# Advanced Ground Improvement Technology and its application for the Coastal area

Mitsuo Nozu, Fudo Construction Inc.
URL:http://www.fudotetra.co.jp,
www.fudo-const.com
mitsuo.nozu@fudotetra.co.jp



## Contents

# 1. Introduction

## What is the problem of soft soil? Why it is necessary?

(1) Instable condition of the slope (Vietnam, Thailand)

Kobe/Rokko island (1995 Kobe earthquake)

Kushiro Port (2003 Tokachi-oki earthquake)

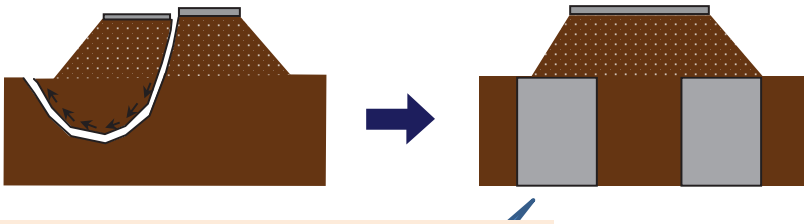
(2) Gap behind the abutment (Ho Chi Minh City, Vietnam）…Long term settlement

(3) Damage due to liquefaction/lateral flow at huge earthquake (Japan)



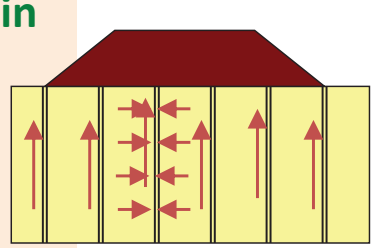
## How to choose the Soil improvement?

- Purpose (1. Increase stability, 2. Reduce settlement, 3. Seismic)
- Ground condition , Soil profile
- Circumstance, Environmental aspect (Vibration, Noise?)
- Logistics (Equipment/Material supply)
- Work Period
- Cost and Effect

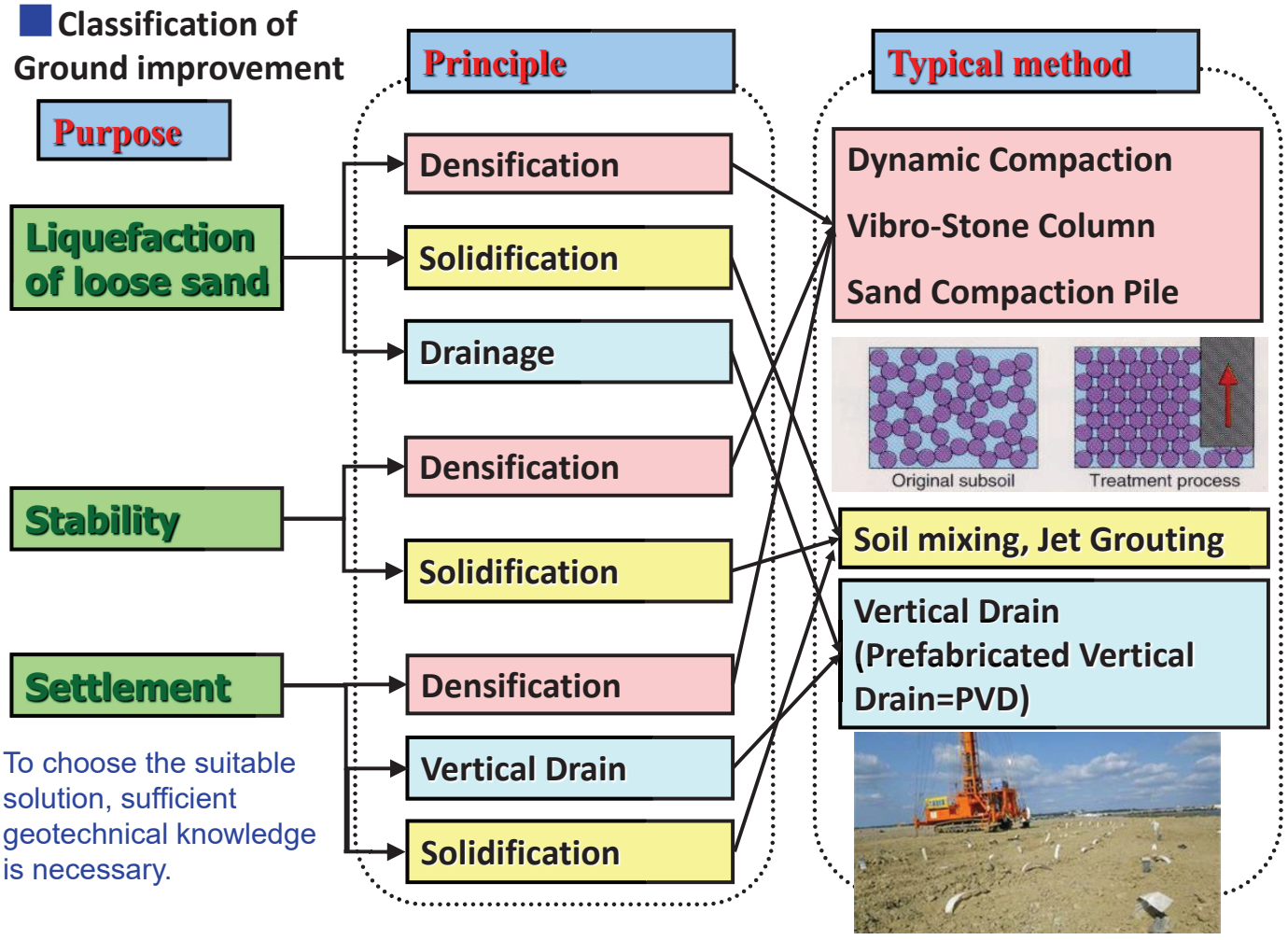


**Principles of Ground improvement methods**

**(1) Drainage……Sand Drain, Plastic board drain**
**(2) Compaction……Sand Compaction method**
**(3) Soil Stabilization….Deep Mixing**
**(4) Right weight material … Air-Foamed**
**(5) Others……Jet Grouting**



■ Classification of Ground improvement



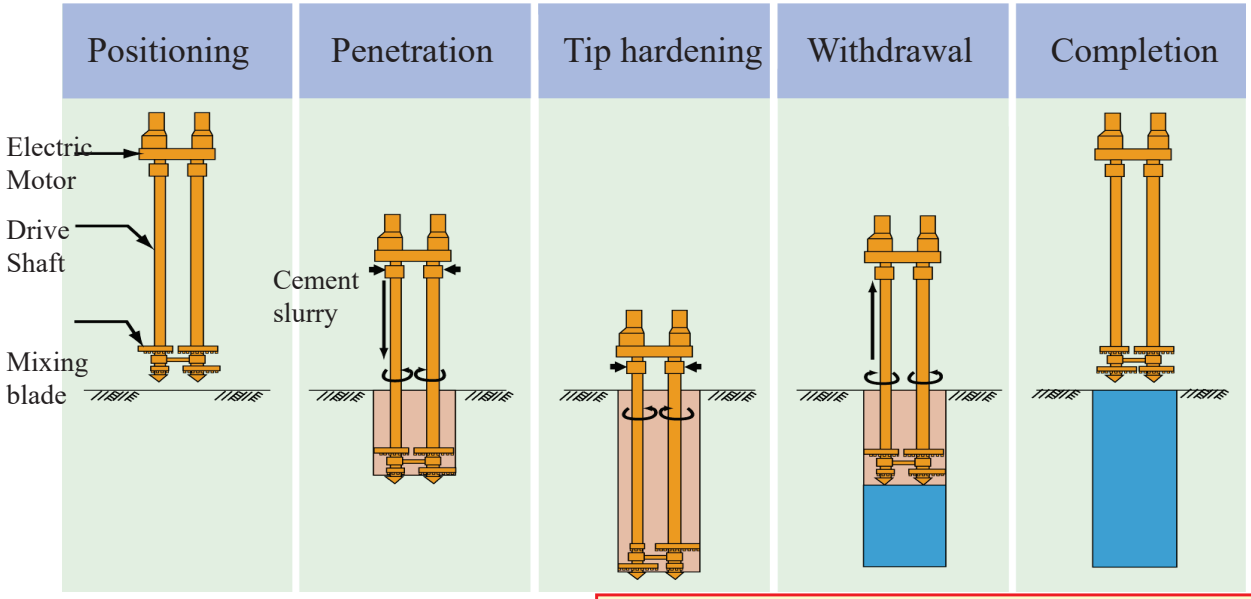

To choose the suitable solution, sufficient geotechnical knowledge is necessary.

# 2. Advanced Ground improvement Technology

## ■ Deep Mixing

Kanazawa Port, Seismic retrofit project

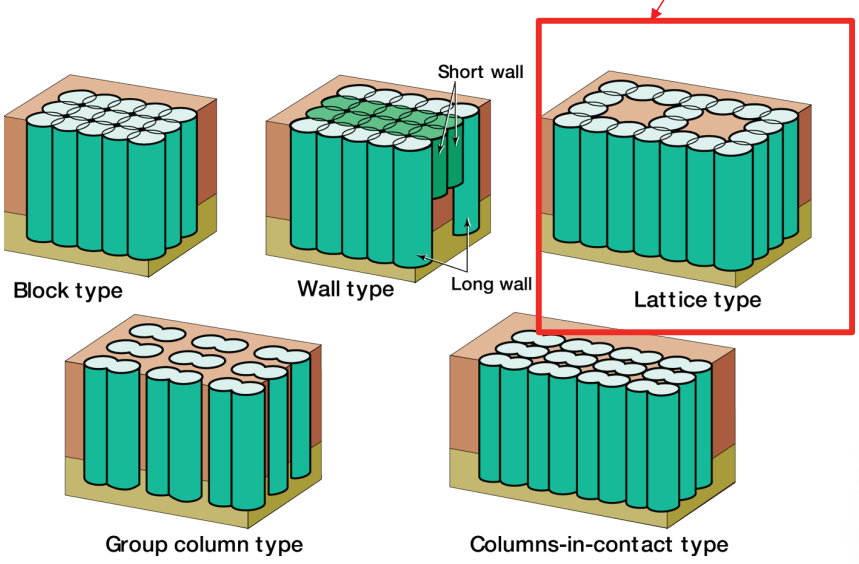
# Work Procedure

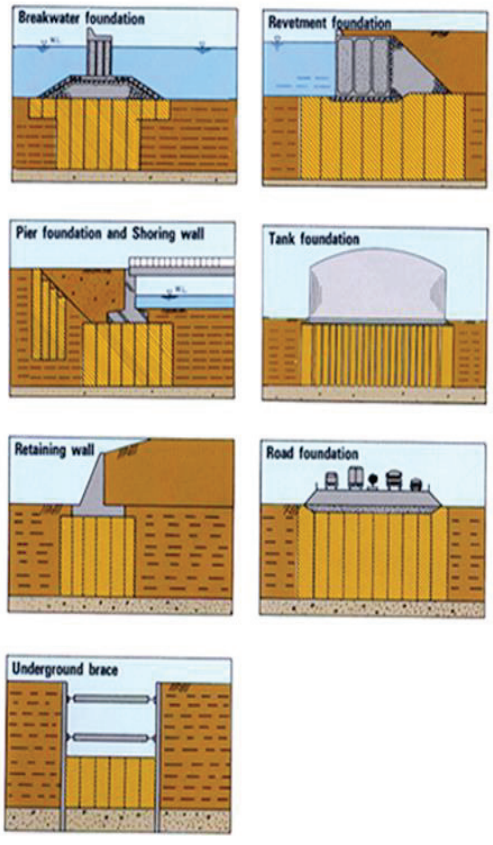



| | |
|---|---|
| Diameter of mixing blade: | 1.0 to 1.6 m |
| Number of mixing shaft: | 1 to 2 |
| Maximum depth: | 48 m |
| Rotating speed of blade: | 20 to 40 rpm |
| Penetration speed of shaft: | 1.0 m/min |
| Withdrawal speed of shaft: | 0.7 to 1.0 m/min |

# Application

It is suitable for liquefaction mitigation to prevent the shear deformation.

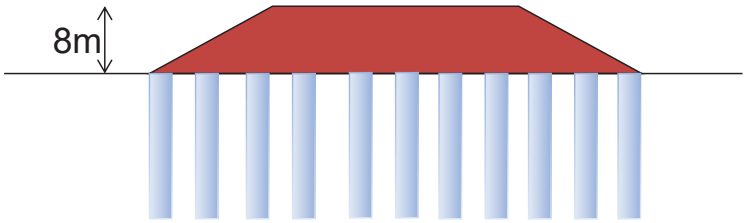


## Comparison between Concrete Pile and DMM

| | Concrete Pile | Deep Mixing |
|---|---|---|
| Method | Fully replaced | Mix with soil |
| Unconfined Compression Strength | 30MPa | 0.2-1MPa |
| Cement Dosage | 300kg/m$^3$ | 120-240kg/m$^3$ |
| Unit Price* | 300-400 USD/m$^3$ | 50-100 USD/m$^3$ |

*It is depend on the cement/labor costs and shifts.

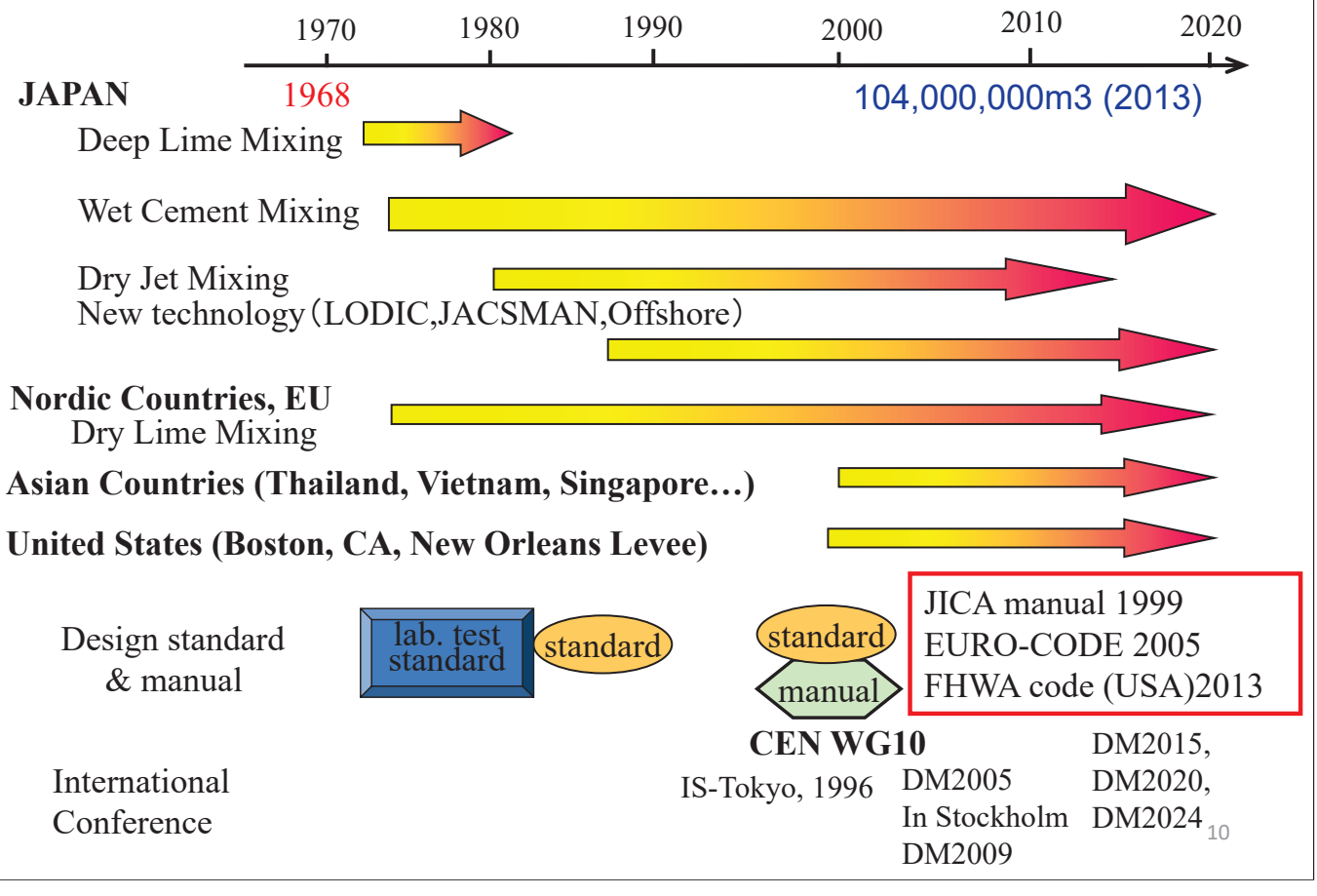


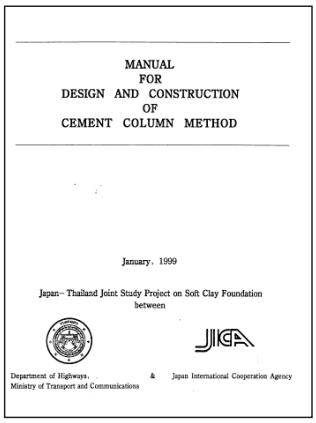

Embankment Height=8m,

Load=8mx20kN/m$^3$=160kPa

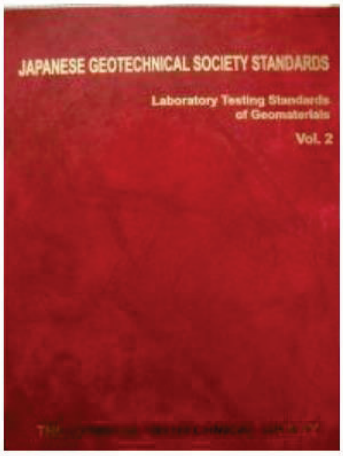
No need the Concrete pile.

## Development History / Documents



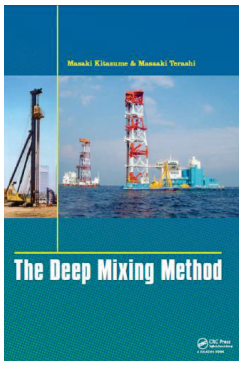



Japan-Thailand Joint Study Project for Soil Soil Treatment（DOH & JICA）,1995-1999

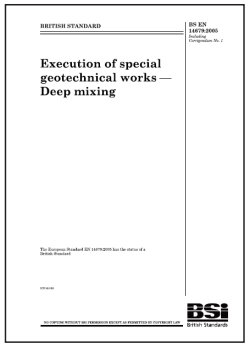




JAPANESE GEOTECHNICAL SOCIETY STANDARDS, Laboratory Testing Standards of Geomaterials (Vol.2) 2017

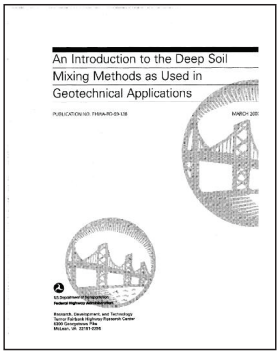
JGS0821: Summary of the Practice for Making and Curing Stabilized Soil Specimens without Compaction




Textbook written by Prof. Kitazume, 2003




Euro Code/BS standard, 2005



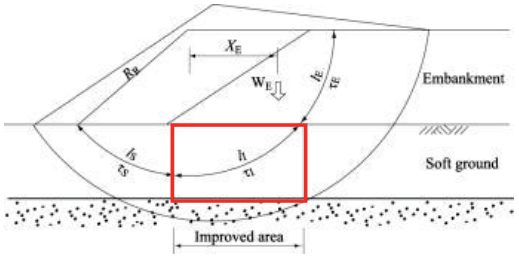

DSM Manual, U.S. Federal Highway Administration, 2013



# QC procedure

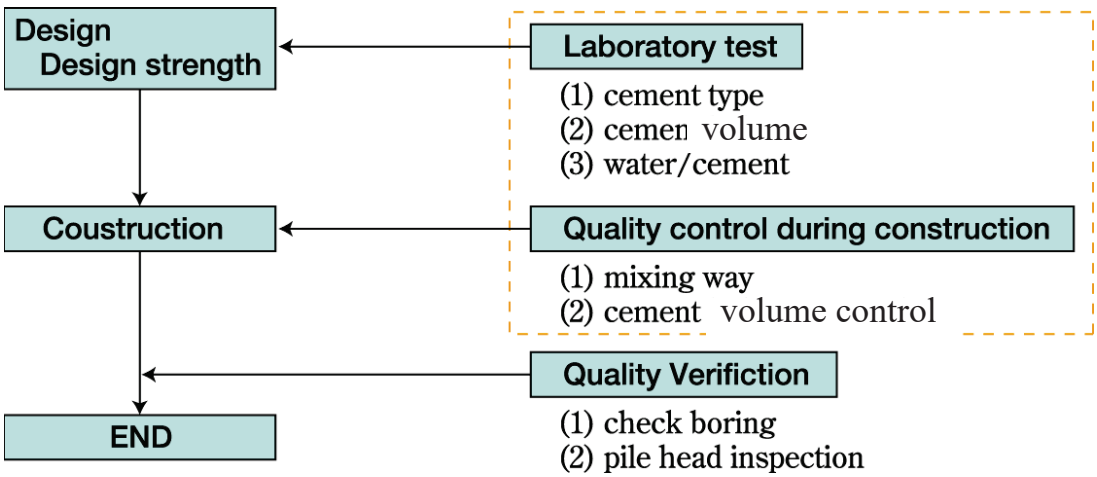
## DMM has Many uncertainties such as,

- Soil properties (Wn, WL, Wp, pH)
- Local cement property
- Mixing degree and Curing condition

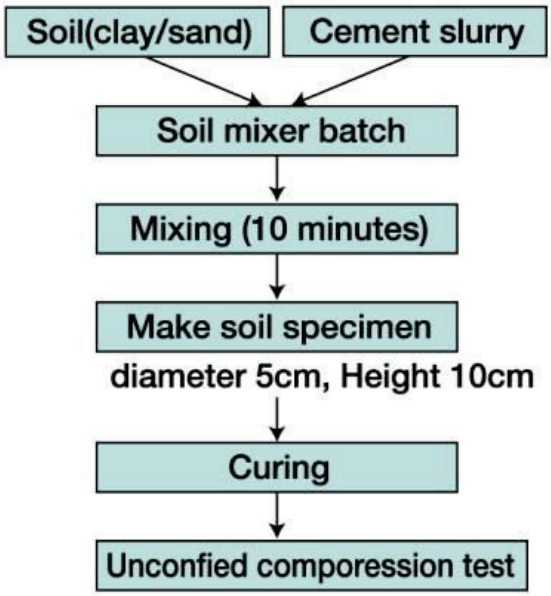



Flow of Design and Construction

Quality control



# Lab. Mix test



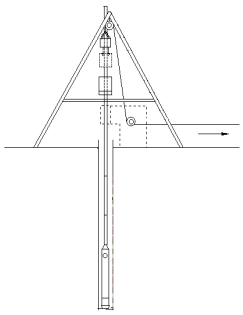

| Item | Description |
|---|---|
| cement type | portland cement |
| water type | city water,sea water |
| additives | No |
| W/C | 60-120% |
| cement volume | 80-200(kg/m³) |
| material age | 1,2,4(week) |
| number of moids | 2 or 3 |

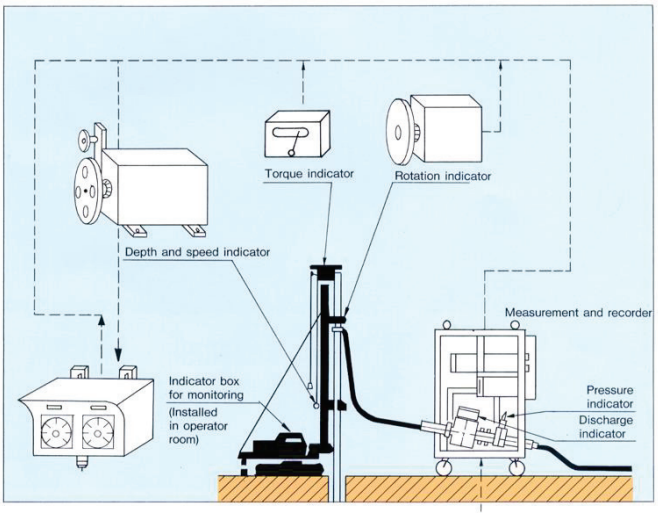
Japanese standard 'Summary of the Practice for Making and Curing Stabilized Soil Specimens without Compaction (JGS0821)'

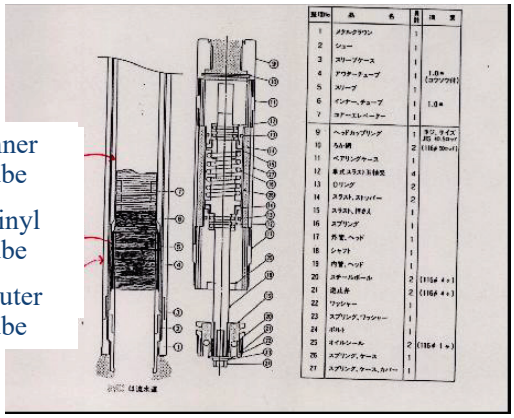


# QC during construction and Check boring

-Need consistent cement grout flow
-Check the density of the grout
-Rotation/penetration speed
-Core boring and UCS test





Inner tube

Vinyl tube

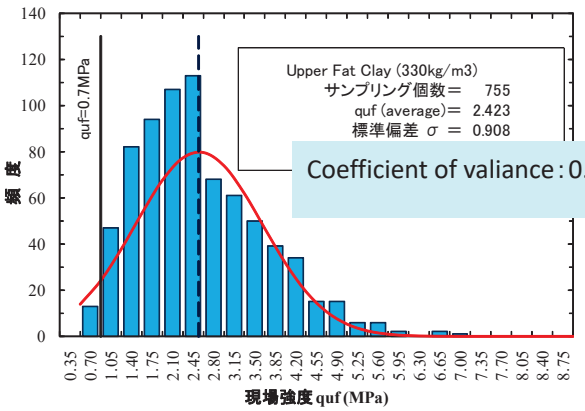
Outer tube

# New Orleans Levee Improvement, USA, Deep Mixing (2009-2011)

## Quality Control for production

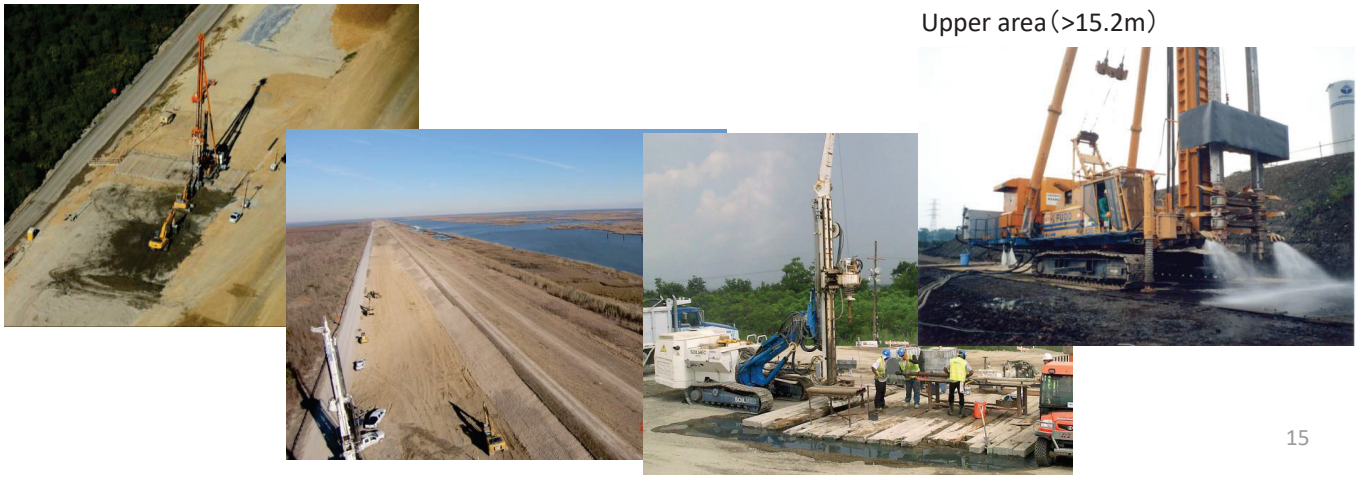
①After Hurricane Katrina disaster, US Corps of Engineers had to raise up the existing levee. To do that the ground needs to be improved by DMM (1.6m diameter twin column) with the Quantity: 7,900pcs, 628,000m3.

② 3% of Total number of Column was checked its strength.



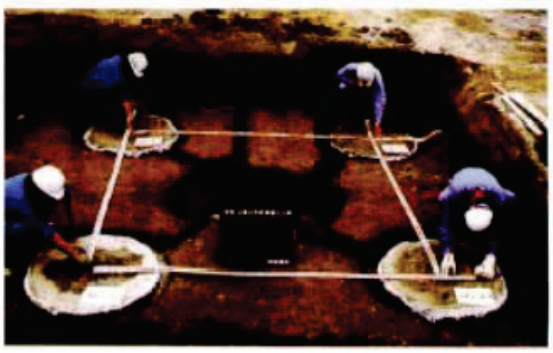

Coefficient of valiance : 0.38

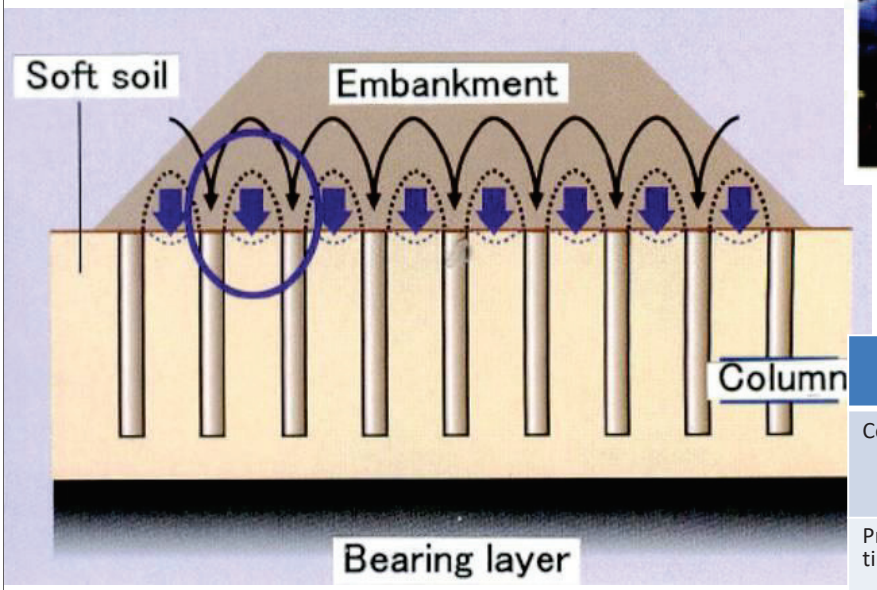
Upper area (>15.2m)





## ■Advanced technology: ALiCC design, Economical & Low improvement ratio, Arch angle in Embankment






**Comparison between ALiCC and PVD**

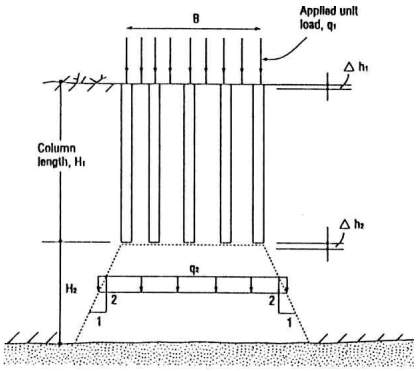
| | ALiCC | PVD |
|---|---|---|
| Concept | Support by DMM columns with wide spacing layout | Drainage by the plastic board drain |
| Production time | Short production time and no long term settlement | Need long waiting time for the consolidation and careful observation and management |
| Cost | 2.0 | 1.0 |

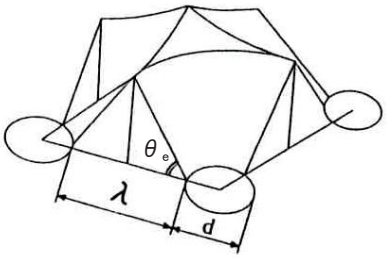
From the results of the joint study, we have establish new soft soil improvement concept as **ALiCC method**. The use of ALiCC technology has spread even to all in Japan because of **its shorter construction time against the conventional PVD option.** We have identified the shape of the arch effect between DM columns with simple formula.

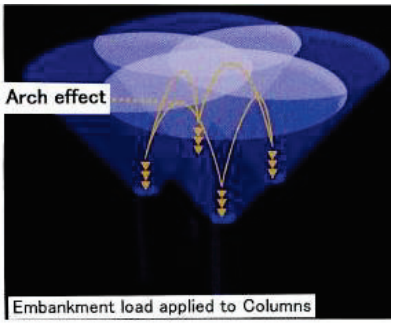
## Formularization of Arch volume（Miki, Nozu, Takeuchi, 2000.6）

$$V_c = \left[ \frac{\lambda(1+d)^2}{2} - \frac{\pi\left\{(\lambda+d)^3 - d^3\right\}}{24} + \frac{(4-\pi)(\sqrt{2}-1)(\lambda+d)^3}{24} \right] \tan\theta$$

Settlement calculation for Floating type foundation



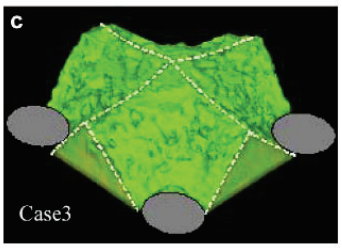




Design items

- Settlement calculation both on DMM pile and soil in between
- Stability analysis
- Bearing capacity at bottom

Ohtani and Hirai（2005）

- X-ray CT scanner can visualize the density change and verify the arch angle, which is similar with the estimated shape.




→Application in Asian countries.

(1) SP-PSA Container terminal

(2) SPCT Container terminal

(3) Hong Kong airport

(4) Patimban port



# 3. Application in Oversea Coastal area

- Off-shore DMM
- Limited binder material (Cement+Gypsum for Organic clay)
- Local Soil Property (Expansive Soil)

## Offshore DMM

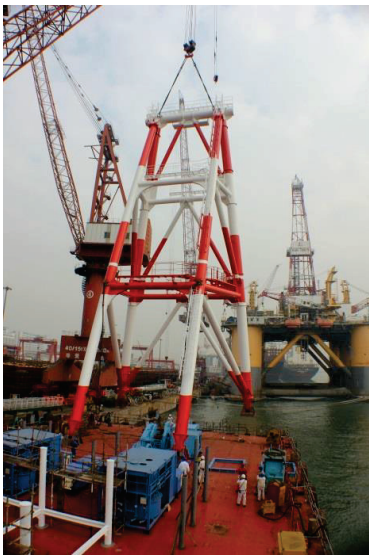
### Hong-Kong International Airport

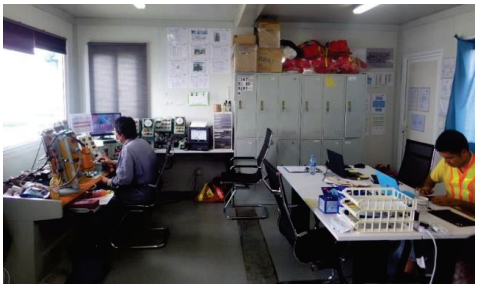
Off-shore DCM (2011, 2014, 2017-2018)

In Hong-Kong new runway project, there is a plan to treat huge amount of deep mixing columns under the new offshore runway, because there is contaminated soil in the water. So it is impossible to apply drainage method such as PVD and Sand drain. First and second trials of DSM has been performed in 2011 and 2014, and the Production work completed in 2018.

In this project, the design concept of large spacing DMM(ALiCC) has been used.

The barge has been mobilized in the Chinese shipyard by using local flat barge and imported parts from Japan.





## Limited binder material

### Vietnam : Can Tho Airport, Wet Deep Mixing Test Trial 2006.

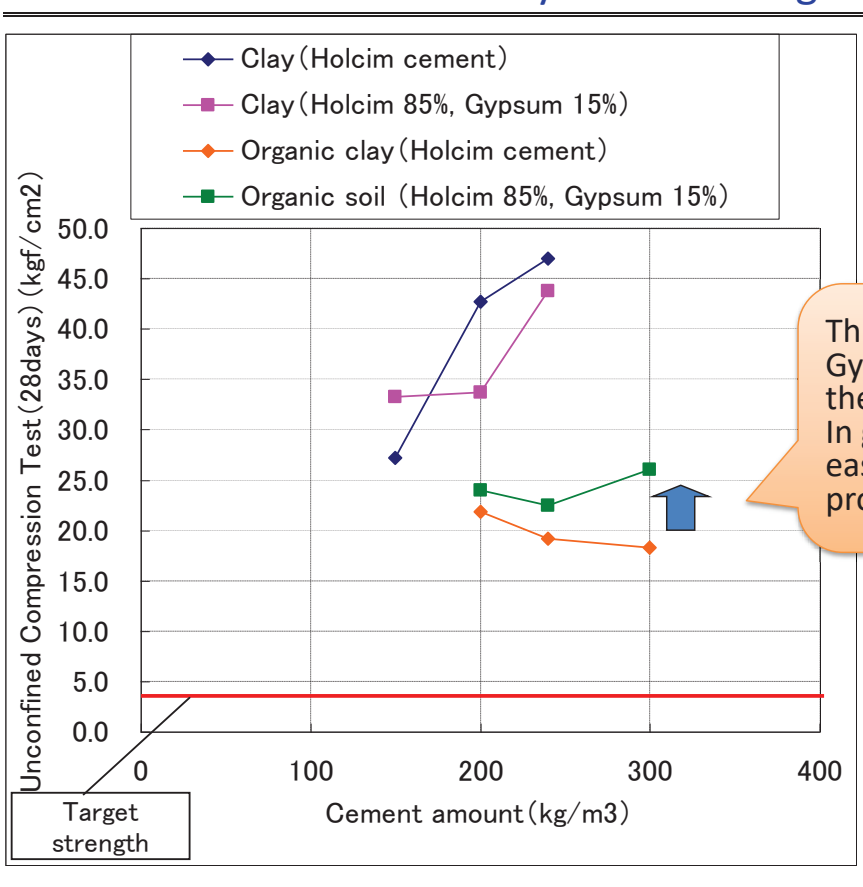
Free Blade is longer than other blade and free from rotation. So it can be fixed in the ground and assists the well mixing.

*Gypsum* was mixed with cement since there is some organic soil with low pH value.

### Soil Property

| GL / Color | Water content (%) | Fine Contents (%) | Liquid Limit (%) | Plastic Limit (%) | Plastic Index Ip (%) | pH* | Organic content (%)* |
|---|---|---|---|---|---|---|---|
| -1.5m / Gray | 69.5 | 98.2 | 103.6 | 38.4 | 65.2 | 4.3<br>4.2 | 9.9<br>13.3 |
| -1.7m / Black | 76.3 | 97.6 | 93.7 | 37.0 | 56.7 | 4.8<br>4.8 | 16.6<br>17.3 |

# Lab Test results after 28 Days from Mixing



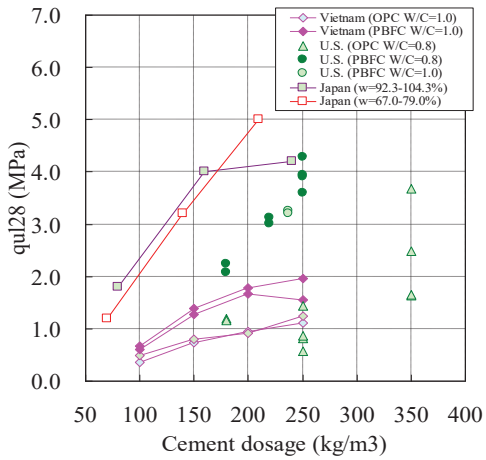

This is the effect of Gypsum inclusion for the organic clay.
In general, Gypsum is easy for the procurement.



## Quality control to Expansive soil (South Vietnam, Indonesia, USA)

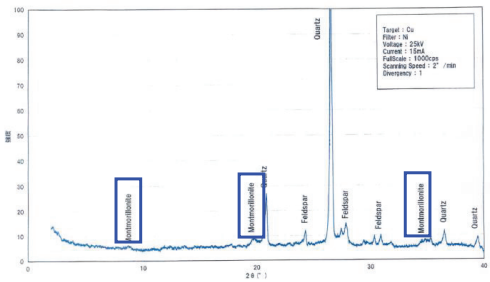
Very sticky, Absorbing water, Unmixed lumps

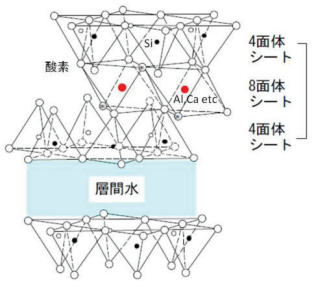
-In U.S. and Vietnam, UCS is rather lower than Japan.
-PBFC (slag cement) is better than OPC for secure UCS.




X-ray Diffraction analysis

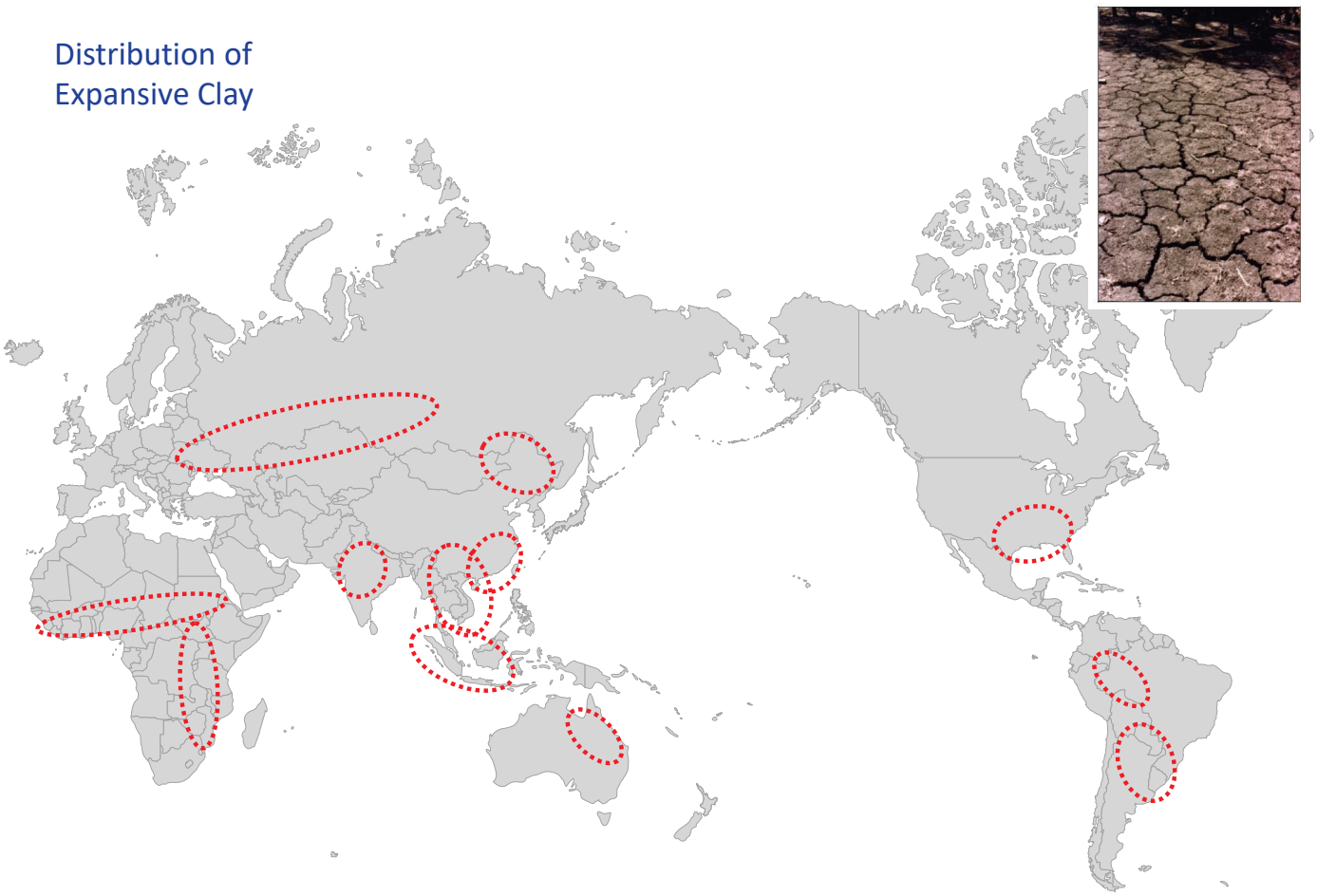
Montmorillonite was detected in Vietnam, Southern US.




United States (Mississippi)

## Distribution of Expansive Clay

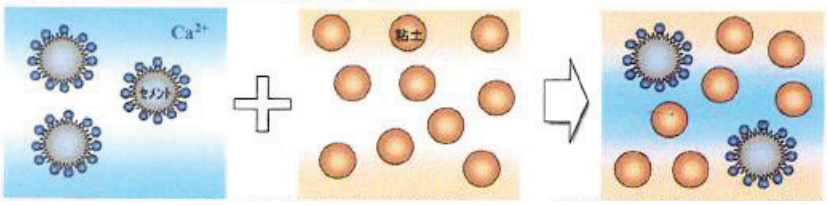




→ It is spread over the world. But basic geotechnical research study for the quality of cement mixing is still on the way.

## Condensation due to cation exchange (Aoyama, 2000)

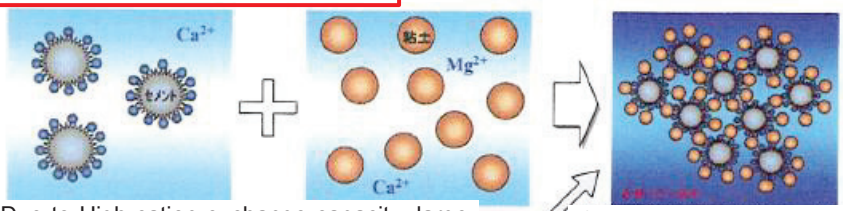
Low cation exchange capacity




Clay is charged by negative electric, so that clay and cement are pulled each other. However due to low cation exchange capacity, no quasi-condensation will be observed.

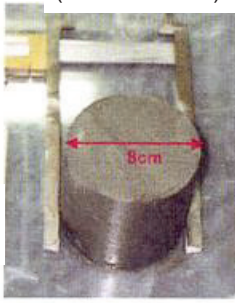

Flow condition
(No condensed)

High cation exchange capacity



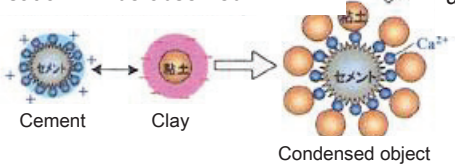

Due to High cation exchange capacity, large quasi-condensation will be observed.

Quasi-condensation object grow up and lose fluidity shortly.




Flow condition
(Quasi-condensed)

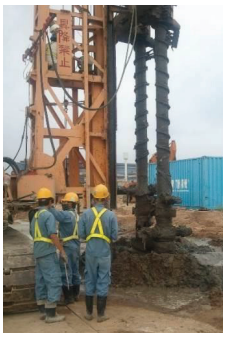
Expansive Clay

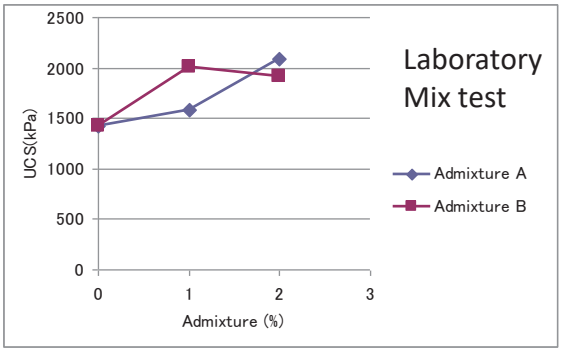


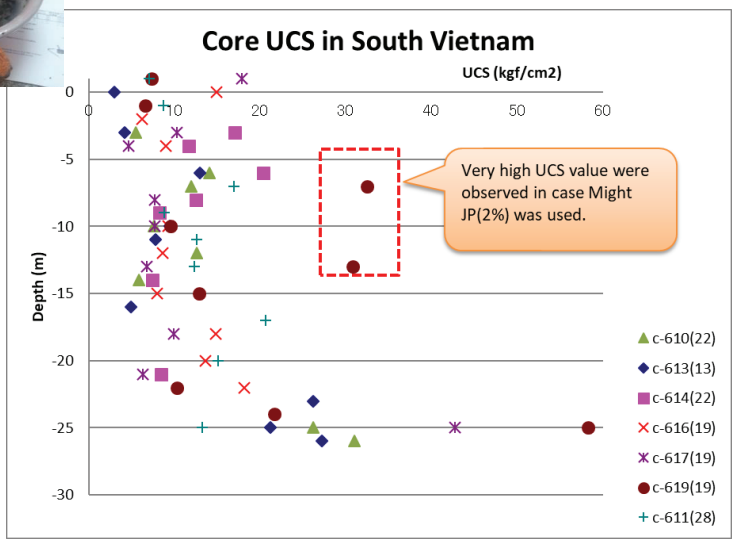

Aoyama has presented before in 2000, in the high cation exchange capacity clay (many minus ion) like Montmorillonite they lose the Ca2+ ion and does not work the hydration and lost the fluidity.

## Effect of Admixture in South Vietnam (Nozu, 2012)

| | Admixture A | Admixture B |
|---|---|---|
| Producer | BASF | KAO |
| Material | Pozzolith No89 (retarder) | Mighty 21JP |






# Conclusion

1. Deep mixing technology and its advanced/economical design is introduced.
2. In the application for oversea coastal area, some effective procedures such as local barge mobilization, gypsum for organic clay and admixture for the expansive clay for the local soil/condition are introduced.

Thank you for your kind attention.