Soil Stabilization-An Eco and Green Approaches for Pavement Construction

Daud
David_daud@chemilink.com

Dr Wu Dong Qing
wu@chemilink.com

Tan Poi Cheong
poicheong_tan@chemilink.com

Chemilink Technologies Group, Singapore
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1. Introduction

Typical Conventional Road Profile

Pavement Construction Methods

a. Conventional (replacement method) → Remove and replace the soft in-situ soil with approved fill materials as construction material.

b. Non-replacement method → Strengthen the engineering properties of in-situ soils which allows in-situ soils to be re-used as source of construction material.
1. Introduction

Estimated of selected fill to be used by replacement method

- Assume to construct 1km length x 7m width of road
- To remove and replace the in-situ soil by selected fill material for Sub-grade, Sub-base and Base layer

<table>
<thead>
<tr>
<th>Road layer</th>
<th>Material</th>
<th>Dimension of the road</th>
<th>Volume of approved fill materials (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-grade layer</td>
<td>Approved fill materials</td>
<td>1km x 7m x 0.3-0.5m</td>
<td>2,100-3,500</td>
</tr>
<tr>
<td>Sub-base layer</td>
<td></td>
<td>1km x 7m x 0.3m</td>
<td>2,100</td>
</tr>
<tr>
<td>Base layer</td>
<td></td>
<td>1km x 7m x 0.25m</td>
<td>1,750</td>
</tr>
<tr>
<td><strong>Total quarry material needed (m$^3$)</strong></td>
<td></td>
<td></td>
<td><strong>5,950-7,350</strong></td>
</tr>
</tbody>
</table>

5.6 million km of Unpaved Road in Developing Countries 33,000-42,000 million

Impact to Global Environments due to

Exploitation of natural resources and CO$_2$ emissions from mining and transportation of material
Eco and Green Approaches Concept on Pavement Construction by Chemical Soil Stabilization Method

Equal or Better Engineering Properties and Durability

Reduce Construction Time

Eco and Green Approaches on Pavement Construction

Re-used and recycling in-situ materials

Reduce Construction Cost: Material Cost, Logistics Cost

Reduce Exploitation of Natural Resources
2. Soil Stabilization for Road Construction

Common Pavement Distress Due to Weak Base or Sub-grade Layer

Load distribution of pavement

Permanent deformation of weak base or sub-grade layer

Vertical compressive stress and strain at the top of sub-grade layer
2. Soil Stabilization for Road Construction

- Soil stabilization:
  The alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil.

- Purposes of soil stabilization:
  a. Soil properties improvement:
     - Reduction of plasticity index (PI), swelling potential
     - Increase in durability and strength.
  b. Thickness reduction of pavement layer
     - Improved the strength and stiffness of the soil layer
     - Permit the reduction design thickness of the stabilized layer compared with un-stabilized or unbound layer.
  c. Effectively utilize of locally available soils and other materials as road construction material.
2. Soil Stabilization for Road Construction

- Soil stabilization methods:
  a. Mechanical stabilization
     Altering the soil properties by:
     ✓ Changing the gradation through mixing with other soils
     ✓ Densifying the soils using compaction efforts
     ✓ Undercutting the existing soils and replacing with granular material

Common remedial procedure for soft sub-grade, sub-base and base layer:
Cover with granular material or partially remove and replace the wet soil with granular material → Conventional pavement construction method.
2. Soil Stabilization for Road Construction

b. Chemical Admixtures or Stabilizing Agents:

- Blending and mixing suitable **chemical admixtures** or **stabilizing agents** with in-situ soils to improve/strengthen the certain properties through chemical reactions for engineering purposes.

- Common chemical reaction involved: Cementation, Hydration, Ion Exchange, Flocculation, Precipitation, Polymerisation, Oxidation and Carbonation.

- Types of **stabilizing agents** that commonly used for Soil stabilization:
  
a. Cement
  
b. Lime: Hydrated lime, Quicklime.
  
c. Fly ash: Class C and Class F fly ash.
  
  
e. Polymer modified cementitious chemical – Chemilink soil stabilization products
Design Requirements on UCS for Cement Stabilized Soils in Various Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Curing Time (day)</th>
<th>Curing Condition</th>
<th>UCS (MPa)</th>
<th>Road Grade / Function</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>7</td>
<td>-</td>
<td>3.0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Brunei</td>
<td>7</td>
<td>Wet-air: 6d</td>
<td>2.0</td>
<td>All/Base</td>
<td>Or per design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soaking: 1d</td>
<td>0.7 ~ 1.5</td>
<td>All/Sub-base</td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>7</td>
<td>Soaking</td>
<td>2.1</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>7</td>
<td>Wet-air: 6d</td>
<td>3.0 ~ 4.0</td>
<td>High/Base</td>
<td>UCS=5~6 for high road grade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soaking: 1d</td>
<td>2.0 ~ 3.0</td>
<td>Low/Base</td>
<td>with more or very heavy loading</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
<td>High/Sub-base</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.5</td>
<td>Low/Sub-base</td>
<td></td>
</tr>
<tr>
<td>Ex-SU</td>
<td>28</td>
<td>Soaking</td>
<td>7.5</td>
<td>Highest/Base</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.0</td>
<td>High/Base</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.0</td>
<td>Low/Base</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
<td>All/Sub-base</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>7</td>
<td>-</td>
<td>4.0 ~ 5.0</td>
<td>M./Base</td>
<td>M.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.5</td>
<td>M./Sub-base</td>
<td>Medium</td>
</tr>
<tr>
<td>Germany</td>
<td>-</td>
<td>-</td>
<td>3.0 ~ 10.0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>7</td>
<td>Wet-air: 6d</td>
<td>3.0 ~ 4.0</td>
<td>Highest/Base</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soaking: 1d</td>
<td>2.5</td>
<td>High/base</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.5 ~ 2.0</td>
<td>Low/base</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.7 ~ 1.3</td>
<td>All/Sub-base</td>
<td></td>
</tr>
<tr>
<td>New Zealand</td>
<td>7</td>
<td>-</td>
<td>1.72</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>7</td>
<td>-</td>
<td>6.0</td>
<td>All/Base</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.5</td>
<td>All/Sub-base</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>7</td>
<td>-</td>
<td>4.5 ~ 15.5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>California</td>
<td>7</td>
<td>Wet-air</td>
<td>5.2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Washington</td>
<td></td>
<td>-</td>
<td>5.8</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>US</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
2. Soil Stabilization for Road Construction

- Chemilink soil stabilization agent:
  - Polymer modified cementitious chemical agent in fine powder form.
  - Designed for soil stabilization especially for sandy and clayey soils under tropical conditions and environment.

- Typical Technical Design:
  - Key component → Dosage Design

<table>
<thead>
<tr>
<th>Layer to be stabilized</th>
<th>CBR (7-day)</th>
<th>UCS (7-day)</th>
<th>Resilient Modulus ($M_R$)-28 day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Course</td>
<td>≥ 80%</td>
<td>≥ 2MPa</td>
<td>3000MPa ~ 20000MPa</td>
</tr>
<tr>
<td>Sub-base Course</td>
<td>≥ 30%</td>
<td>0.7-1.5MPa</td>
<td></td>
</tr>
</tbody>
</table>

Note:
Data shown above are typical technical performance achievable for different applications.
2. Soil stabilization for road construction

Application Method of Chemical Soil Stabilization

1. In-situ recycling method

**Spreading**
- By Mechanical
- By Manual

**Mixing**
- By Stabilizer
- By Rotovator

**Compaction**
- By Compactor
2. Soil stabilization for road construction

Application Method of Chemical Soil Stabilization

2. Central-plant mixing method

Central Mixing Plant  Mixture after Compaction
3. Case Studies by Chemical Soil Stabilization Method for Road Construction


- In-situ soil condition:
  a. Inorganic clay (CL) ⇒ LL=48%, PI=28%
  b. High plasticity clay (CH) ⇒ LL=88%, PI=55%
  c. Beach sands, Crushed stones and Their mixtures (Reclaimed land)

- Design and construction considerations:
  a. Minimize the period of risks and impact of inconveniences caused by construction activities.
  b. Avoid extensive excavation and backfilling to reduce the negative impact on the environment
  c. Cost effectiveness
3. Case Studies by Chemical Soil Stabilization Method for Road Construction

- Construction schedule: Closing time: 1:00am-7:00am → 6 hours
  Effective pavement construction time: 2:00am-6:00am → 4 hours

By Conventional construction method is difficult to achieved those design considerations and construction schedule
3. Case Studies by Chemical Soil Stabilization Method for Road Construction

- Proposed design by Chemilink soil stabilization method: stabilized **300mm** of in-situ soils as **Base Course**

  a) Spreading  
  b) In-situ Mixing  
  c) Compaction

Completion of Runway Widening in Changi International Airport Runway II (after 3 years)
3. Case Studies by Chemical Soil Stabilization Method for Road Construction

- **Average values:**

<table>
<thead>
<tr>
<th>Testing items</th>
<th>Chemilink soil stabilization</th>
<th>Specification requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBR-7 days</td>
<td>219%</td>
<td>≥90%</td>
</tr>
<tr>
<td>UCS-7 days</td>
<td>3.10MPa</td>
<td>≥1.5MPa</td>
</tr>
<tr>
<td>Resilient Modulus (M_R)-28 days</td>
<td>12,000MPa</td>
<td>≥3000MPa</td>
</tr>
</tbody>
</table>

- **Construction results by Chemical soil stabilization method:**
  a. High construction speed → Completed in 60 working days which completion time is 6 months
  b. Low construction cost → Do not need extensive earthworks
  c. Less disruptions to airport operations and environmental friendly
  d. Good quality of engineering properties
3. Case Studies by Chemical Soil Stabilization Method for Road Construction

B. Brunei Darussalam:


- Brunei Highway design
- In-situ soil condition: Backfilled Sandy Soils/Swampy area.
- Original design:
  100% of Pilling foundation and Geogrid system as Base and Sub-base course ➔ serious differential settlements after few years by previous highway construction
- Design consideration:
  Eliminate differential settlement and allow total settlement within the control limits
3. Case Studies by Chemical Soil Stabilization Method for Road Construction

- Proposed design by Chemilink soil stabilization method:
  a. 30% of piling foundation for important crossroad cable and pipes
  b. Stabilized 350mm of in-situ soil as Sub-base course and stabilized 220mm of Crusher run as Base course

a. Opened road cross section
b. Road after 2-year completion
3. Case Studies by Chemical Soil Stabilization Method for Road Construction


- Average Site testing results:

<table>
<thead>
<tr>
<th>Testing items</th>
<th>Chemilink Soil Stabilization</th>
<th>Specification Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBR-7 days</td>
<td>80%</td>
<td>≥90%</td>
</tr>
<tr>
<td>UCS-7 days</td>
<td>1.60MPa</td>
<td>≥1.5MPa</td>
</tr>
<tr>
<td>Modulus of sub-grade reaction (k)-28days</td>
<td>780MPa/m</td>
<td>≥3000MPa</td>
</tr>
<tr>
<td>Degree of compaction</td>
<td>&gt;97%</td>
<td>&gt;95%</td>
</tr>
</tbody>
</table>
3. Case Studies by Chemical Soil Stabilization Method for Road Construction

C. Malaysia:

(1) Runway/Taxiway widening of Sultan Ismail International Airport of Malaysia (2007).

- In-situ soil condition:
  Clay content > 80%, LL=70-90%, PI=40-50%, water content=40%

- Proposed design by Chemilink soil stabilization method:
  Stabilized 300mm of in-situ soil as Base/Sub-base course.

- Construction speed:
  1.5 months ahead from construction schedule (4 months)
3. Case Studies by Chemical Soil Stabilization Method for Road Construction

Runway/Taxiway widening of Sultan Ismail International Airport of Malaysia (2007).

Average Site testing results:

<table>
<thead>
<tr>
<th>Testing items</th>
<th>Chemilink Soil Stabilization</th>
<th>Specification. Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBR-7 days</td>
<td>120%</td>
<td>≥90%</td>
</tr>
<tr>
<td>UCS-7days</td>
<td>2MPa</td>
<td>≥1.5MPa</td>
</tr>
<tr>
<td>Resilient Modulus (M_R)-28 days</td>
<td>6,000MPa</td>
<td>≥3000MPa</td>
</tr>
<tr>
<td>Degree of compaction</td>
<td>~97%</td>
<td>&gt;95%</td>
</tr>
</tbody>
</table>
3. Case Studies by Chemical Soil Stabilization Method for Road Construction

Runway/Taxiway widening of Sultan Ismail International Airport of Malaysia (2007)

a) Excavation

b) Spreading
3. Case Studies by Chemical Soil Stabilization Method for Road Construction

Runway/Taxiway widening of Sultan Ismail International Airport of Malaysia (2007)

c) In-Situ Mixing
d) Compaction
3. Case Studies by Chemical Soil Stabilization Method for Road Construction

Runway/Taxiway widening of Sultan Ismail International Airport of Malaysia (2007)

e) Paving Asphalt Concrete

f) Completion of Widening
3. Case Studies by Chemical Soil Stabilization Method for Road Construction

C. Malaysia:

(2) FELDA Plantation Access (2009)

- In-situ soil condition: Swampy and High water table areas

Before stabilization  |  After stabilization
3. Case Studies by Chemical Soil Stabilization Method for Road Construction

E. China: Low cost rural road in Xizang, Tibet (2007)

- Local condition: High altitude, extreme of temperature and humidity.
- Construction consideration: Limited of natural resources as road construction materials and long transportation distances to the job-site.
### General comparison by different aspects between Conventional and Soil stabilization method for roads construction

#### a. Impact to environments

<table>
<thead>
<tr>
<th>Comparison Items</th>
<th>Conventional Method</th>
<th>Soil stabilization Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Quantities of quarry materials required</td>
<td>Very high</td>
<td>Limited to None</td>
</tr>
<tr>
<td>b. Disturbances to public</td>
<td>More</td>
<td>Less</td>
</tr>
<tr>
<td>c. Non-toxic, environmental safe and stable</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>d. Carbon emissions due to mining and transportation of quarry material</td>
<td>Very high</td>
<td>Less</td>
</tr>
</tbody>
</table>

#### b. Construction

<table>
<thead>
<tr>
<th>Comparison Items</th>
<th>Conventional Method</th>
<th>Soil stabilization Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction cost (Materials, Transportation, Waste disposal)</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Construction speed</td>
<td>Slower</td>
<td>Faster</td>
</tr>
</tbody>
</table>
General comparison by different aspects between Conventional and Soil stabilization method for roads construction

c. Applications

<table>
<thead>
<tr>
<th>Comparison Items</th>
<th>Conventional Method</th>
<th>Soil stabilization Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. On good sub-grades</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>b. On swampy or weak sub-grades</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>c. Applicable soil types</td>
<td>---</td>
<td>Normal soils such as sandy, silty and clayey soils</td>
</tr>
</tbody>
</table>
4. Conclusion

a. By using chemical soil stabilization method for road construction
   → Decrease the dependence of approved fill materials (especially for those region or countries with limited of natural resources)
   → Decrease the global environment impact in term of CO$_2$ emissions due to less mining and transportation aspects.

b. Benefits of using soil stabilization for road construction:
   ✓ In-situ soil properties improvement → Strength and Stiffness of soil layer.
   ✓ Improve the long-term durability of road compared with un-stabilized or unbound layer
   ✓ Reduce the construction cost and time of road due to effectively utilize of locally available soils and other materials as road construction material.
4. Conclusion

c. With chemical stabilization method, many technical difficulties, especially the total and differential settlements, at clayey, swampy or low-lying land areas with peaty soils have successfully been resolved.

d. Chemilink soil stabilization has technically and commercially been proven to be the effective and durable method especially for road and airfield construction in this region, based on the performance and durability of numerous projects with Chemilink soil stabilization method.

e. Wide ranges of Chemilink soil stabilization method application for road construction, from high profile projects (airfield and highway construction) to low cost rural road.
THANK YOU
FOR YOUR ATTENTION