PIANC Asian Seminar 2024

Ground improvement technologies for soft soils: Japan's experiences in coastal development

軟弱地盤の地盤改良法：沿岸開発における日本の経験

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北海道大学　渡部 要一

Ground Improvement 地盤改良

Technologies to strengthen the ground 地盤を強くする技術

Purposes

Increasing shear strength (in stability problem)

せん断強さを増加させる（安定問題）

Reducing compressibility (in settlement/consolidation problem)

圧縮性を低下させる（沈下問題）

Almost common
ほぼ共通

Lightening and strengthening (in stability problem)

固化・軽量化させる（安定問題）

Increasing liquefaction resistance (in seismic problem)

液状化抵抗を増加させる（地震防災）

Increasing shear strength (in stability problem)

せん断強さを増加させる（安定問題）

Principles for ground improvement 基本的な地盤改良の原理：

Densification for clay 粘土を密詰め状態にする

Vertical drains to promote consolidation
(→ **SD**: Sand Drains, **PVD**: Prefabricated Vertical Drains)
鉛直ドレーン（→ サンドドレーンSD，プラスチックボードドレーンPBD）

Replacement with good material 良い材料で置き換える

Displacement method (→ Ground displacement, **SCP**: Sand Compaction Piles)
置換工法，サンドコンパクションパイルSCP

Solidification 固化処理する

DMM: Deep Mixing Method (CDM: Cement Deep Mixing Method) 深層混合処理
Shallow Mixing Method 浅層混合処理
Cement Treated Soil セメント固化処理土，気泡混合処理土（軽量土）

Reducing compressibility (in settlement/consolidation problem)

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Principles for ground improvement 基本的な地盤改良の原理：

Densification for clay 粘土を密詰め状態にする

Vertical drains to promote consolidation with preloading
(→ **SD**: Sand Drains, **PVD**: Prefabricated Vertical Drains)
+ **Preloading** (surcharge by sandfill/vacuum)
鉛直ドレーン（サンドドレーンSD，プラスチックボードドレーンPBD）
＋プレロード（盛土，真空圧＝大気圧による圧密）

Solidification 固化処理する

Cement Treated Soils セメント固化処理土，気泡混合処理土（軽量土）
Lightness with shear strength

Most of these technologies are common with that for increasing shear strength

Lightening and strengthening (in stability problem)

軽量化と**固化**（安定問題）

Principles for ground improvement 基本的な地盤改良の原理：

Solidification (+ Lightning) 固化処理する（＋軽量化する）

Cement **Treated Soils**

Mixture of **Dredged clay + Cement**

Mixture of **Dredged clay + Cement + Air-foam**

セメント固化処理土，気泡混合処理土（軽量土）

Increasing liquefaction resistance (in seismic problem)

液状化強度を増加させる（地震防災）

Principles for ground improvement 基本的な地盤改良の原理：

Densification for sand 砂を密詰め状態にする

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(**SCP**: Sand Compaction Piles, **CPG**: Compaction Grouting, Vibro-floatation)

締固め（サンドコンパクションパイルSCP，静的圧入締固めCPG，バイブロフローテーション）

Rapid dissipation of excess pore water 過剰間隙水圧の速やかな消散

Drainage (**Gravel Drains**)

排水（グラベルドレーン）

Replacement of pore fluid （間隙水の固化）

Chemical grouting

(→ by **injection**, **permeation**, cement/chemical **grouting**)

薬液注入（浸透固化，セメントグラウティング，ケミカルグラウティング）

Measures to prevent liquefaction other than ground improvement

地盤改良以外の液状化対策

Enclosing diaphragm wall/sheet pile, Lowering ground water level (Deep well)

変形抑制工，地下水低下工法（ディープウェル工法）

Increasing shear strength (in stability problem)

せん断強さを増加させる（安定問題）

Densification 密詰め状態にする

Vertical drains for clay to promote consolidation

(→ **SD**: sand drains, **PVD**: Prefabricated Vertical Drains)

鉛直ドレーン（→ サンドドレーンSD，プラスチックボードドレーンPBD）

Reducing compressibility (in settlement/consolidation problem)

圧縮性を低下させる（沈下問題）

Densification for clay by 粘性土を密詰め状態にする

Vertical drains to promote consolidation with preloading

(→ **SD**: Sand Drains, **PVD**: Prefabricated Vertical Drains)

+ preloading (surcharge by sandfill/vacuum)

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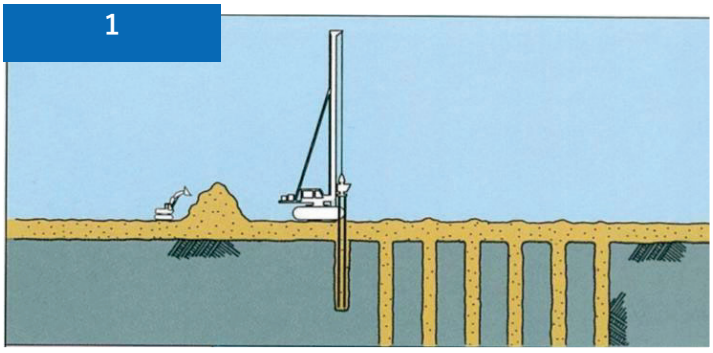
＋ プレロード（盛土，真空圧＝大気圧による圧密）

Almost common
ほぼ共通

Vertical drains + Preloading

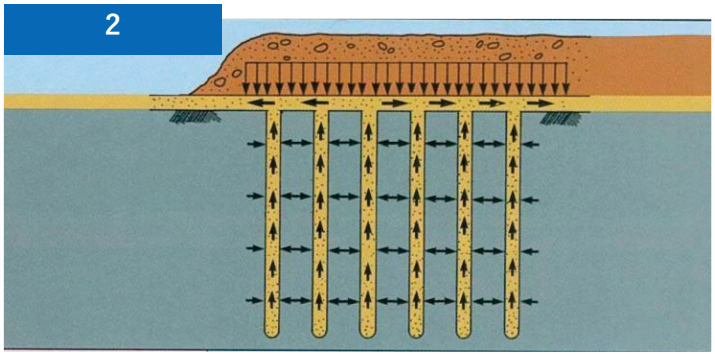
Illustration by Kanto Regional Development Bureau, MLIT

1



Installation of sand drains

2



Earth filling
→ Consolidation under a preload

Sand Drain method (SD)

Permeable sand is installed as **drain columns**

-The most popular and proven technology in coastal engineering in Japan
-To **accelerate/promote** the consolidation settlement in a wide area
-High installation ability
-High drainage capacity

Installation of Sand Drains (SDs)

Offshore construction

Land (onshore) construction

Prefabricated Vertical Drains (PVDs)

プラスチックボードドレーン（PBD）

Permeable **prefabricated vertical drains (PVDs)** are installed into soft deposit/ultra-soft deposit

- -The most popular and proven technology in coastal engineering in the world
- -To **accelerate/promote** the consolidation settlement in a wide area
- -**Continuity** of vertical drainage is ensured even in a dredged clay deposit
- -Small disturbance of the ground during the installation
- -Uniform drain performance in the longitudinal direction

Increasing shear strength (in stability problem)

せん断強さを増加させる（安定問題）

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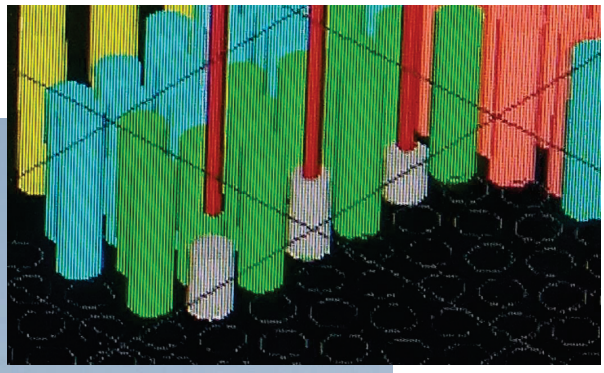
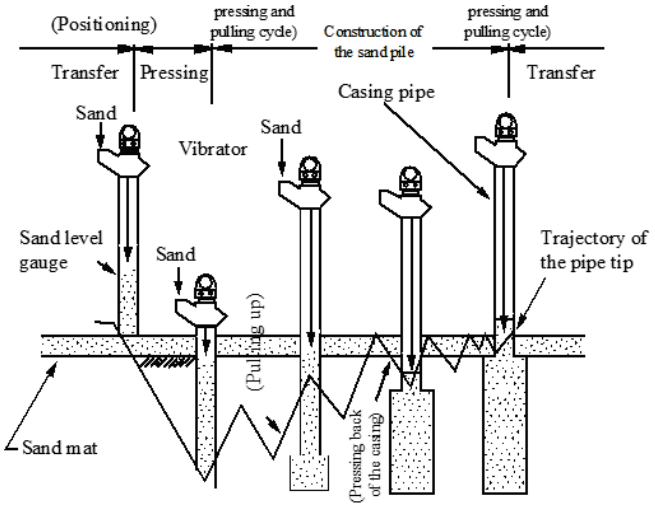
置換工法，サンドコンパクションパイルSCP

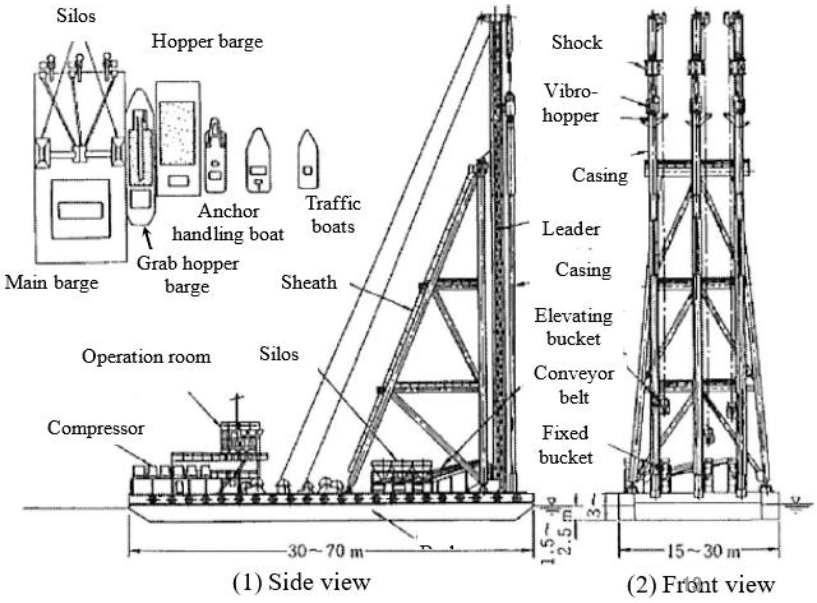
Sand Compaction Piles (SCPs)

サンドコンパクションパイル SCP





(a) Sand pile formation by vibro-driving and vibro-pulling-out



(1) Side view (2) Front view

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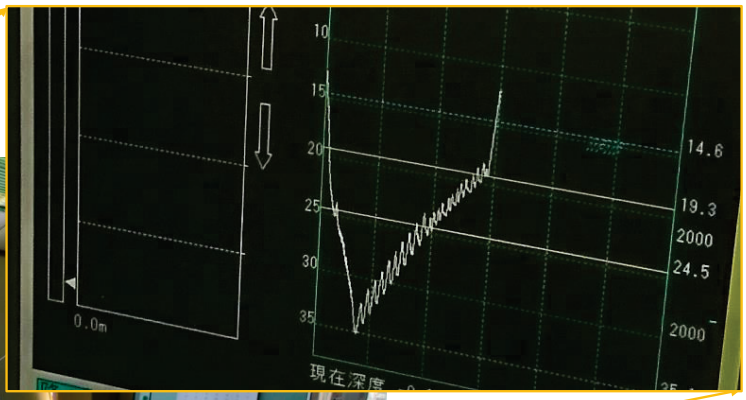
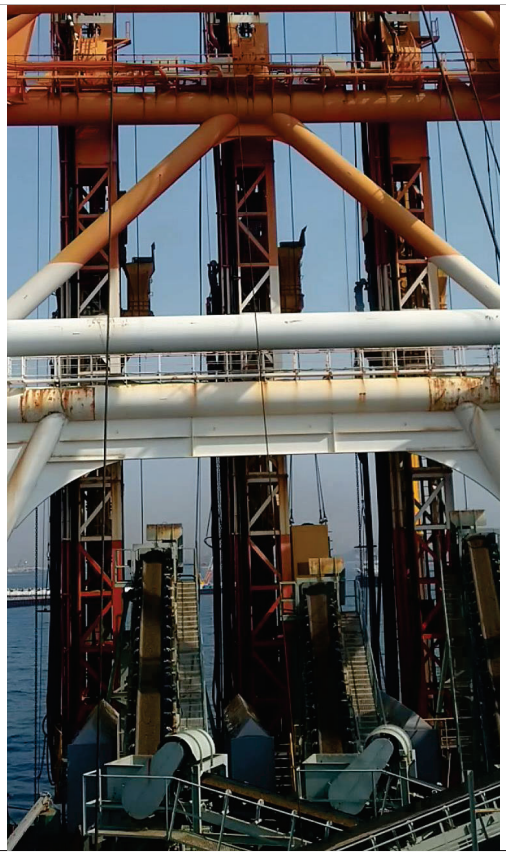
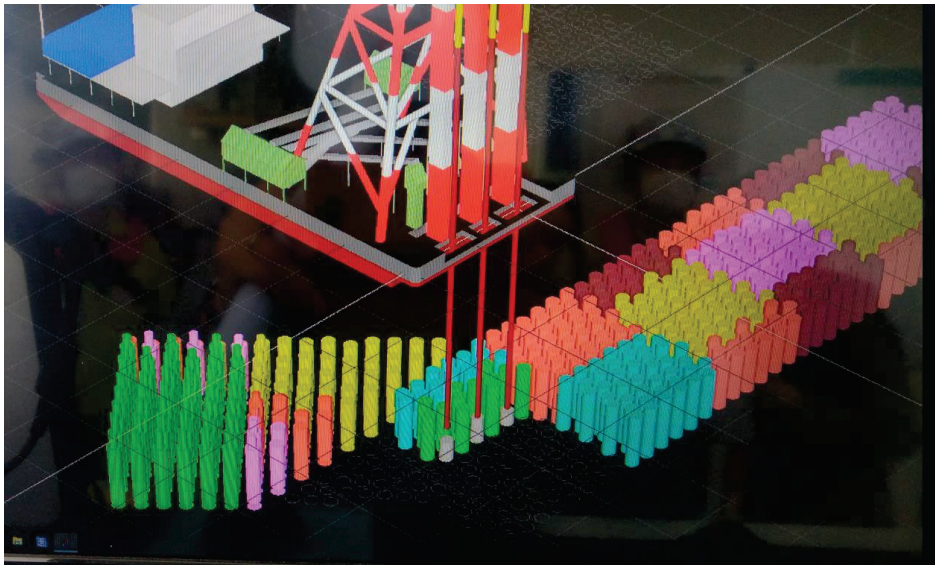
Operation room of SCP vessel





Installation of SCPs



Offshore construction

Land (onshore) construction

Increasing shear strength (in stability problem)

せん断強さを増加させる（安定問題）

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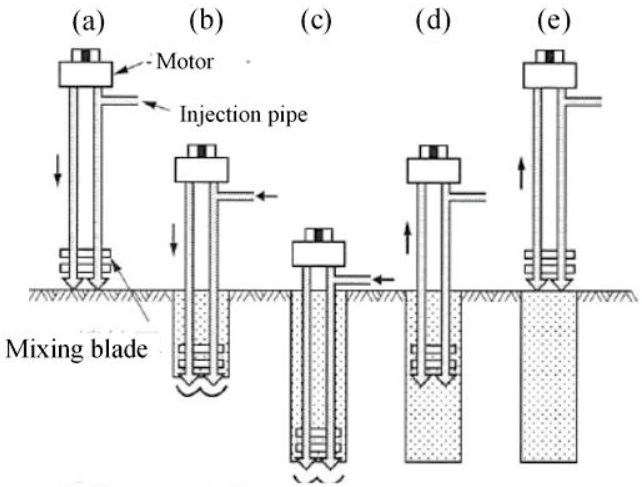
Shallow Mixing Method 浅層混合処理

Solidification (+ Lightning) 固化処理する（＋軽量化する）

Cement Treated Soil セメント固化処理土，気泡混合処理土（軽量土）

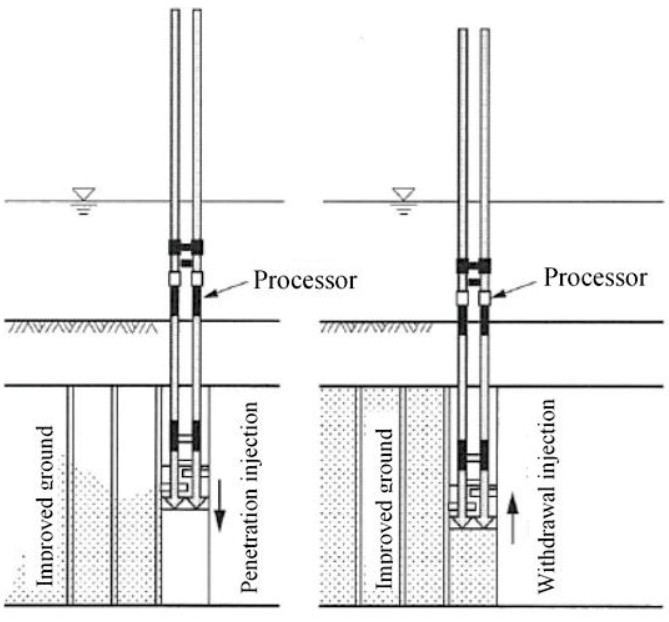
Deep Mixing Method (DMM) 深層混合処理工法(CDM)



(a) Start penetration

(b) Penetration, Injection, Mixture

(c) Finish penetration



Penetration injection method　Withdrawal injection method

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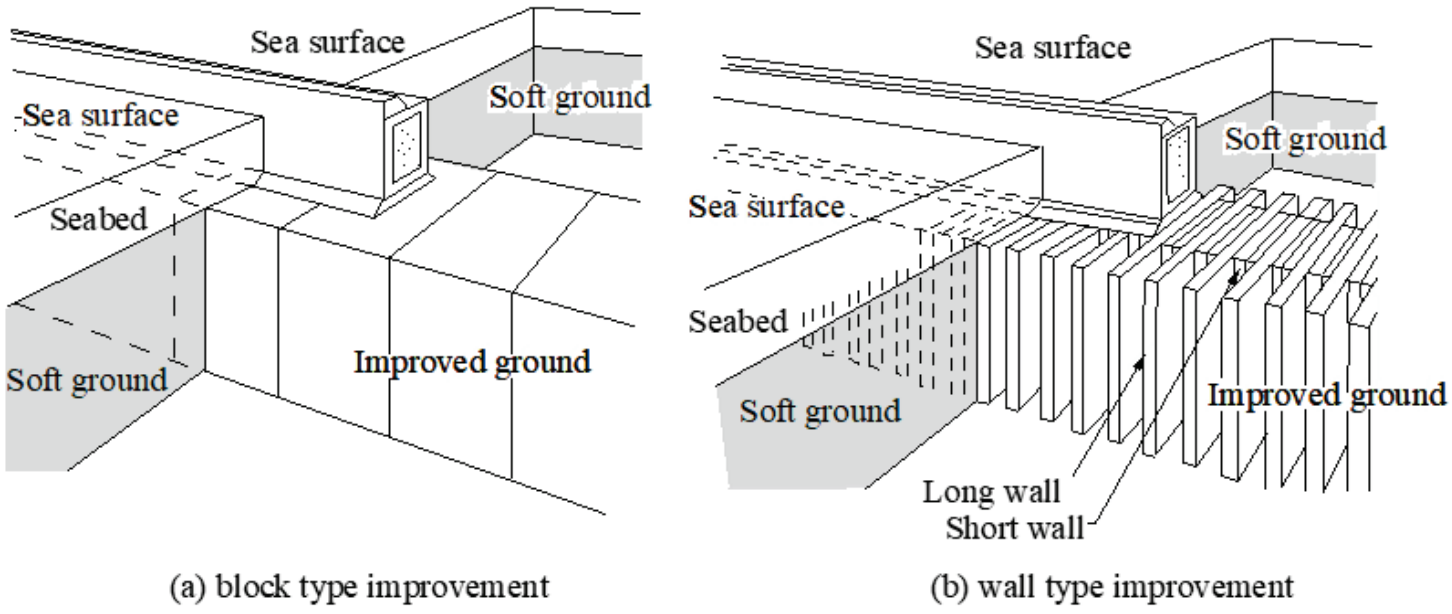
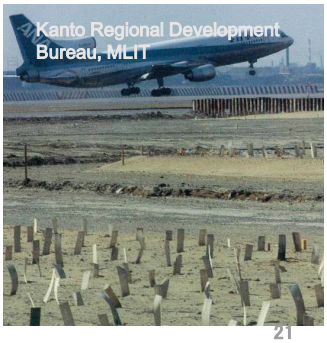


Typical Improvement Patterns in the Deep Mixing Method
DMM improvements are designed as a solid structure in the ground

Shallow Mixing Method

Preparation for ground improvement
→ Lime/cement-mixing for trafficability (surface treatment)

Ground improvement with Prefabricated Vertical Drains PVD



Lightening and strengthening (in stability problem)

軽量化と**固化**（安定問題）

Principles for ground improvement 基本的な地盤改良の原理：

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Cement Treated Soils

Mixture of **dredged clay + cement**

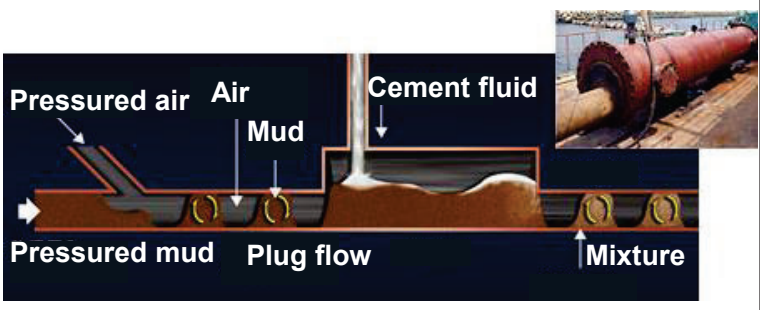
Mixture of **dredged clay + cement + air-foam**

セメント固化処理土，気泡混合処理土（軽量土）

Cement Treated Soils セメント固化処理土

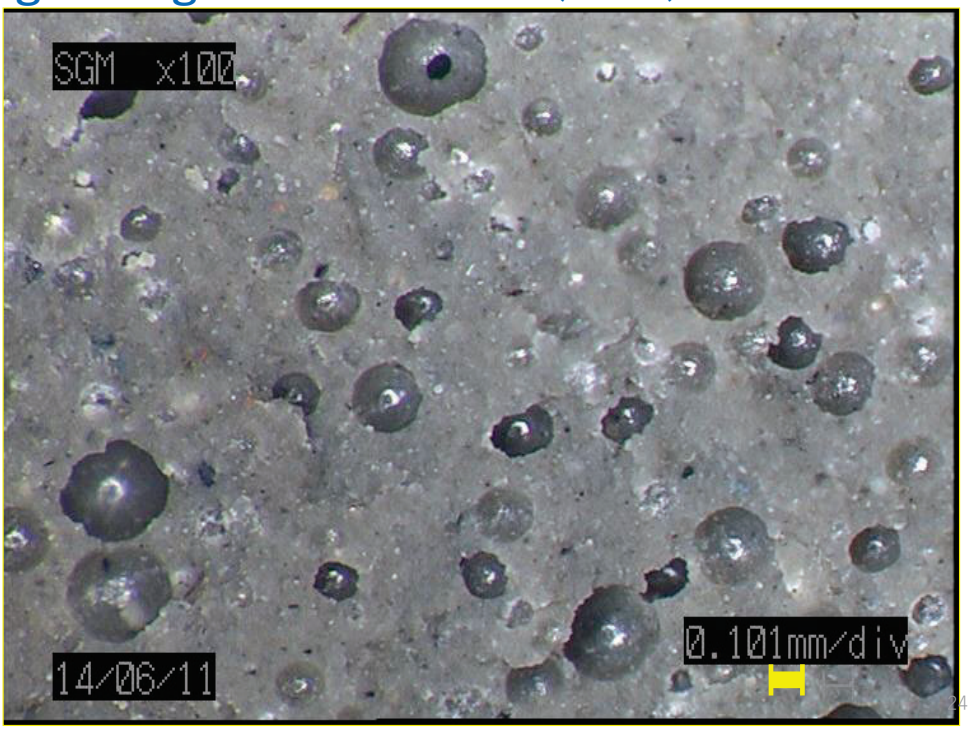
Pneumatic Flow Mixing Method

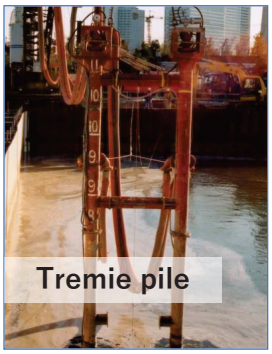
管中固化処理土 → Dredged clay + Cement



Cement Treated Soils セメント固化処理土

Air-foam treated Light weight Geo-Material (LGM) 気泡混合処理土（SGM）

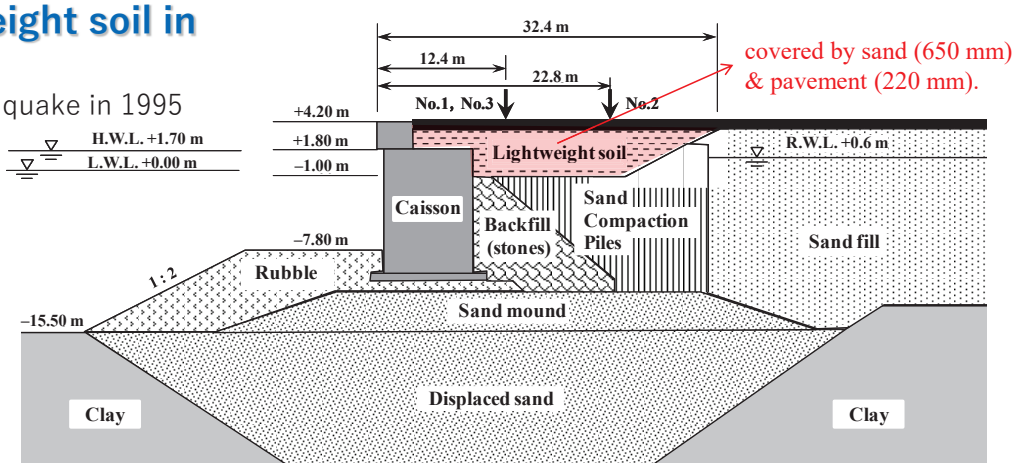




Air-foam treated lightweight soil in Kobe Port Island

Restoration work after Kobe Earthquake in 1995

阪神淡路大震災で被災した
神戸ポートアイランドの復旧断面
SGM軽量混合処理土が採用された



Physical properties of the material soil

Natural water content w (%)	Soil particle density ρ_s (g/cm^3)	Grain size fraction				Liquid limit w_L (%)	Plastic limit w_p (%)
		Gravel (%)	Sand (%)	Silt (%)	Clay (%)		
122.0	2.71	3.0	14.0	54.0	28.0	97.0	41.0

Mix proportion (per 1 m^3) of the air-foam-treated lightweight soil

	Slurry (kg)	Cement (kg)	Airfoam (m^3)	Density in design (g/cm^3)	Unconfined compression strength in design (kPa)
Above water level	849	140	0.279	1.0	196
Below water level	952	140	0.196	1.2	196

Increasing liquefaction resistance (in seismic problem)
液状化強度を増加させる（地震防災）

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Rapid dissipation of excess pore water 過剰間隙水圧の速やかな消散
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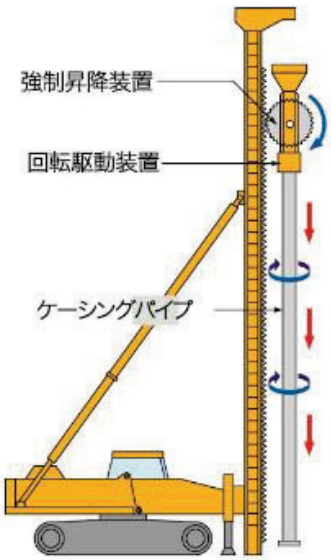
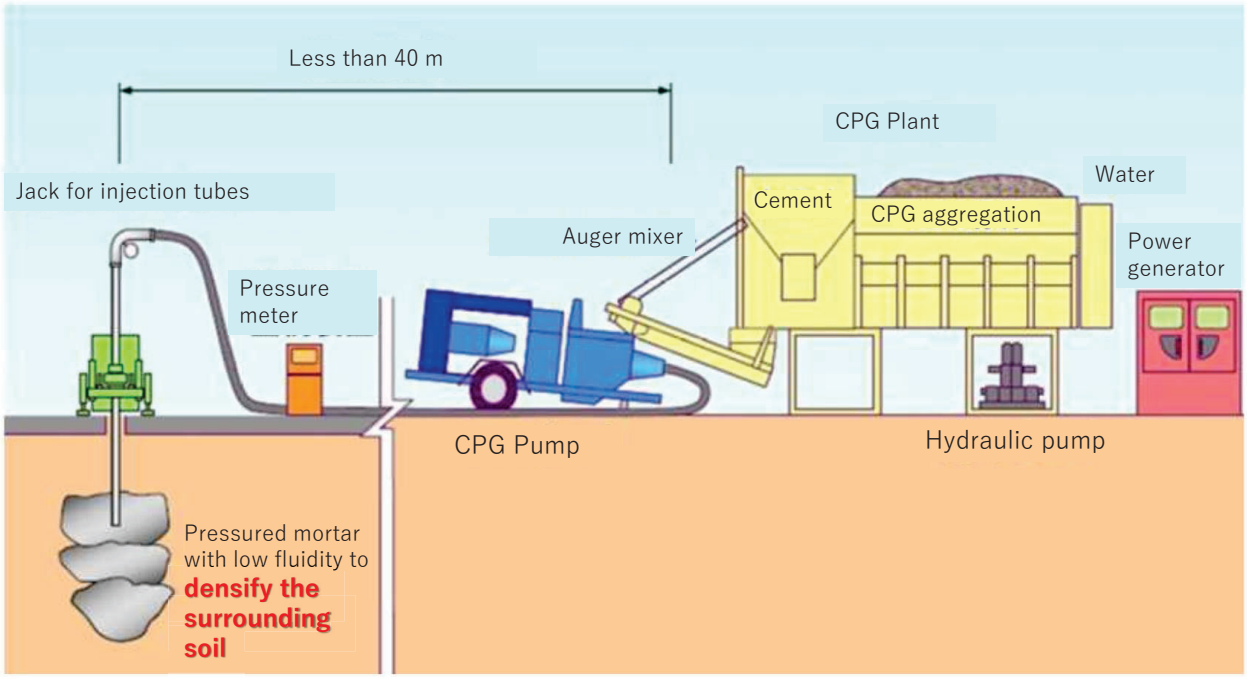
Sand Compaction Piles (SCPs) サンドコンパクションパイル SCP

Non-vibratory sand compaction pile methods 静的締固め工法
mainly in inland/onshore construction（主に陸上工事）
SCP method **with rotation instead of vibration**



https://www.fudotetra.co.jp/solution/soil/save_composer/

Compaction Grouting Method (CPG) 静的圧入締固め工法



https://www.sanshin-corp.co.jp/engineer/improvement/compaction/01.html

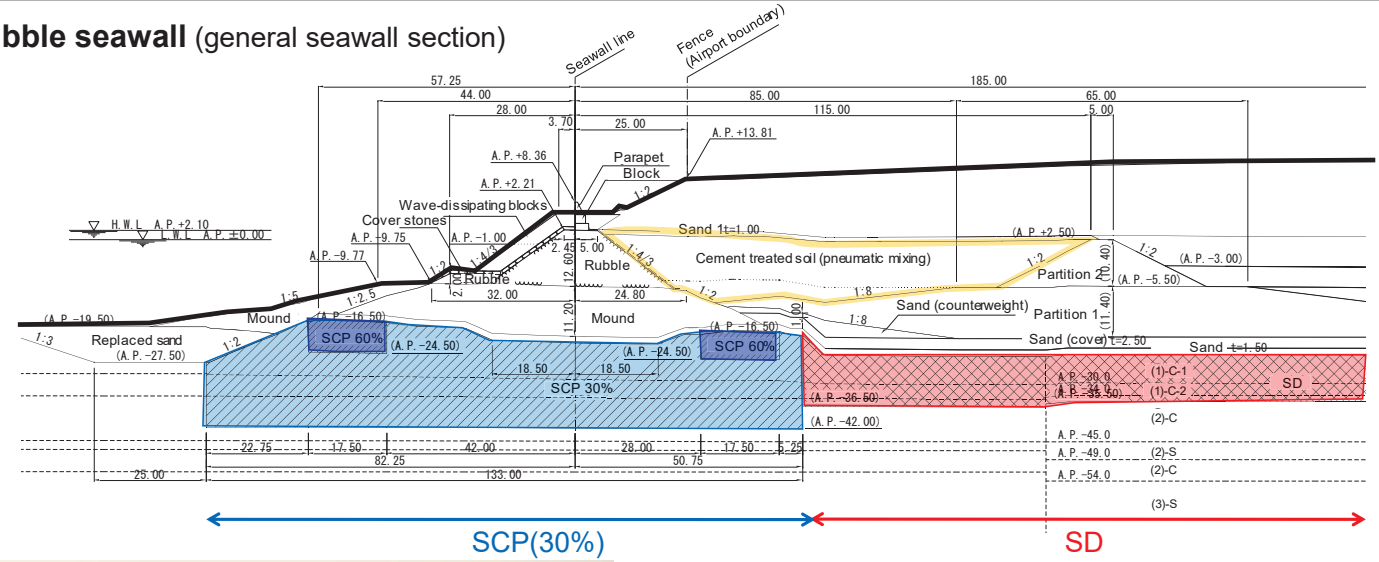
Integration of ground improvement technologies

Technologies used for a manmade island at Tokyo Haneda Airport (D-Runway):

1. with vertical drains (acceleration/promotion of consolidation)
2. to be replaced by good material (clay → sand)
3. to be strengthened (cement treatment)

- Soft clay deposit **inside the reclamation section** → improved by **1** (**SD**=Sand Drains)
- Under the **ruble seawall** → improved by **1** and **2** (**SCP** with low replacement ratio)
- Under the **important seawalls** → improved by **3** (**DMM**, **CDM**=Cement Deep Mixing)

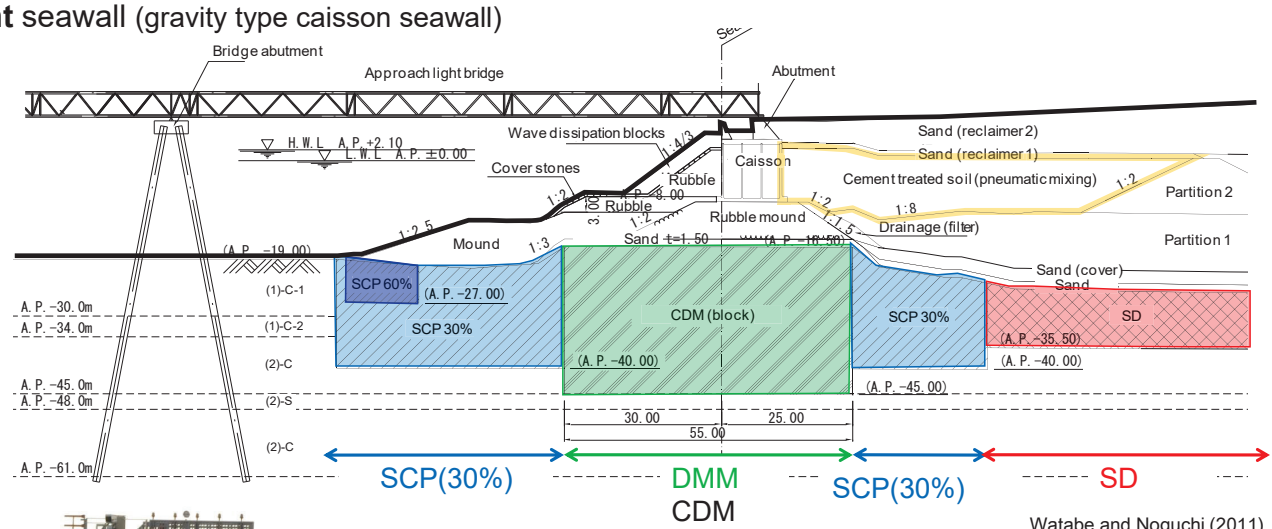
Rubble seawall (general seawall section)



Watabe and Noguchi (2011)

1. **with vertical drains** (acceleration of consolidation)
2. **to be replaced by good material** (clay → sand)
3. **to be strengthened** (cement treatment)
4. **Lightening and solidification**

Approach light seawall (gravity type caisson seawall)



Watabe and Noguchi (2011)

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2. **to be replaced by good material** (clay → sand)
3. **to be strengthened** (cement treatment)
4. **Lightening and solidification**

The right ground improvement method is applied in the right place.

Thank you
for your kind attention

ご清聴ありがとうございました