A Brief History of the Use of the Deep Mixing Methods in the United States

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Agenda

1. In the Beginning
2. Some Landmark Projects and Events
3. New Arrivals
4. Studies, Researches and Conferences
5. Final Remarks

1. IN THE BEGINNING

Key Dates

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

1. IN THE BEGINNING (continued)

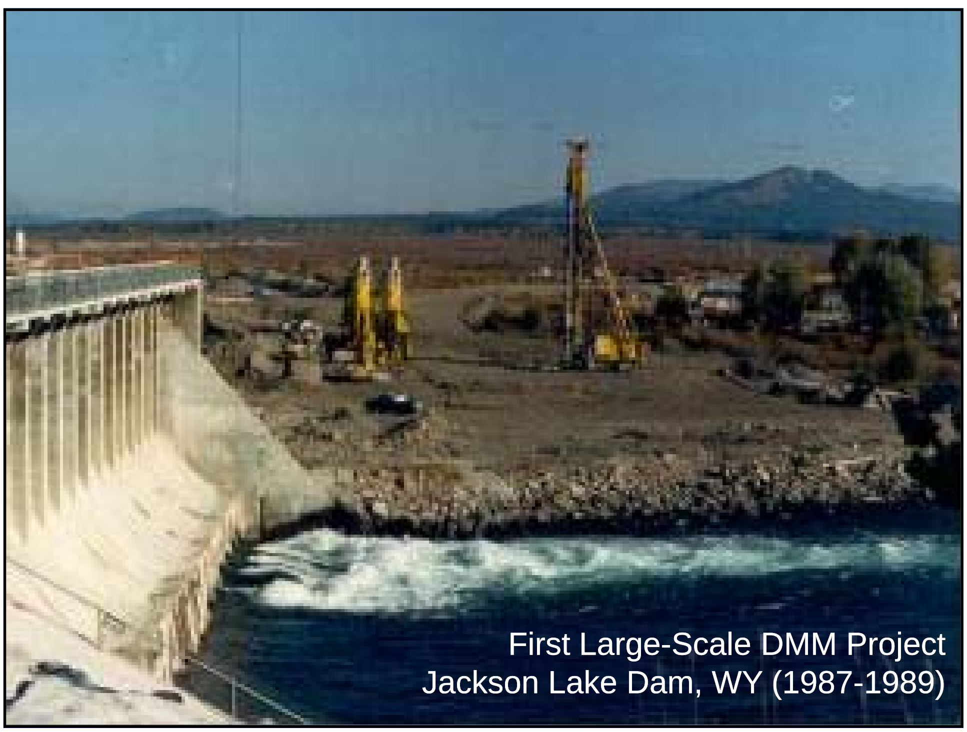
Key Dates

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
2013	Increasing DFI support for DMM

2. SOME LANDMARK PROJECTS & EVENTS

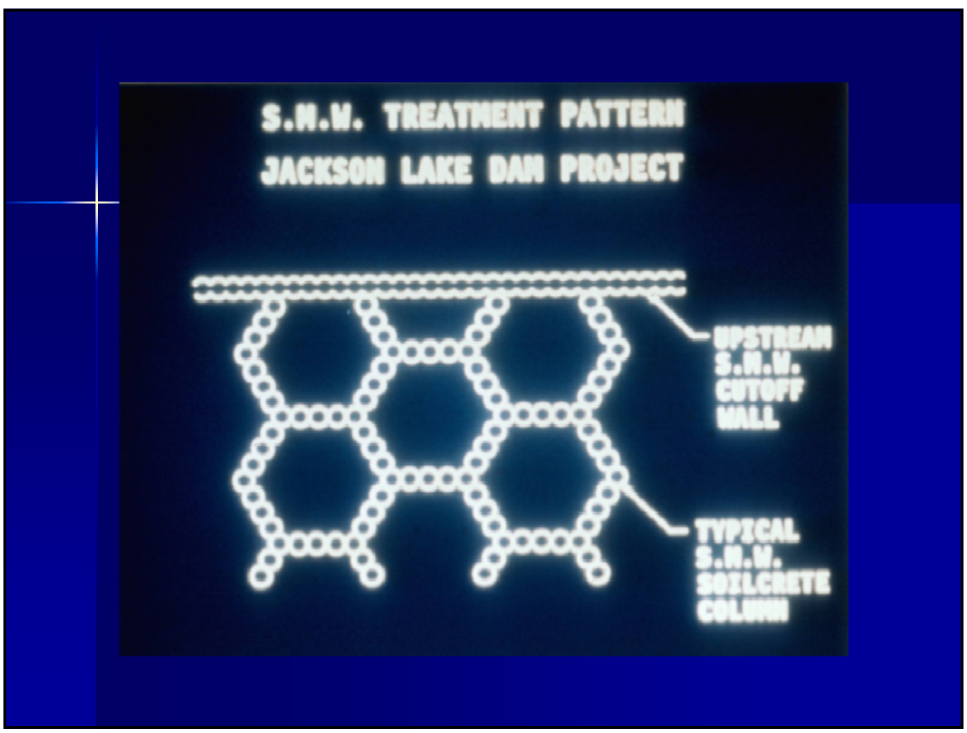
Caveats and Apologies

- Incomplete (e.g., important DMM projects conducted in Bay Area, the Pacific Northwest, and on California Dams and Levees)
- No contractor preference
- Thanks for all the contractors who sent images – including: Fudo, GeoSolutions/GeoCon, Golder Construction; Hayward Baker; Malcolm; Nicholson; Raito; Schnabel Foundations; TREVIICOS; Underpinning and Foundations



First Large-Scale DMM Project
Jackson Lake Dam, WY (1987-1989)


S.M.W. SEIKO, INC


S.M.W. TREATMENT PATTERN
JACKSON LAKE DAM PROJECT
UPSTREAM S.M.W. CUTOFF WALL
TYPICAL S.M.W. SOILCRETE COLUMN

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

First Large-Scale SSM Project
(~1989)

CO7A1, Boston, MA
(1992-1994)

Lake Parkway, Milwaukee

225,000 sf 1996

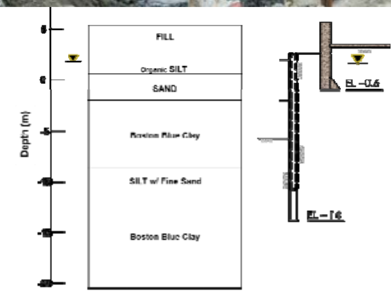
First Dry Mixing Project
Queens, NY (1996)

Pascagoola, MS
(~1998)

One of the first DMM projects in the Mississippi Deltaic Deposits

Boston Museum of Fine Arts
(2007-2008)

- Stiff wall to limit ground movements – W 24x162
- Permanent groundwater cutoff
- Prevent hydrostatic uplift from a confined aquifer



Composite Soil Boring

BART – Warm Spring Extension
Partial Cutoff w/ Jet Grouted Base Slab
(2010-2011)

Exposed Soil-Cement

Waterproofing Applied

318,000 sf

San Pablo Dam, CA
(2007-2009)

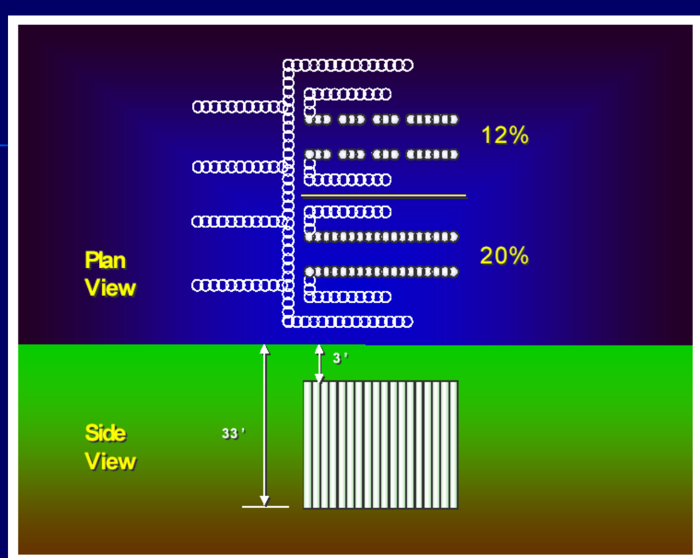
LPV 109, New Orleans, LA
(2011)

Deep Mixing in New Orleans

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

Phase 1: Test 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).



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

Extraction of Column

Cell A fully loaded with 1 million kilograms of steel
(177 kN/m^2)

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, <u>and hopefully deep mixing will play an integral role</u>" (underline added).

Four TFG Projects (2006)

- Orleans Avenue Interim Closure Structure
- 17th Street Canal Interim Closure Structure
- Homeplace Levee Enlargement
- Gainard Woods Pump Station
- IHNC Deep Mixed Cutoff Wall (proposed, not built)

(Full details of mix designs, quantities, etc., are provided in the paper.)

Phase 2: Wet Mixing at Orleans Avenue

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

Dry Mixing
Homeplace Levee Enlargement (P24)

Dry Mixing
IHNC Floodwall

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

Phase 3: LPV 111 (2010-2011)

- Lake Pontchartrain and Vicinity Hurricane Protection System Contract 111 extended 9 km along 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 cost effective solution for foundation soils.
- Details covered in subsequent four related papers in this session.

LPV 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	*SHTON*	457,693
TOTAL TRUCK-LOADS (approx.)	*N*	17,500
TOTAL WATER USED	*GAL*	136,832,094
TOTAL CORING	*N*	506
TOTAL UCS TESTS	*N*	5,082
OVERALL AVERAGE UCS (required = 100 psi)	*PSI*	292
TOTAL FAILING UCS TESTS (<100 psi)	*N*	66
TOTAL FAILING UCS TESTS (10% allowed)	*%*	1.30%

Observations

- The Phase 1 USACE Test Program was, in retrospect, an extraordinarily timely, 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.

Conference Papers on LPV 111 (New Orleans, February 2012)

- Overview of Deep Mixing at Levee LPV 111, New Orleans, LA (Cali et al. (2012)
- Deep Mixing Design for Raising Levee Section, LPV 111, New Orleans, LA (Cooling et al. 2012)
- Construction Operations and Quality Control of Deep Mixing at Levee LPV 111 in New Orleans (Schmutzler et al. 2012)
- Bench-Scale testing and Quality Control/Quality Assurance Testing for Deep Mixing at Levee LPV 111 (Bertero et al. 2012)
- Use of Deep Mixing Return Material for Levee Construction at LPV 111 (Druss et al. 2012).

3. NEW ARRIVALS

Original Classification of Deep Mixing Methods (FHWA 2000)

- DM Methods
  - Fluid Grouts
    - Rotary
      - Shaft Mix — e.g., DSM, Trevimix, Schnabel
      - End Mix — e.g., SSM, SCC, Mectool, Hayward Baker
    - Rotary and Jet Grout
      - End Mix — e.g., GeoJet
  - Dry Materials
    - Rotary
      - End Mix — e.g., Lime-Cement Columns

Levels: Nature of Material Placed; Mixing/Blending Principle; Mixing/Blending Location; U.S. Examples

Updated DMM Classification (Bruce, 2010)

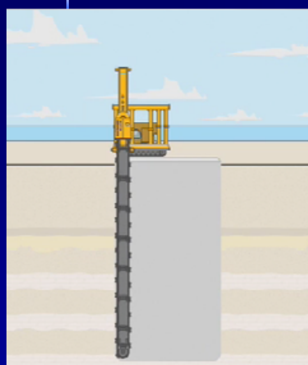
- Rotary Vertical Axis
  - Wet End Mix
  - Wet Shaft Mix
  - Dry End Mix
- Jet Assisted Vertical Axis (Turbojet)

"Conventional"

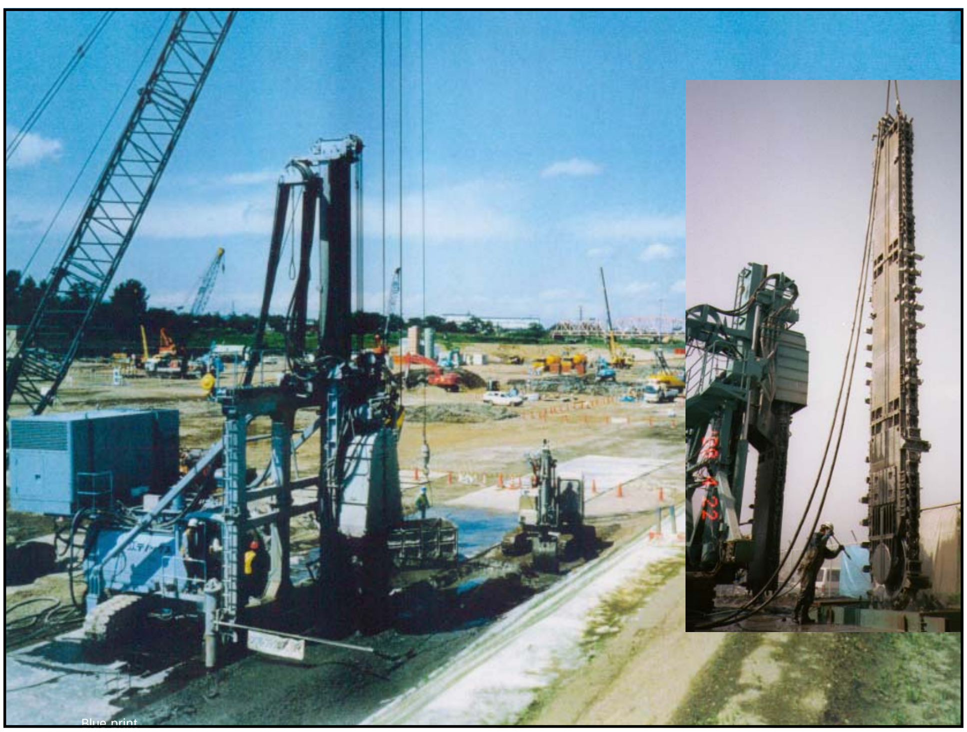
- Trench Cutting and Mixing (TRD)

- Horizontal Axis Cutting and Mixing
  - Low Pressure (CSM)
  - High Pressure (CT Jet)

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.




Blades vary according to soil condition
A
B
C
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).

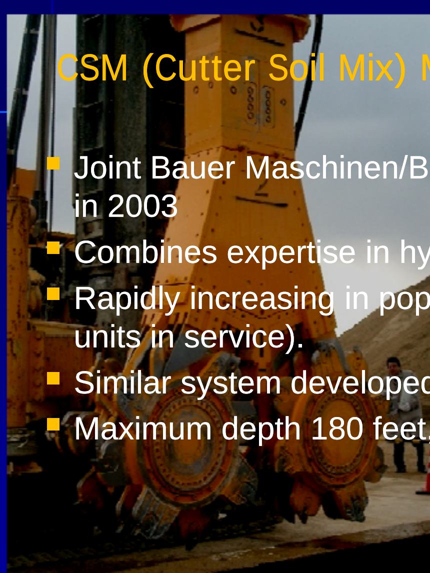
- High degree of real time QA/QC.
- Adjustability of cutting teeth.
- Can operate in low headroom (20 ft).
- Very quite, modest size support equipment, “clean” operation.

TRD

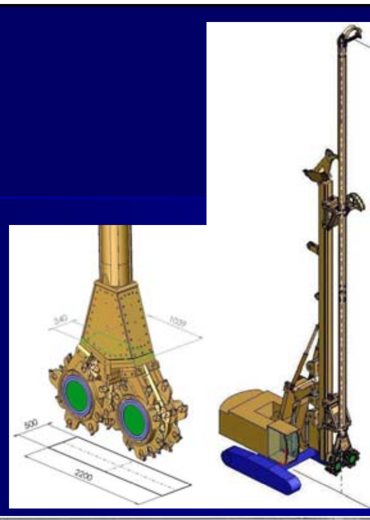
Potential Drawbacks

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

CSM (Cutter Soil Mix) Method



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



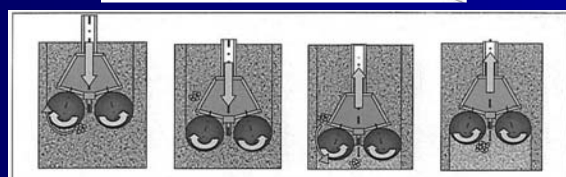
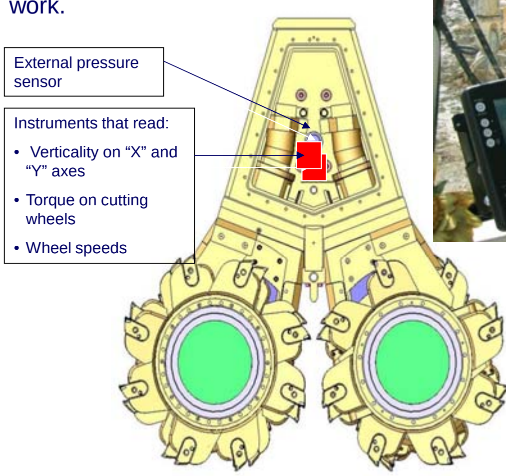


Diagram showing the CSM process

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.



BAUER B-Tronic system


WILLIAMS
EARTH SCIENCES


CSM at Brunswick, GA
(~2010)

CSM at Watson Lake, BC
Alaska Highway (~2010)

CSM

Particular Advantages

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

CSM

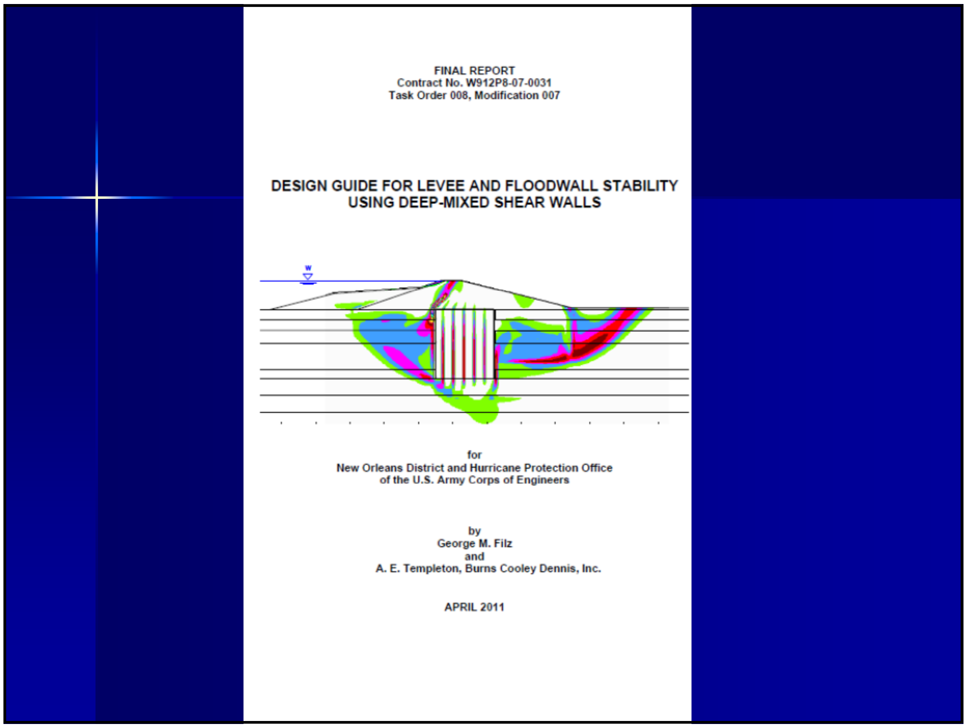
Potential Drawbacks

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

4. STUDIES, RESEARCHES AND CONFERENCES

Studies and Researches

- FHWA State of Practice (3 Volumes) 2000-2001
- National Deep Mixing Program (early 2000's)
- National Deep Mixing Program (2007-present)
- Design Guide (USACE) (2011)
- Papers in DFI and ADSC regular publications
- Chapter 3 in new textbook "Specialty Construction Techniques for Dam and Levee Remediation" (2012)



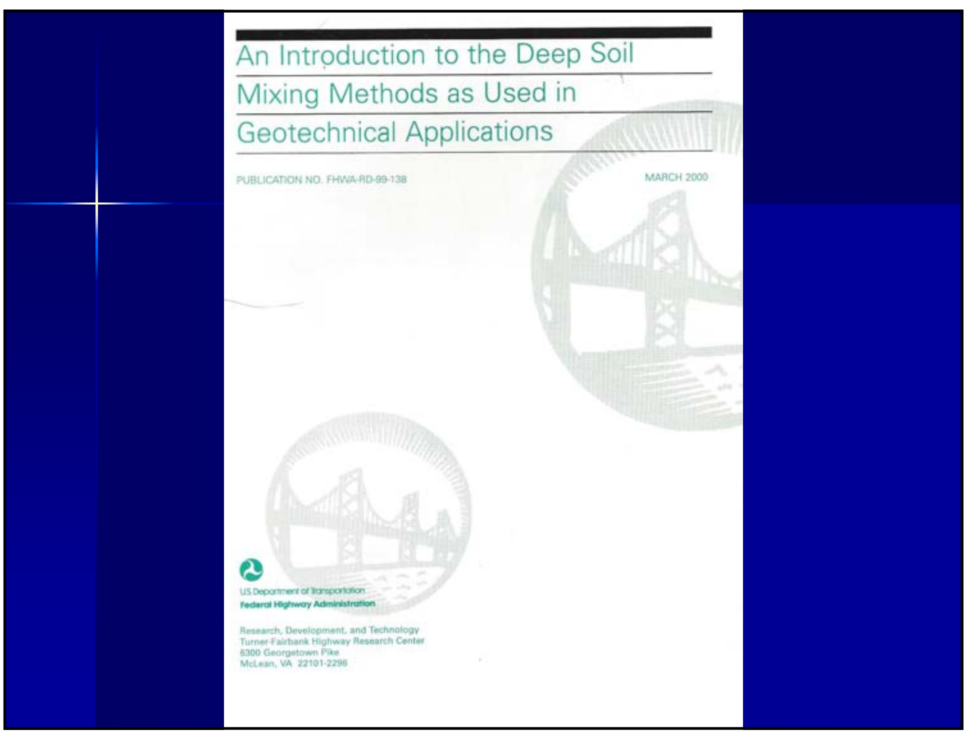
FINAL REPORT
Contract No. W912P8-07-0031
Task Order 008, Modification 007

DESIGN GUIDE FOR LEVEE AND FLOODWALL STABILITY USING DEEP-MIXED SHEAR WALLS

for
New Orleans District and Hurricane Protection Office
of the U.S. Army Corps of Engineers

by
George M. Filz
and
A. E. Templeton, Burns Cooley Dennis, Inc.

APRIL 2011



An Introduction to the Deep Soil Mixing Methods as Used in Geotechnical Applications

PUBLICATION NO. FHWA-RD-99-138

MARCH 2000

US Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

4. STUDIES, RESEARCHES AND CONFERENCES

Conferences and Workshops

- Tokyo (1996, 2004)
- New Orleans (2003, 2012)
- Stockholm (2005)
- Okinawa (2009)
- DFI: several workshops (2008-2012) in New York, New Orleans and Oakland

5. FINAL REMARKS

- Technology is in rude health
- Conventional methods continue to be modified and updated
- New methods are being introduced
- Growing pool of excellent design and QA/QC texts and references
- Concern about lack of “big jobs” after HHD, Louisiana and Sacramento