Content:
1. New underground construction technology using
   1) Super absorbent polymer material
   2) Air foam material
   with the Toda Corporation.
2. Chemical grouting technology using
   3) High concentration silicate material
   for the enhancement of sand liquefaction resistance
   with the Chemical Grouting company.
1) Super absorbent polymer material

Super absorbent polymer material with water is employed in the Cast-in-place pile method-AWARD-Sapli Method. (AWARD is the name of novel construction method group.)

AWARD-Sapli Method

(AWARD-Super Absorbent-Polymer-Liquid)

- Method to use soil slurry (Sapli Slurry) using a super-absorbent polymer material instead of a conventional bentonite-based slurry
- Ensure quality of pile and reduction of waste volume

※ Joint technology development among Waseda University, Toda Corporation and Magma Co., Ltd. ← Award is the common name of method.
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**Sapli Slurry**

- **Viscosity measuring device**
- **Funnel viscometer**

**Blending example**

<table>
<thead>
<tr>
<th>Water</th>
<th>Superabsorbent polymer (GEOSAP)</th>
<th>Specific gravity</th>
<th>Funnel viscosity</th>
<th>Filtered water quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 kg</td>
<td>0.5 ~ 0.2 kg</td>
<td>1.00 ~ 1.01</td>
<td>20 ~ 60 s</td>
<td>5 ~ 30 ml</td>
</tr>
</tbody>
</table>

**Properties of supplemental stabilizer**

- **Funnel viscosity**
- **Specific gravity**

**Performance Requirements**

a) Achieve the stability of pile hole wall even in highly permeable sandy soils.

b) Influence on quality of concrete pile can be reduced even in the case for a cohesive soil ground with a lot of fines tending to cause deterioration of the slurry and thick mud film on the pile hole wall.

c) Reduce the amount of industrial waste disposal by separating Slurry after use into water and mud.

d) Small amount of material used & costs reduction by reducing industrial waste disposal costs.
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Slurry: Various performance confirmation laboratory tests

- Performance as drilling slurry (Hole wall stability and fluidity)
  - Water barrier test
  - Bottom expansion pile wall simulation
  - Flowability test (Table flow test)
- Impact on quality of concrete piles
  - Pressure filtration test (mud film thickness)
  - Rebar pull-out test
  - Concrete replacement test
- Separation characteristics
  - Separation Mechanism (movie)
- Environmental characteristics
  - Confirmation test of temperature, pH etc.

Slurry Separation characteristics

- Soil sapl Slurry:
  Suspension during drilling process.
  - Adding calcium chloride CaCl₂
    → Absorbed water is released due to osmotic pressure.
    Swelling gel → small
  - Separation:
    Sediment (soil mud) & water.
    Sediment (soil mud) be treated as sludge,
    Separated water be discharged to sewage.
  - Reduction:
    Amount of Industrial Waste Disposal

Separation image

- Water absorptive polymer
- Separating agent addition
- Release water and shrink
- Setting
- Suspending polymer (small density)
- Separating polymer (large density)
- Water
- Mud
- Mud sink
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■ Slurry Separation characteristics(movie)

Solid soil particle is easily separated and settled down to the bottom.

Field Application

Site Location: Saitama City, Japan
Construction site: Distribution center

■ Foundation piling: Earth Drill Method
  - Pile diameter: φ 1.7 to 1.9 m (Enlarged base φ 2.2 to 3.4 m)
  - Pile length: 53.7m
  - Number of piles: 20
  - Total drilled depth: 55.5m
  - Amt. of drilled soil: 3,000m³

■ Application effect on site
  - Reduction of Industrial Waste Disposal
    - Separate waste slurry (about 200m³),
    - About 80% Reduction (separated water 160m³, mud 40m³)
Site management test

<table>
<thead>
<tr>
<th>Test item</th>
<th>Test method</th>
<th>Control criteria</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity</td>
<td>Funnel</td>
<td>23 ~ 35 (s)</td>
<td>Reproducing outside the standard value</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>Viscometer</td>
<td>1.01 ~ 1.10</td>
<td>(Geosap・Fresh water addition)</td>
</tr>
<tr>
<td>pH</td>
<td>pH meter</td>
<td>7.0 ~ 11.0</td>
<td></td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>Electrical</td>
<td>1.000 (μS/cm) Or less</td>
<td>Adjustment required above standard</td>
</tr>
<tr>
<td>meter</td>
<td>conductivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>meter</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Applicable Range

Superabsorbent polymers property:
- If Seawater: high electroconductivity Ec (high ion conc.)
- Water absorption performance ↓, Slurry viscosity ↓,
- ※ Confirm properties of on-site groundwater and used water.
- ※ Groundwater, Tap water Ec=100～300μS/cm
  (Not affected by seawater, ground improvement, heavy metals)

Difficult Area to be used
- Landfill site and coastal area influenced by seawater
- Plant site: soil contamination
- Ground improvement with cement in the past
- Demolition site: foundation pile of existing structure left and remained in the soil.
2) Air foam material

The aim of this technology development is to produce an air form suspension for use in stabilizing the trench wall surface during a diaphragm wall excavation using air foam, in stead of bentonite clay slurry suspension.

WALLS built mixed/stirred with in-situ soil and cement slurry.
- Generation of the high amount of sludge
- High machine/equipment ownership cost
- Long term occupation of the site

[Social Request]
Reduction on Environmental impact and construction period
- Environmental impact reduction: Foam Drilling Method
- Reduce work period: New construction method needed

Conduct R&D on New Construction Method
Featuring Air-Foam Drilling Method

AWARD-Para Method
Foaming agent
(Synthetic surfactant)

Dilution and Foaming

Excavated Soil+Water

Air foam

Mixing

Air foam suspension

Production of air foam suspension.

1)Stabilization of Trench Wall

Rapid formation of unsaturated layer on trench wall.

Fluidity increase by Bearing Effect among soil particles.

Deforming by adding antifoaming agent and volume reduction.

Legend:
○ Air-foam
● Soil particle

2)Bearing Effect

Fluidity increase by Bearing Effect among soil particles.

Compacted soil
After foam mixing soil

Friction among soil particles Reduced friction

Legend:
○ Air-foam
● Soil particle

3)Defoaming and Volume Reduction

Defoaming agent addition

Trench Wall stabilization

High Water Barrier

High Liquidity

Easy Volume Reduction

⇒ Airfoam Drilling Method
Funnel viscosity (s)

Management chart for bentonite clay slurry suspension.

TF value (mm)

Unit weight (kN/m$^3$)

Management chart for air foam suspension.
Implement a new construction method to make use of features of air foam drilling method and reduce the work period and the environmental impact.

- **Conventional method with bentonite**
  - Target soil + Water + Cement + Bentonite slurry → Wall body + Sludge
  - 90-100% of wall volume

- **Air-foam drilling method**
  - Target soil + Water + Air foam slurry + Cement → Wall body + Sludge
  - Less water, Less cement
  - Volume reduction by Defoaming

**Sludge volume reduction mechanism**
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**Work Period Reduction**

- Improvement of operation rate of construction machine, increase of construction amount of panel per day → Construction period is reduced to approx. 1/2

**Comparison with Conventional Construction Method**

- **Improved work cycle**
  - Separate three processes → Reduce loss of construction work time
  - → Improve operation rate of construction machine

- **Reducing Lap Length between Panels**
  - Change panel layout (partially overlap circle method)
  - → Increase the amount of construction work

**Comparison of construction period**

- **Conventional method**
  - Core material process after drilling/solidification
  - Drilling process
  - Solidification process

- **AWARD-Para method**
  - Drilling process
  - Solidification process
  - Core material process

- **About 50% work period reduction**
  - (Parallel work effects)

**Condition**

- In the case of depth 20m × extension 200m

**Lap Length Comparison**

- Conventional Layout
  - Full Lap Method
  - Work length L=900mm

- AWARD-Para Layout
  - Partial overlap method
  - Lap Length Comparison

**Work Period Reduction**

- Reducing Lap Length between Panels
  - Partially overlap circle method
  - 7 panels per day
  - 4 panels per day
  - Conventional method: Work cycle per day
  - AWARD-Para method: Work cycle per day
Award Para Method: Field Test Construction

Machine (Solidification process used only)
Panel layout
Field soil profile

Field Test Construction

Whole View
Drilling 1
Drilling 2
Foam discharging
Equipment
Solidification Machine
Field test construction results.

- **Reduction of Cement Material**: approx. 30%
- **Reduction of Sludge Volume**: approx. 30%
- **Achieving Construction Period Reduction**: 50%
  
  Verification High-speed construction with the machine dedicated solidification process.

- **Ensuring construction quality**: Trench Wall Stability, continuity of wall body, ensuring vertical accuracy, and verification of constructed body strength.

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3) **High concentration silicate material**

**Aim**: Enhancement of sand liquefaction resistance under the strong earthquake ground motion by injecting the liquid glass with a high concentration silicate material.

- **Grouting machine**
- **Grouted sand balls**
- **Improved area**
What is the chemical grouting? …

- Chemical grouting is one of the soil improvement methods, which is grouting material controlled hardening time in the void of the soil.
- Grouting material replaces the water in the void and the soil strength increases and the permeability decreases.

The strength after soil improvement using the standard grout is as follows.
- Liquefaction resistance ratio: 0.3~0.6 (Unconfined compressive strength: 50~100 kN/m²) ⇒ Strength is not enough, if subjected to the strong earthquake.
- Higher strength chemical grouting is required for the countermeasure against the liquefaction under the strong earthquake.

⇒ Liquefaction resistance ratio: more than 1.2 and unconfined compressive strength at lab.: 400 kN/m² and in the field: 200 kN/m².

Selection of chemical solution type

Required performance
- $\sigma_{28} \geq 400$ kN/m² (Ratio of lab./site strength is 2)
- Gel time: about 6 hours
- Less Permeability

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Items</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>Keise No.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Density of soil particle</td>
<td>$\rho_s$</td>
<td>g/cm³</td>
<td>2.62</td>
</tr>
<tr>
<td>Maximum void ratio</td>
<td>$E_{\text{max}}$</td>
<td>-</td>
<td>0.931</td>
</tr>
<tr>
<td>Minimum void ratio</td>
<td>$E_{\text{min}}$</td>
<td>-</td>
<td>0.613</td>
</tr>
<tr>
<td>Relative density</td>
<td>$D_r$</td>
<td>%</td>
<td>60</td>
</tr>
<tr>
<td>Size of specimen</td>
<td>$\Phi_{\text{h}}$</td>
<td>mm</td>
<td>5.0, h10.0</td>
</tr>
<tr>
<td>The method of making specimen</td>
<td></td>
<td>-</td>
<td>Dropping in the grouting material</td>
</tr>
</tbody>
</table>

Test result

<table>
<thead>
<tr>
<th>Items</th>
<th>Unit</th>
<th>Special neutrality-acid silica</th>
<th>Special silica</th>
<th>Organic compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration</td>
<td>%</td>
<td>10.29 (11.78)</td>
<td>13.25 (15.44)</td>
<td>10.74 (12.09)</td>
</tr>
<tr>
<td>Unconfined strength (28 days)</td>
<td>kN/m²</td>
<td>582 ~ 698</td>
<td>557 ~ 674</td>
<td>557 ~ 753</td>
</tr>
<tr>
<td>Gel time</td>
<td>6 hour</td>
<td>6 hour</td>
<td>6 hour</td>
<td>2~5 min.</td>
</tr>
<tr>
<td>Permeability</td>
<td>☎</td>
<td>×</td>
<td>△</td>
<td>×</td>
</tr>
<tr>
<td>Result</td>
<td>☎</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Special neutrality acid silica material is the best!!
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Strength characteristics: laboratory test

The evaluation method

- Unconfined compression testing (JGS 0511)
- Curing period: 540 days
- Condition: Same of the test of selecting chemical solution type.
- Curing method: In the air

Target value is achieved by high strength grouting material!!

Required strength characteristics

- \( \sigma_{28} > 400 \text{kN/m}^2 \) (ratio of lab./site strength is 2)
- Strength is kept constant.

Test result

<table>
<thead>
<tr>
<th></th>
<th>28 days</th>
<th>540 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required strength</td>
<td>400 kN/m^2</td>
<td>400 kN/m^2</td>
</tr>
<tr>
<td>Standard grout</td>
<td>275 kN/m^2</td>
<td>360 kN/m^2</td>
</tr>
<tr>
<td>High strength</td>
<td>551 kN/m^2</td>
<td>770 kN/m^2</td>
</tr>
</tbody>
</table>

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Durability characteristics: laboratory test

Leaching test

Grouted sand specimen was embedded in the sand, and grouted sand specimen is exposed to water flow to leach the silica material within the grout. Silica (SiO\(_2\)) content within specimen is measured by ICP test.

Experimental condition

<table>
<thead>
<tr>
<th>Tank size</th>
<th>( \Phi )</th>
<th>( H )</th>
<th>( ot )</th>
<th>( \Phi 30,24 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic gradient</td>
<td>( \text{i} )</td>
<td>1.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coefficient of permeability</td>
<td>( \text{k} ) m/sec</td>
<td>( 1.0 \times 10^{-3} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow rate</td>
<td>( Q ) cm(^3)/sec</td>
<td>1.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period</td>
<td>1, 2, 3 and 4 month (4 case)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Silica content distribution within grouted sand after leaching test (normalized value: silica content / initial silica content)
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**Durability characteristics : Numerical simulation**

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Standard</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffusion coefficient D</td>
<td>mm/year</td>
<td>21</td>
<td>24</td>
</tr>
<tr>
<td>Initial silica amount C₀</td>
<td>mg/g-dry</td>
<td>19.5</td>
<td>27.0</td>
</tr>
<tr>
<td>Analysis region length B</td>
<td>mm</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>Limit silica amount at diffusion Cₗₜₜₜ</td>
<td>mg/g-dry</td>
<td>8.2</td>
<td></td>
</tr>
</tbody>
</table>

Axial symmetric diffusion equation

1D Diffusion equation

Prediction of deterioration depth from the surface 100 years.

- Standard grout: 35 mm
- High strength: 27 mm

**Field testing**

**Overview of grouting test**

- **Purpose**: Verification experiment of High strength grouting material
- **Place**: Kanagawa prefecture in Japan
- **Size**: L × W × D = 5.0 × 5.0 × 4.7m

**Soil properties**

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of soil particle pₛ</td>
<td>g/cm³</td>
<td>2.74</td>
</tr>
<tr>
<td>Wet density pₜ</td>
<td>g/cm³</td>
<td>1.90</td>
</tr>
<tr>
<td>Void ratio ø</td>
<td></td>
<td>0.68</td>
</tr>
<tr>
<td>Fine content Fₑ</td>
<td>%</td>
<td>3.8</td>
</tr>
<tr>
<td>Liquefaction resistance Rₑₛₚₜ</td>
<td>g/m²</td>
<td>0.206</td>
</tr>
<tr>
<td>SPT N value</td>
<td></td>
<td>less than 10</td>
</tr>
</tbody>
</table>

**Plan view and cross section**

Check boring

![Plan view and cross section](image-url)
Field testing

General relations between unconfined compression strength and silica content

Unconfined compression strength (28 days) vs. amount of silica content

<table>
<thead>
<tr>
<th>Unconfined compression strength (28 days)</th>
<th>amount of silica content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target value 400 kN/m²</td>
<td>~</td>
</tr>
<tr>
<td>Standard grout 255 kN/m²</td>
<td>14.22 mg/g-dry</td>
</tr>
<tr>
<td>High strength 652 kN/m²</td>
<td>27.13 mg/g-dry</td>
</tr>
</tbody>
</table>

Injection rate decision by water injection test → <12(L/min)

Grouting specification.

<table>
<thead>
<tr>
<th>Silica concentration</th>
<th>Diameter</th>
<th>Injection rate</th>
<th>Injection total quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>% (wt)</td>
<td>m</td>
<td>L/min</td>
<td>kL</td>
</tr>
<tr>
<td>Standard grout</td>
<td>6.19</td>
<td>1.50</td>
<td>10.0</td>
</tr>
<tr>
<td>High strength</td>
<td>10.29</td>
<td>1.50</td>
<td>10.0</td>
</tr>
</tbody>
</table>
**Field testing**

**Sequence of grouting**

1. No.1 Shallow point of standard grout
2. No.2 Shallow point of high strength
3. No.3 Deep point of high strength
4. No.4 Deep point of standard grout

**Field testing**

**Procedure of grouting**

1. Boring
2. Grouting after packer expansion
3. Boring
4. Grouting
5. Pull-out
Field testing

Photo of field test

- Transporting soil
- Compacting ground
- Standard penetration test (SPT)
- Chemical grouting method (boring and grouting)
- Grouting plant

Field testing

Photo of field test

- Check boring
- Core sample of grouted soil
- Excavation
- Measuring grouted soil
- Block sampling
- Needle penetration test
Field testing
Recorded data during grouting

<table>
<thead>
<tr>
<th>Unit</th>
<th>Standard</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grouting volume (design) kL</td>
<td>upper: 0.800</td>
<td>lower: 0.800</td>
</tr>
<tr>
<td></td>
<td>total: 1.600</td>
<td></td>
</tr>
<tr>
<td>Grouting volume (result) kL</td>
<td>upper: 0.815</td>
<td>lower: 0.488</td>
</tr>
<tr>
<td></td>
<td>total: 1.303</td>
<td></td>
</tr>
<tr>
<td>Grouting pressure MPa</td>
<td>upper: 0.020</td>
<td>lower: 0.054</td>
</tr>
</tbody>
</table>

- In the case of high strength grouting, viscosity is high and grouting pressure is high.
- In the case of high strength at shallow and standard grout at deep, grouting material was observed to leak.

Field testing
Compressive strength of grouted sand

<table>
<thead>
<tr>
<th>Unit</th>
<th>standard</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Samples</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Average(site) kN/m²</td>
<td>106</td>
<td>306</td>
</tr>
<tr>
<td>permeability m/sec</td>
<td>$2.75 \times 10^{-8}$</td>
<td>$7.15 \times 10^{-10}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit</th>
<th>required</th>
<th>standard</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory kN/m²</td>
<td>400</td>
<td>255</td>
<td>652</td>
</tr>
<tr>
<td>Site kN/m²</td>
<td>200</td>
<td>106</td>
<td>306</td>
</tr>
<tr>
<td>Strength ratio</td>
<td>2.00</td>
<td>2.41</td>
<td>2.13</td>
</tr>
</tbody>
</table>

- Compressive strength of high strength is greater than the required value.
### Field testing

**Liquefaction resistance ratio**

![Graph showing liquefaction resistance ratio](image)

- **R_{L20.5%}** of high strength grout is greater than required value.

### Test result summary of grouted sand

**Liquefaction resistance ratio & unconfined compressive strength**

<table>
<thead>
<tr>
<th></th>
<th>σ_{28} (lab.)</th>
<th>σ_{28} (site)</th>
<th>Lab./site</th>
<th>R_{50.5%} (lab.)</th>
<th>R_{50.5%} (site)</th>
<th>permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Required value</strong></td>
<td>400</td>
<td>200</td>
<td>2.0</td>
<td>1.200 ( \times 10^{-7} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Standard grout</strong></td>
<td>255</td>
<td>106</td>
<td>2.41</td>
<td>0.922</td>
<td>0.559</td>
<td>2.75 ( \times 10^{-8} )</td>
</tr>
<tr>
<td><strong>High strength grout</strong></td>
<td>652</td>
<td>306</td>
<td>2.13</td>
<td>1.432</td>
<td>1.639</td>
<td>7.15 ( \times 10^{-10} )</td>
</tr>
</tbody>
</table>

High strength grout achieved the required value.

Liquefaction resistance ratio: greater than 1.2

Unconfined compressive strength: greater than 200 kN/m²
**Field testing**

Shape of standard grout

<table>
<thead>
<tr>
<th>The result of grouting test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>unit</strong></td>
</tr>
<tr>
<td>Grouting volume</td>
</tr>
<tr>
<td>Grouting pressure</td>
</tr>
<tr>
<td>Volume of actual improvement</td>
</tr>
<tr>
<td>Calculated volume (grouting volume and porosity)</td>
</tr>
<tr>
<td>Volume ratio B/C</td>
</tr>
</tbody>
</table>

Shape of high strength grout

<table>
<thead>
<tr>
<th>The result of grouting test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>unit</strong></td>
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<tr>
<td>Volume of actual improvement</td>
</tr>
<tr>
<td>Calculated volume (grouting volume and porosity)</td>
</tr>
<tr>
<td>Volume ratio B/C</td>
</tr>
</tbody>
</table>
Summary

- Laboratory test
  1) Unconfined compressive strength of lab. specimen is greater than 400 kN/m².
  2) Durability: prediction of deterioration region is 27mm/1000mm during 100 years.

- Field test
  1) $R_L^{20.5\%}$ of core sampled specimen is greater than 1.2.
  2) Unconfined compressive strength of core sample is greater than 200 kN/m².

Concluding remarks:

1. New underground construction technology using
   1) Super absorbent polymer material
   2) Air foam material
   has been successfully demonstrated.
2. Chemical grouting technology using
   3) High concentration silicate material
   for the enhancement of sand liquefaction resistance
   has been successfully demonstrated.
Thank you!

(at Waipara winery, NZ, August, 2006)