Methods for Land Reclamation using Soft Soil and Waste

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Outline

• Part 1. Overview of land reclamation methods
• Part 2. Methods for land reclamation using soft or dredged soil
• Part 3. Suggested reclamation and soil improvement procedure for using soft soil for large scale land reclamation
• Part 4. Use of waste for land reclamation
Part 1
Overview of land reclamation methods

According to fill materials used

- **Granular materials**, either dredged or excavated sand (Marina, Tuas, Changi East etc.)
- **Hill cut materials** (Changi airport, Kansai Airport, etc.)
- **Clay slurry dredged from seabed** (Tianjin Port, silt pond at Changi, Shanghai Pudong Airport, Kita-Kyushu Airport, Tokyo International Airport, Brisbane Port, Wenzhou, etc)
- **Cement treated clay slurry dredged from seabed** (Central Japan Airport, Pasir Pajang etc)
1). Use of sand fills

One of the creations of HDB

Changi East Reclamation Project

Area = 2000 ha  
Sand = 272 M m³  
PVD = 140 Mm

<table>
<thead>
<tr>
<th>Project</th>
<th>Area (Hectares)</th>
<th>Volume of Sand (Mm³)</th>
<th>Length of Vertical Drain (Mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE 1A</td>
<td>501</td>
<td>65</td>
<td>–</td>
</tr>
<tr>
<td>PHASE 1B</td>
<td>520</td>
<td>75</td>
<td>28</td>
</tr>
<tr>
<td>PHASE 1C</td>
<td>451</td>
<td>68</td>
<td>49</td>
</tr>
<tr>
<td>AREA &quot;A&quot; - NORTH</td>
<td>90.7</td>
<td>12</td>
<td>13.3</td>
</tr>
<tr>
<td>AREA &quot;A&quot; - SOUTH</td>
<td>450</td>
<td>52</td>
<td>50.4</td>
</tr>
</tbody>
</table>
2). Use of hill cut materials

Kansai Airport
to settle 11.5 m over 50 years

3). Use of dredged soft soil
Tianjin Port

Mainly over water depth of up to 5 m. Sometimes to 10 m.

More than 190 km$^2$ of land has been reclaimed around the Tianjin Port in Tanggu using clay slurry

Wenzhou, China

200 km$^2$ land is being reclaimed. Total 448 km$^2$
Use of lumpy clay dredged from seabed in Tuas

Use of ultra soft soil at Changi East
Port of Brisbane

Channel maintenance dredging materials consisting of river muds capped with sand was used. The thickness of the fill was up to 9 m. The seabed compressible clay was over 30 m.

New Kitakyushu Airport

After Terashi and Katagiri (2005)
4. Use of cement treated soil - Central Japan international airport

After Kitazume (2007)

Cemented soil placement

After Kitazume (2007)
Part 2
Methods for land reclamation using soft or dredged soil

Difficulties in the use of soft soil for land reclamation

- **Major difficulty:** The top surface is too soft for workers and machines to go on top to carry out soil improvement works.
- **Key technical challenge:** How to form a work platform.

- **Which method to use?** The one with the lowest unit cost!
# Methods for creating a working platform

<table>
<thead>
<tr>
<th>#</th>
<th>Method</th>
<th>Description / Mechanisms</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sun drying</td>
<td>Reduce the water content of soil and form of a desiccation layer</td>
<td>Simple and economical</td>
<td>Very time consuming; Depth of improvement is shallow</td>
</tr>
<tr>
<td>2</td>
<td>Capping with sand or good earth</td>
<td>Place sand or good earth in thin layers</td>
<td>Relatively cheap</td>
<td>Slow and difficult to implement</td>
</tr>
<tr>
<td>3</td>
<td>Use of geotextile</td>
<td>Place a layer of geotextile to the top of soft soil before soil or fill is placed.</td>
<td>Relatively expensive</td>
<td>Relatively quick and reliable</td>
</tr>
<tr>
<td>4</td>
<td>Lime or cement mixing</td>
<td>Use lime or cement mixing to strengthen a layer of soil at the top to form a working platform</td>
<td>Expansive</td>
<td>Difficult in controlling the properties and consistence of the cement treated layer</td>
</tr>
<tr>
<td>5</td>
<td>Dewatering</td>
<td>Use special drainage method to dewater or consolidate the a layer of soil at the top to form a working platform</td>
<td>Relatively cheap</td>
<td>Require special equipment and procedure. The method needs to be further developed</td>
</tr>
</tbody>
</table>

1). Sun drying

![Graph showing water content (%) vs. depth (cm) over time](image)
2). Sun drying + place sand or good earth as a cap layer – Brisbane port

After Berthier et al. (2009)
3). Sand spreading for silt pond

Use of geotextile for silt pond at Changi East
Use of geotextile and sand

1. temporary raising water level
2. spreading geotextile sheet
3. spreading sand

geotextile sheet of 100 kN/m in tensile strength was spread on the dredged ground surface from a small working pontoon towed from the dike. The sheet was expected to function to separate the dredged soil from the sand mat and to increase stability of the dredged clay.

After Kitazume (2007)

5). Use of cement mixed soil

In-situ treatment of dredged materials for Port of Valencia, Spain. Cement mixing was used to form a working platform on top of muddy deposit ($c_u=75$ kPa)(Burgos et al. 2007)

After Allu, Finland (http://www.allu.net)
5). Dewatering using PVD or circular drains

Installation of short PVDs or drains over water or soft top layer

Part 3
Suggested large scale land reclamation procedure
An innovative Land Reclamation Method using the Enhanced Vacuum ground improvement scheme

Floating PVD Installation machine

Courtesy of Prof Yan
Alternative fill materials

- Excavated clay/soil
- Copper slag (400,000 t or 200,000 m³/yr)
- Sewage sludge (240,000 t/yr or 240,000 m³/yr)
- Rubber tyres, plastics etc.
Using Sludge for Land Reclamation

- There is a shortage of land reclamation materials in Singapore. So it would be highly desirable if sludge can be treated and used for land reclamation.
- For this purpose, the stabilized sludge and other wastes have to meet the following three requirements:
  - Adequate geotechnical properties,
  - Minimum environmental impact,
  - Cost-effective.
### Physical Properties of Sewage Sludge

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content</td>
<td>% 514</td>
</tr>
<tr>
<td>Solids Content</td>
<td>% 16.3</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>(Mg/m³) 1.02</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.634</td>
</tr>
<tr>
<td>Liquid Limit (LL)</td>
<td>% 397</td>
</tr>
<tr>
<td>Plastic Limit (PL)</td>
<td>% 63</td>
</tr>
<tr>
<td>Plasticity Index (PI)</td>
<td>% 334</td>
</tr>
</tbody>
</table>

**Consolidated under 80 kPa**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content</td>
<td>% 180</td>
</tr>
<tr>
<td>Undrained Shear Strength</td>
<td>kPa 14</td>
</tr>
<tr>
<td>Compression Index</td>
<td>1.2</td>
</tr>
<tr>
<td>Permeability</td>
<td>m/s $10^{-10}$</td>
</tr>
</tbody>
</table>

### Methods of Treatment

- Chemical treatment, e.g., use cement or other binders.
- Mechanical treatment, e.g., consolidation.
- Thermal treatment, e.g., firing.
- A combination of the above.
Combined Method

• A method combining both the chemical and mechanical approaches can be used to treat sludge.

• To adopt this combined method, sludge is mixed with binders first. The mixture can then be consolidated under a surcharge.
Method 1: On-site Consolidation

- Mix dewatered sludge with cement and other waste materials, e.g., copper slag and marine clay, using a modified concrete mixer or mix on-site.
- Dispose the mixed sludge into a reclaimed site.
- Install horizontal/vertical drains and consolidate the sludge using vacuum preloading.

Sludge Mixer

Sludge output:
20,000 t /mth:
= 666 t/day
~ 650 m³/day

Need 130 trips per day.
Horizontal Drainage for Vacuum Preloading

Vacuum pump

Sludge

Sludge

Horizontal drain

Dike

Vertical + Horizontal Drains + Vacuum Preloading

Vacuum pump

Membranes

Sand

Sludge

Horizontal + vertical drain

Dike
Method 2: Geotextile Bags

- Mix dewatered sludge with binders and other waste materials and put the mixture into geotextile bags of 60x40 cm.
- The bags can be piled up before dumping for the mixture to consolidate.
- The bags are then dumped to the seabed.
- The bags will be capped by a sand layer.
Conclusions

• This presentation shows that ultra-soft, high water content soil or sludge can be used as fill materials for land reclamation.

• The key in treating slurry type of soil is the formation of a working platform. The methods to create a working platform include: 1) sun drying; 2) capping with sand or competent soil; 3) use of geotextile; 4) cement mixing; and 5) dewatering. The use of some of these methods are illustrated using case histories.
Conclusions (Cont’d)

• To convert sewage sludge into fill material for land reclamation, a combined chemical and mechanical treatment method is required.

• Two methods of using sewage sludge for land reclamation are suggested. In both methods, the sludge will be mixed with 10-12% of cement and waste materials (marine clay or copper slag) before disposal and disposed sludge mixture will be consolidated on site.

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