

The History and Technology of the Deep Mixing Methods in North America



Dr. Donald A. Bruce, Geosystems, L.P.

GEOSYSTEMS, L.P.
724-942-0570



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
	<u>Key Dates</u> 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

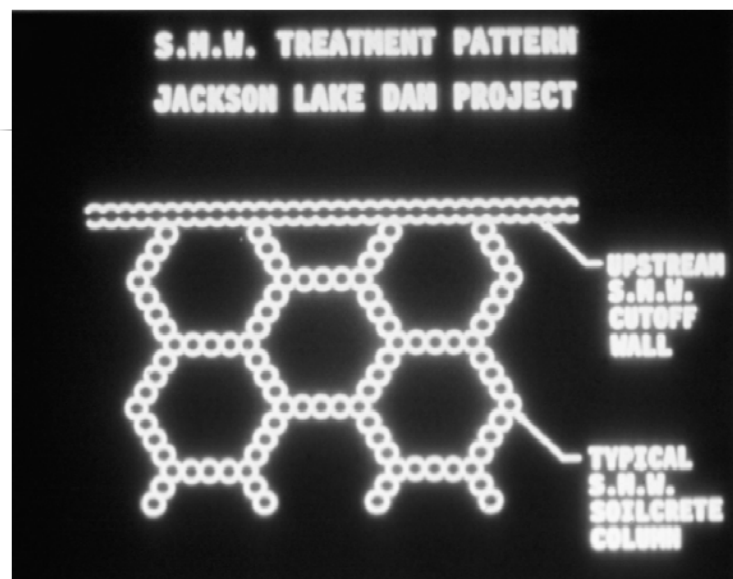
	1. IN THE BEGINNING (continued)
	<u>Key Dates</u> 2000-2003 Desk, Bench and Field Tests, New Orleans 2001-2005 National Deep Mixing Research Program (States Funded) 2003 International Conference in New Orleans 2005 Katrina and Rita 2006 Task Force Guardian 2006 CSM brought to Canada and TRD brought to 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 to be inferred
- Thanks for all the contractors who sent images – including: Fudo, GeoSolutions/GeoCon, Golder Construction; Hayward Baker; Malcolm; Nicholson; Raito; Schnabel Foundations; TREVICOS; Underpinning and Foundations
- Projects and developments outside the U.S. are not referred to



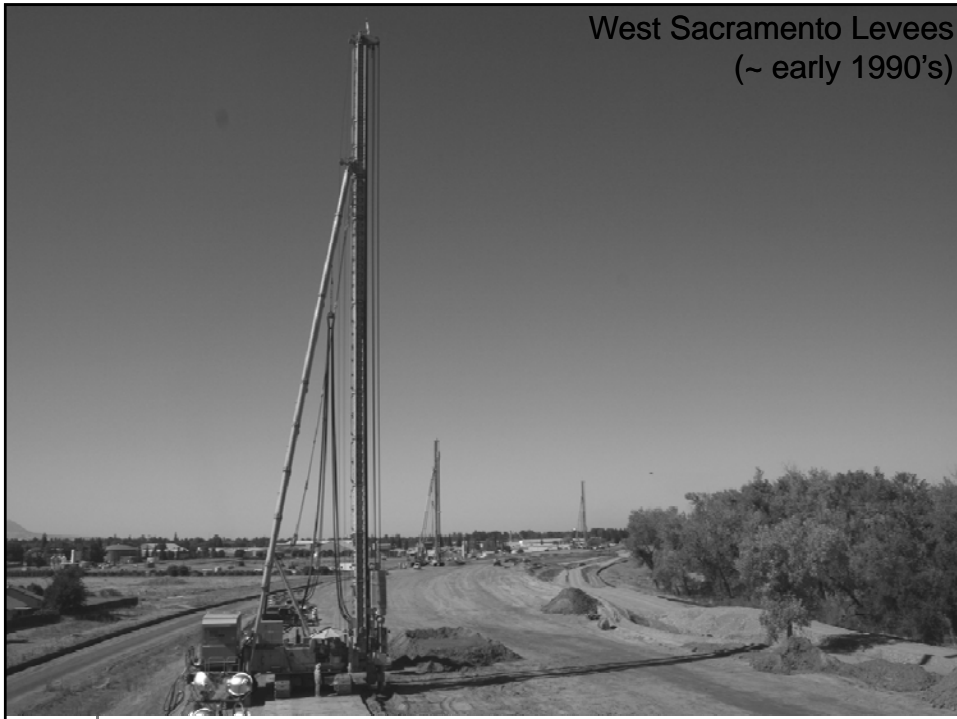


First Multiple Auger Drill
Manufactured in U.S.
Hialeah, FL (~1988)





First Large-Scale SSM Project
(~1989)



West Sacramento Levees
(~ early 1990's)



CO7A1, Boston, MA
(1992-1994)





Lake Parkway, Milwaukee



225,000 sf 1996

First Dry Mixing Project
Queens, NY (1996)



Pascagoola, MS
(~1998)

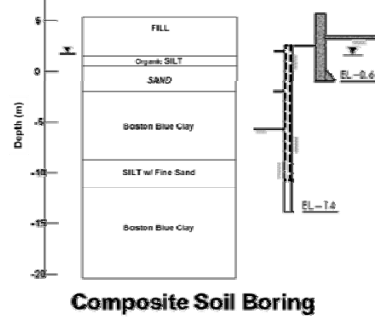
One of the first DMM
projects in the Mississippi
Deltaic Deposits



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



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)




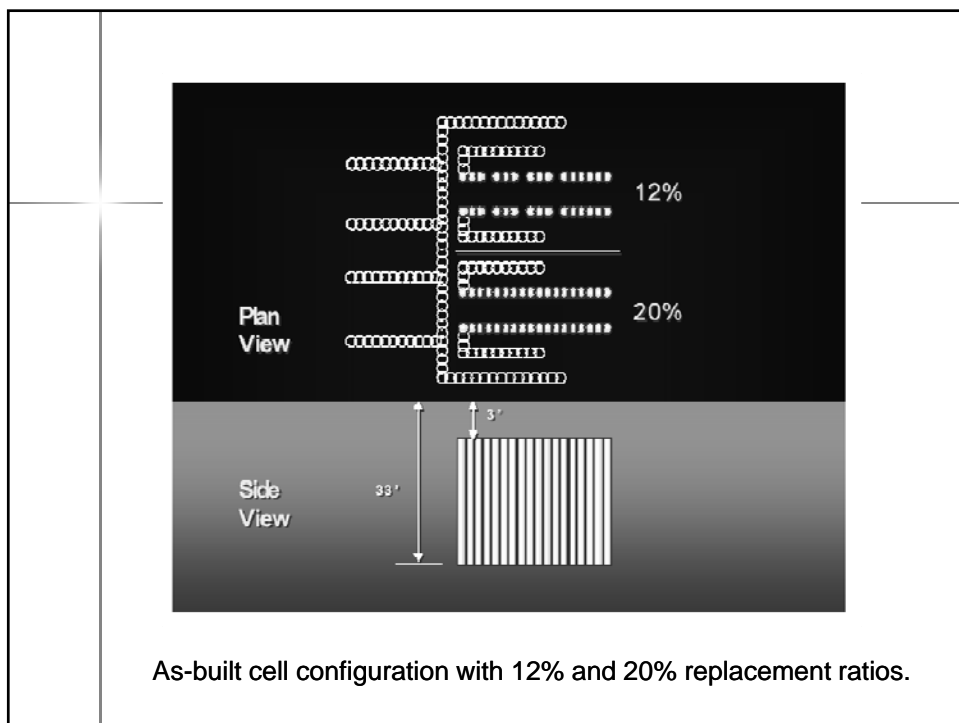
LPV 109, New Orleans, LA
(2011)





	<h3>Deep Mixing in New Orleans</h3> <ol style="list-style-type: none"> 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)

	<h2>Phase 1: Test Program (2001)</h2>	
	<ul style="list-style-type: none"> • No prior history of DMM in the area despite very poor soils and huge levee infrastructure. • Usual reasons can be cited: <ul style="list-style-type: none"> — 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: <ul style="list-style-type: none"> — Desk study (feasibility in local soils). — Lab study (properties of mixed soils). — Full-scale field test (performance of columns at different replacement ratios). 	







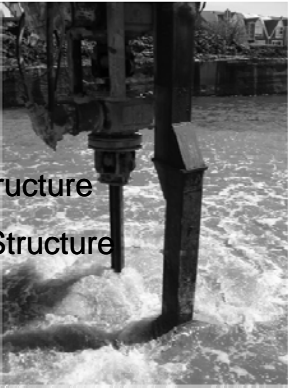
Extraction of Column




Cell A fully loaded with 1 million kilograms of steel
(177 kN/m²)

	<h2>Outcome of Test Program</h2>
	<p>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.”</p> 

	<h2>Phase 2: Task Force Guardian and Beyond (2006-2010)</h2>
	<ul style="list-style-type: none"> • 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: <p>“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).</p> 

	<p>Four TFG Projects (2006)</p>	
	<ul style="list-style-type: none"> • 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) <p>(Full details of mix designs, quantities, etc., are provided in the paper.)</p>	

	<p>Phase 2: Wet Mixing at Orleans Avenue</p>	

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



Dry Mixing
Homeplace Levee Enlargement (P24)

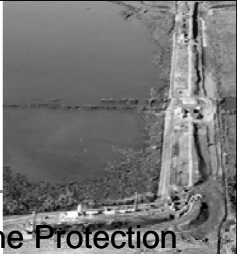


Dry Mixing IHNC Floodwall




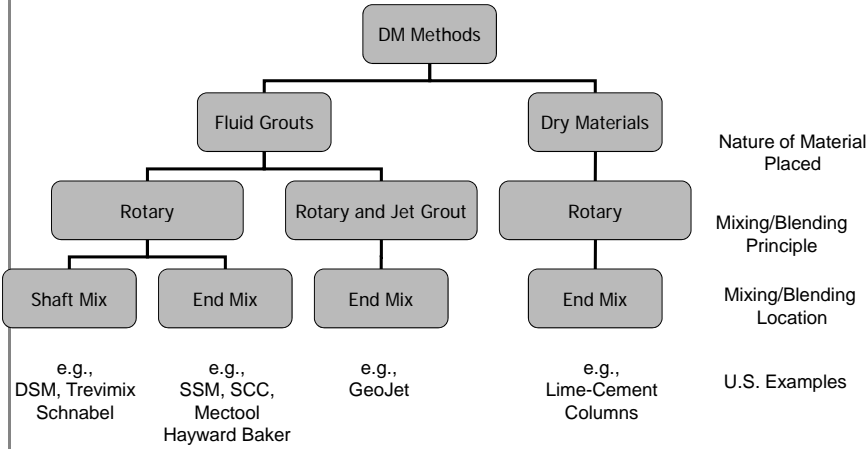
Phase 2 Projects (Task Force Guardian to 2010)

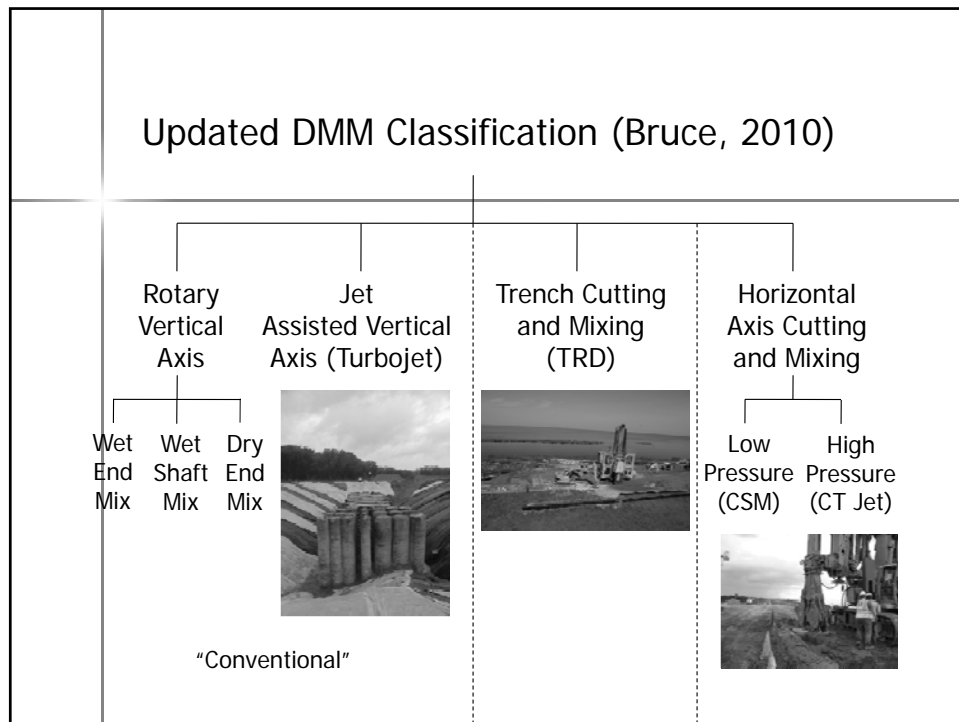
PROJECT NAME	START DATE	APPLICATION	DETAILS	CONTRACTOR
17 th Street Canal	2006	Overwater mixing for interim canal closure structure in cellular grid pattern.	2,200 DRE columns, 800 mm diameter, 18 m deep	Hayward Baker, Inc.
Orleans Avenue Canal	2006	Overwater mixing for interim canal closure in rows and "hammer heads."	Triple axis WRE in rows and square grid. About 6,000 cubic meters of treated soils.	Raito, Inc.
Gainard Woods Pump Station	2006	Emergency levee repair.	Triple axis WRE.	Raito, Inc.
P24 Plaquemines Parish	2006	Foundation stabilization with rows of columns for levee raising.	4,600 DRE columns, 800 mm diameter, 13 m deep	Hayward Baker, Inc.
Westwego Interim Phase 1	2008	Flood wall replacement.	Triple axis WRE.	Raito, Inc.
Westminster Pump Station	2008	Ground improvement for new structure in cellular grid.	DRE columns, 800 mm diameter	Hayward Baker, Inc.
Westwego Pump Station Phase 2	2009	T-wall foundation stabilization.	Triple axis WRE.	Raito, Inc.
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.

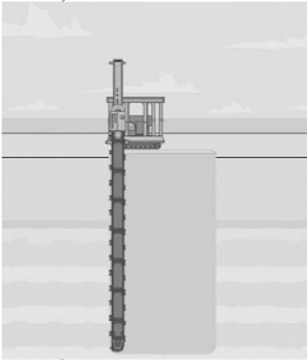
	Phase 3: LPV 111 (2010-2011)	
	<ul style="list-style-type: none"> • Lake Pontchartrain and Vicinity Hurricane Protection System Contract 111 extended 9 km along north bank of the Gulf Intracoastal Waterway (GIWW). • Bordered on both sides by the Bayou Sauvage National Wildlife Refuge. • Levee raising 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. 	

	<h3 style="text-align: center;"><u>LPV Production</u></h3> <p style="text-align: center;">Some numbers....</p>	
	PRODUCTION START DATE	1/14/2010
	PRODUCTION COMPLETION DATE	3/18/2011
	TOTAL CALENDAR DAYS	<i>N</i> 439.00
	TOTAL MONTHS	<i>N</i> 14.43
	TOTAL SHIFTS WORKED (as of 3/18/2011)	<i>N</i> 3,309
	TOTAL MANHOURS (as of 3/18/2011)	<i>N</i> 502,817
	TOTAL DMM ELEMENT INSTALLED	<i>N</i> 18,028
	TOTAL VOLUME TREATED	<i>CY</i> 1,681,579
	TOTAL CEMENT USED	<i>SHTON</i> 457,693
	TOTAL TRUCK-LOADS (approx.)	<i>N</i> 17,500
	TOTAL WATER USED	<i>GAL</i> 136,832,094
	TOTAL CORING	<i>N</i> 506
	TOTAL UCS TESTS	<i>N</i> 5,082
	OVERALL AVERAGE UCS (required = 100 psi)	<i>PSI</i> 292
	TOTAL FAILING UCS TESTS (<100 psi)	<i>N</i> 66
	TOTAL FAILING UCS TESTS (10% allowed)	<i>%</i> 1.30%

	<div> <div>Observations</div>  </div>
	<ul style="list-style-type: none"> • 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.

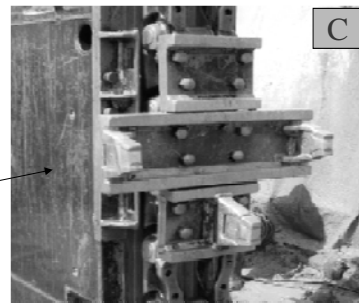
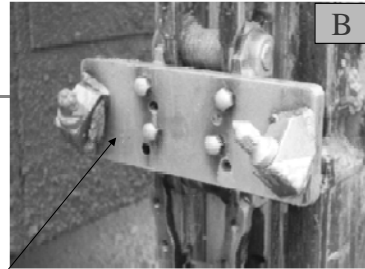
	<div>3. NEW ARRIVALS</div>
	<div>Original Classification of Deep Mixing Methods (FHWA 2000)</div>  <pre> graph TD DM[DM Methods] --> FG[Fluid Grouts] DM --> DMat[Dry Materials] FG --> R1[Rotary] FG --> RJG[Rotary and Jet Grout] R1 --> SM[Shaft Mix] R1 --> EM1[End Mix] RJG --> EM2[End Mix] DMat --> R2[Rotary] R2 --> EM3[End Mix] </pre> <div> <div>e.g., DSM, Trevimix Schnabel</div> <div>e.g., SSM, SCC, Mectool Hayward Baker</div> <div>e.g., GeoJet</div> <div>e.g., Lime-Cement Columns</div> <div>U.S. Examples</div> </div>



TRD (<u>T</u> rench <u>R</u> e-Mixing and Cutting <u>D</u> eep Wall) Method	
	<ul style="list-style-type: none"> ■ 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) Standard blade
- B) Rounding blade for hard clay
- C) Long-nosed blade for boulder



	<p>TRD</p> <p><u>Particular Advantages</u></p>
	<ul style="list-style-type: none"> ▪ Continuous, homogeneous, joint-free wall in all soil and many rock conditions. ▪ Productivities can be extremely high (instantaneous production > 400 sft/hour). <div data-bbox="467 630 732 886" data-label="Image"> </div> <ul style="list-style-type: none"> ▪ 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.

	<p>TRD</p> <p><u>Potential Drawbacks</u></p>
	<ul style="list-style-type: none"> ▪ Sharp alignment changes. ▪ Especially hard/massive/abrasive rock. ▪ Trapping of “post” in soilcrete or “refusal” on boulders/rock. ▪ Only one (excellent) contractor! <div data-bbox="667 1556 1015 1818" data-label="Image"> </div>

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, 28-47 inches wide.

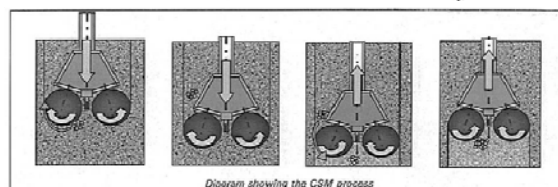
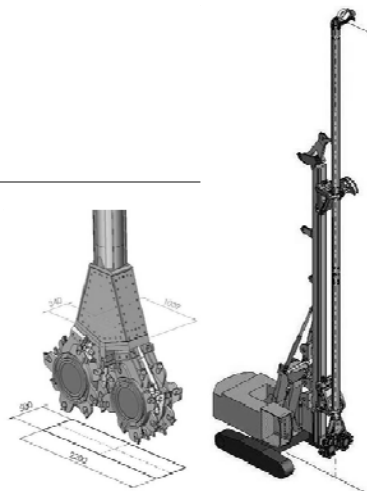
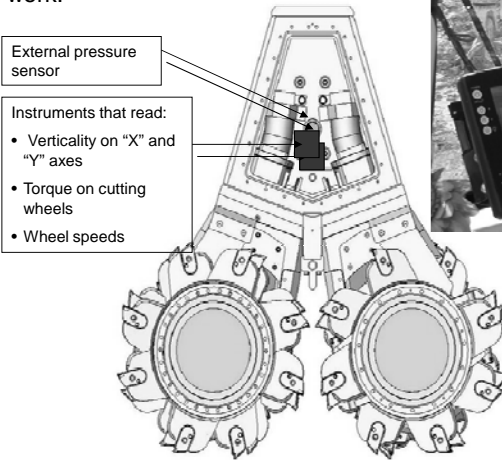


Diagram showing the CSM process

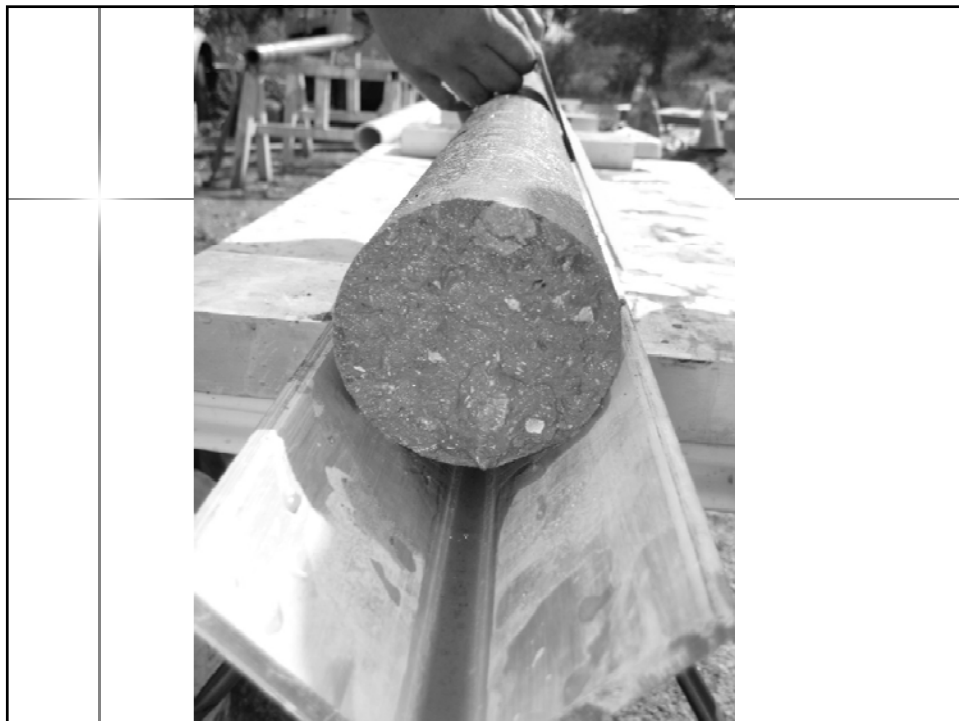
CSM Quality Control Systems

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


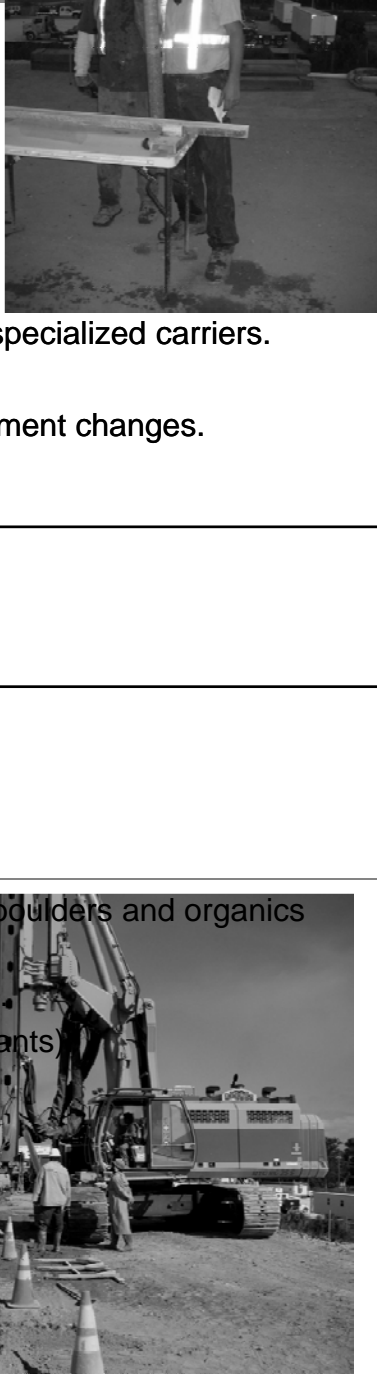





CSM at Brunswick, GA
(~2010)



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

	<p>CSM</p> <p><u>Particular Advantages</u></p>	
	<ul style="list-style-type: none"> ▪ 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. 	

	<p>CSM</p> <p><u>Potential Drawbacks</u></p>	
	<ul style="list-style-type: none"> • 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

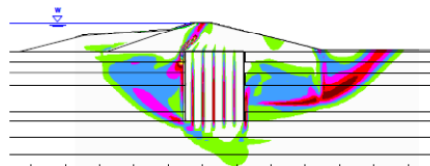
Studies and Researches

- 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. W512P8-07-0031
Task Order 008, Modification 007

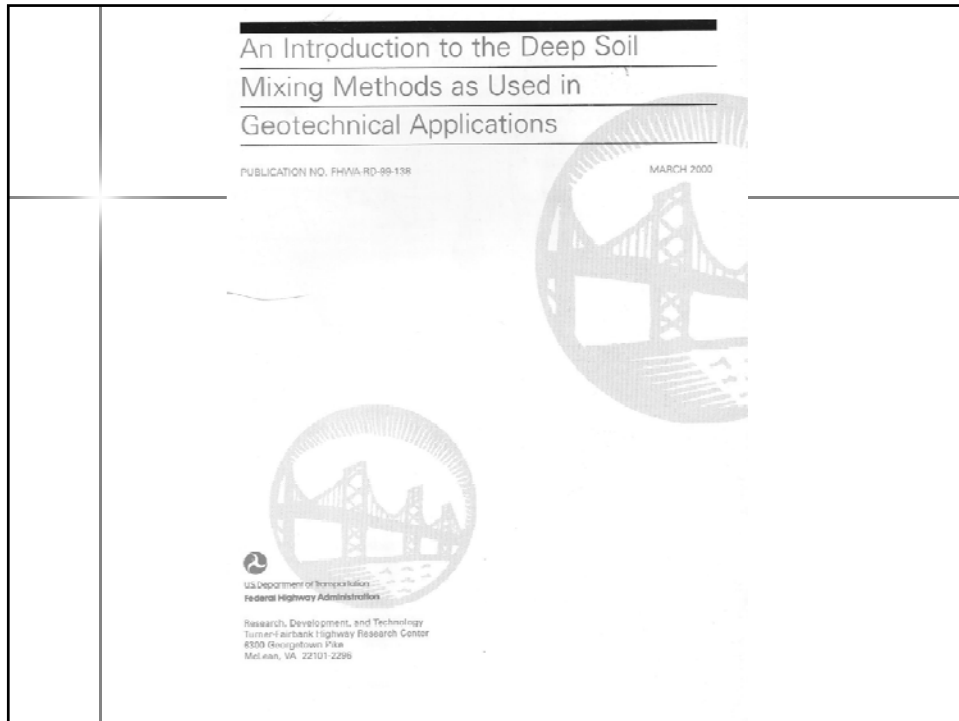
DESIGN GUIDE FOR LEVEE AND FLOODWALL STABILITY USING DEEP-MIXED SHEAR WALLS



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



4. STUDIES, RESEARCHES AND CONFERENCES

Conferences and Workshops



- Tokyo (1996, 2004)
- New Orleans (2003, 2012)
- Stockholm (2005)
- Okinawa (2009)
- DFI: several workshops (2008-2013) in New York, New Orleans, Oakland and San Francisco

5. FINAL REMARKS

- Technology in the U.S. 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
- Lessons learned, and evolution of technology are equally applicable to projects in this region also

