Deep Mixing Method, The Japanese Experience and Recent Advancement

Advance in Concrete Technology by Hong Kong Concrete Institute

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Masaki Kitazume, Dr. Eng.
Tokyo Institute of Technology

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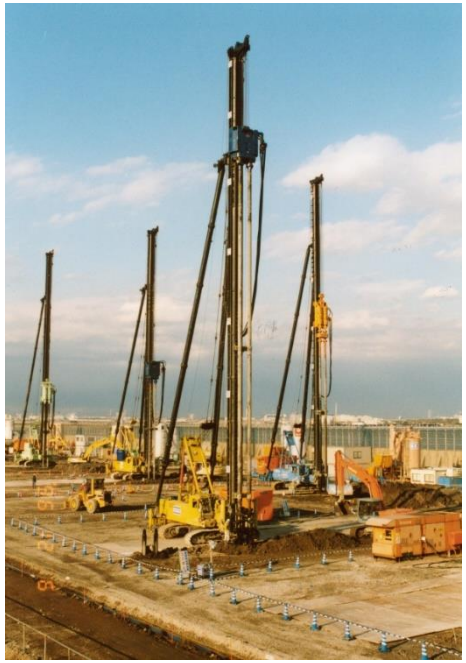
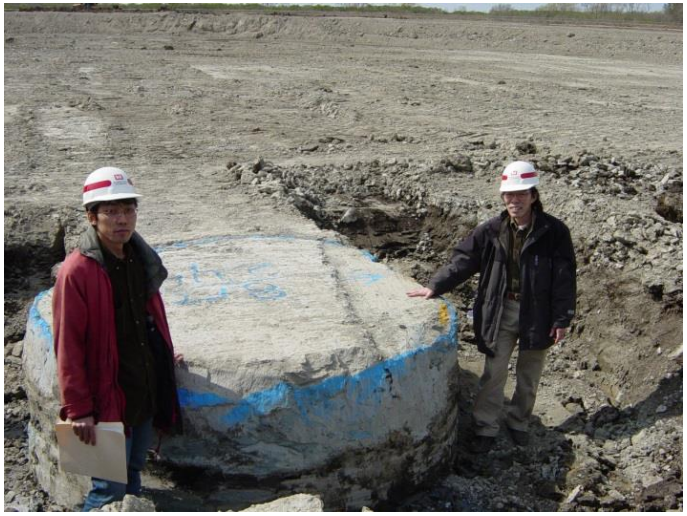
Classification of admixture stabilization techniques

Place of mixing		Type of mixing	Method
In-situ	Surface and shallow stabilization	mechanical mixing	surface treatment, shallow stabilization
	Mid depth stabilization	mechanical mixing	mid-depth mixing
	Deep stabilization	mechanical mixing high pressure injection hybrid of above two	deep mixing
Ex-situ	Mixing during transportation	mixing on belt conveyor	pre-mixing
		mixing in pipeline	pipe mixing
	Batch plant mixing	mechanical mixing	pre-mixing
		mechanical mixing	lightweight geo-material
		mechanical mixing and high pressure dewatering	dewatered stabilized soil

Deep Mixing Method



A deep in-situ soil admixture stabilization technique using cement or lime
column diameter : 1 to 1.5 m
column strength : 200 to 2,000 kPa



Deep Mixing Method
-historical review of R&D in Japan-

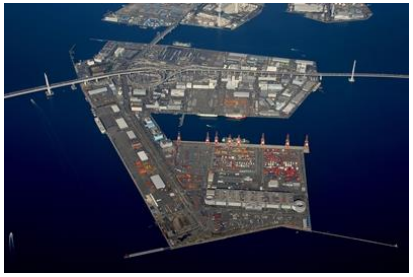
1970 1980 1990 2000 2010

machine development





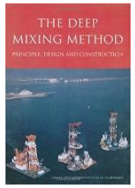
projects

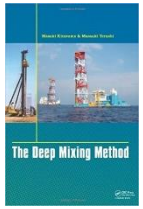



1968, field trial 1971, first work 1994, Kansai Airport 2010, Haneda Airport

Design standard & manual







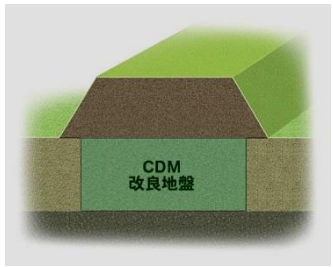
1979, lab. test 1990, design, lab. test 2002 2007, design 2013

Deep mixing

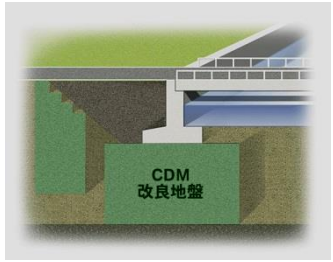
- Deep Mixing method
  - Mechanical mixing
    - Slurry type (wet method) — Cement slurry
      - CDM method
        - CMC method
        - DCM method
        - POCOM method
        - Demmick method
        - DECOM method
        - Oval-DM method
        - CDM-Mega method
        - CDM-LODIC method
        - CDM-Column21 method
        - CDM-Land4 method
        - CDM-Lemni2/3 method
      - Tenocolumn method
      - CI-CMC method
      - MR-D method
      - JST method
      - SWING method
    - Powdery material type (dry method)
      - Lime — DLM method
      - Pulverized cement — DJM method
  - Combination of mechanical and high pressure injection
    - JACSMAN method
    - SDM method
  - High pressure injection
    - Binder injection — Binder slurry
      - CCP method
      - Minimax method
      - JMM method
      - FTJ method
    - Air and binder injection — Binder slurry
      - JSG method
      - Superjet method
    - Water, air and binder injection — Binder slurry
      - Column jet grout method
      - SSS-MAN method
      - TSK method
      - JEP method
      - LDis method
      - SDM method
      - S-RJP method
      - X-jet method

applications

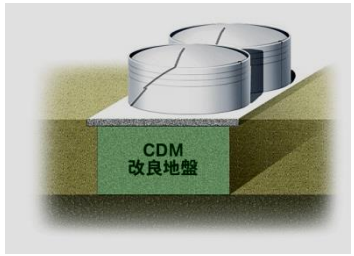
slip failure prevention
settlement reduction



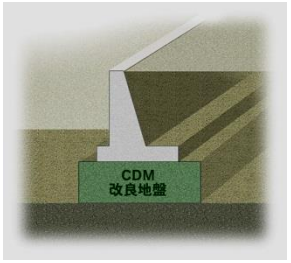
foundation of retaining wall

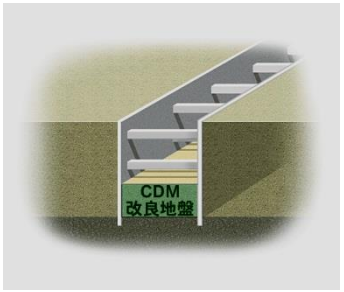


foundation of tank

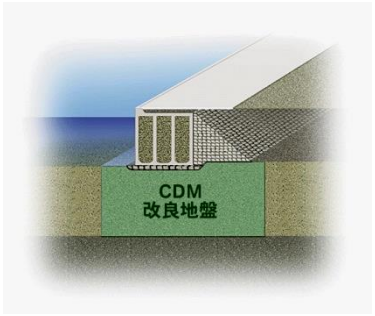


heaving prevention

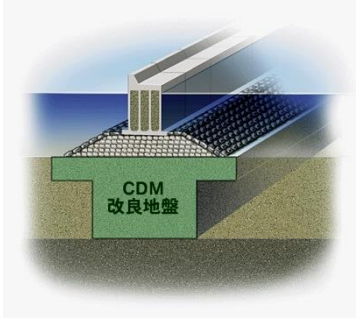




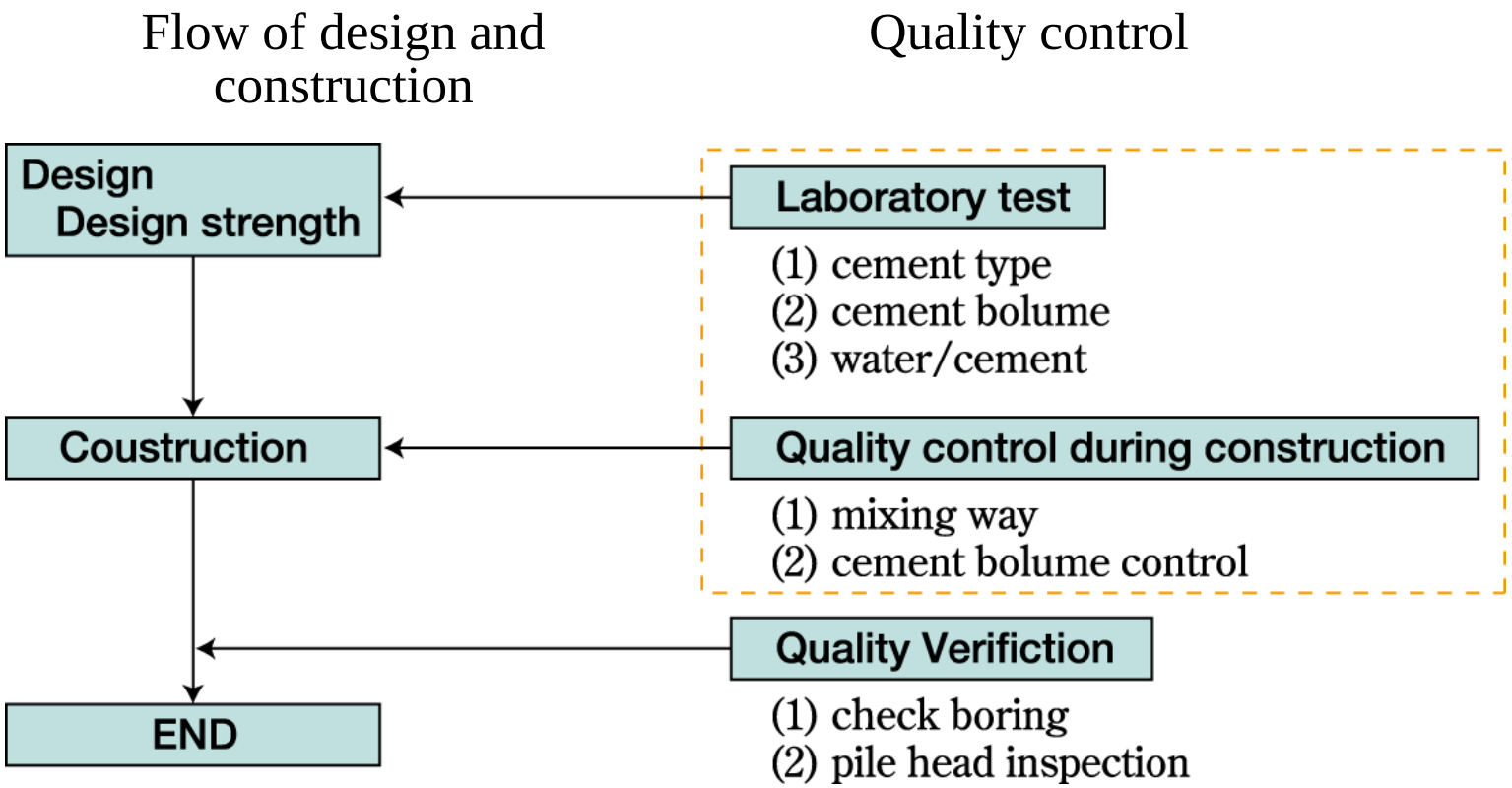
quay wall
revetment



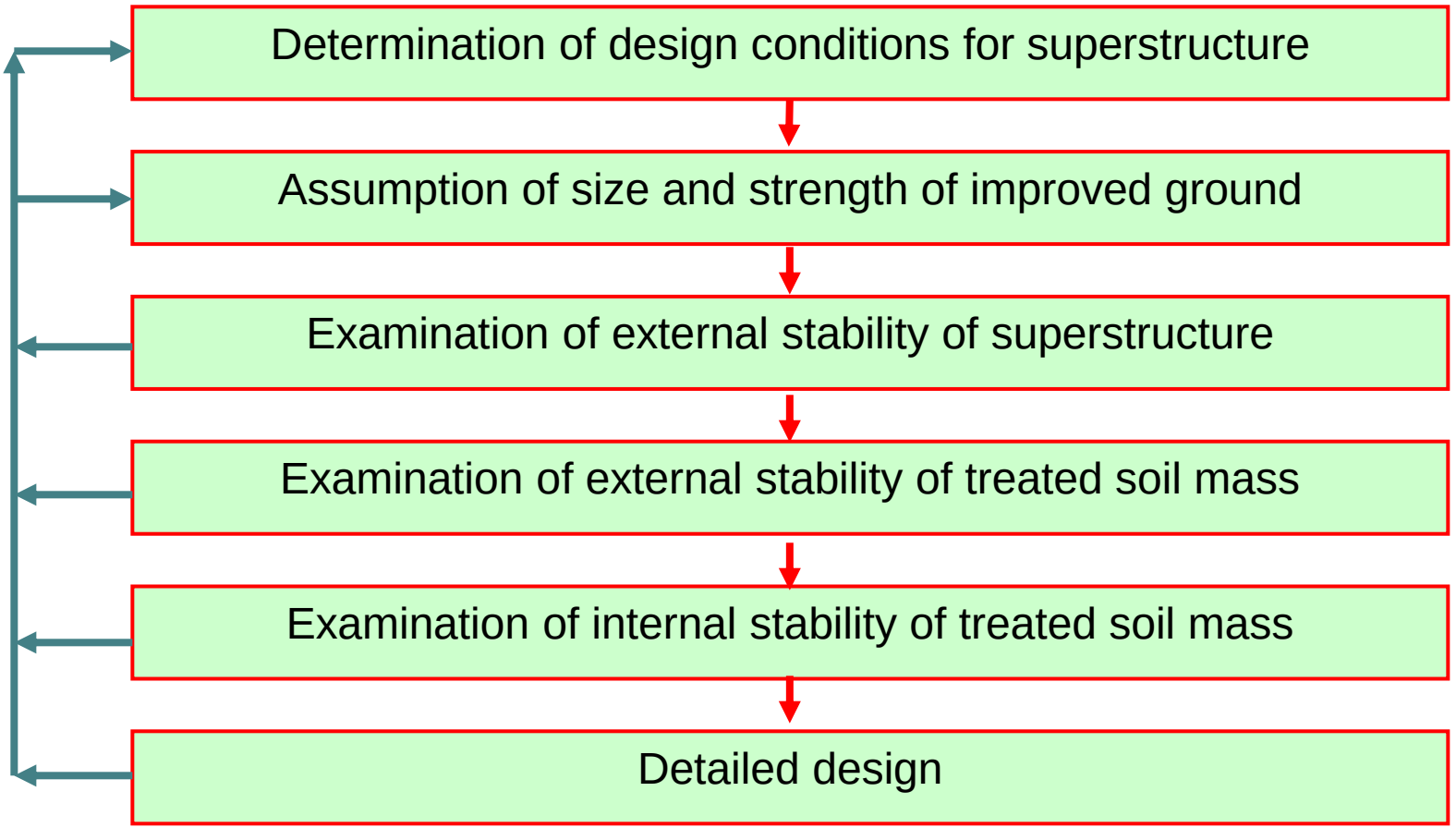
break water



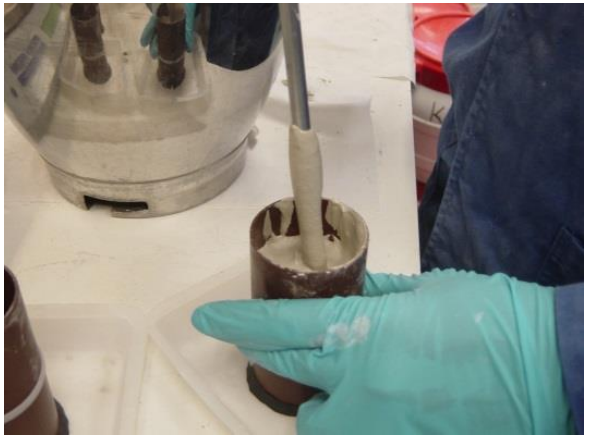
Design and construction procedure



Design procedure for block / wall type improved ground

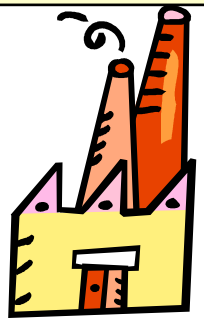


Laboratory test



Concrete vs. stabilized soil

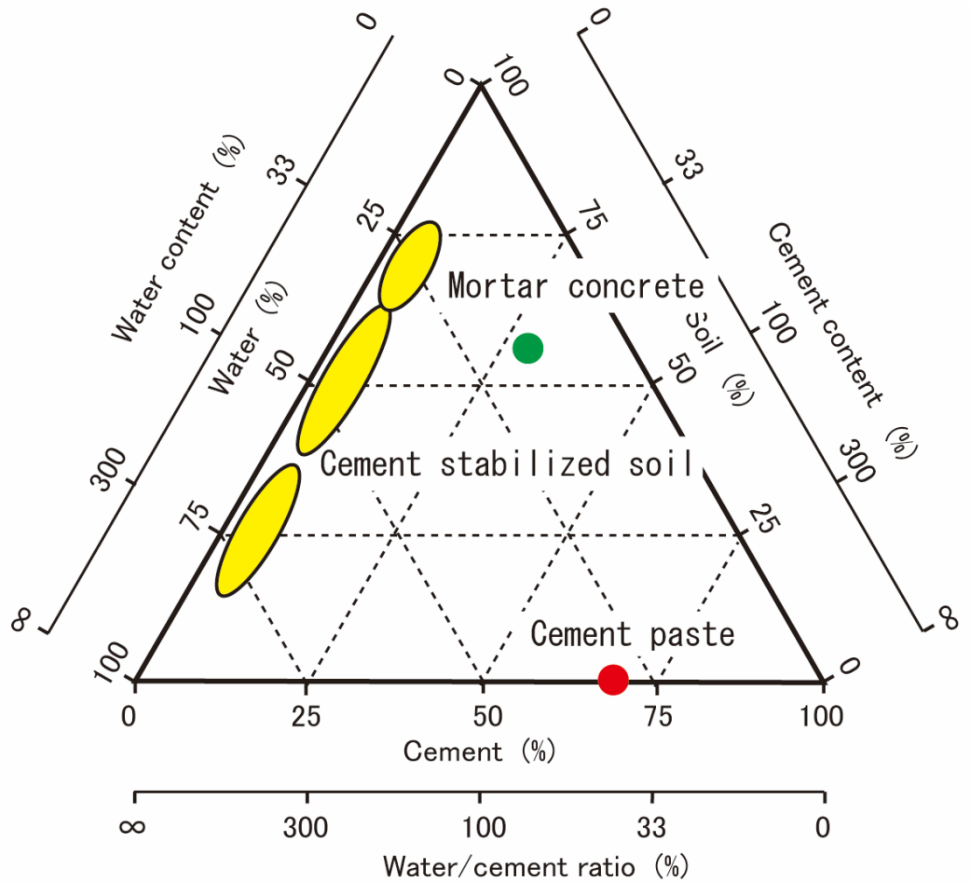
Properties	Concrete	Stabilized soil
UCS	18,000 – 45,000 kPa (100,000kPa)	500 – 2,000 kPa
CoV of UCS (lab.)	10 %	10 %
CoV of UCS (field)		25 – 35 %
strength ratio (field/lab.)	1.0	0.3 - 1.0
mixing	cement, water, aggregate, additives	cement, water, soil (sand, clay, organic soil, etc.)
mixing place	in plant and transport to site	field



factory manufacturing

order manufacturing

Concrete vs. stabilized soil



cement content

10～20%

water content of soil

30% (sand)

50～100% (clay)

300% (organic soil)

water/cement ratio

30～300%

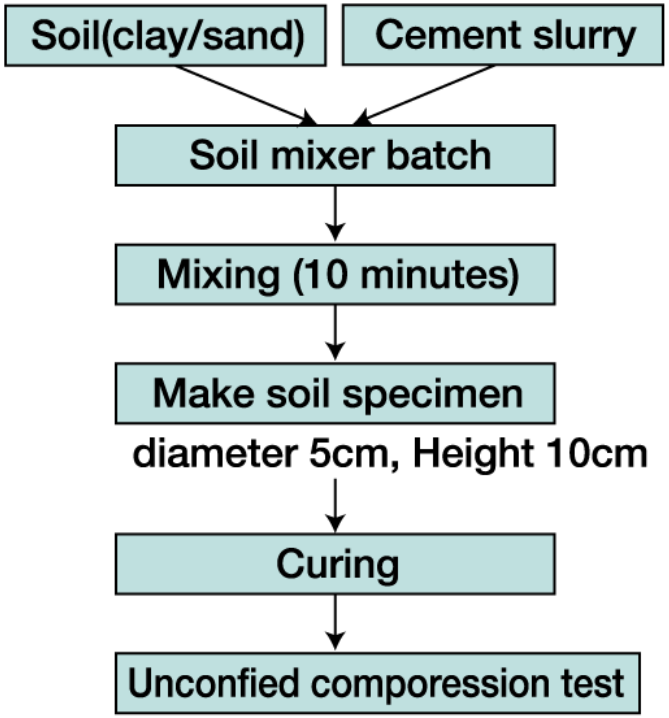
Factors Affecting Strength Increase

1.	Characteristics of binder	Type of binder Quality Mixing water and additives
2.	Characteristics and conditions of soil	Physical, chemical and mineralogical properties of soil Organic content pH of pore water Water content
3.	Mixing conditions	Degree of mixing Timing of mixing/re-mixing Quantity of binder
4.	Curing conditions	Temperature Curing time Humidity Confining pressure Wetting and drying/freezing and thawing, etc.

Laboratory test

OBJECTIVES:

To obtain the mixing condition to achieve the design strength at field.



mixing

trimming

molding

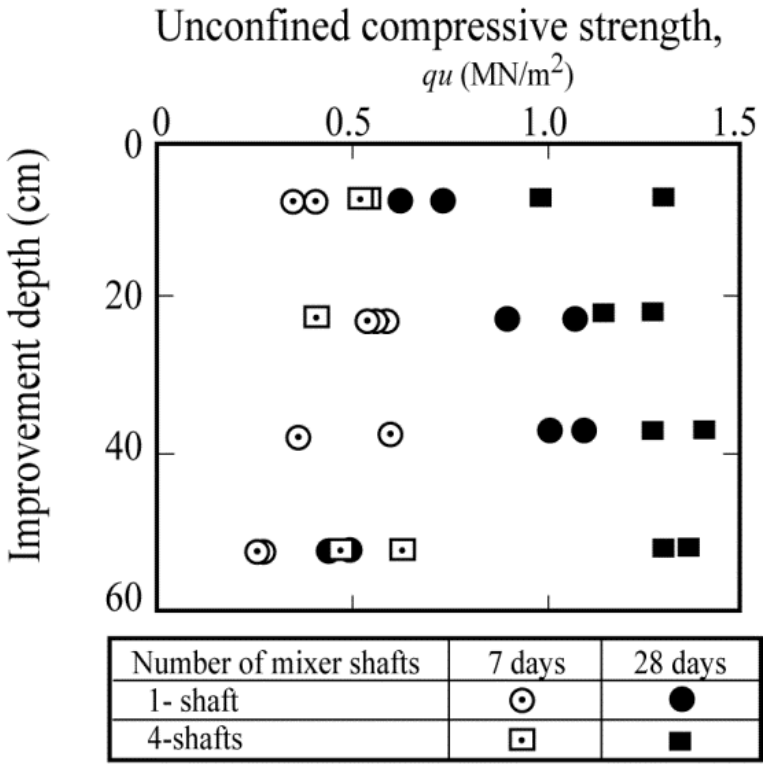
measuring

capping

testing

DM machine

Effect of number of mixing shafts

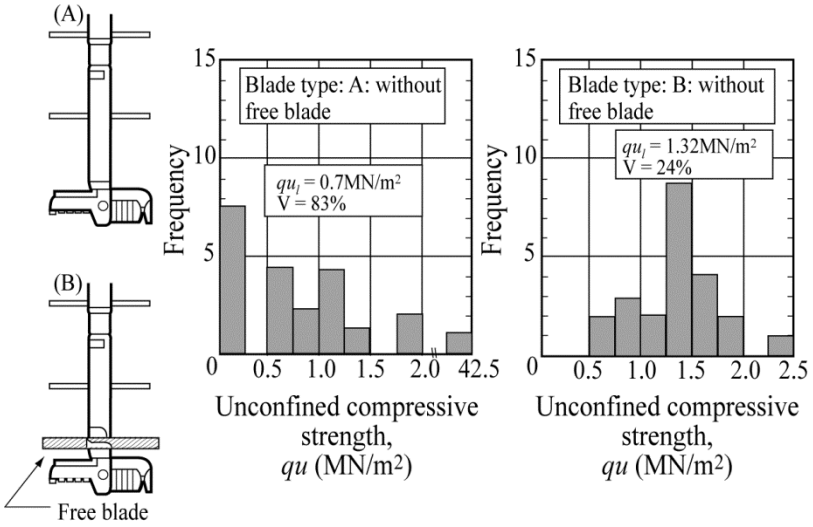


entrained rotation phenomenon
a condition in which disturbed soil adheres to and rotates with the mixing blade without efficient mixing.

Multi mixing shafts type machine usually has a bracing plate to keep the distance of the two mixing shafts. The plate is also expected to function to increase mixing degree by preventing the "entrained rotation phenomenon".

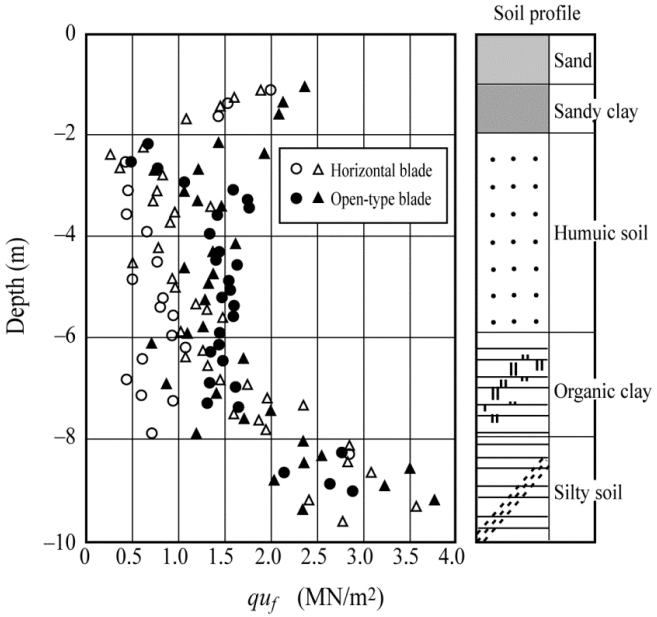
Effect of shape of mixing blade

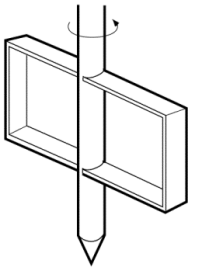
effect of free blade



The free blade increases mixing degree by preventing the "entrained rotation phenomenon".

effect of open-type blade

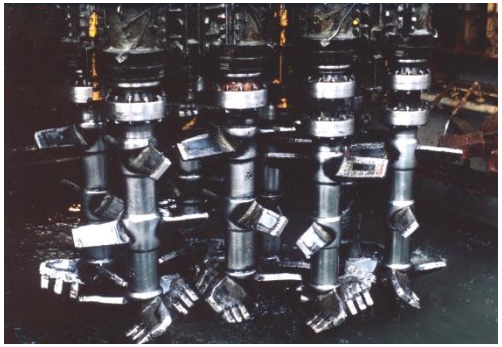




Line up of Cement Deep Mixing Method machines

Mixing blades

Japan



Nordic countries

USA

comparison of wet and dry method

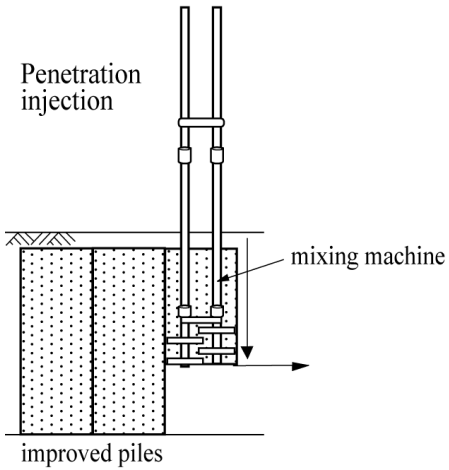
- machinery -

	Cement Deep Mixing		Dry Jet Mixing
	for marine	for on land	
number of mixing shaft	2 - 8	1 - 4	1 - 2
diameter of mixing blade	1.0 - 1.6 m	1.0 - 1.3 m	0.8 - 1.3 m
max. depth to be improved	-70 m (below sea level)	-48 m	-33 m
position of agent outlet	rod and blade	rod and blade	rod
injection pressure	100-300 kPa	100-300 kPa	700 kPa (air)

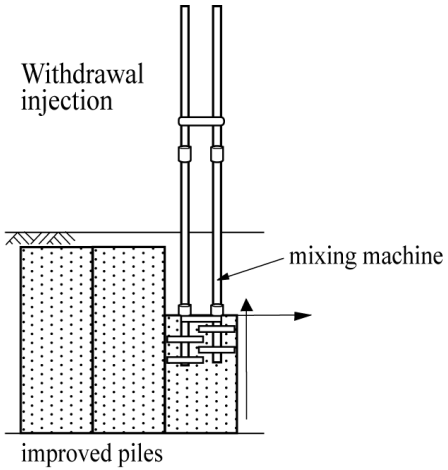
Execution

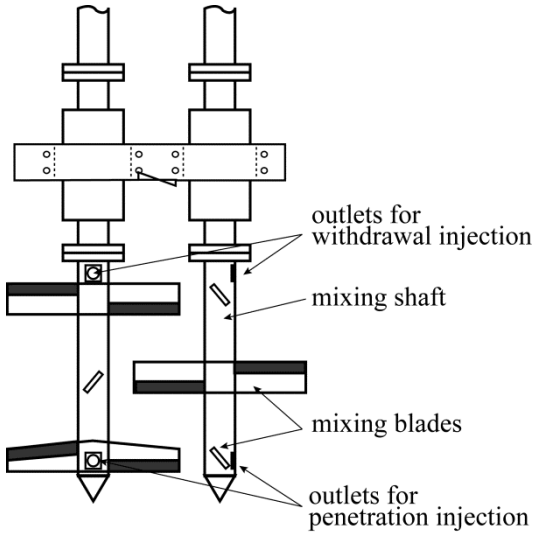
execution procedure

penetration injection



withdrawal injection



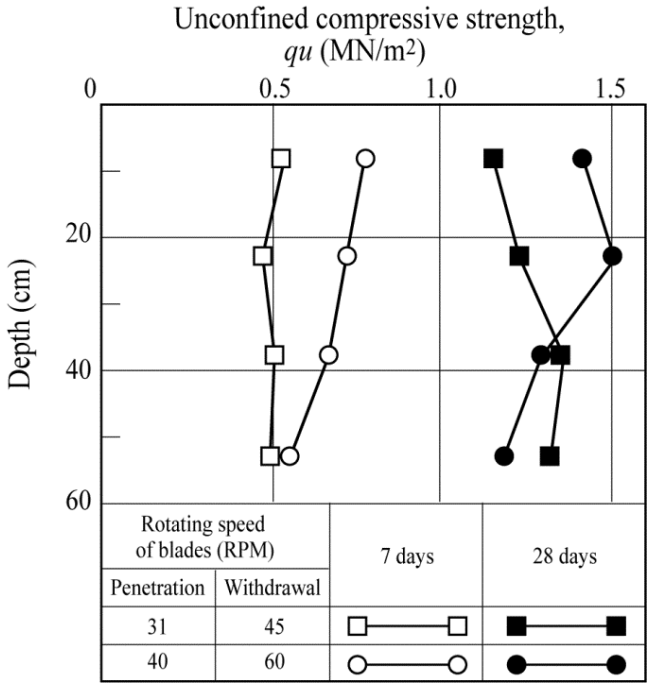


The penetration injection method:
beneficial for the homogeneity of column strength by mixing original soil twice.
risk to deadlock or cause serious damage to the machine during penetration.

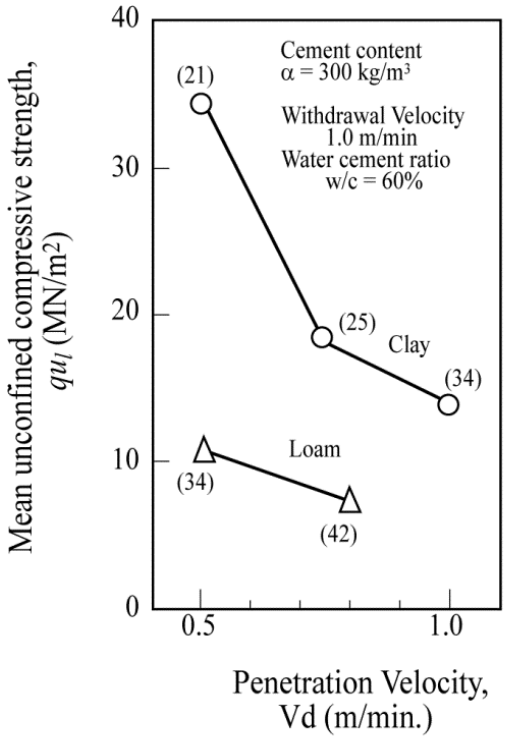
Injection outlet should be installed according to the injection method.

Effect of execution procedure

effect of rotation speed

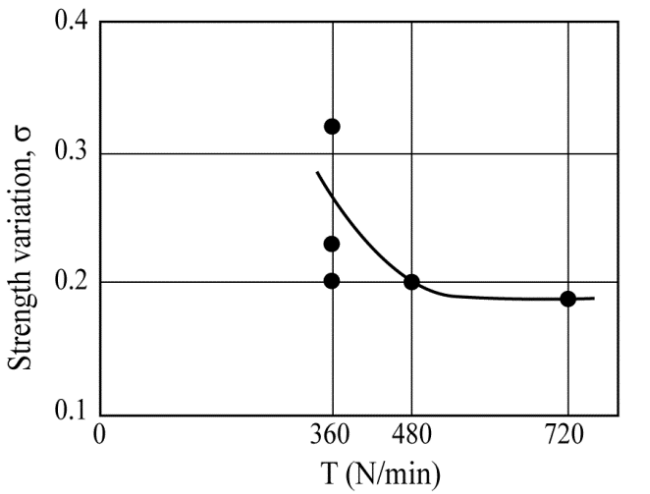


effect of penetration speed



( ) means
coefficient of variation

Blade rotation number



Total of rotations of mixing blades passing through 1 m shaft movement .

$$T = \Sigma M \cdot \left(\frac{N_d}{V_d} + \frac{N_u}{V_u} \right)$$

where

- T: blade rotation number (N/m)
- N_d: number of rotation of mixing blades during penetration (N/min)
- N_u: number of rotation of mixing blades during withdrawal (N/min)
- V_d: penetration speed of mixing blades (m/min)
- V_u: withdrawal speed of mixing blades (m/min)
- ΣM: total number of mixing blades

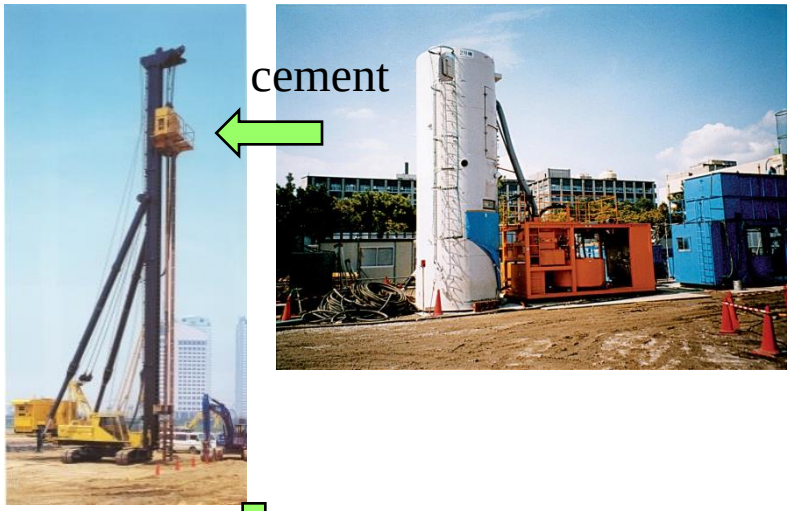
comparison of wet and dry method

- execution -

	Cement Deep Mixing		Dry Jet Mixing
	for marine	for on land	
penetration speed of shaft	1.0 m/min	1.0 m/min	1.0 - 2.0 m/min
withdrawal speed of shaft	1.0 m/min	0.7 - 1.0 m/min	0.7 - 0.9 m/min
rotation speed of blade	20 - 60 rpm	20 - 40 rpm	24 - 64 rpm
blade rotation number	350 /m	350 /m	274 - 284 /m
amount of stabilizing agent	70 - 300 kg/m^3	70 - 300 kg/m^3	100 - 300 kg/m^3
injection phase	penetration withdrawal	penetration withdrawal	withdrawal

Quality control

Execution



$$amount\,of\ cement = flow\,rate/\min. \times travel\,time$$

How to control amount of cement to be mixed ?

Plant:

supply cement slurry constant at rate

DM machine:

keep constant penetration and withdrawal speeds.

requires high capacity to plant and DM machine:

Plant:

manufacturing cement slurry

supplying cement slurry to DM machine

DM machine:

high power in driving mixing shafts and mixing blades.

QC/QA

blade rotation number

$$T = \Sigma M \cdot \left(\frac{N_d}{V_d} + \frac{N_u}{V_u} \right)$$

where

T : blade rotation number (n/m)

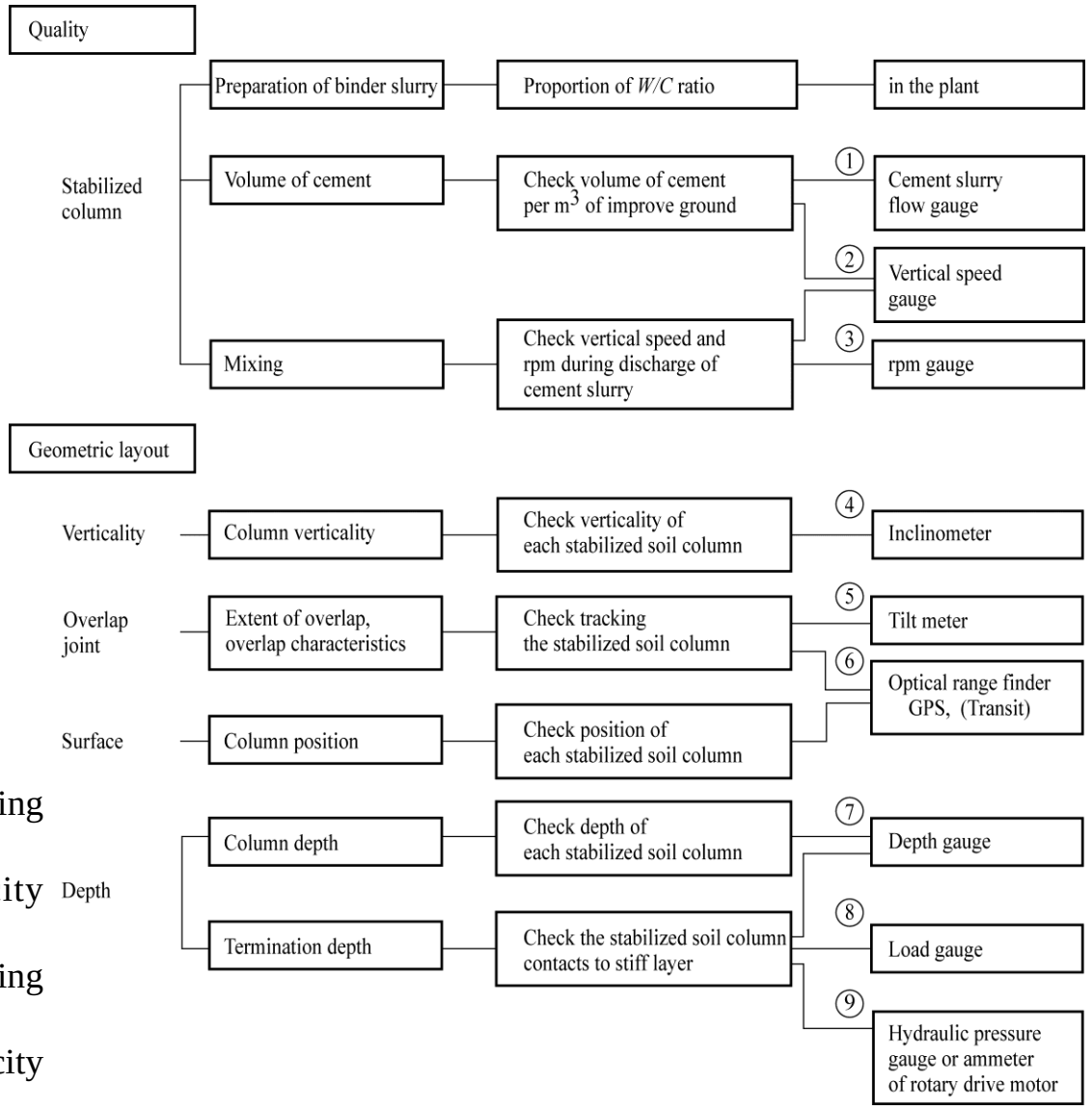
$\sum M$: total number of mixing blades

N_d : rotation speed of the blades during penetration (rpm)

V_d : mixing blade penetration velocity (m/min)

N_u : rotational speed of the blades during withdrawal (rpm)

V_u : mixing blade withdrawal velocity (m/min)



Quality assurance

Core boring

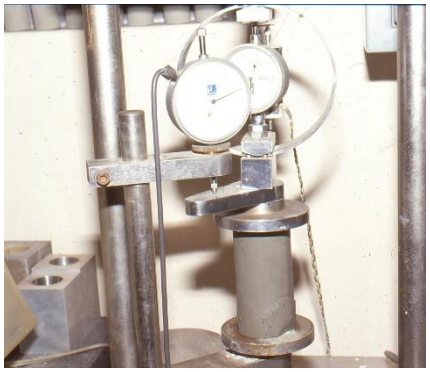
On land works:

3 cores < 500 columns
+ 1 core for every 250 columns

Marine works:

3 cores < 500 columns
+ 1 core for every 500 columns

UC test

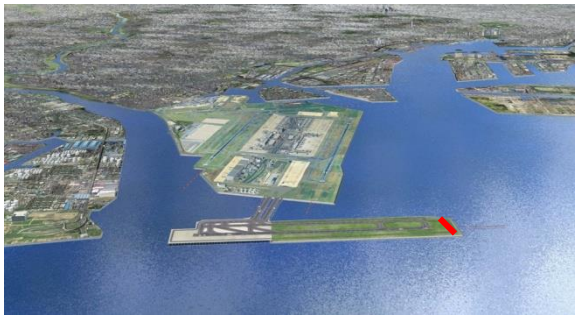


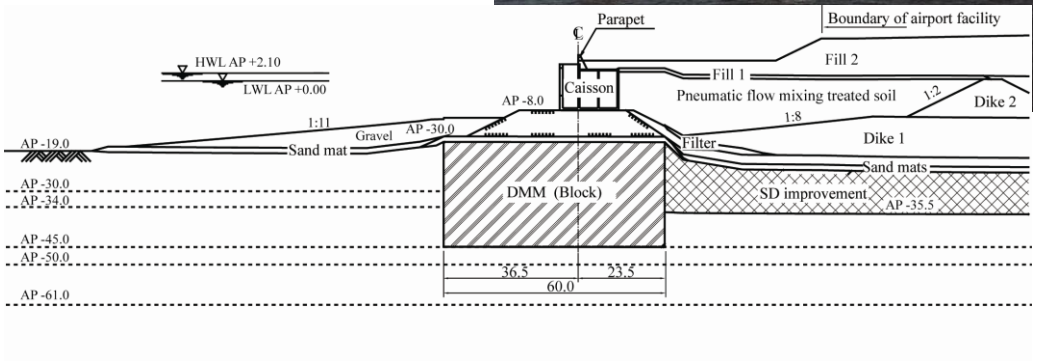
The JGS standard of UC test for cohesive soil is applied.

Case history

Mixing condition

- Tokyo/Haneda Airport -





	depth	soil property					cement factor	
		w_n (%)	ρ_t (g/cm^3)	w_l (%)	w_p (%)	*Ip*	CW rev. (kg/m^3)	CN rev. (kg/m^3)
surface layer	-19 to -21m	168-177	1.29	-	-	-	165	165
clay 1-C1	-21 to -30m	132-145	1.34-1.36	132-137	51-54	78-85	140	145
clay 1-C2	-30 to -34m	42-117	1.38-1.79	41-118	22-47	19-70	130	135
clay 2-C	-34 to -45m	35-52	1.75-1.84	32-55	18-24	14-31	110	120
sand 2-S	-45m deeper	37	1.827	-	-	-		

field strength

	depth	no. of specimen	field strength, q_{uf28} ave. (kN/m^2)	max. (kN/m^2)	min. (kN/m^2)	CV (%)	binder factor CW rev. (kg/m^3)		CN rev. (kg/m^3)	
surface layer	-19 to -21 m	20	3,409	5,608	2,391	27.1	165	160	165	160
clay 1-C1	-21 to -30 m	36	4,009	7,981	2,568	28.9	140	120	145	125
clay 2-C2	-30 to -34 m	16	3,929	6,116	2,257	21.3	130	110	135	120
sand 2-C	-34 to -45 m	44	4,534	7,595	2,617	26.4	110	80	120	85
total		116	4,094	7,981	2,257	28.3				

> 3,375 kN/m^2

< 35 %

field strength after modification

	depth	no. of specimen	field strength, q_{uf91} ave. (kN/m^2)	max. (kN/m^2)	min. (kN/m^2)	CV (%)	binder factor CW rev. (kg/m^3)	CN rev. (kg/m^3)
		30	3,568	6,923	2,027	35.8	160	160
surface layer	-19 to -21 m	16	4,010	6,052	2,009	31.7	160	160
clay 1-C1	-21 to -30 m	72	4,410	7,313	2,013	29.8	120	125
clay 1-C2	-30 to -34 m	32	4,561	7,726	2,092	33.9	110	120
clay 2-C	-34 to -45 m	88	3,871	6,076	2,038	26.2	80	85
total		238	4,066	7,313	2,009	31.4		

$> 3{,}375\ kN/m^2$ $< 35\ \%$

Concluding remarks

Japanese techniques and experiences on DMM is briefly introduced to show a similar to but quite different technology from concrete technology.

I hope this lecture will promote mutual understanding in concrete engineering and geotechnical engineering.