Deep Soil Mixing
For Underground Construction

Alan R. Ringen, P.E.

JAFEC USA, Inc.
GEOTECHNICAL CONSTRUCTORS

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Presentation Outline

• Introduction
• Soil mixing equipment
• Installation procedure
• QC/QA
• Engineering properties of soil-cement
• Applications
Deep Soil Mixing is the in situ mechanical mixing of a cement grout with soil to produce an a variety of engineered geometries and soil properties to suit the application.
Deep Soil Mixing (DMM, CDM, CDSM, DSM)

- Deep Soil Mixing (DSM) is an in situ soil treatment technology whereby native soils are blended in situ with cementitious materials, typically Portland cement.

- Geotechnical - The soil-cement mixture created by DSM has increased strength, lower permeability and reduced compressibility.

- Environmental – In situ solidification and stabilization; Groundwater barrier for containment.
Deep Soil Mixing Equipment
Two and three axis rigs & mixing tools
Deep Soil Mixing Equipment
Four & six axis rigs & mixing tools
Backhoe Mounted Soil Mixing Tool
Backhoe Mounted Soil Mixing Tool

Mixing tool for cohesive soil

Mixing tool for granular soil

Conventional mixing tool

WILL mixing tool
Soil Mixing Support Equipment

- Cement Silo
- Water Supply
- Generator
- Grout Pump
- Batch Plant
- Soil Mixing Rig
Soil Mixing Support Equipment

- Slurry batch plant
- QC system
Installation procedure

Positioning . Grout injection and soil mixing . Completion
Installation procedure - Alternating

Installation Procedure for Cutoff Wall and Shoring Wall Alternating, i.e. Primary & Secondary sequence

- **Step 1**: 1
- **Step 2**: 1, 3
- **Step 3**: 1, 3
- **Step 4**: 1, 2, 3

100% Column overlap for cutoff wall continuity
Installation procedure – Proceeding

Proceeding installation procedure for cutoff & shoring walls

Proceeding installation procedure for ground improvement cells

100% Column overlap for cutoff wall continuity

Partial overlap for ground improvement
Deep Soil Mixed Wall Plan

WIDE FLANGE SOLDIER BEAM

4'-0'' O.C. TYP.

SOIL-CEMENT COLUMN

36'' TYP.
Factors affecting soil-cement properties

- Soil type
- Mix design
- Mixing Energy
Quality control

Mix design
- Cement factor
- Water cement ratio

Mix energy
- Rotation speed
- Penetration & withdrawal rate
Quality control

Real-time QC monitoring & recording system

Mixing Tool Location, Amendment, & Treatment

Real-time monitoring & control on:

• **Depth / Location**
• **Penetration rate**
• **Mixing tool rotation rate**
• **Grout flow / dosage rate**
Core sampling & testing
Engineering properties
UCS vs curing age

Laboratory Mix Designs

Engineering properties

Tensile strength

Tensile strength, $\sigma_t$ (MN/m$^2$)

Unconfined compressive strength, $qu$ (MN/m$^2$)

Quick Lime

Cement

$\psi = 120\%_w$

$\psi = 100\%

$\psi = 140\%

$\psi = 200\%

$\sigma_t = 0.15 \times qu$

Deep Soil Mixing Applications

- Increased Bearing Capacity
- Settlement Reduction
- Support of Excavation
- Liquefaction Mitigation
- Seepage Control
DSM for Tunnel Construction

- DSM walls and slabs for excavation support and groundwater control

- DSM for support of launching & receiving of TBM machine

- DSM ground improvement outside launching & receiving shafts
DSM Applications

Block

Cell
DSM Applications

Shear wall & columns

Ring
DSM Product and Applications

Exposed soil-cement produced by WILL Method

Core Samples

Ground improvement for tunnel shaft

Ground improvement adjacent to structures
Top of soil-cement elements

Top of exposed DSM elements
DSM Foundation Support
Infrastructure & industrial facility

Soil-cement cells for
- Bearing capacity
- Settlement control
- Liquefaction mitigation
Deep Soil Mixed Shaft Wall
Excavation support & groundwater control

Cypress Freeway Replacement Project, Oakland, CA
Boston Central Artery/Tunnel (CA/T) Mass DOT

1-1 Bird Island Flats (C07A1) – DSM was used to install excavation support wall for construction of cut-and-cover tunnel.

1-2 Fort Point Channel Crossing (C09A7) – DSM was used for ground improvement for the construction of cut-and-cover tunnel and boat sections.

- **I-93** – To expand existing six-lane highway to an eight-to-ten-lane underground expressway, constructed directly beneath existing roadways, buildings, and subways in downtown Boston.
- **I-90** – To extend I-90 from its existing terminus south of downtown Boston to Logan Airport through the Ted Williams Tunnel under Boston Harbor and a tunnel beneath the Fort Point Channel.

*Courtesy of Dr. T.D. O’Rourke and A.J. McGinn, Cornell University; Massachusetts Turnpike Authority; Federal Highway Administration and Bechtel/Parsons Brinckerhoff (Illustration)*
Installation of DSM (SMW) Wall at Bird Island Flats

Source: 1) Taki and Yang 1991; 2) Lessons Learned for Ground Movements and Soil Stabilization from the Boston Central Artery T. D. O'Rourke, M.ASCE1; and A. J. McGinn, M.ASCE2, 2005 Ralph B. Peck Award Lecture
Subsurface profiles at BIF

East Wall

West Wall

Source: Lessons Learned for Ground Movements and Soil Stabilization from the Boston Central Artery
T. D. O’Rourke, M.ASCE1; and A. J. McGinn, M.ASCE2, 2005 Ralph B. Peck Award Lecture
Base stabilization scheme

Source: Lessons Learned for Ground Movements and Soil Stabilization from the Boston Central Artery
T. D. O'Rourke, M.ASCE1; and A. J. McGinn, M.ASCE2, 2005 Ralph B. Peck Award Lecture
Cross section of BIF base stabilization

1. DSM buttress
2. Jet grouting
3. Final subgrade

Source: Lessons Learned for Ground Movements and Soil Stabilization from the Boston Central Artery
T. D. O’Rourke, M.ASCE; and A. J. McGinn, M.ASCE, 2005 Ralph B. Peck Award Lecture
The interchange at FPC consists of a network of tunnels and depressed roadway (boat section), viaducts and bridges requiring braced excavations as deep as 18.3 m in very soft to soft soils.
Subsurface conditions

- Fill
- Organic Deposits
- Sand/Inorganic silt
- Marine clay
- Glacial deposits

The critical junction between jacked and immersed tube tunnels is located in deep, low strength deposits of Marine Clay and Organics.

Representative construction conditions at Ramp D

Representative long-term conditions at Ramp D

Fort Point Channel DSM construction

Courtesy of Dr. T.D. O'Rourke and A.J. McGinn, Cornell University; Massachusetts Turnpike Authority; Federal Highway Administration and Bechtel/Parsons Brinckerhoff
DSM equipment at FPC site

Trans-Tokyo Bay Highway Project

Tunnel section – 9.6 km, 60m below sea bed
Bridge section – 4.4 km

Ukishima access
Kawasaki man-made island
Kisarazu man-made island

Kawasaki City

Trans-Tokyo Bay HWY = 15.1 km
Marine zone = 14.3 km

Courtesy of Dr. Masaki Kitazume, Tokyo Institute of Technology, Tokyo, Japan
Trans-Tokyo Bay Highway Project

Kawasaki man-made island

Kisarazu man-made island

Bridge section

Ukishima access

Kawasaki man-made island

Kisarazu man-made island

Bridge section

Courtesy of Dr. Masaki Kitazume, Tokyo Institute of Technology, Tokyo, Japan
Kisarazu man-made island

Ground improvement

- Deep soil mixing
- Sand compaction pile
- Premix soil-cement fill

Sheet pile cells for control of lateral deformation

Courtesy of Dr. Masaki Kitazume, Tokyo Institute of Technology, Tokyo, Japan
Kisarazu man-made island

Ukishima access

Shield tunnel advanced through soil-cement zones installed by premixing and deep soil mixing (DSM)

Deep mixing barge and mixing tool for seabed stabilization

Courtesy of Dr. Masaki Kitazume, Tokyo Institute of Technology, Tokyo, Japan
Kawasaki man-made island

Ground improvement

- Deep soil mixing
- Sand compaction pile

Sheet pile cells for control of lateral deformation

Courtesy of Dr. Masaki Kitazume, Tokyo Institute of Technology, Tokyo, Japan
Kawasaki Man-made island

Courtesy of Dr. Masaki Kitazume, Tokyo Institute of Technology, Tokyo, Japan
Questions?

Thank You!
Company history

- **JAFEC** (Japan Foundation Engineering Company, Ltd.) was established in 1953. The U.S. subsidiary, JAFEC USA, Inc., was established in 2009.

- Ground improvement technologies:
  - Deep soil mixing
  - Deep power compaction
  - Sand compaction piles / Stone columns
  - Grouting
Alan R. Ringen, P.E.
Senior Vice President
JAFEC USA, Inc.
2025 Gateway Place, Suite 180
San Jose, CA 95110
408.472.6175