Historical Evolution of Deep Mixing Method

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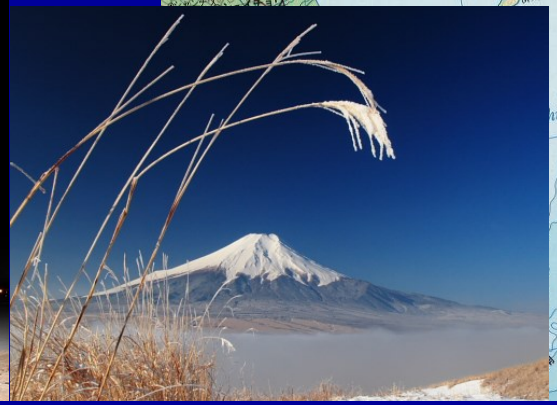
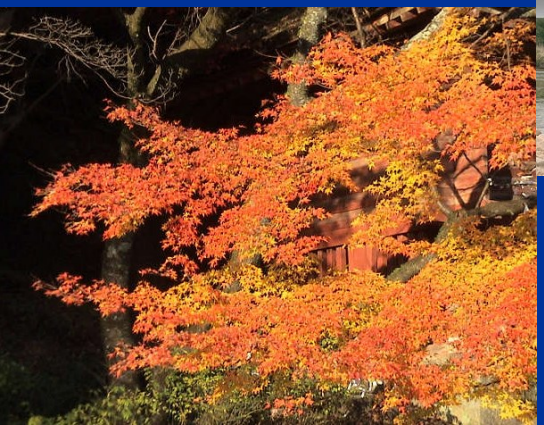
Quick look at Japan

Consists of four major islands and numerous smaller islands.

Total area is about 378,000 km2 but more than 70 % is mountains.

Population is nearly 120 million





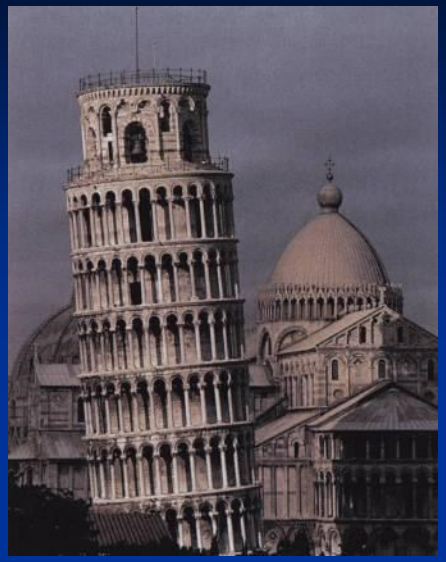
No natural resources. Full of disasters such as typhoon, earthquake, landslides, and volcanic eruption. Cities are on soft ground along the coast.

Introduction

why ground improvement
and
what is deep mixing

Engineering Issues that need Ground Improvement

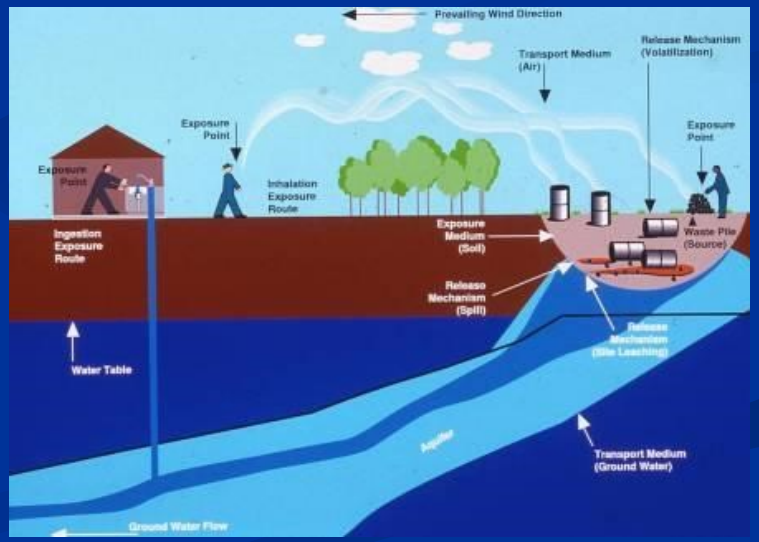
Failure of soft ground under test embankment KL



Consolidation Settlement

Liquefaction induced settlement of loose saturated sand

Failure of sea wall during backfilling



Risk to human health

Classification of GI Technologies available today

Replacement: Removal of poor soil material and replacement by good quality foreign materials such as gravel or sand.

Densification: Densification of loose granular soils most often by impact loading and vibration.

Consolidation/ Dewatering: Preconsolidation with or without vertical drains will increase strength and reduce future settlement.

Grouting: Placement of a pumpable material which will subsequently set or gel in pre-existing natural or artificial openings in the soil.

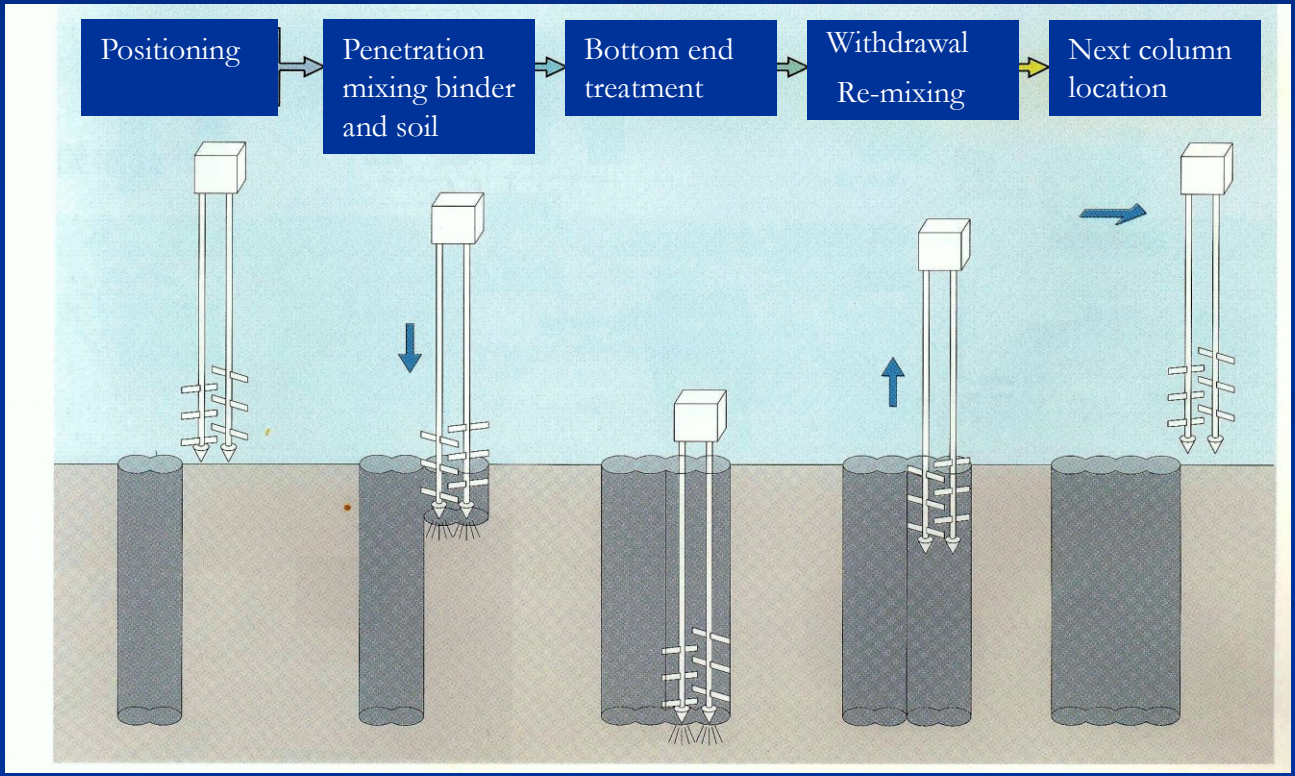
Admixture Stabilization: A technique of mixing chemical additives with soil to improve the consistency, strength, deformation characteristics, and permeability of the soil.

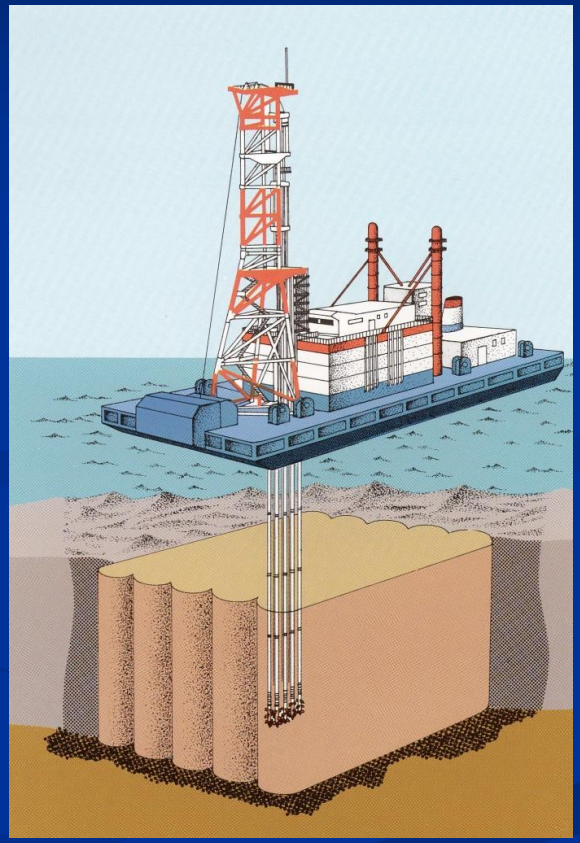
Thermal Techniques: Heating up to 300 to 1,000 ° C has been a usual practice for permanent soil improvement or freezing for temporary purpose.

Reinforcement: Creating in-situ a composite reinforced soil system by inserting

Deep Mixing Method:

A technique of mixing binders and soil in situ, to improve the consistency, strength, deformation characteristics, and permeability of the soil. As the improvement becomes possible by chemical reactions between clay and binder, constant supply of binder and sufficient in-situ mixing governs the quality of treated soil.

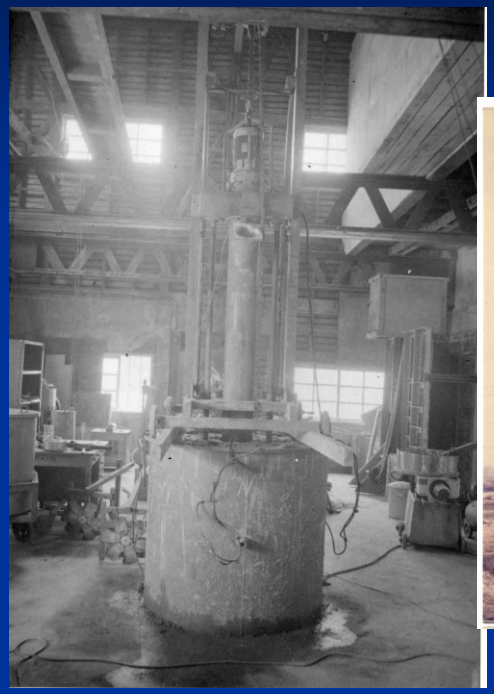




Although a variety of binder have been developed, most frequently used binders are lime and cement due to its availability and cost.

Development of deep mixing Execution System

R & D of deep mixing was started in 1968



1968 – 1970
Lab scale test

1970
Small scale field trial

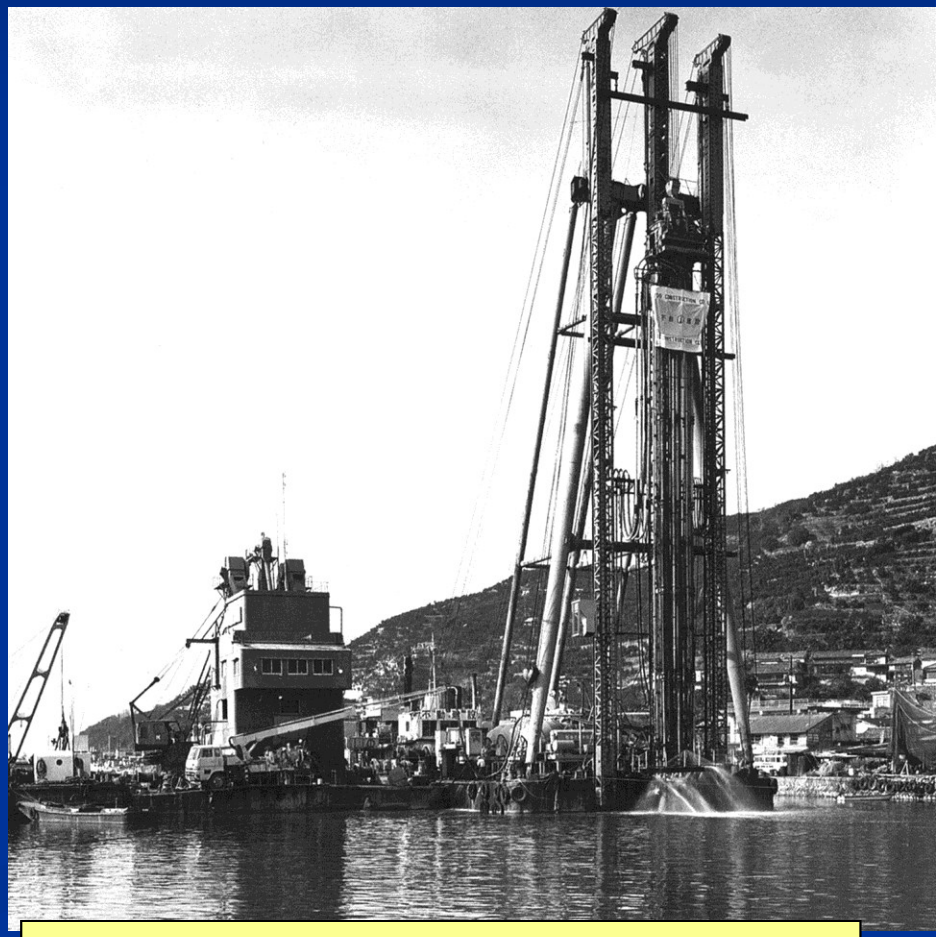
1971
First test on the sea

The binder used in the early stage was granular quick lime, the problem was the uniformity of treated soils.

Development of the wet method (cement mortar)

In the middle of 1970s, contractors started to improve the uniformity of treated soil. Cement mortar and cement-water slurry took over the granular lime soon.

DCM-1 barge in Tokyo Port in November 1976



CMC barge in operation at Yawatahama Port In August 1976

Current mixing tool of Wet method _ marine work

DMM barges working at
TTB project site

Two to eight mixing shafts

Development of wet method for on-land works

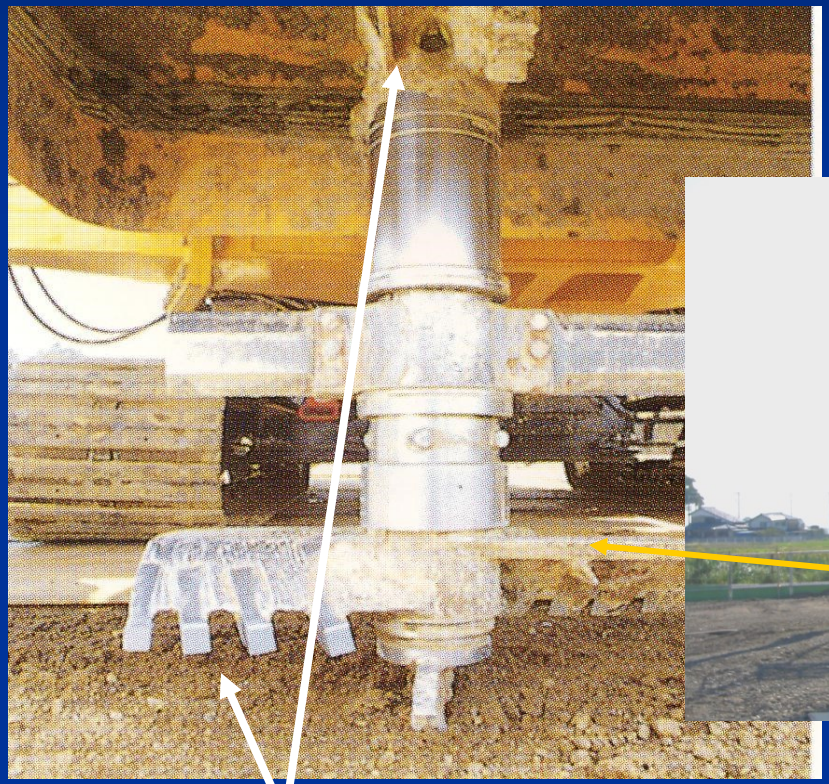
- The first application of the wet method for on-land work may be in March 1976 by cement mortar.
- The machines for on-land work also has taken over the tradition of marine machines.
- The machines have more than two mixing shafts with multiple blades at different levels.

Development of dry method for on-land works

- Public Works Research Institute and Japan Construction Method and Machinery Research Institute started R&D in 1978.
- The purpose was to develop lightweight machine capable of maneuvering on the soft ground and discharging dry powdered binder such as cement, lime, gypsum and slag.
- The first application was in May 1981. Several problems such as constant feed of binder, retrieval of air, uniformity of mixture were solved gradually until 1985.

Mixing tool for Dry method

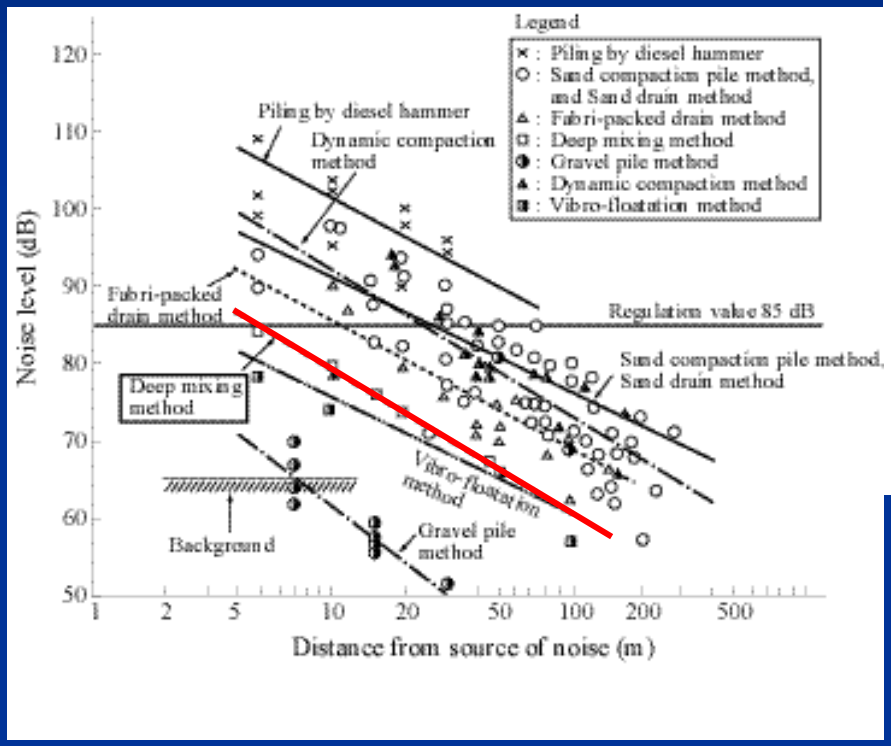
Single or two shafts machine

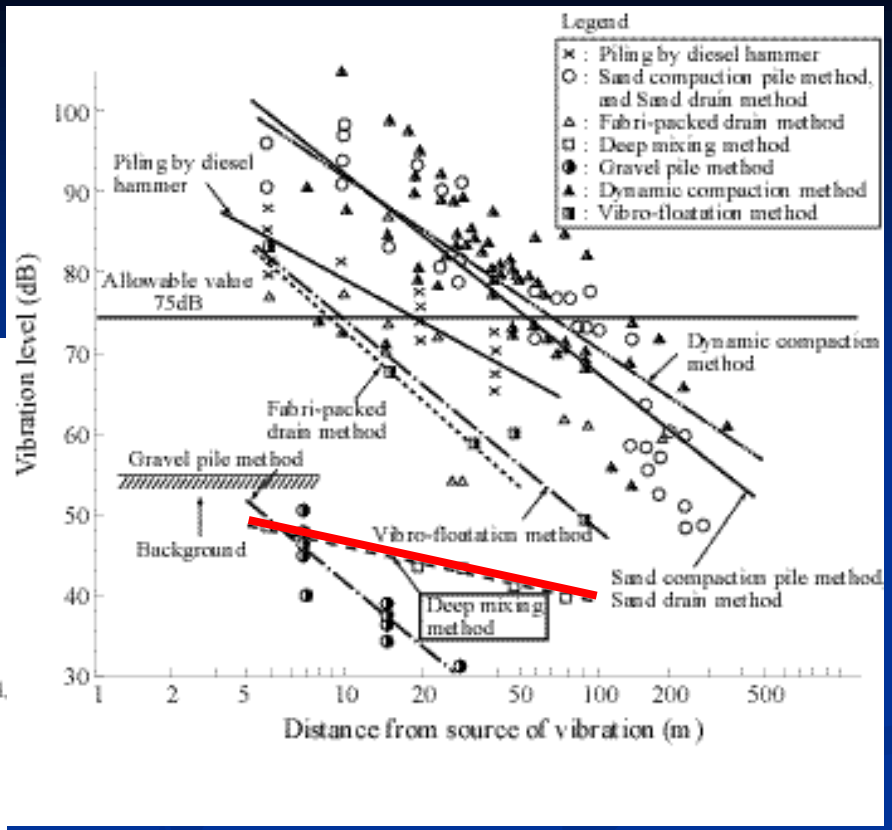


Two mixing blades at different levels

R&D was initiated by the Government at PHRI

- R&D was started in 1968 at the Port and Harbour Research Institute. The primary purpose of development in Japan was to cope with the needs of rapid construction especially on soft compressible ground, which was the reflection of the miraculous economic growth of Japan at those days.
- When developed, the method proved to have further merits over the other ground improvement methods, such as lower noise and lower vibration, smaller impact on the nearby existing structures, relative ease in creating the soil mass with any arbitrary shape, effective irrespective to the soil types etc.
- Due to these merits, the method found additional applications such as renovation and rehabilitation of old infrastructures especially in the urban area, liquefaction countermeasure, and remediation of contaminated sites etc.
- Deep Mixing is often classified into two; the wet method and the dry method. The former is called CDM and the latter DJM.





Smaller Noise and Vibration

Recent developments addressed to improving work efficiency _ wet method for on-land work

CDM Land4 with four mixing shafts

CDM Colum21 with diameter 1.5 –1.6 m required sophisticated mixing tool.

Recent Developments to cope with special requirements

Deep mixing operation causes the horizontal displacement of the soft ground and affects the nearby structures.

Hirai et al. 1996, IS-Tokyo

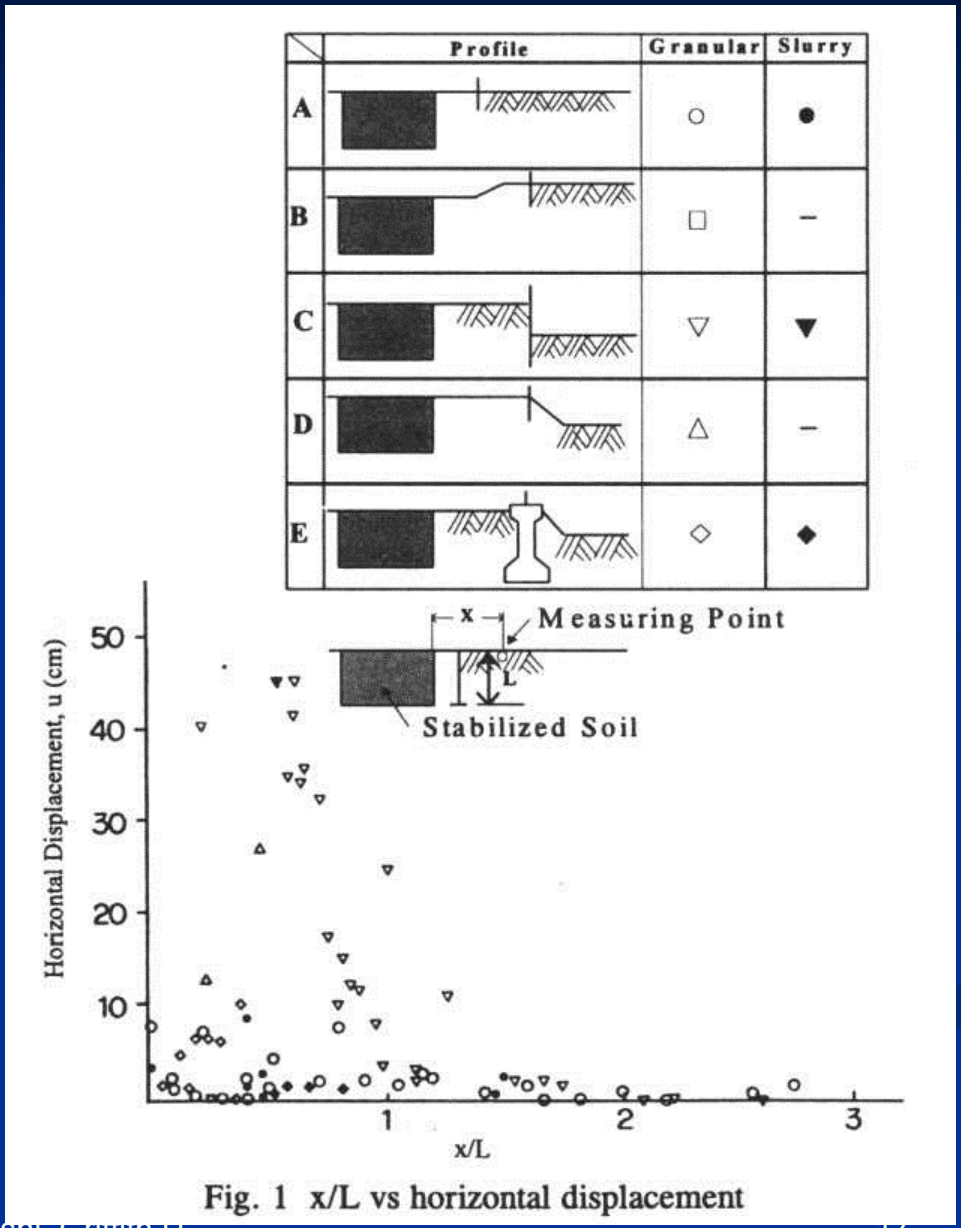
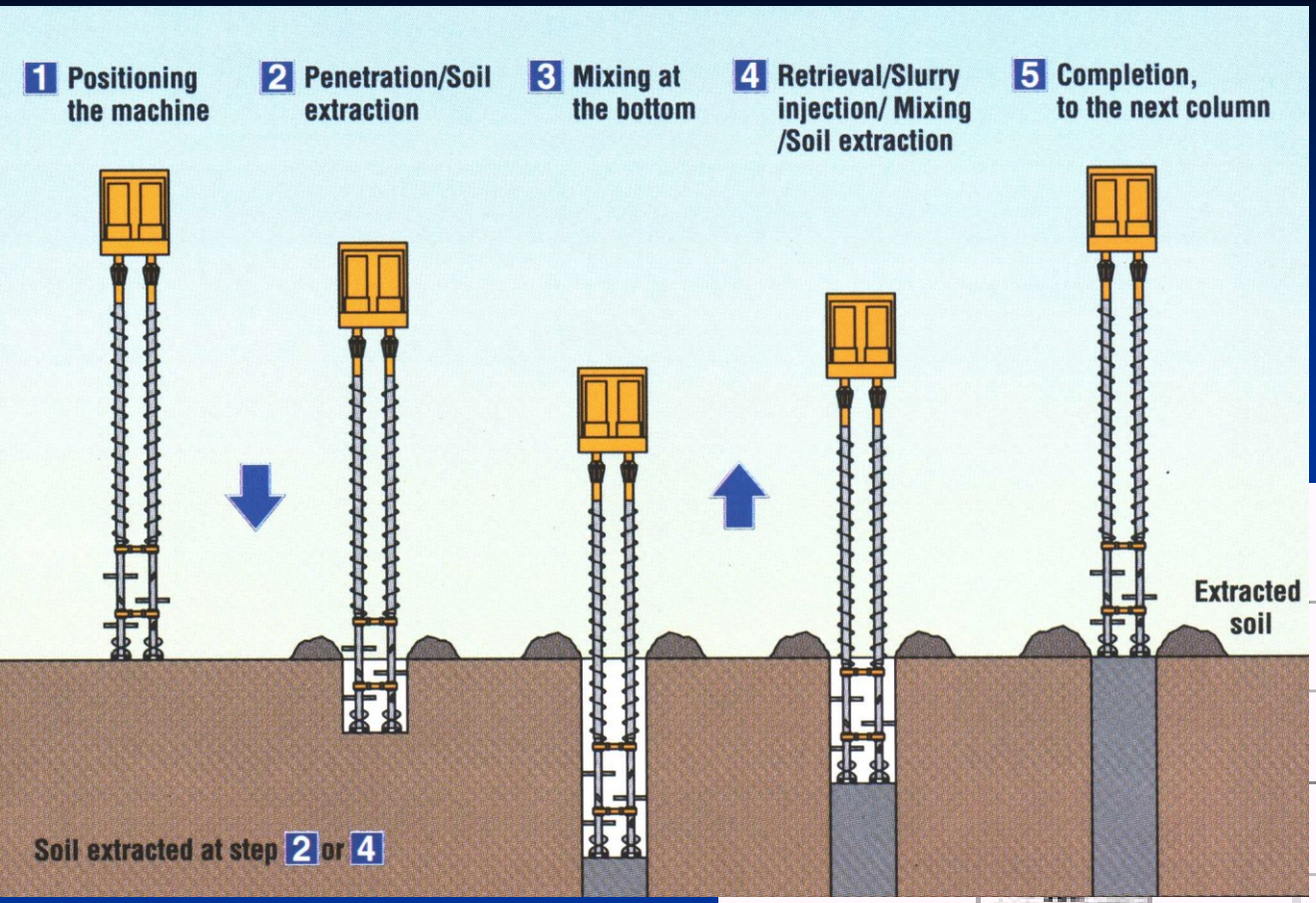
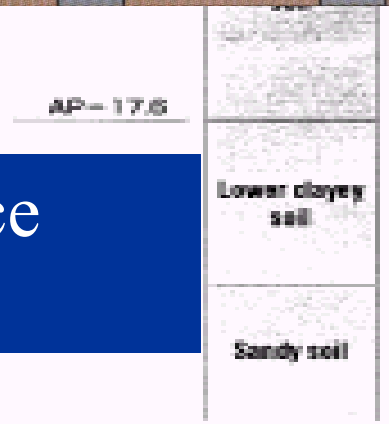
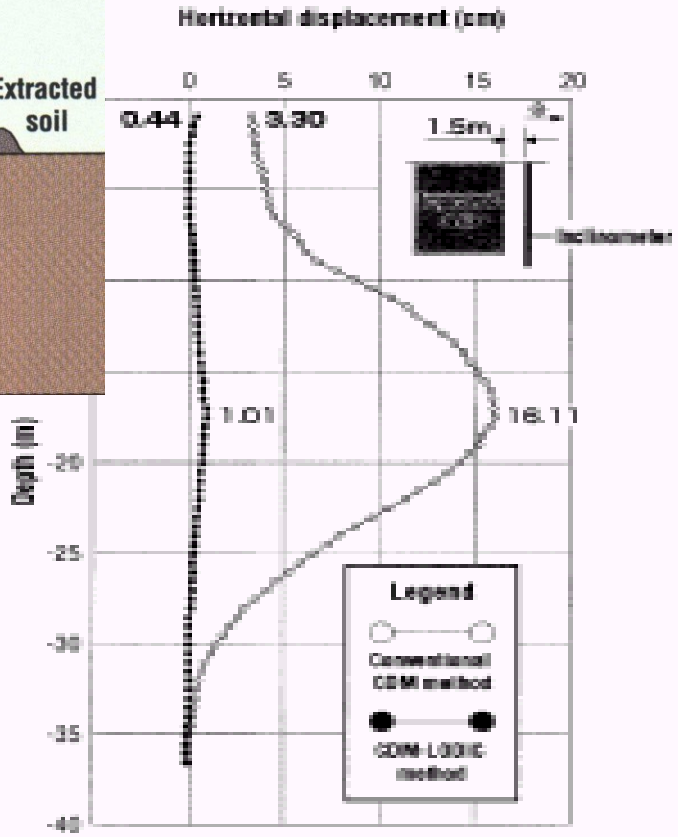


Fig. 1 x/L vs horizontal displacement







LODIC system to reduce ground displacement

Hybrid method creates enlarged diameter
and enables construction close to obstacles

SWING horizontal jet

JACSMAN **cross jet**

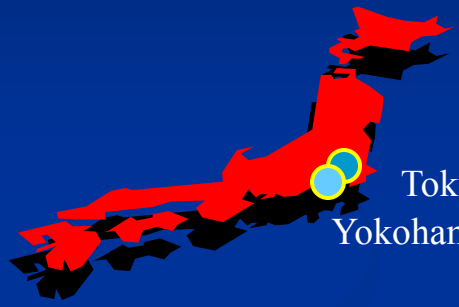
Development and Improvement of deep mixing

- Fundamental requirements for deep mixing machines are;
  1) constant or controlled supply of binder
  2) efficient in-situ mixing of binder and soil.
- To satisfy these fundamentals and to improve the work efficiency and accuracy, further efforts may continue.
- New applications or restrictions necessitates the modification of the systems, such examples are JACKSMAN and LODIC.
- Limited space & headroom necessitate the use of single-shaft and skid type DJM machine.
- The modifications to the system may continue in the future as well, to cope with new applications and new restrictions.

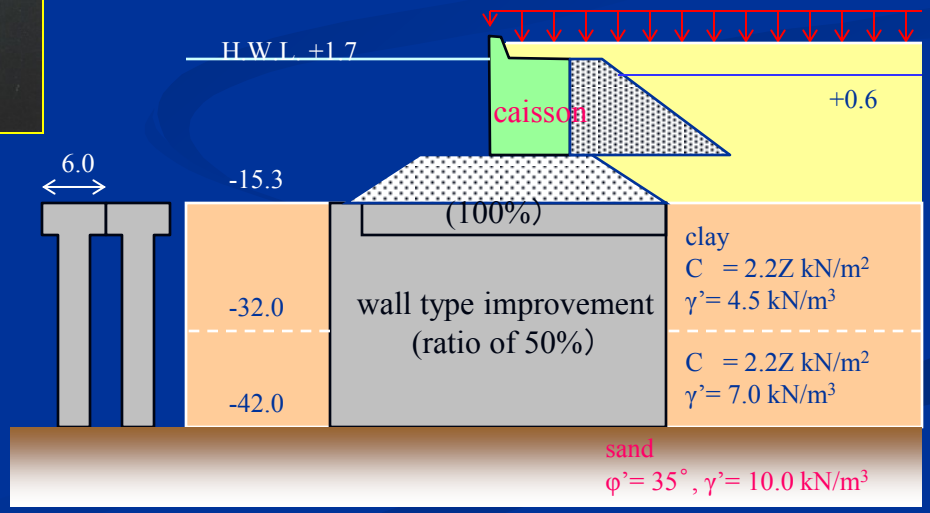
Diversified applications in Japan and North America

Landmark project for the wet method

Daikoku wharf at Yokohama Port
(1977-1988)



wall type improvement
σca = 6.0 kgf/cm^2
α= 160 kg/m^3



Daikoku project is a Landmark of wet method enhanced further developments of the technology

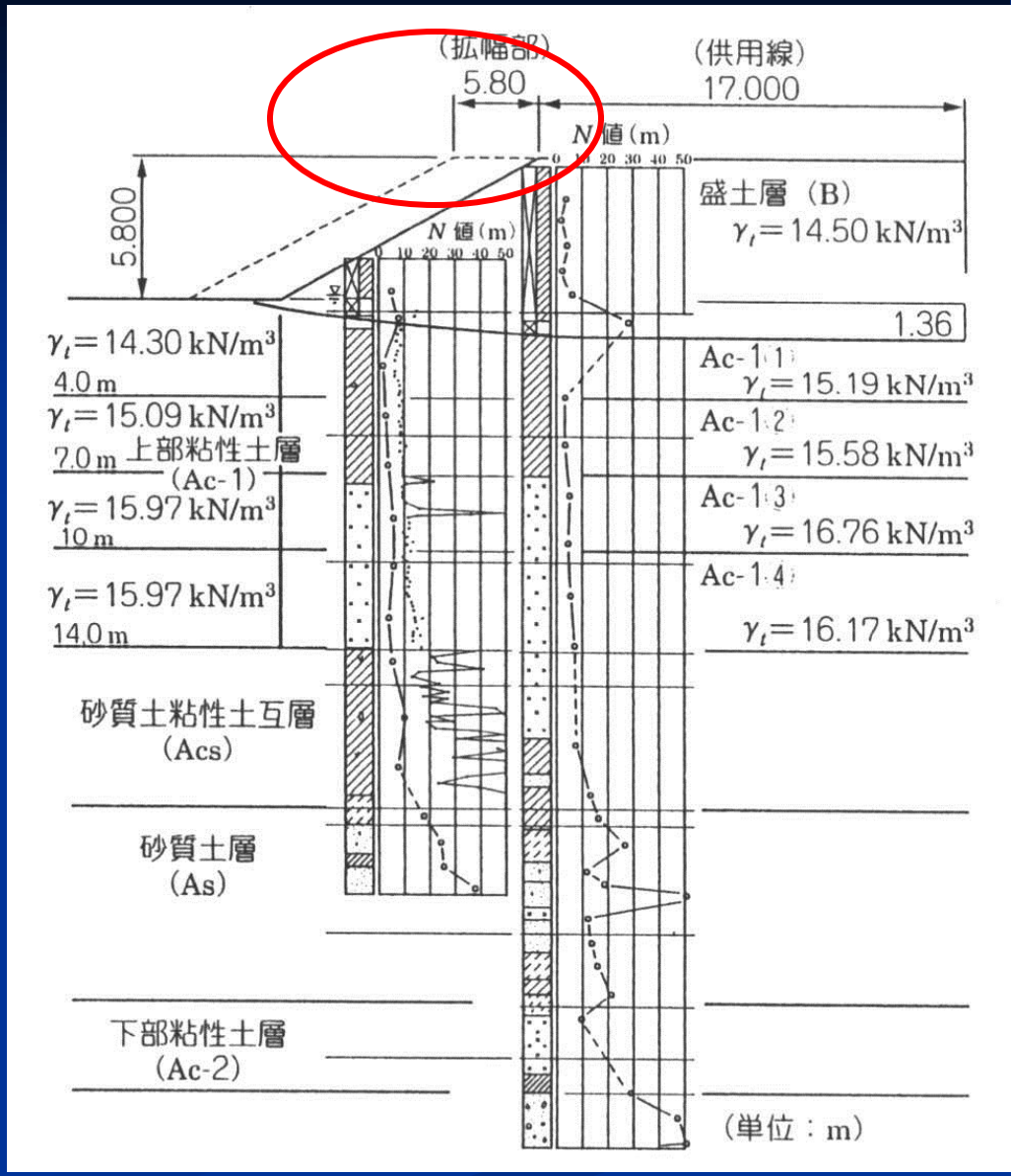
- By intensive field test program, the construction control and quality control of the method was established during the Daikoku project.
- Computerized positioning system with optical finders and later with GPS were developed to improve the accuracy and work efficiency.
- A number of contractors developed special barges for deep mixing and put them to the Daikoku project.

Widening of highway embankment at Atsugi interchange 1990-1991

Original embankment was constructed 30 years ago by preloading with vertical drains.

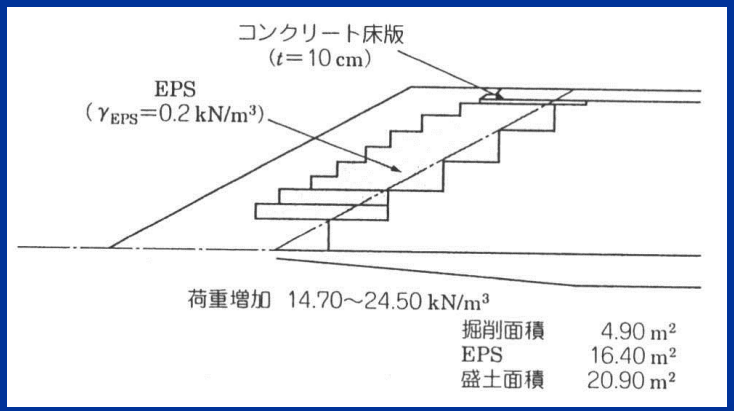
Estimated settlement at the shoulder by widening was around 1 m.

Technical issue was the adverse influence of the settlement to the highway in operation and nearby structures.

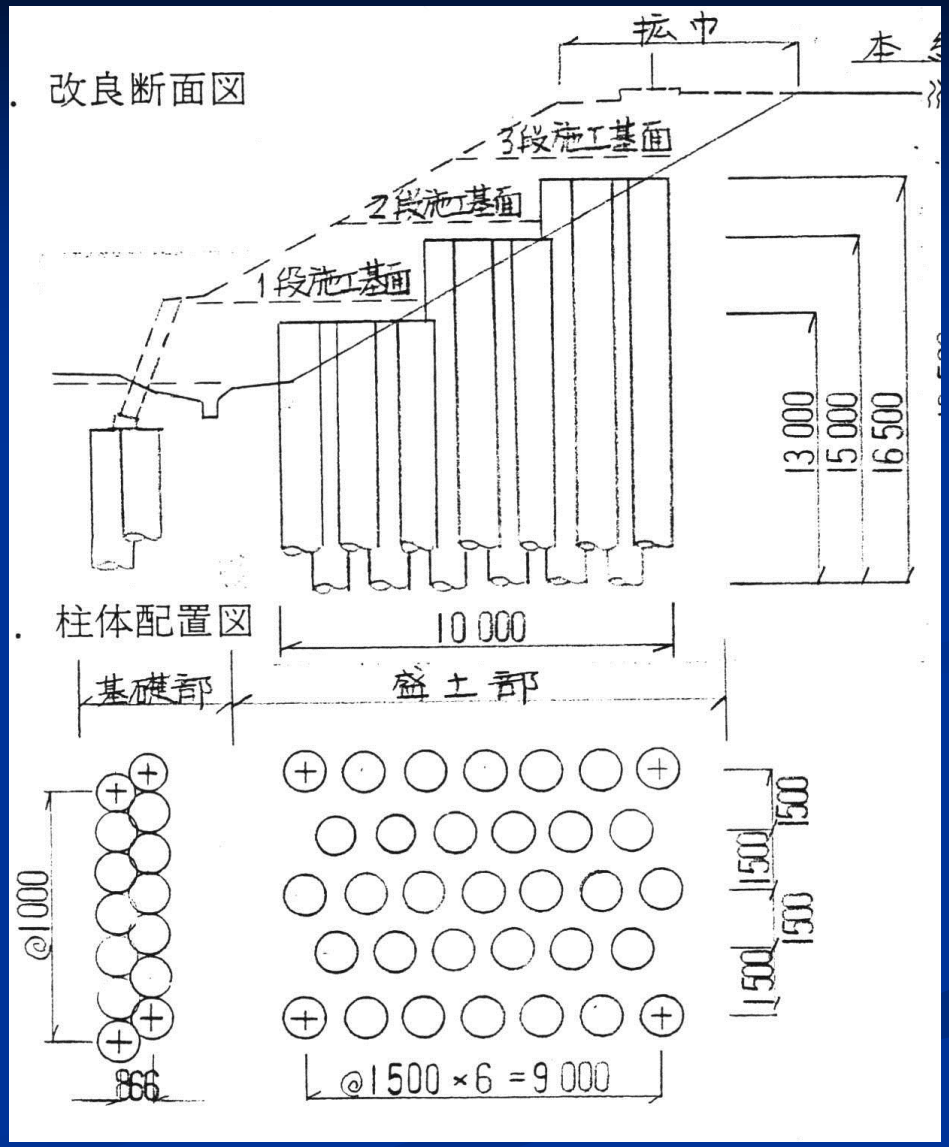


Atsugi, 1990-1991

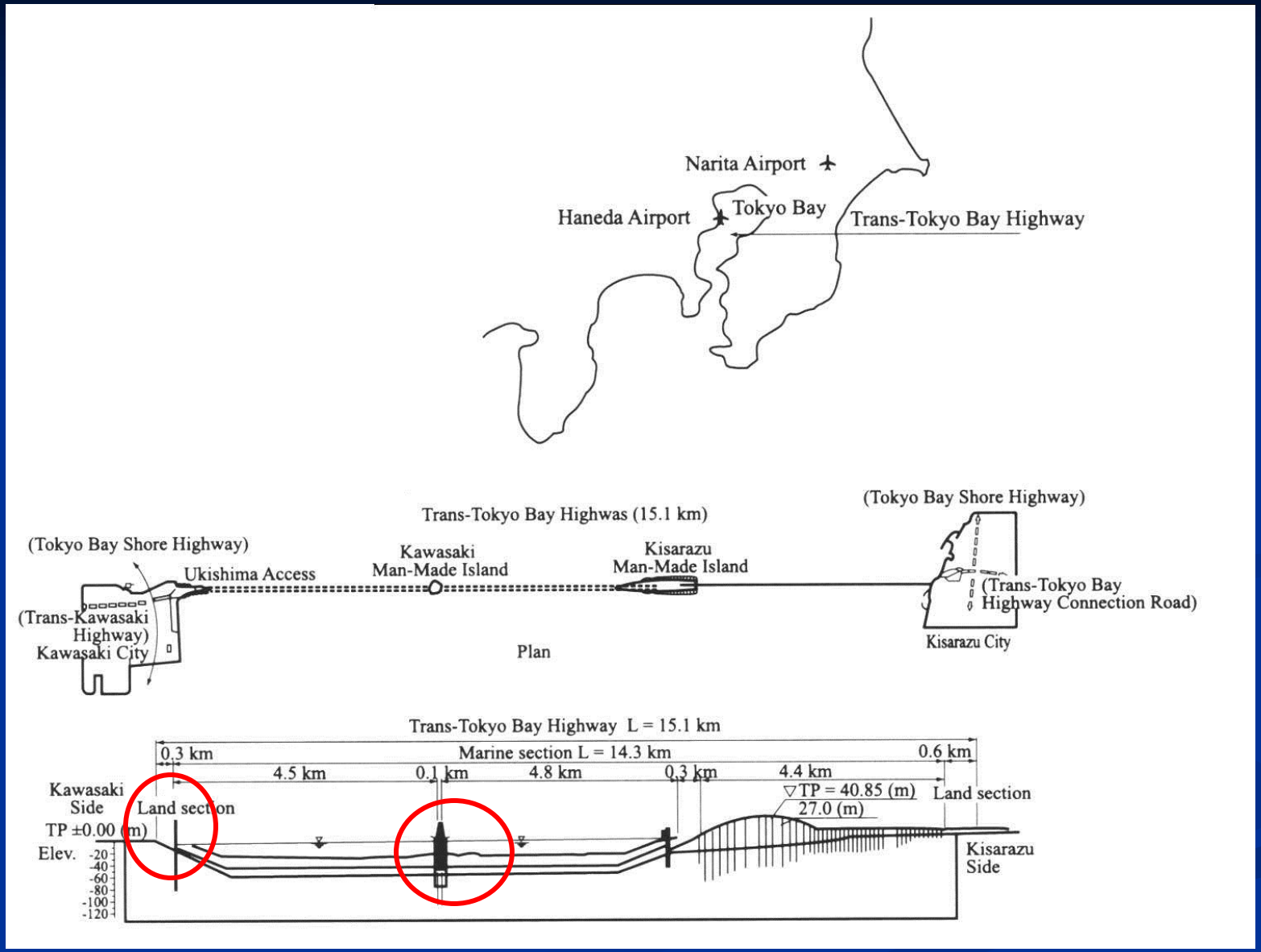
One of the alternate plans was light- weight fill by EPS



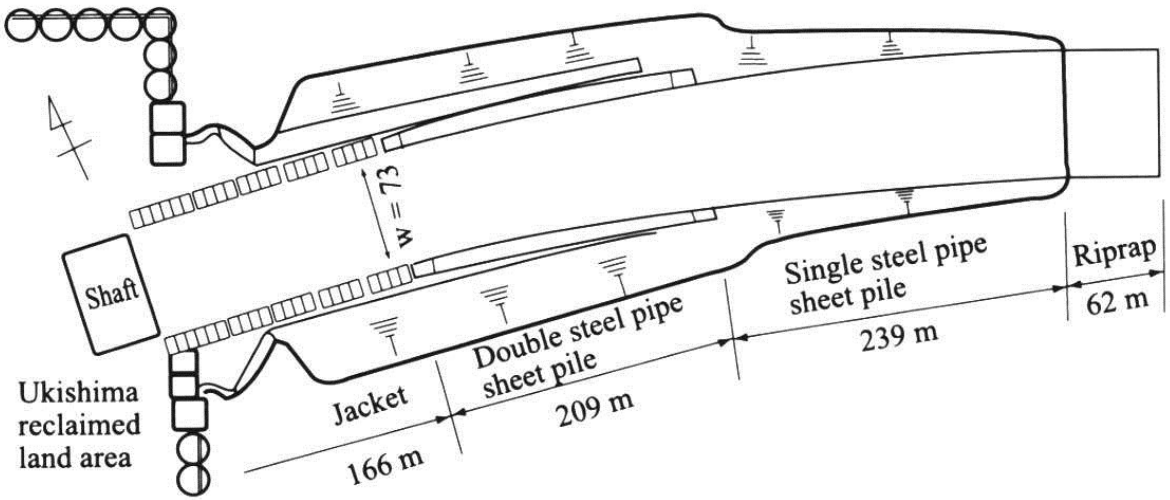
Contractors Final Drawing

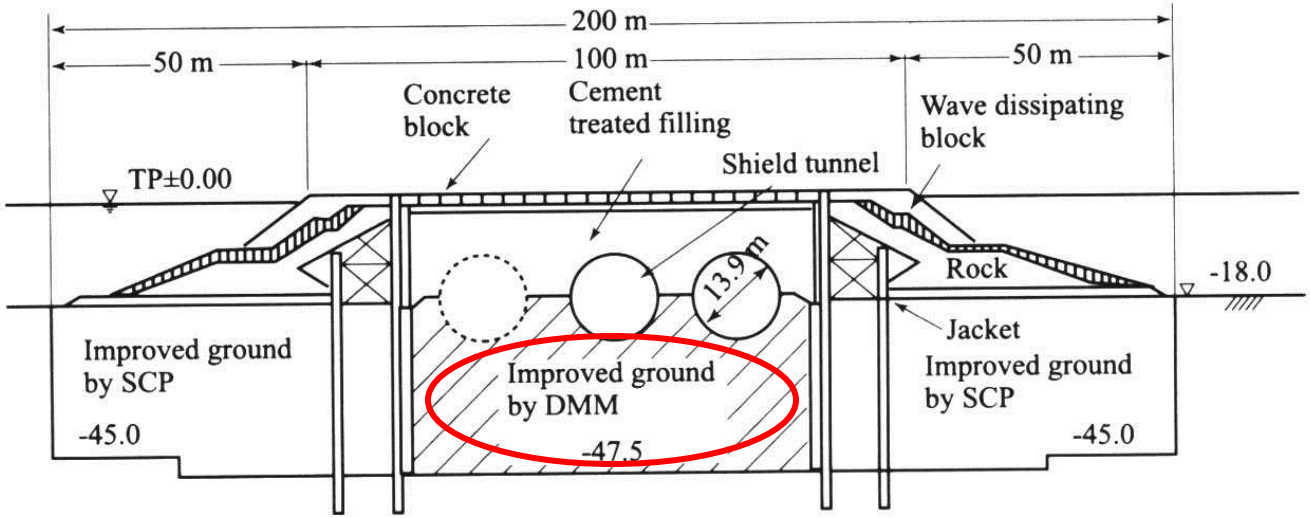


Trans-Tokyo Bay Highway completed in 1997



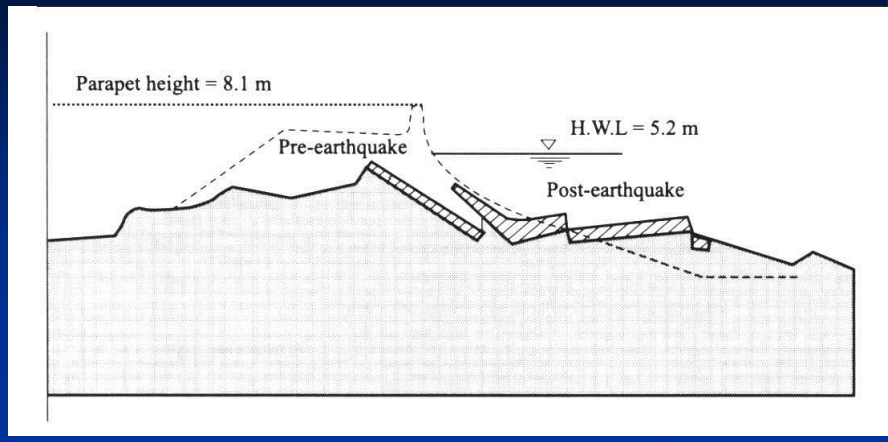
Shield Tunnel in underwater embankment

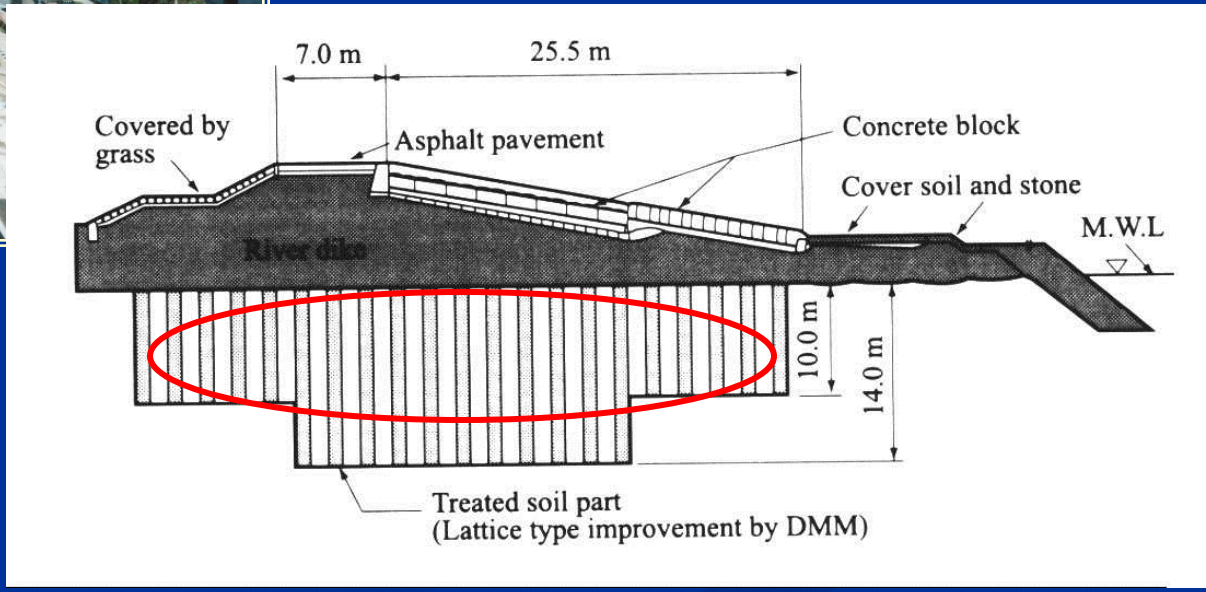




Wet method was employed to reduce the settlement by the underwater embankment.

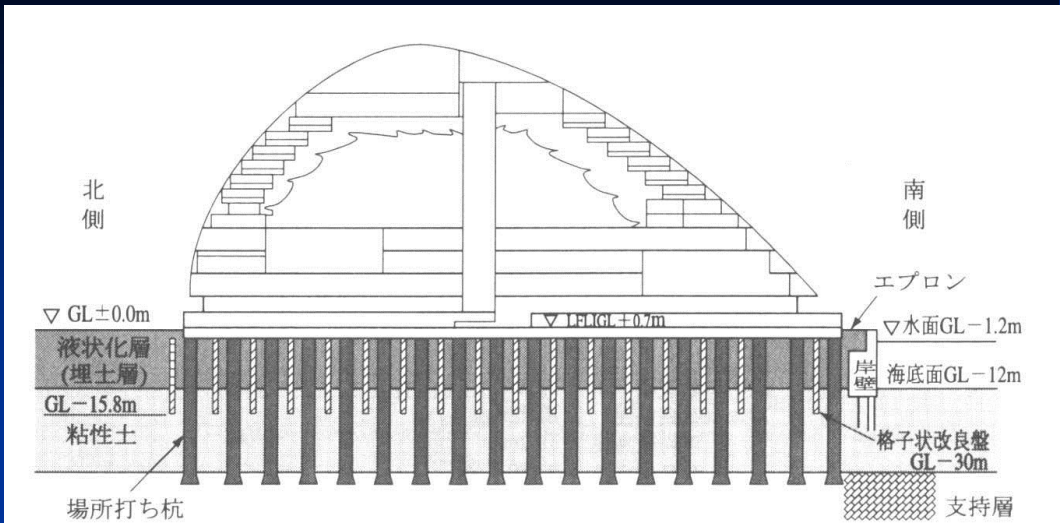
Restoration of dike damaged due to Earthquake





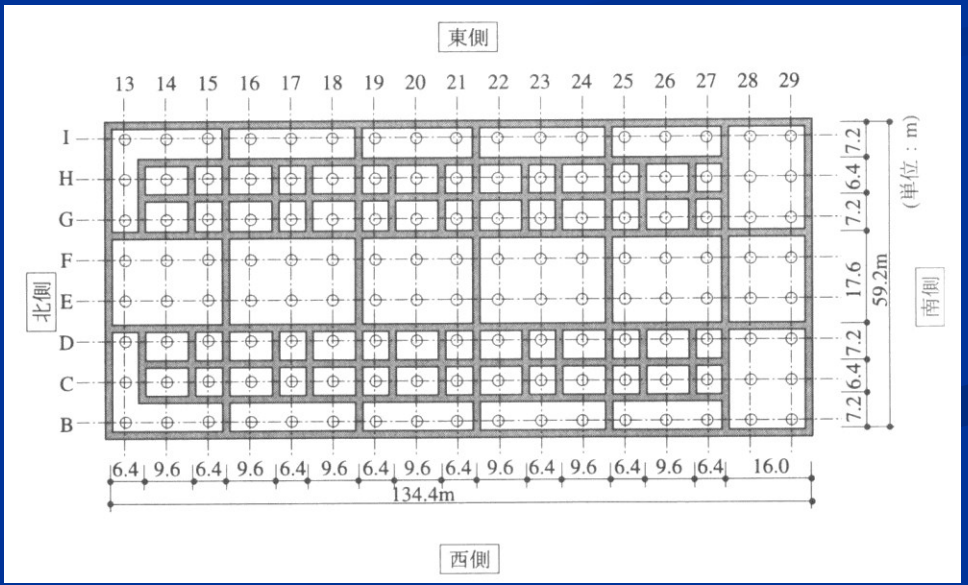
More than 50 DMM machines were simultaneously put into operation for rapid restoration.

Improve horizontal resistance of piles & Liquefaction counter-measure

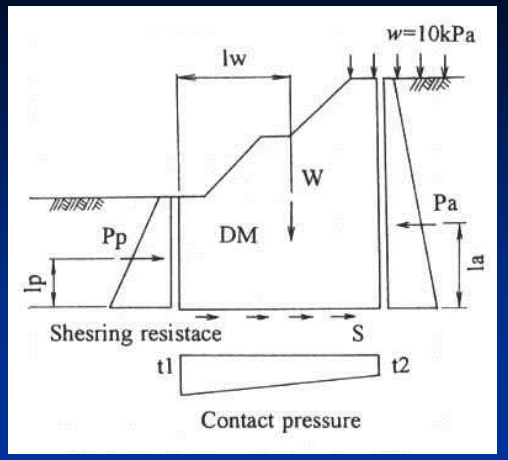


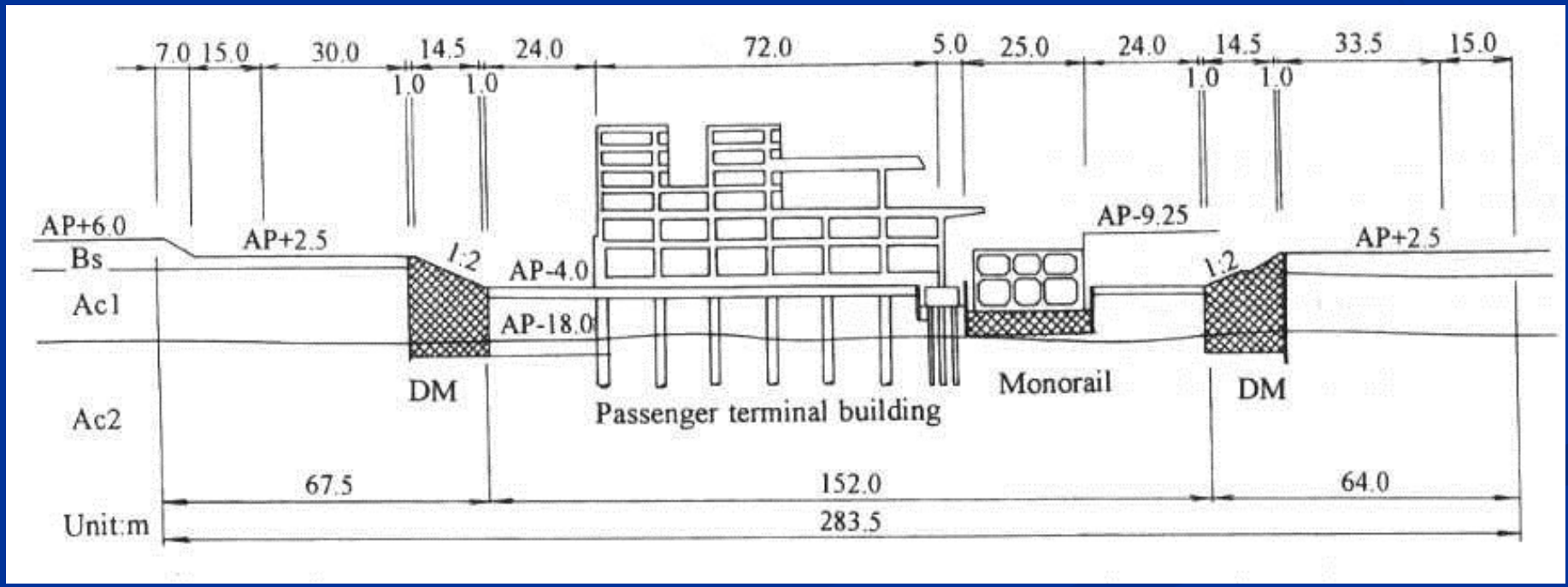
資図－6.8.4 断面図

A hotel building under construction survived 1995 huge earthquake in Kobe, although nearby seawalls were heavily damaged.

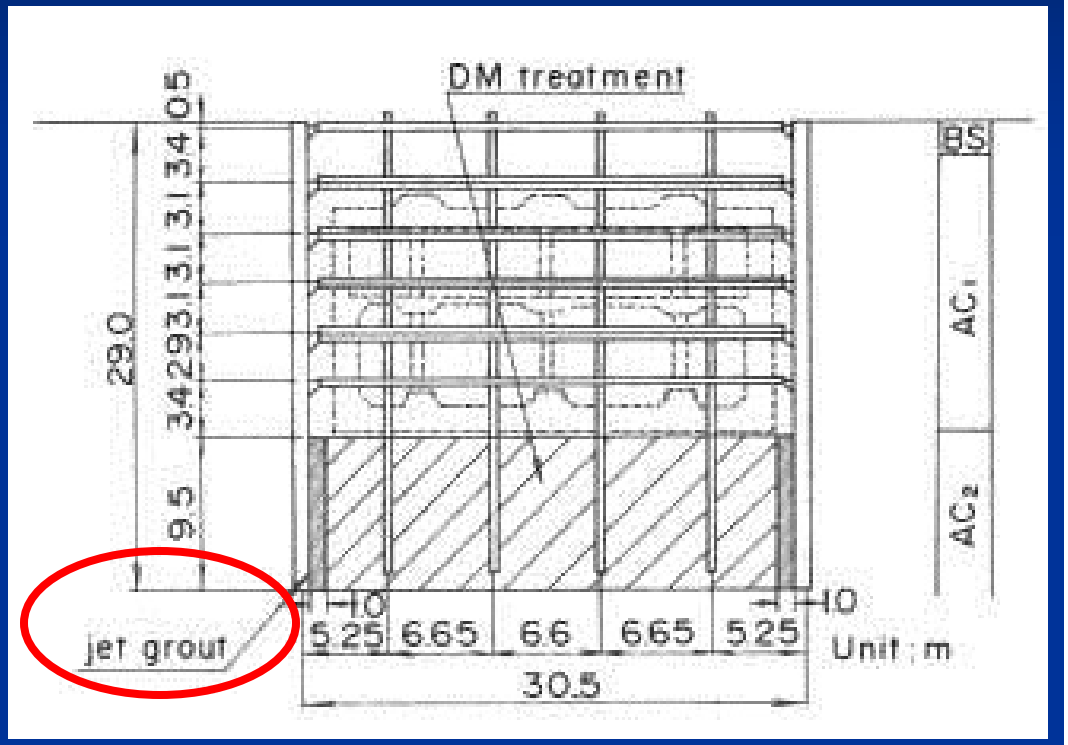


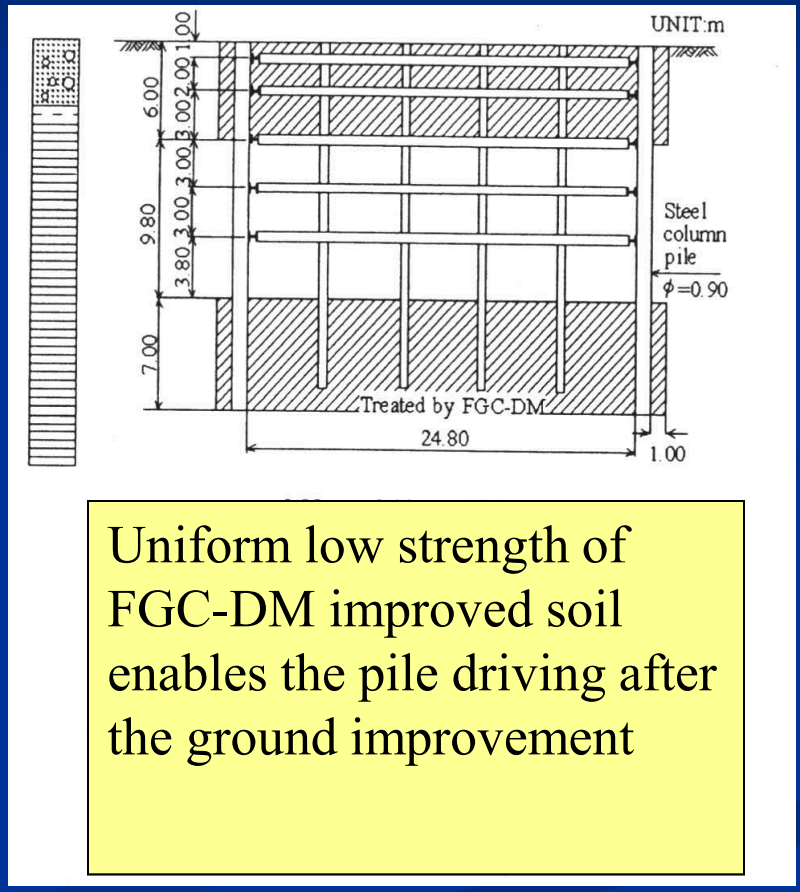
Excavation Support
Self-retaining wall





Excavation Support
Braced Excavation





Uniform low strength of FGC-DM improved soil enables the pile driving after the ground improvement

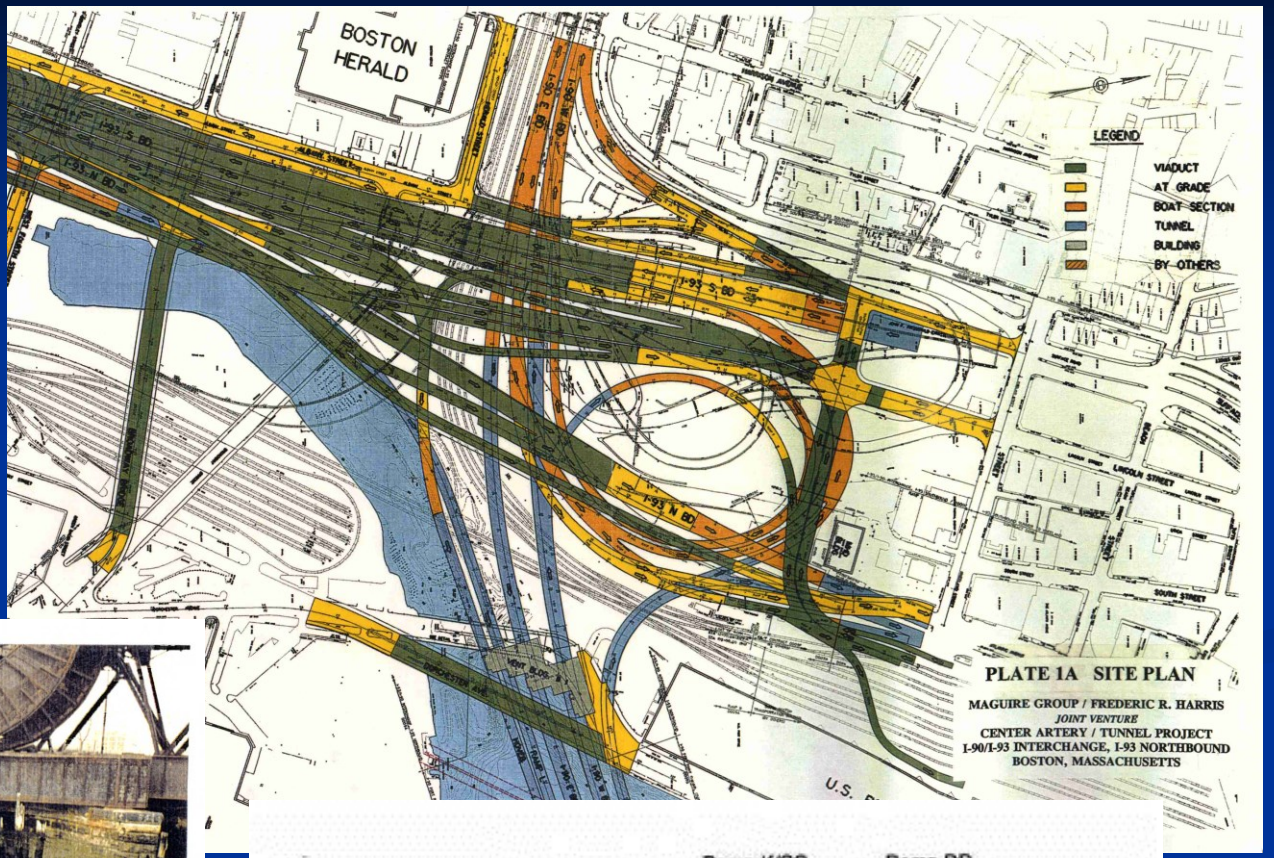
Ordinary deep mixing requires the supplemental technique such as jet grouting

Boston Big Dig Project

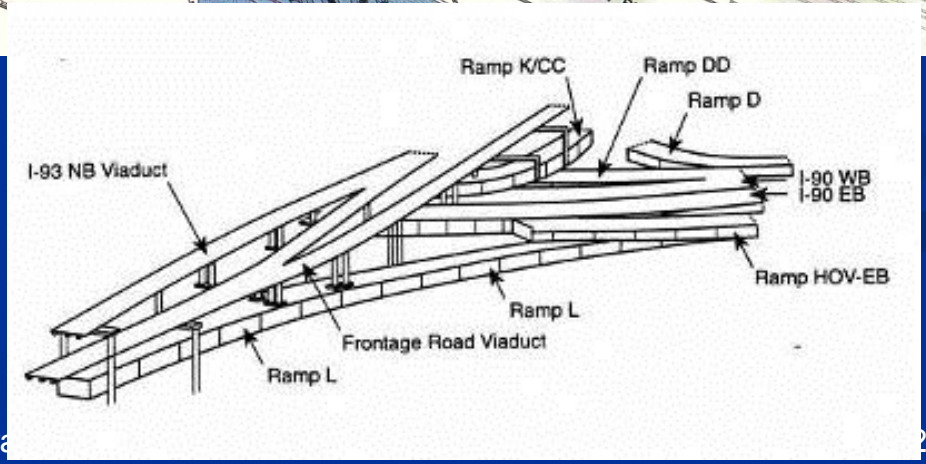
Boston Central Artery Tunnel Project - I-93NB / I-90 Interchange

Reduce impact on existing infrastructures

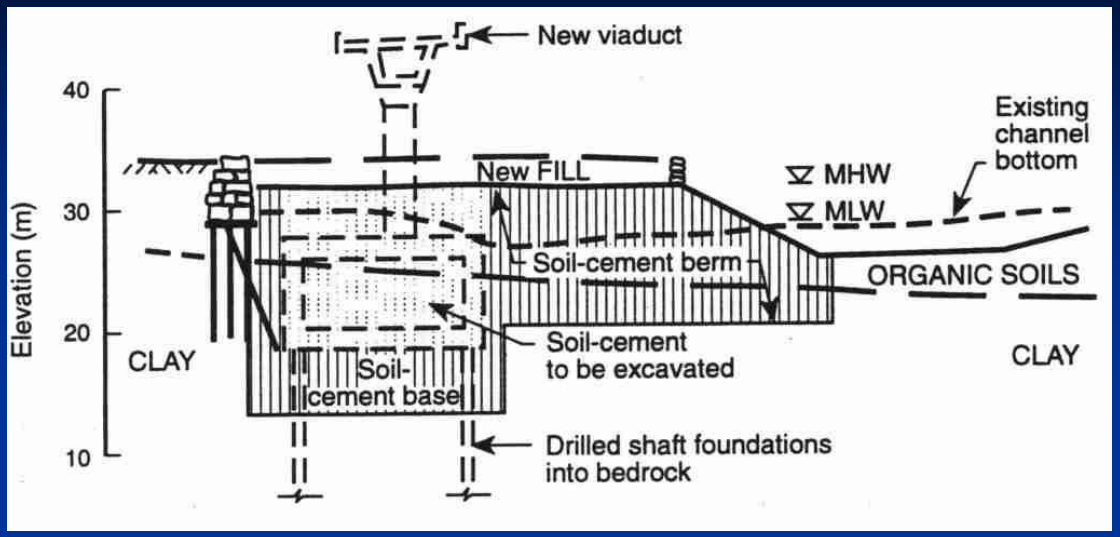
Numerous obstacles

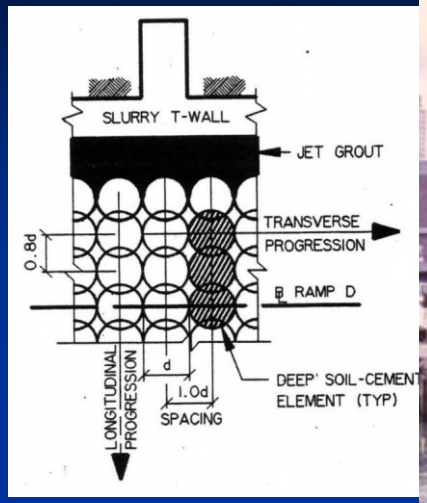


PHOTOGRAPH 5 - EXISTING DORCHESTER BRANCH RAILROAD BRIDGE - MIDDLE SPAN PIERS

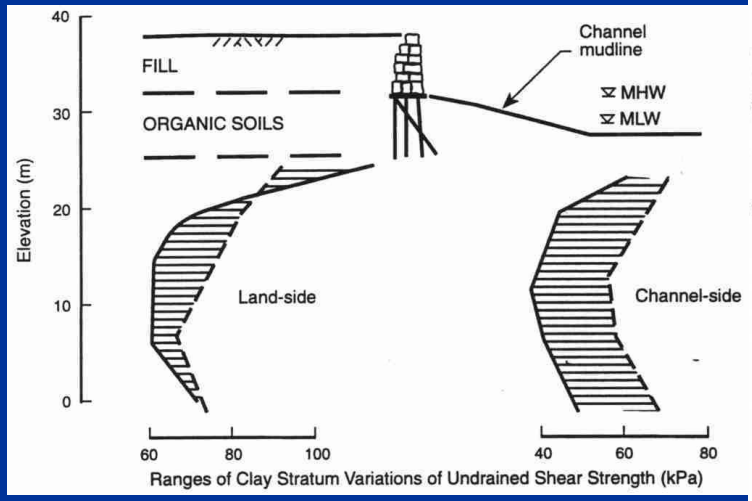


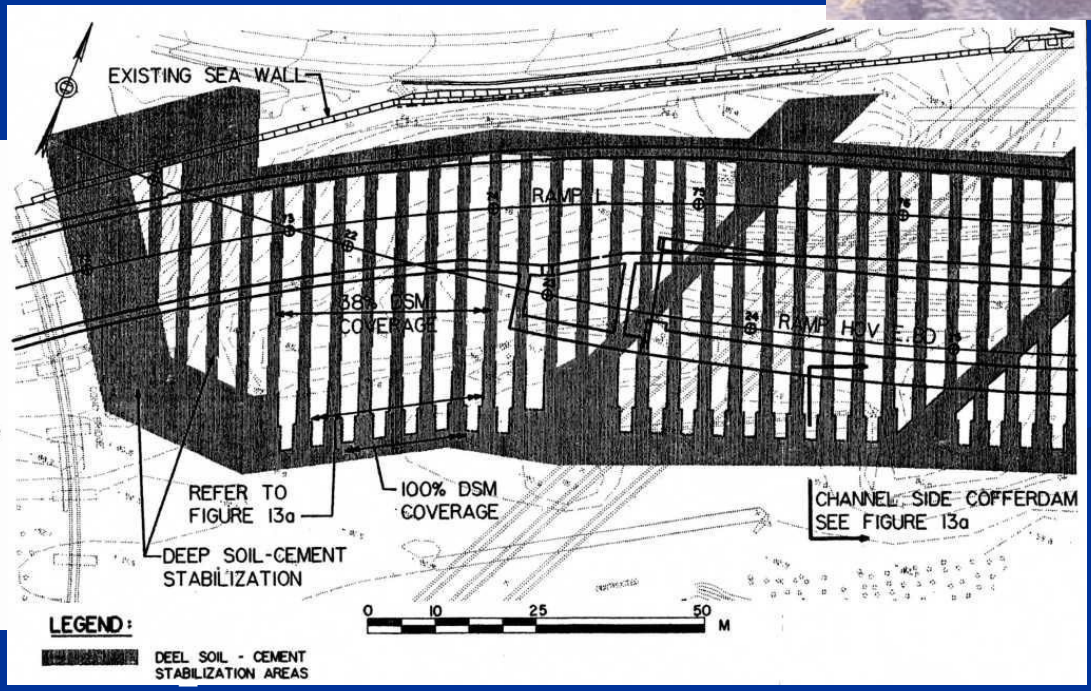
SMW, Jet Grout and Deep Mixing saved the difficult project



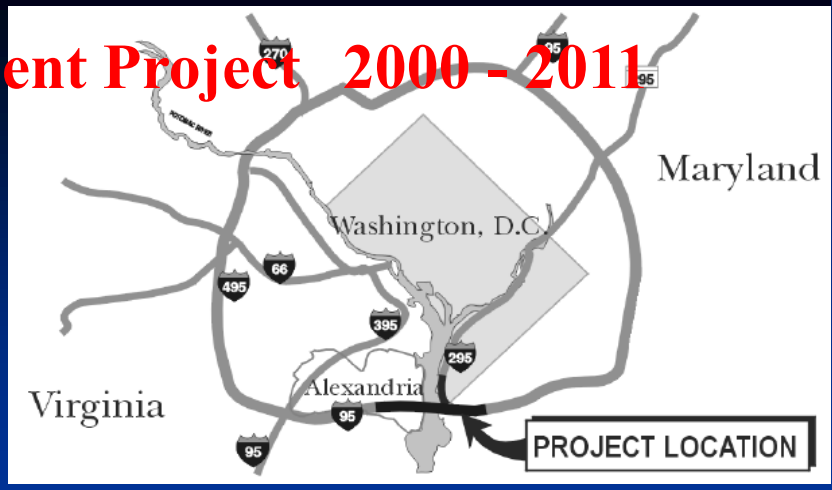


Lambrechts (1997)



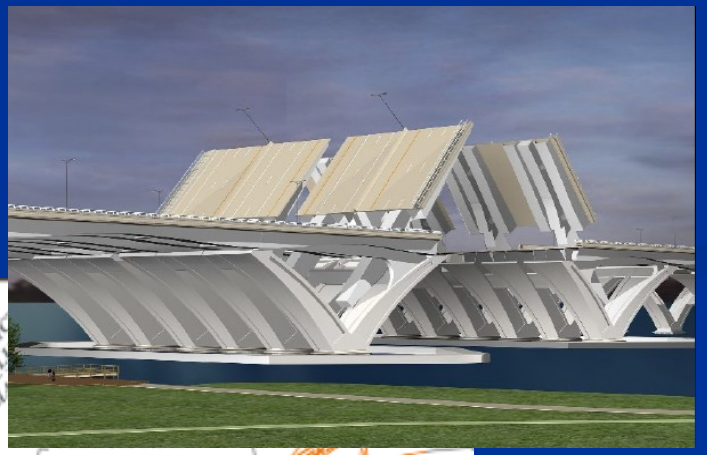


Woodrow Wilson Bridge Replacement Project 2000 - 2011



As part of US $ 2.45 Billion WWB project, I-95 was widened. The site is underlain by 9 m thick alluvial deposits of very soft highly organic compressible silts and clay.

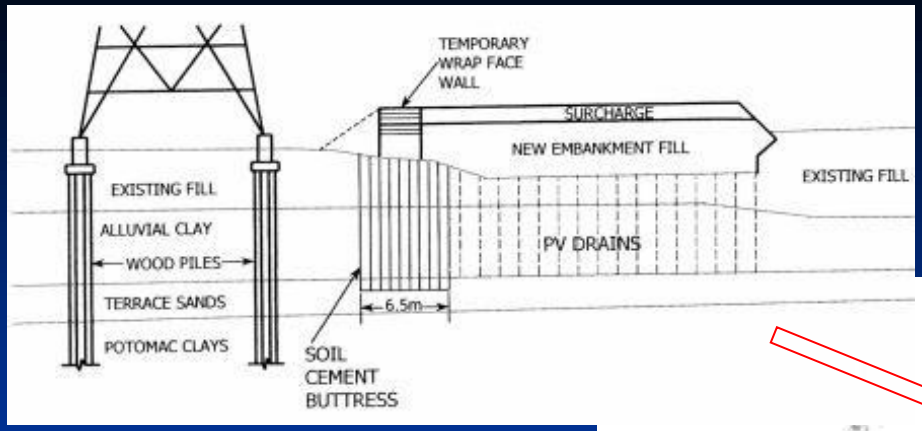
Reduction of long term settlement, stability at the shoulder of new embankment and the impact on the nearby structures were the problem.



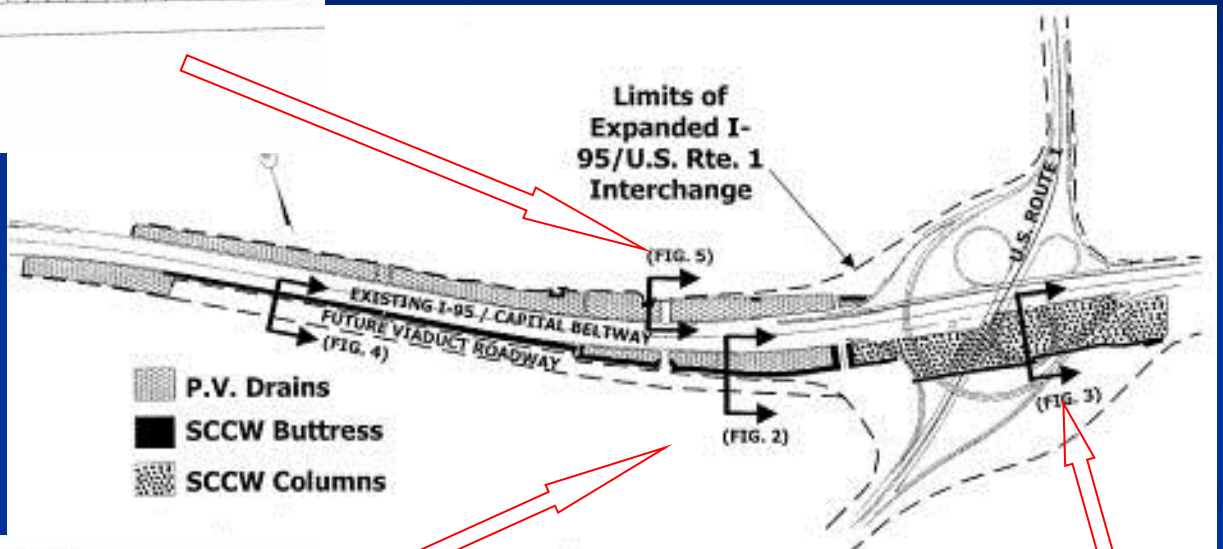
Website: www.wilsonbridge.com

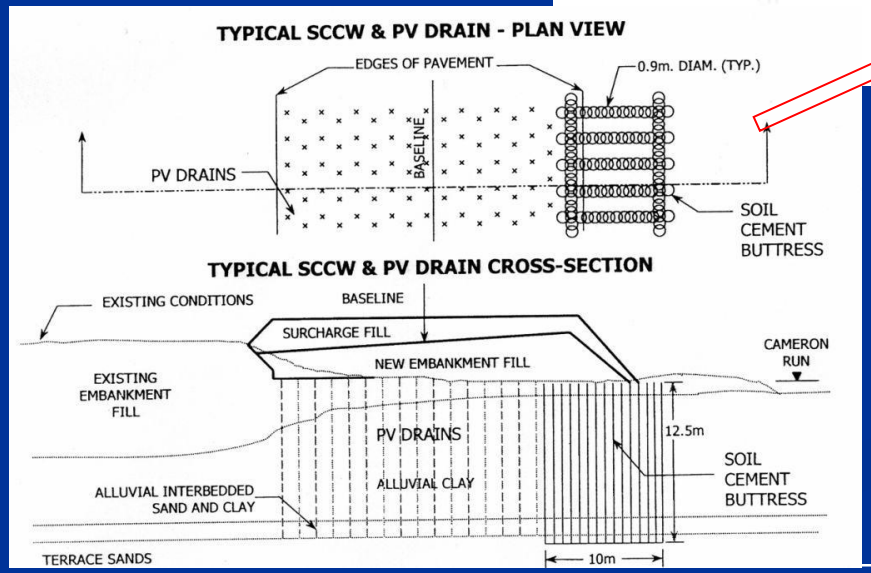
WWB Project

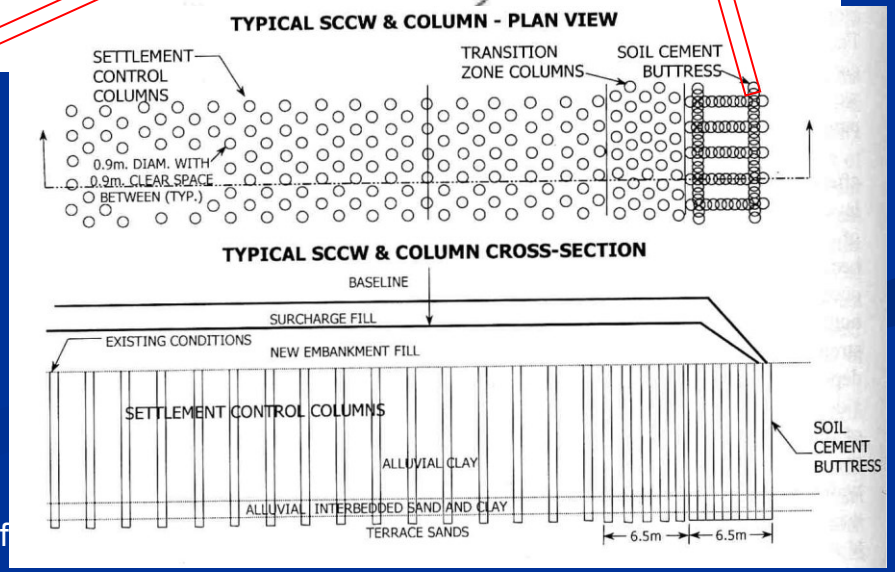
Vertical drain and deep mixing (wet)



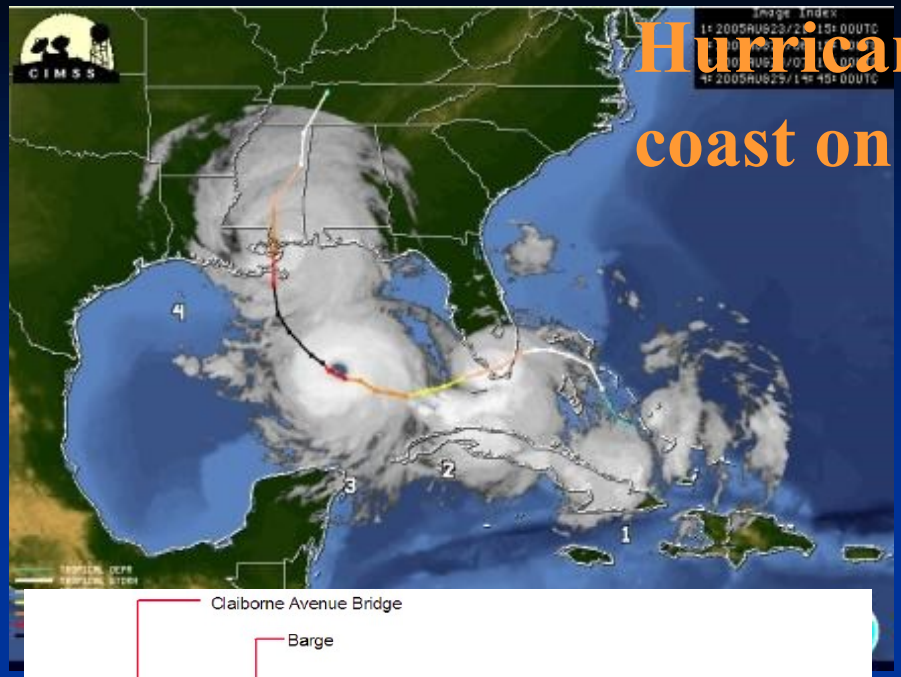
Lambrechts, 2003

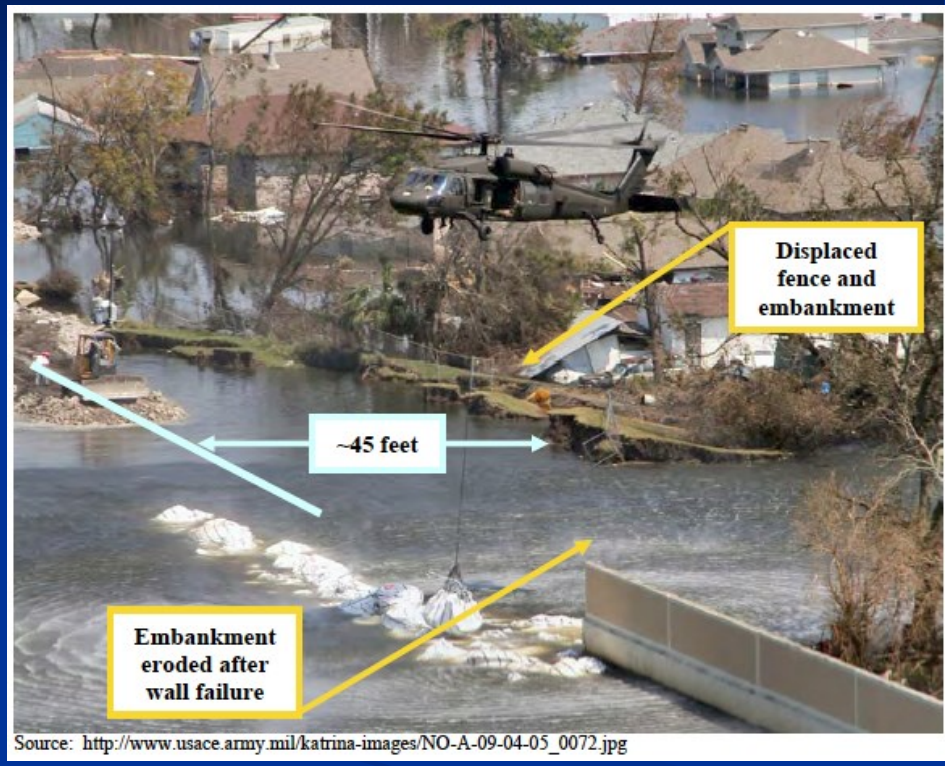






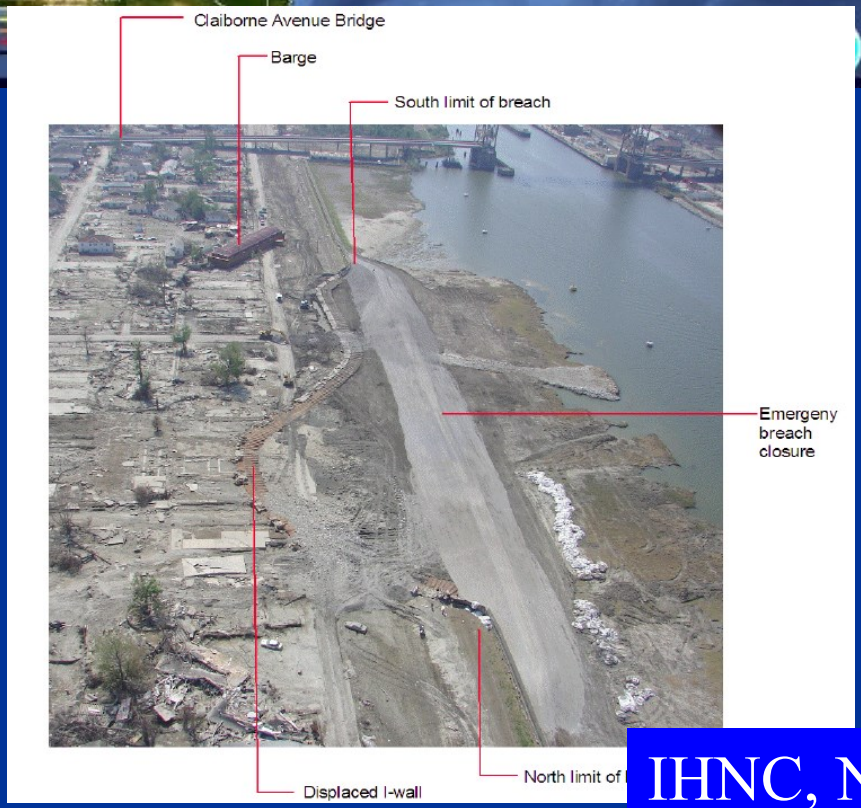
Hurricane Katrina attacked Gulf coast on August 29, 2005





Source: http://www.usace.army.mil/katrina-images/NO-A-09-04-05_0072.jpg

17th Street Canal



IHNC, Ninth Ward

Source:

ASCE Preliminary Report Nov. 05

USACE IPET Report June, 06

Urgent Restoration by USACE Task Force Guardian

Peter Cali, PhD & Mark Woodward, PE

Mission Statement:
To restore the flood protection to pre-Katrina levels by 1 June 2006
Approximately 169 miles of levees and floodwalls repair work

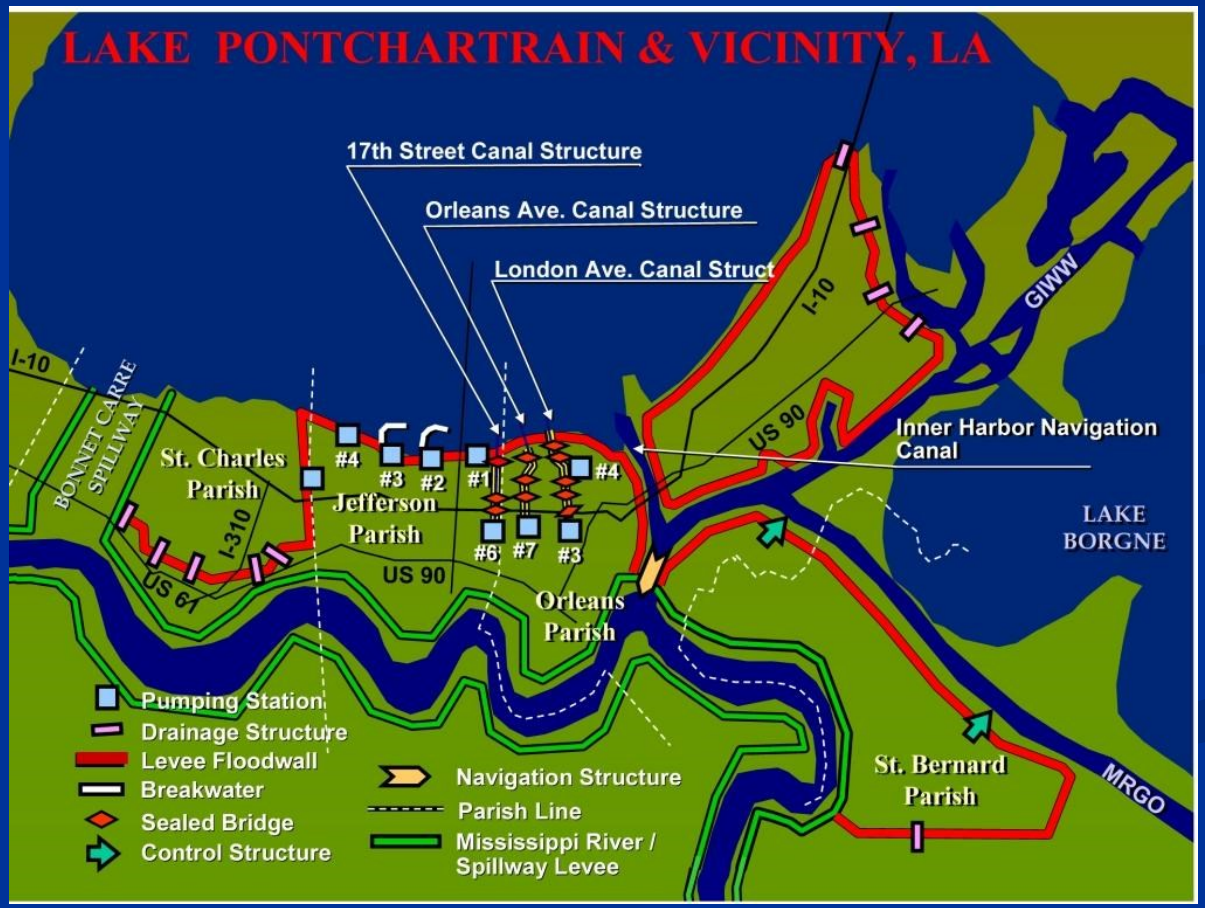
Deep mixing was employed at:

17th Street Canal Interim Closure Structure

Orleans Avenue Interim Closure Structure

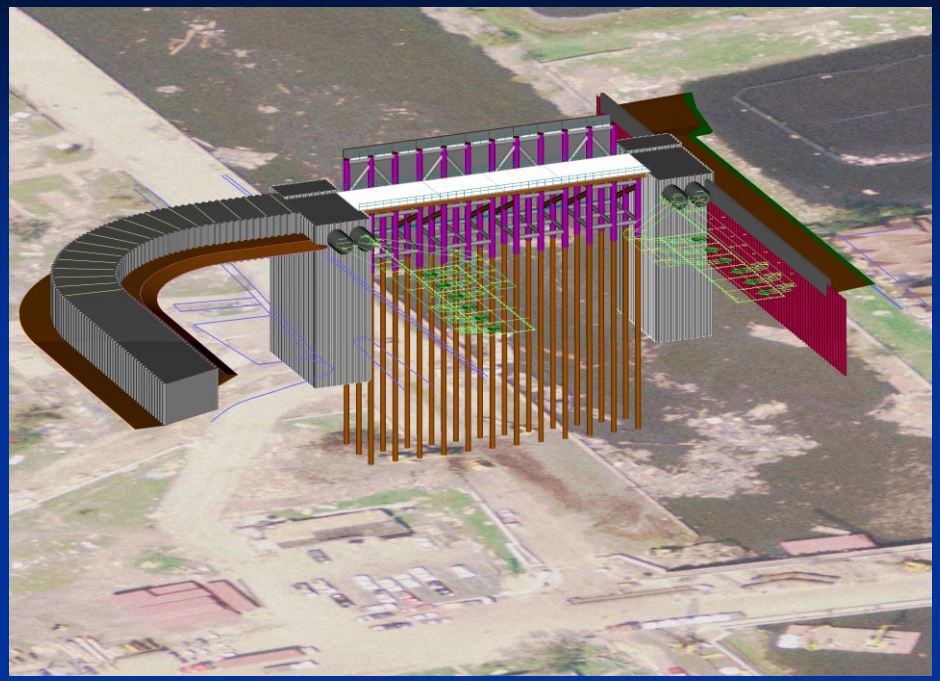
IHNC Deep Mixed Cutoff Wall

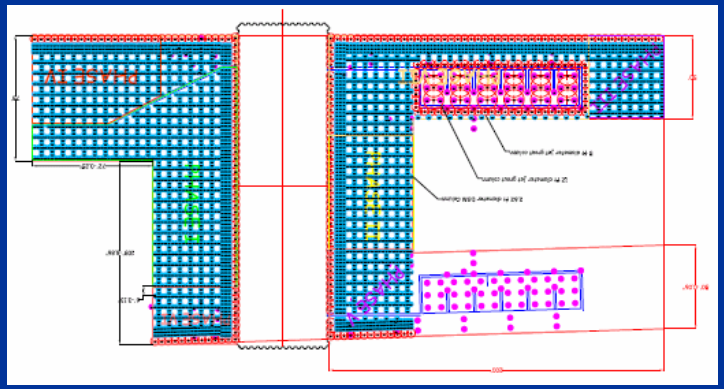
Homeplace Levee Enlargement



Terashi_Griffith U. Source: IPET Report June 1, 2006

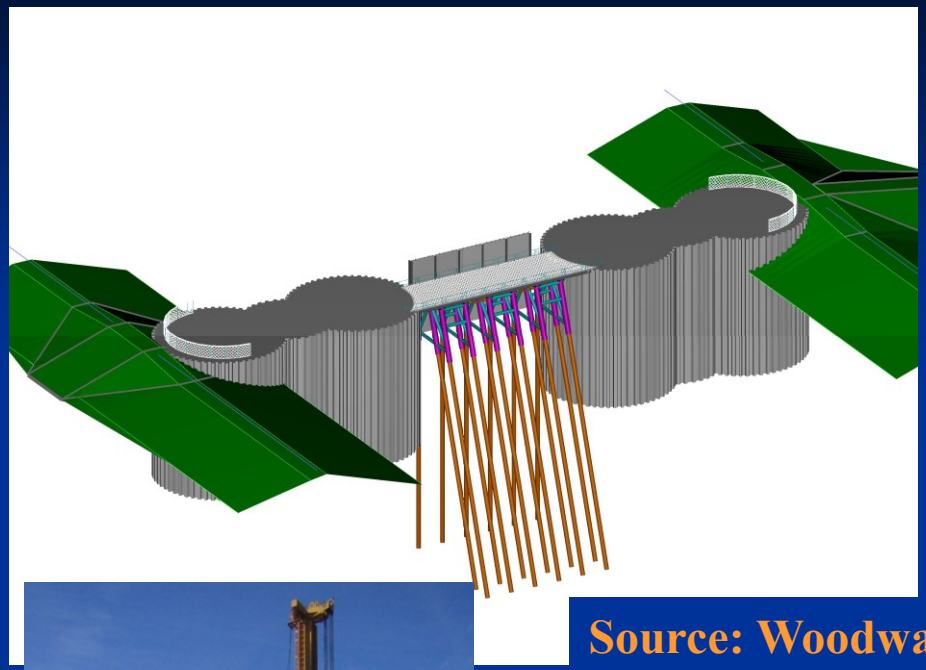
Interim Closure at 17th Street Canal (Woodward, USACE)

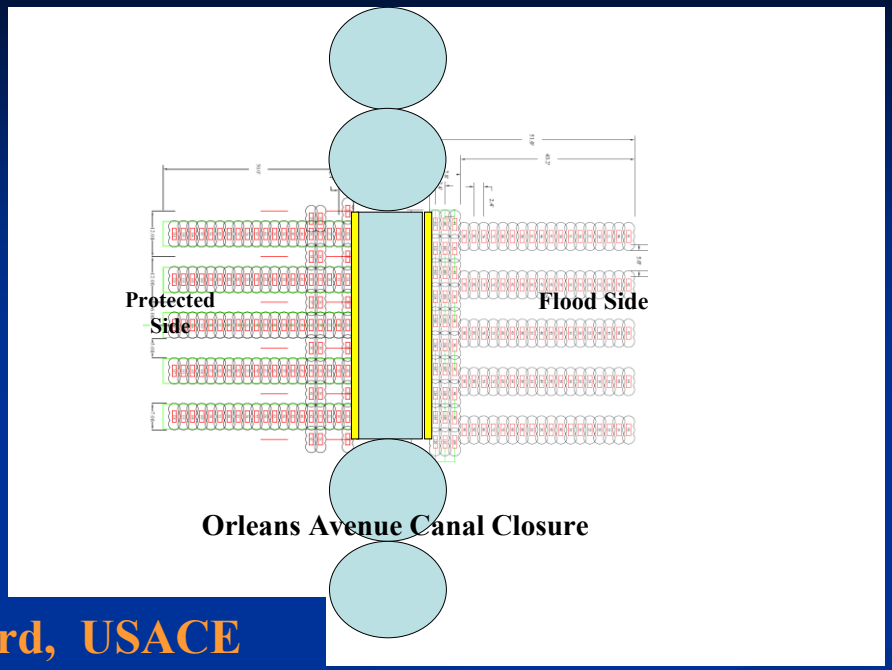




Nordic dry method
Hayward Baker + LCM

Interim Closure at Orleans Avenue Canal





Source: Woodward, USACE

Raito Inc, Japanese Wet method

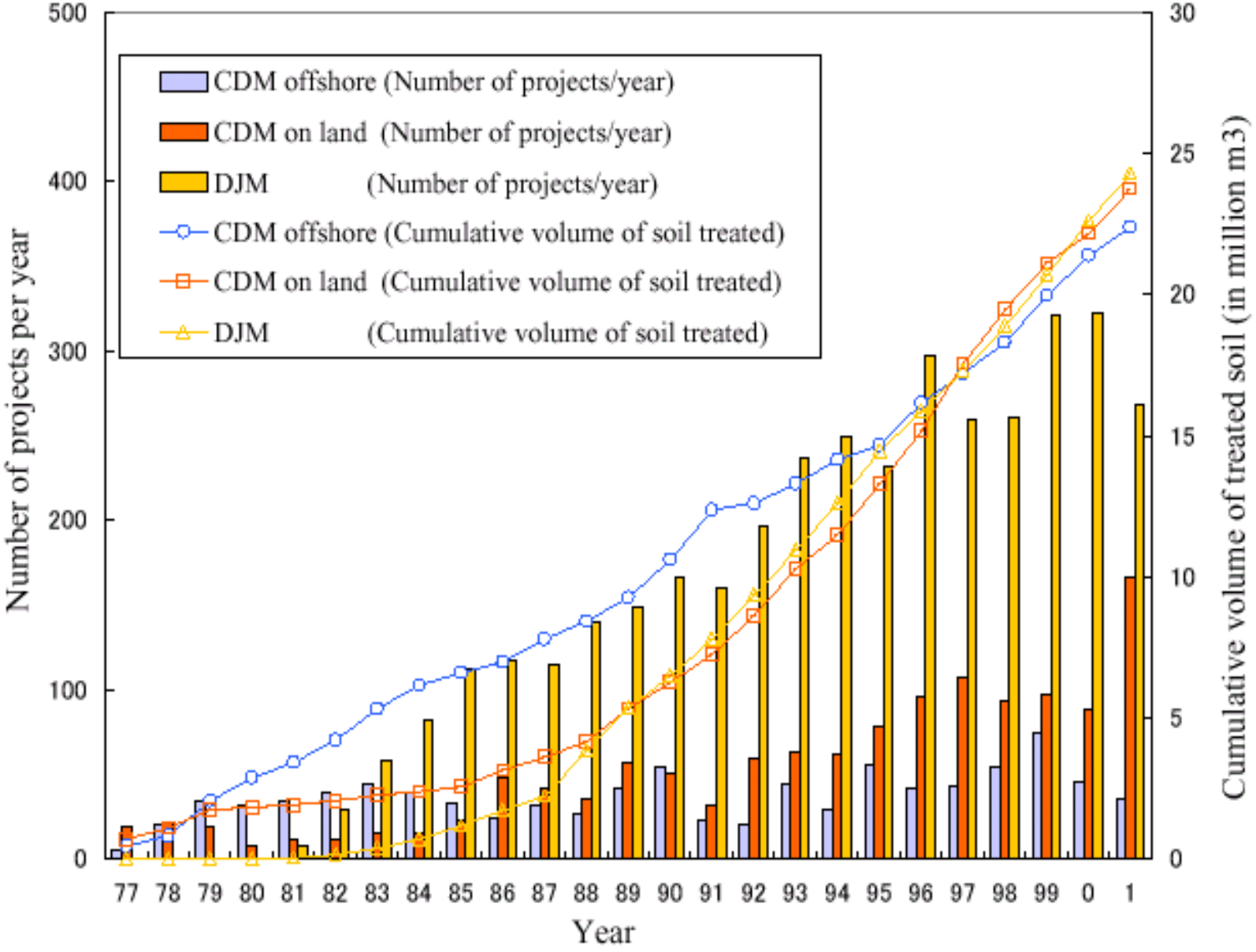
Summary

Size of deep mixing market
International comparison

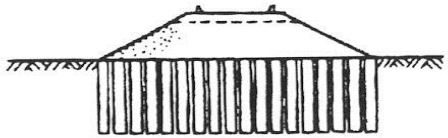
- Dry Mixing:
- Japan, cumulative quantity 1980 - 2004: 26,243,000 m3
- Sweden, 2003 annual volume: 587,000 m3
- United States, cumulative from 1996 to 2005: No data.
  <500,000 m3

- Wet Mixing:
- Japan, cumulative through 2004: 55,000,000 m3
- United States, cumulative through 2004: < 3,500,000 m3

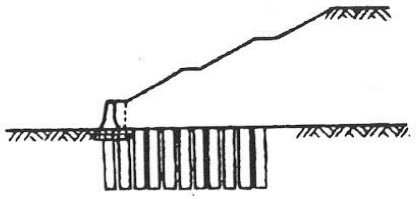
US data estimated by Druss and Yang (2005)


CDM offshore (Number of projects/year)
CDM on land (Number of projects/year)
DJM (Number of projects/year)
CDM offshore (Cumulative volume of soil treated)
CDM on land (Cumulative volume of soil treated)
DJM (Cumulative volume of soil treated)
Number of projects per year
Cumulative volume of treated soil (in million m3)
Year
0
100
200
300
400
500
0
5
10
15
20
25
30
77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 0 1

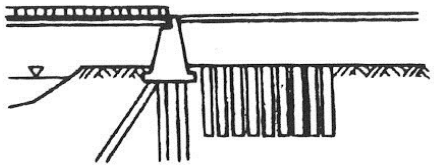
Summary of various applications



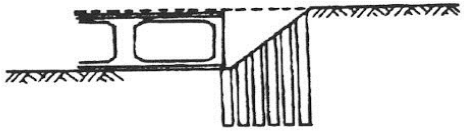
Road Embankment
stability / settlement



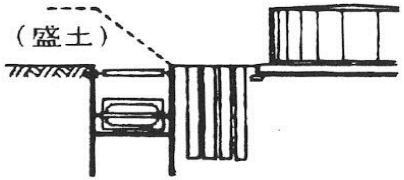
High embankment
stability



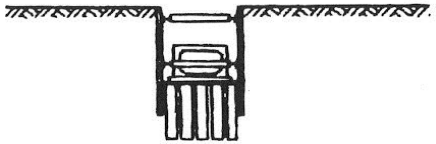
Bridge Abutment
uneven settlement



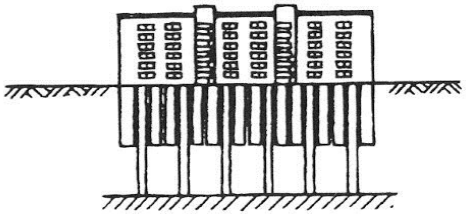
Stability of Cut Slope



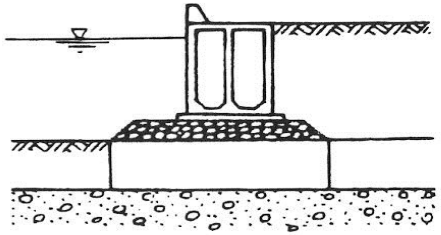
Reducing the influence
from nearby construction



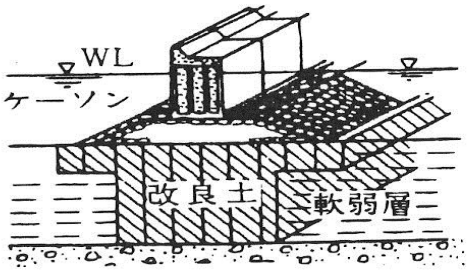
Braced Excavation
earth pressure/ heave



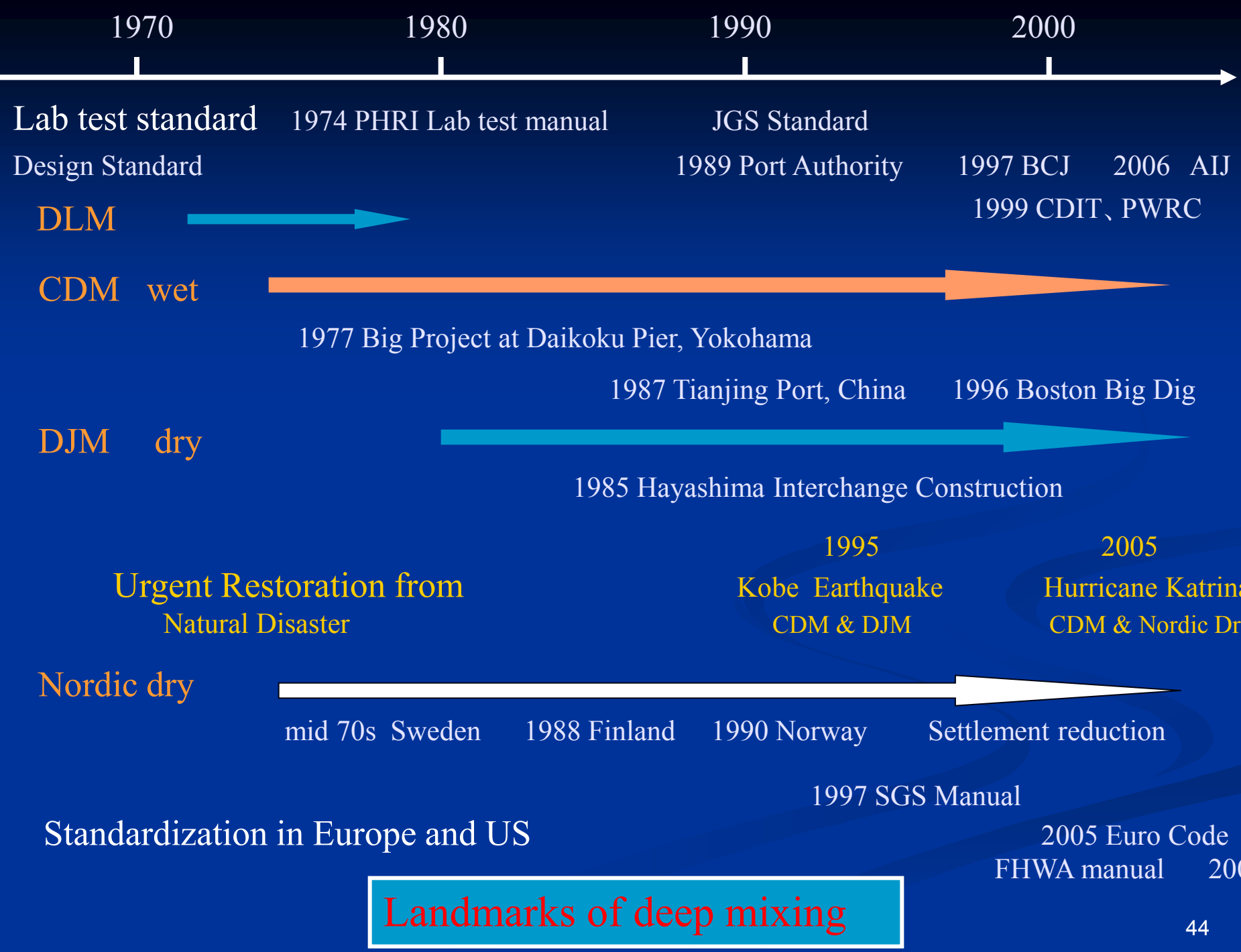
Pile foundation
lateral resistance



Sea wall
bearing capacity



Break-water
bearing capacity



Landmarks of deep mixing

Further information

- Ground improvement
- Mitchell, J.K.(1981). “State of the Art - Soil Improvement”. Proc. 10th International Consference on Soil Mechanics and Foundation Engineering.. Stockholm. 4, 509-565.
- Rathmayer H.G. and Saari, K.H.O. Editors (1984) "Improvement of Ground". Proc. 8th ECSMFE, Helsinki, 3 volumes, Balkema
- Terashi, M. and Juran, I. (2000). “Ground Improvement - State of the Art”. Proc. International Conference on Geotechnical & Geological Engineering, GeoEng2000, Vol. 1, 461-519
- Deep mixing
- Grouting and Deep Mixing, Yonekura, Terashi and Shibazaki editors; Balkema, May 1996
- Dry Mix Methods for Deep Soil Stailization, Bredenberg, Holm and Broms editors, Balkema, 1999
- The Deep Mixing Method – Principle, Design and Construction, Kitazume and Terashi editors, CDIT, Balkema, June 2002
- Deep Mixing Tokyo Workshop, Kitazume and Terashi editors, Port and Airport Research Institute, October 2002
- Grouting and Ground Treatment, Johnson, Bruce and Byle editors, ASCE Geotechnical Special Publication No. 120, 2003
- Deep Mixing – Best Practice and Recent Advances-, Swedish Deep Stabilization Research Centre, May 2005

2009 Okinawa Symposium

For the successful application of deep mixing and admixture stabilization

Okinawa, Japan, May 19-21, 2009

International Symposium on Deep Mixing & Admixture Stabilization, OKINAWA 2009

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