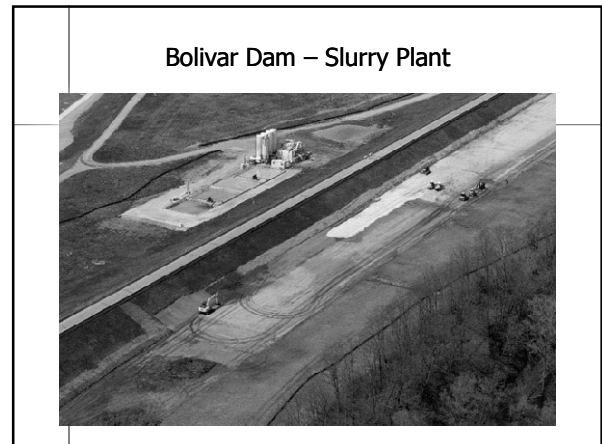
The slurry charged with soil particles is pumped through a pipe to the de-sanding plant where it is cleaned and returned into the trench.



Conventional Secant
Pile Method







Particular Advantages of Category 1 Cut-Offs

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

Particular Potential Drawbacks of Category 1 Cut-Offs

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

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

CASE HISTORY: WOLF CREEK DAM, KY

- 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 karstification. Retains Lake Cumberland and protects Tennessee.

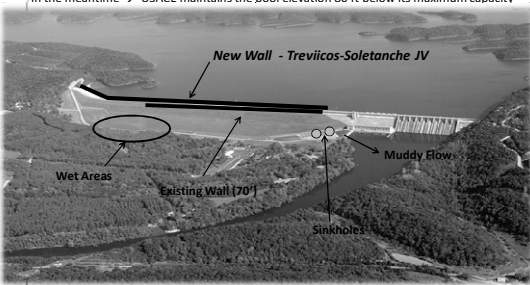


- Designed in the 1930's, built from 1941-1943 and 1945-1952.
- Severe hydraulic distress observed after impoundment leading to emergency grouting by USACE in 1968-1970 and 1973-1975.



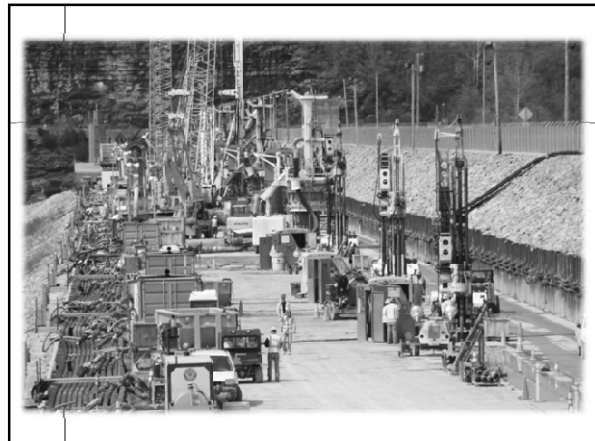
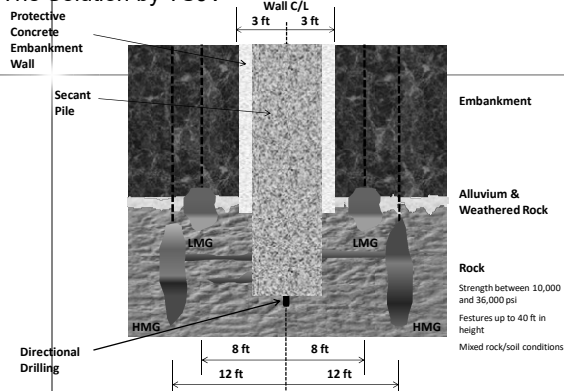
The Solution by the USACE

- 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



- 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



DATE AND YEAR OF REPAIR	CONTRACTOR	TYPE OF WALL	CONSTRUCTION MATERIALS	STONE FOUNDATIONS	FUNCTION OF WALL	RESULTS OF PROJECT				REFERENCES
						AREA	PERCENTAGE	DEPTH	LENGTH	
J. WALF CRENK, JR. 1970-1979	ICDS	24-inch diameter Prestayl Pipes joined by 24-inch diameter cast-in-place concrete walls at each placement of rock.	Concrete	Down PILL and ALL PILL with concrete and cast-in-place concrete walls at each placement of rock.	To provide a Pillar concrete cut-off through dam and into area to the right (Phase 2)	2.7-2.000 sq ft (Phase 1) plus 247,000 sq ft (Phase 2)	24 in	Max. 360 ft	0.000 ft old 1.250 ft	ICDS brochures (unknown) + Faber (1980)
J. W. F. GEORGE, JR. 1981	Solondike (Phase 1)	35-inch thick panels using cast-in place concrete and reinforced concrete	Plastic various	Random, supermarket PILL and concrete cut-off walls 24- inch (Phase 1)	To provide a basement concrete cut-off through the dam and into area to the right (Phase 2)	110,000 sq ft (Phase 1) plus 1,100 sq ft (Phase 2)	24 in	Max. 138 ft	1.000 ft	+ Solondike Brochure (unknown)
1993-1995	Benson Dawson (Phase 2)	24-inch panels cast-in place concrete walls at each placement of rock	3,000 psi Concrete	ALL PILL with concrete cut-off walls 24- inch (Phase 2)	To provide a basement concrete cut-off through the dam and into area to the right (Phase 2)	490,000 sq ft (Phase 2) plus 720,000 sq ft (Phase 2)	24 in	Max. 160 ft	1.000 ft	Benson Dawson Brochure (unknown)
J. AUGUSTO ARAU BUNZON, JR. Completed in 1982 (Phase 1) 1982-83	Solondike*	35-inch thick panels using cast-in place concrete and reinforced concrete walls at each placement of rock	Sell concrete	Down PILL, and concrete cut-off walls 24- inch (Phase 2)	To provide seepage and down through core	611,000 sq ft (Phase 2) plus 720,000 sq ft (Phase 2)	35 in	Max. 140 ft typically 15 to 17 ft	0.330 ft plus 4.200 ft	Solondike Brochure (unknown)
A. ST. STEPHENS, SC. 1994	Solondike	35-inch thick panels using cast-in place concrete and reinforced concrete walls at each placement of rock	Concrete and sell concrete	Down PILL, and concrete cut-off walls 24- inch (Phase 2)	To provide a cut-off through dam	78,000 sq ft (Phase 2) plus 20,000 sq ft (sell benefits)	24 in	Max. 208 including 0 ft into shale	1.000 ft	+ LIDAGE Report (1986) + Solondike Brochure (unknown) + Faber (1980) + Benson (1985) + Benson (1985)

* Solondike has operated in the U.S. under different business identities over the years. "Solondike" is used herein as the generic term.

Project Listing Showing Chronology Type of Cut-Off and Specialty Contractor to 2005

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

Note:

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

2006-2013 Update

DAM	STATE	SCOPE	STATUS OF PROJECT AS OF FALL 2012
Wolf Creek	KY	Approximately \$400M Category 1 cutoff to 275' depth.	90% complete.
Clearwater	MO	Approximately \$100M Category 1 cutoff to 150' depth.	Complete.
Center Hill	TN	Approximately \$110M Category 1 cutoff to 300' depth.	10% complete.
Herbert Hoover Dike	FL	About 22 miles of Category 1 and 2 cutoff to 90' depth.	Complete.

In addition, major cutoff walls are in design stage for other USACE DSAC 1 and 2 dams including East Branch, Bolivar, Mohawk and Addicks & Barker Dams.

	Category 1 Cut-Offs (Excavate and Replace)
	Q&A

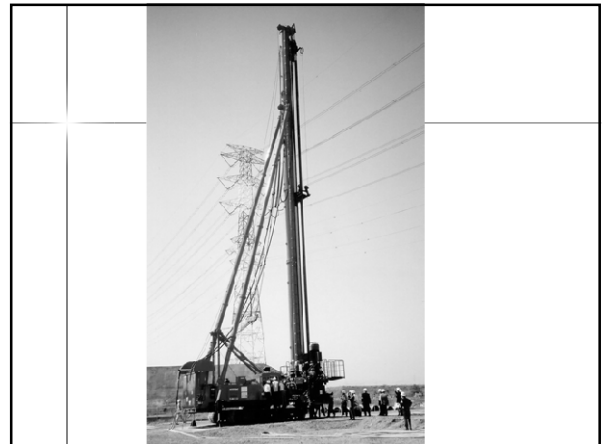
3. Category 2 Cut-Offs (Mix in Place)

DMM (Deep Mixing Methods)

- 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"

		
	Conditions Favoring DMM ■ Ground is neither very stiff nor 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	





"Conventional" DMM

Particular Advantages

- Low vibration, moderate noise.
- Applicable in most soil conditions.
- In appropriate conditions, good homogeneity and continuity can be achieved.
- Productivities can be high – 2,000/3,000 sf/shift.
- Unit prices are low - moderate.
- Several good, experienced contractors in the U.S.



"Conventional" DMM

Potential Drawbacks

- Large, heavy equipment.
- Practical depth 110 feet (vertical).
- Method sensitive to very dense or stiff soil, organics, boulders.
- Mobilization/demobilization costs high.

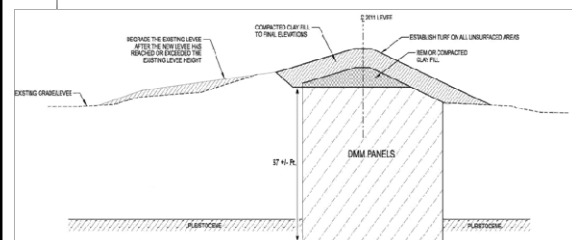
During hurricane Katrina a substantial percentage of New Orleans East Levee System failed, including LPV111

The Hurricane Protection Office of the US Army Corps of Engineers attributed the failure of the system to overtopping, erosion, and subsequent breaching of levees along the GIWW



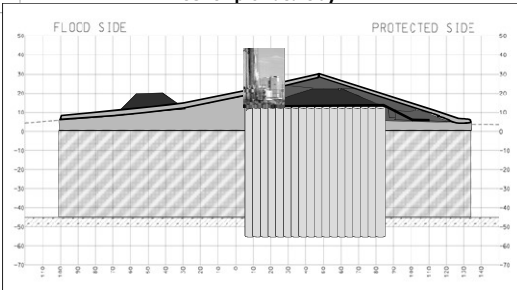
LPV 111 Project Overview

In order to address the technical and logistical demands of the project, deep mixing method was designed as the most suitable technology utilizing "Early Contractor Involvement".



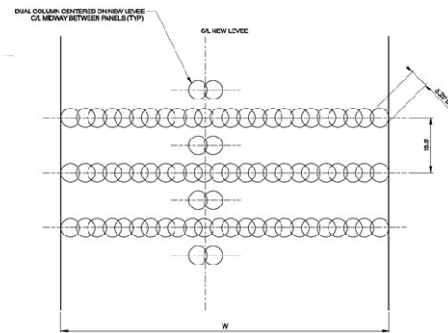
Sequence of Operations

Proceed with construction and grout placement
BSCAE provided Clay



TREVIICOS Corporation
38 Third Avenue, 3rd Floor – Boston National Historic Park-Charlestown, MA

Design



Technology

Over 60% of the ground improvement was accomplished with the Trevi Turbo Mix technology, single and double axis.

The TTM method is 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.



Pre-Construction

The contract required that pre-construction activities be performed during the design phase to determine the most appropriate construction parameters and technical solutions:

- Soil Investigation (2 phases)
- Desk Study
- Bench Scale mixing program (4 phases)
- Field Validation Test program (5+ phases)

Due to schedule constraints, only the first stages of the pre-construction activities were accomplished before the beginning of the actual production. The remaining stages were performed as work areas became available .

Production

Some numbers....

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

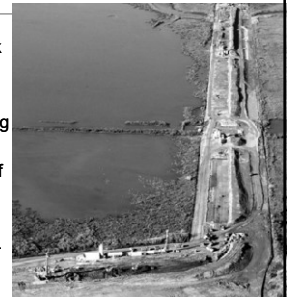
...that makes LPV111 the largest land-based deep soil mixing job ever undertaken outside of Japan

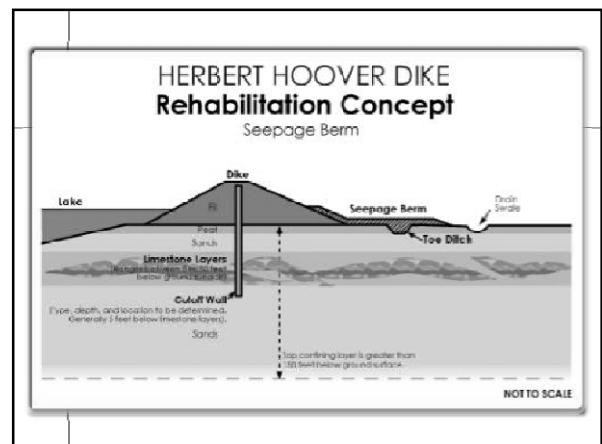
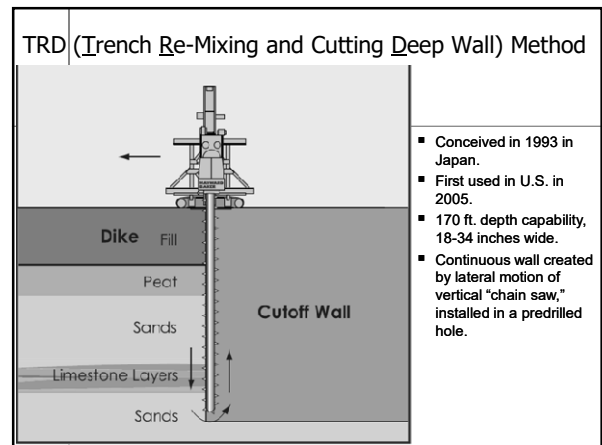
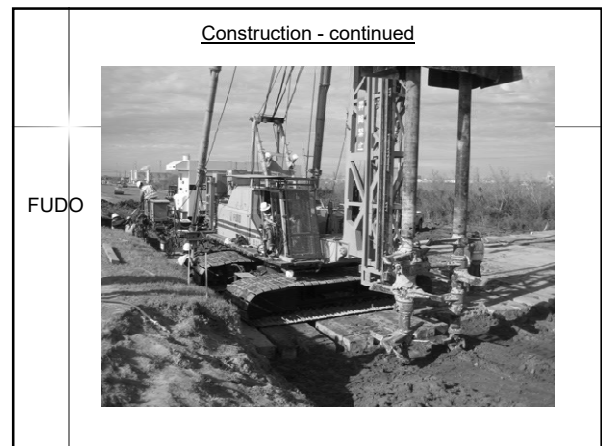
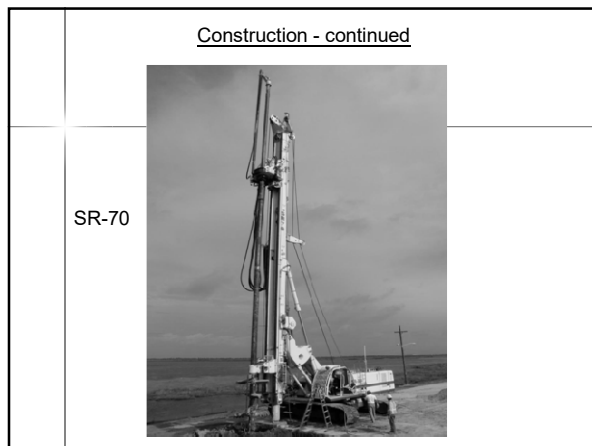
Construction

LPV 111 CHALLENGES:

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

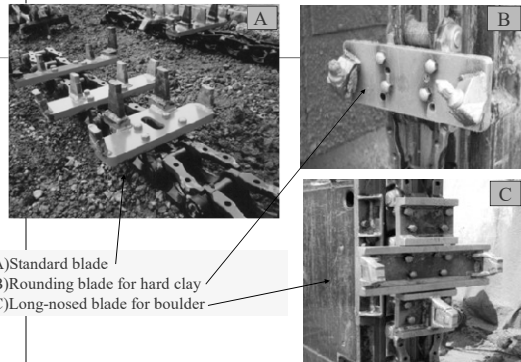
- 2x12 hrs/shifts, 5.5 days/week
- 6 dual auger + 2 single auger rigs
- 8 active batch plants producing ≈ 50 cy/hr of grout
- approximately 460,000 tons of cement used → 17,500 trucks
- 3 coring rigs
- over 500,000 man-hours in 14 months of production







Blades vary according to soil condition



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



TRD

Particular Advantages

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



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

TRD

Potential Drawbacks

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



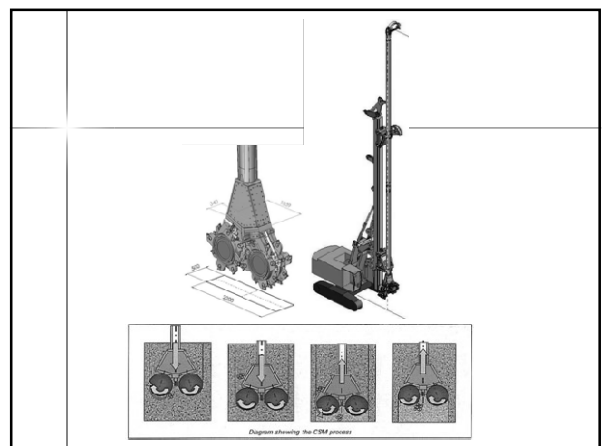
DeWind "One Pass Trenching"





Cutter (utter Soil Mix) Method

- Bontlauer Maschinen/Bachy Soletanche development in 2003
- Combines expertise in hydro-poll and deep mixing.
- Rapidly increasing in popularity worldwide (over 30 units in service).
- Similar system developed by Trevi (CT Jet).
- Maximum depth 180 feet, 20-47 inches wide.



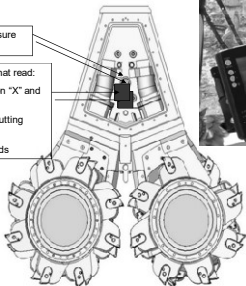
CSM Quality Control Systems

The CSM 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

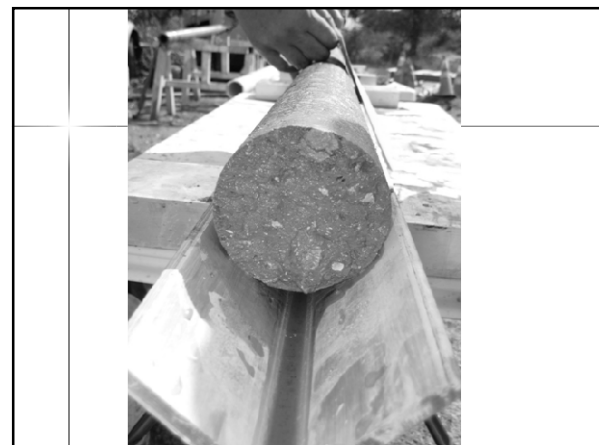
Instruments that read:

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





BAUER B-Tronic system



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

CSM	
<u>Potential Drawbacks</u> - As for all DMM variants, rock, boulders and organics are challenges. - Needs considerable headroom. - Cost base (as for all DMM variants)	

Overview of Category 2 Walls

METHOD	PRINCIPLE	WALL DIMENSIONS	PROPERTIES OF BACKFILL	COSTS			RELATIVE BENEFITS/PROBLEMS		
		DEPTH	WIDTH	UCS	K	MOISTURE	UNIT PROD.	PROS	CONS
Category 1 – Excavate and Replace (i.e., under seismic duty)									
Clamshell	Various types of clam can be used to remove soil in pieces	Max 750' typically < 150'	14-60" typically 25-30"	Wide range of materials can be used for backfill depending on project requirements	Low-Moderate	Moderate-High		- Experience - Adaptability - Wide range of backfills - Considerable depth capability	- Spills handling - Blockers - Block - Vertically control - Loss of slurry - Access/haulroom
Hydromill	Large fines with cutting wheels and receive circulation and pump to remove soil in pieces	Max over 800'	24-40" typically 31-39"	Wide range of materials can be used for backfill depending on project requirements	Moderate-Very High	High-Very High		- Greater depth capability - Can penetrate all conditions - Can be very fast - Variability control	- Cost time - Loss of slurry during excavation - Spills handling - Access/haulroom
Backhoe	Modified long reach excavator to create continuous trench	Max 130' typically < 80'	24-36"	Mainly used with SB backfill, but feasible with SCB and CB	Very Low	Very Low		- Very high productivity - Low cost - Experience - Many practitioners - Precise to tight access/low haulroom conditions	- Depth limitation - QA/QC - Obstructions/obscure soil - soilrock
Category 2 – Mix in Place									
Conventional 30M	Vertically excavated shafts are rotated into the soil creating panels of soilcrete	Maximum practical about 140'	24-48"	150-1,500 psi	5x10 ⁴ to 1x10 ⁵ cm/s	Moderate-High	Low to Moderate	- Large equipment needs good access and virtually unobstructed haulroom - Depth limits - Very sensitive to obstructions - Variable homogeneity with depth - Cost time	- Spill - Experience - Several practitioners - High productivity

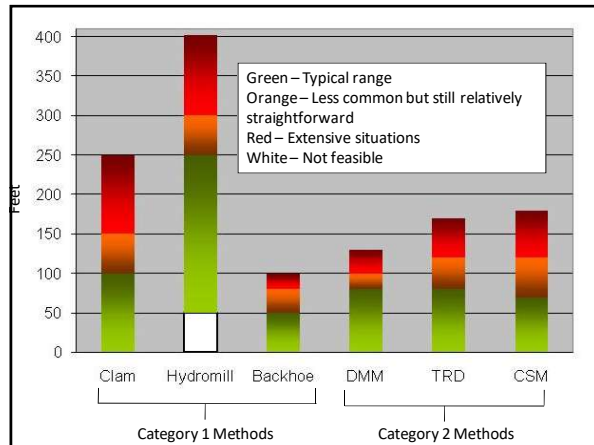
(continues)

METHOD	PRINCIPLE	WALL DIMENSIONS		PROPERTIES OF BACKFILL		COSTS		RELATIVE BENEFITS/PROBLEMS	
		DEPTH	WIDTH	UCS	K	MOISTURE	UNIT PROB.	PROS	CONS
TRD	Vertical chamber providing simultaneous cutting and mixing of soil to produce continuous soilcrete wall	Maximum 70'	18-34"	100-3,000 psi	1 ⁴ " to 1 ⁶ " cm/s	Moderate-Very High	Moderate-High	- Continuity of cut-off is automatically assured - Homogeneity - Speed - Quality - Adaptability to wide range of ground conditions - Low noise and vibrations - Low haulroom potential - Reduced diaphragm pressure - Wide range in cut-off properties can be engineered - Fast construction - Homogeneity - Speed - Adaptable to conventional concrete - Wide range in cut-off properties can be engineered - Can accommodate steep geometry changes	- Difficult wall geometries - Medium-hard rock and boulder rebar - Currently only one U.S. contractor - Requires very specialized equipment - Cost time
CSM	Cutting and mixing wheels mounted on horizontal axes create vertical soilcrete panels (Deeper and wider with CT Jetvariant)	Max 180'	28-47"	100-3,000 psi	1 ⁴ " to 1 ⁶ " cm/s	Low-Moderate	Moderate	- Large equipment needs good access and relatively unobstructed haulroom - Depth limits - Very sensitive to obstructions - Variable homogeneity with depth - Cost time	- Spill - Experience - Several practitioners - High productivity

Key to Costs

Subcontract		Unit Costs	
(Rate, 20% per square foot of cut-off)			
< \$50,000	Very Low	< \$1	Very Low
\$50,000-150,000	Low	\$10-\$20	Low
150,000-300,000	Medium	\$20-\$50	Medium
300,000-600,000	High	\$60-\$100	High
> \$600,000	Very High	> \$100	Very High

Key to Costs	
Notes/Details	Unit Costs (\$/sq. yd. per square foot of cut-off)
< \$50,000	Very Low
\$50,000-\$100,000	Low
\$100,000-\$200,000	Moderate
\$200,000-\$500,000	High
> \$500,000	Very High



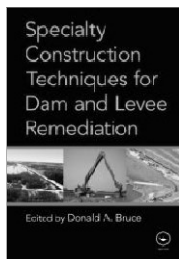
Acknowledgements

Dick Davidson (URS)
Jim Hussin/George Burke (HAYWARD BAKER)
Brian Jasperse (formerly GEOCON)
Charlie Krug (DeWIND)
Mario Mauro and Stefano Valagussa (TREVISO)
Al Neumann (formerly BAUER, now LAYNE)
Gilbert Tallard
David Yang (JAFEC)
USACE



Dedicated to the memory of our late friends,
Renato Fiorotto, formerly of Casagrande and Bauer Maschinen, and
Arturo Ressi, ICOS

New Data Source



Chapters on:

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

Q&A
80