Geoharbour Construction Group

Solution for Infrastructure Construction in soft clay area under condition of underground climate change by VCM Method

Dr. Liu Yu
2018.3, Bangkok
About Geoharbour

- Founded Date: Jan. 28th, 2000.
- Employees: 5,000
- Objective: Advanced and Innovative Geotechnical Contractor
- Professional entity specializing in Geotechnical Research, Design, Construction and Consultancy.
- Chief Editor of Chinese National Code for Reclamation Soil Treatment.
- Director member of Technical Committee of China Soft Soil Treatment.
- Vice President of China Association of Inventions.
- More than 30 patents for ground improvement method.
About Geoharbour

Research and Design Institution of Geoharbour is,

- The Directorate institution of the Soft Soil Improvement Technology Committee in China
- Editorial Unit of National Technical Code for Soft Soil Foundation and Dam Engineering in China
- Editorial Unit of the National Technical Code for Chemical Engineering Piperracks and Pipesleepers in China
- Editorial Unit of the National Technical Code for Coral Reef Foundation Treatment in China
- Editorial Unit of the National Technical Code for Foundation Treatment in Indonesia
2016.11, Invited by President of Indonesia.
Geoharbour sign a contract with MOU and Geotechnical Academy of Indonesia to Edit National Geotechnical code for Indonesia.
About Geoharbour

**Services**

- Ground Improvement
- Piling Foundation
- Deep Foundation Pit
- Slope Protection
- Reclamation
- Harbor Construction

**Techniques**

- Dynamic compaction, VCM, HVDM, Stone/Sand Column, Deep Cement Mixing
- Pre-Casting > Bore Pile
- SMW > Diaphragm Wall > Soldier Pile Retaining Structure
- Grid Beam > Anchor Cable > Anchor Bolt > Turf Planting > SNS
- Cutter Suction > Pump–convey–hydraulic Fill
- High Pile > Counterfort Wall > Gravity Retaining Wall
About Geoharbour

• Since 2007, Geoharbour started the first oversea project. 
  Till now, Geoharbour has been a *International professional Geotechnical Engineering solutioner*.
• Over 10 subsidiary companies: Singapore, Indonesia, Malaysia, Vietnam, Myanmar, Thailand, Middle-East Area, Australia, Panama, India, Iran...
• Over 500 large-scale projects (include China).
• Soft Soil Treatment more than 15,000 Ha (Include China).
• 50+ ongoing projects.

• [Subsidiary in Thailand : Geoharbour(Thailand)Co.,Ltd](#)
# About Geoharbour

**Common Ground Improvement Techniques**

<table>
<thead>
<tr>
<th>CONSOLIDATION METHODS</th>
<th>REINFORCEMENT METHODS</th>
<th>COMPACTION METHODS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prefabricated Vertical Drains</td>
<td>Semi-Rigid Inclusion</td>
<td>Dynamic Compaction</td>
</tr>
<tr>
<td>Cement Columns/ Deep Soil Mixing</td>
<td>Natural Inclusion (sand, stone, etc)</td>
<td>Dynamic Replacement</td>
</tr>
<tr>
<td>Vacuum Consolidation/HVDM</td>
<td>Jet Grout Columns</td>
<td>Vibro Replacement</td>
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<td></td>
<td>Vibro</td>
<td>Vibro Compaction</td>
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</table>

**Innovative High Vacuum Densification Method (HVDM) Technique**

HVDM is one of Geoharbour Construction Group’s series of patented technology, which outperforms dynamic compaction, one of traditional ground improvement methods. HVDM enables soil consolidation process expediated by a pressure gradient acted within the ground, which is formed between positive pressure (i.e., excess pore water pressure from dynamic compaction) and negative pressure (i.e., vacuum pumping). HVDM extends the treatment scope of dynamic compaction to saturated silty soil. By using HVDM, an over consolidated hard crust is formed in the subsurface, which helps mitigate the post-treatment settlement of a job site.
About Geoharbour

1) The Special Prize
2) The Gold award for the best international invention
3) The Leading Innovation Award.

Thailand Inventor’s Day in 2014
About Geoharbour

Business Coverage
As a global entity, Geoharbor Construction Group has completed more than 500 projects and exported its core patent technologies to more than 20 countries.
Content

1 Geotechnical Problems for the Soft Soil Ground
2 Traditional Method for Soft Soil
3 VCM Development
4 Typical VCM Construction Sequence
5 Typical VCM Application for Road Project
6 Conclusion
1 Geotechnical Problems for the Soft Soil Ground

Soft soil layout in Thailand

- **Central**
  - Bangkok, Samut Prakan, Nonthaburi, Pathum Thani, Nakhon Pathom,

- **West**
  - Phetchaburi, Prachuap khiri khan

- **South**
  - East: Nakhon Si Thamarat, Songkhla
  - Phangnga, Pattani, Narathiwa,
  - West: Krabi, Surat Thani, Ranong,
  - Chumphon, Phuket, Satun, Trang, Phattalung

- **East**
  - Chonburi, Rayong, Chanthaburi
1 Geotechnical Problems for the Soft Soil Ground

For the soft soil ground, there will be some Geotechnical problems, mainly include:

1.1 Ground Settlement Problem
1.2 Ground Stability Problem
1.3 Problem of Negative skin friction for Pile

With the underground environment change widely, make this problem more serious.
1.1 Ground Settlement Problem

Problem of Settlement for Road
1.1 Ground Settlement Problem

Settlement Problem Without Improvement
1.1 Ground Settlement Problem

Settlement Problem Eliminated by Improvement
1.2 Ground Stability Problem

Before Improvement
1.2 Ground Stability Problem

After Improvement
1.3 Problem of Negative skin friction for Pile
For Pile Vertical Bearing Capacity

Pile Vertical Bearing Capacity = $Q_p + Q_s$

Pile Vertical Bearing Capacity will decrease because of $Q_{nsf}$
For Pile Lateral Bearing Capacity

Lateral Movement: depending on soil strength nearby Pile
2 Traditional Method for Soft Soil Improvement

- **Soil Replacement**
  - Embankment Fill
  - Excavation with Backfilling
  - Soft Soil

- **PVD + Surcharge**
  - Prefabricated Vertical Drain
  - Fill
  - Sand Mat
  - Soft Soil
  - Stiff Soil
  - Without Counterweight Berm
  - With Counterweight Berm

- **Sand Drain + Surcharge**
  - Fill
  - Sand Drain
  - Soft Soil
  - Stiff Soil

- **Soil Cement Column (SCC)**
  - Soil Cement Column

- **RC Piled Slab**
2 Traditional Method for Soft Soil

<table>
<thead>
<tr>
<th>Method</th>
<th>Technical Difficulty</th>
<th>Fill Material</th>
<th>Time</th>
<th>Cost</th>
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<tbody>
<tr>
<td>1. No Ground Improvement</td>
<td></td>
<td></td>
<td>1.1~1.2X</td>
<td>X</td>
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<tr>
<td>2. Conventional PVD</td>
<td></td>
<td></td>
<td>1.1~1.2X</td>
<td>X</td>
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<tr>
<td>3. Vacuum Consolidation</td>
<td></td>
<td></td>
<td>1.1~1.2X</td>
<td>Depend on the surcharge price</td>
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<tr>
<td>4. Soil Cement Column</td>
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<td>2~3X</td>
<td></td>
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<tr>
<td>5. Pile Slab</td>
<td></td>
<td></td>
<td>3~4X</td>
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</tbody>
</table>

Overall Comparisons – During Design Stage
Why VCM?

1) VCM method is consolidation method, soil body itself can be improved basically and soil strength increased;

2) The improvement of soil itself can be high-compacted Integrity, greatly increase the resistance to the external environment, such as underground water level changing;

3) VCM method is technically high reliability, quality guaranteed, cost-saving comparing to traditional methods.
3 Vacuum Consolidation Method (VCM) Development

Vacuum Consolidation Method (VCM) is for soft ground improvement, using atmospheric pressure as a temporary surcharge for Soil Consolidation.

1) The Method was proposed by Kjellman in 1952;

2) China started to apply this Method widely for soft clay improvement since 1958, it has been a mature technique.

3) In the past 10 years, Geoharbour Group successfully finished 100 projects (about 20 Million sq.m) in roadways, airport runways, port stack yards, petrochemical facilities, ground reclamation, power plants and industrial parks etc fields with VCM, Covering China, Indonesia, Vietnam, Singapore, Thailand, etc.
3 Vacuum Consolidation Method (VCM) Development

TYPICAL VCM SYSTEM – Geomembrane Type

VACUUM PUMP

Extensometer (Option)

Vacuum Gauge

Surface Settlement Plate

Piezometer

GEOMEMBRANE

GEOTEXTILE

PHS

VACUUM PUMP

SEALING TRENCH/WALL

Inclinometer (Option)

SAND BLANKET

WATER

80 kPa

SOFT SOIL

PVD

SEALING TRENCH/WALL
3 Vacuum Consolidation Method (VCM) Development

- **Surcharge**
  - $p' = \frac{2}{3} \sigma' \_1$
  - $K_o = 0.5$
  - $\sigma' \_1 = 80kPa$
  - $\sigma' \_2 = 40kPa$
  - $\sigma' \_3 = 40kPa$

- **Vacuum**
  - $p' = \sigma' \_1$; $K_o = 1$
  - Isotropic
  - $\sigma' \_1 = 80kPa$
  - $\sigma' \_2 = 80kPa$
  - $\sigma' \_3 = 80kPa$

- **$K_r$ (failure line)**

- **Active Zone**
  - $\varepsilon_h < 0$

- **Passive Zone**
  - $\varepsilon_h > 0$

- **Vacuum Consolidation**

**Diagram:**
- Points A, B, E
- Lines indicating stress and strain paths
- Diagram showing stress-strain relationship under surcharge and vacuum conditions.
3 Vacuum Consolidation Method (VCM) Development

Consolidation Degree Calculation:

\[ U = 1 - (1 - U_v) \times (1 - U_h) \]

Carrillo formula (Das, 1985)

-Consolidation time can be greatly shorten by VCM method because it has improved the efficiency of the Consolidation drainage capacity of the soil.

<table>
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<tr>
<th>Type</th>
<th>( C_h ) (m²/yr)</th>
<th>( k_h/k_s )</th>
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<td>PVDs (SP-W5-001T)</td>
<td>2.62</td>
<td>9.2</td>
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<td>PVDs (SP-W5-031T)</td>
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<td>Vacuum-PVDs (MSA-ZB36)</td>
<td>3.56</td>
<td>7.3</td>
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<td>Vacuum-PVDs (MSA-ZB42)</td>
<td>4.83</td>
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</tbody>
</table>

By Prof. D.T. Bergado (2002)
## 3 Vacuum Consolidation Method (VCM) Development

<table>
<thead>
<tr>
<th>Comparative Item</th>
<th>Vacuum-surcharge preloading</th>
<th>Conventional surcharge preloading</th>
</tr>
</thead>
</table>
| **Surcharge height**     | Vacuum pressure (70 kPa), equivalent to 4m sand surcharge  
Usually consider settlement compensation | H= 6.0-7.0m                                           |
|                          |                                                                                           | Surcharge removal                                      |
| **Improvement period**   | Total about **5-6 months**                                                                 | Total about **12-18 months**                           |
|                          |                                                                                           |                                                       |
| **Loading phases**       | One time of surcharging                                                                    | Layer by layer  
Carefully control the surcharge height and cycle time |
| **Sliding Stability**    | No sliding                                                                                 | Potential sliding risks                                |

By Prof.D.T.Bergado (2002)
4 Typical VCM Construction Sequence

Stage 1: Working Platform (Sand Blanket)
Stage 2: VCM System Install

- Vacuum Gauge
- Surface Settlement Plate
- Extensometer (Option)
- Piezometer
- Inclinometer (Option)
- VACUUM PUMP
- SEALING TRENCH/WALL
- SAND BLANKET
- GEOMEMBRANE
- GEOTEXTILE
- PHS
- WATER
- 80kPa
- PVD
- SOFT SOIL
Stage 3: Fill Surcharge During VCM

- Vacuum Pump
- Geotextile
- Geomembrane
- PHS
- Sealing Trench/Wall
- Sand Blanket
- Surcharge
- 80kPa
- Soft Soil
- Water
- PVD
Stage 4: Consolidation settlement by VCM
Post Construction after VCM Finish

- Soft Soil
- Sand Blanket
- Embankment
- PAVEMENT/Footing
- Finish Level
How the improved soil can have the high resistivity to the effect of underground water?

- Void ($e_0$) is small;
- Permeability Coefficient of Clay is low ($10^{-6}$~$10^{-8}$ cm/s)

Just like soft Tofu contains water

After dehydrated just like dried Tofu
5 Typical VCM Project Case for Road
By Geoharbour
## 5.1 General Introduction

Typical VCM for Road Project (2011 ~ 2016)

<table>
<thead>
<tr>
<th>No.</th>
<th>Project</th>
<th>Duration</th>
<th>Area</th>
<th>Location</th>
<th>Method</th>
<th>Status</th>
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<tbody>
<tr>
<td>1</td>
<td>Kayu Agung-Palembang Toll Road section 1</td>
<td>2016</td>
<td>450,000</td>
<td>Indonesia</td>
<td>Vacuum Preloading</td>
<td>On going</td>
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<tr>
<td>2</td>
<td>Kayu Agung-Palembang Toll Road section 2</td>
<td>2016</td>
<td>330,000</td>
<td>Indonesia</td>
<td>Vacuum Preloading</td>
<td>On going</td>
</tr>
<tr>
<td>3</td>
<td>Palembang - Indralaya Toll Road</td>
<td>2015</td>
<td>850,000</td>
<td>Indonesia</td>
<td>Vacuum Preloading</td>
<td>On going</td>
</tr>
<tr>
<td>4</td>
<td>Nakhon Si Thammarat Airport (Taxiway)</td>
<td>2015</td>
<td>40,000</td>
<td>Thailand</td>
<td>Vacuum Preloading</td>
<td>Completed</td>
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<tr>
<td>5</td>
<td>Guihua 8th road, jiangbei road, jinger road, wanyunroad, hexu road,</td>
<td>2014</td>
<td>652,929</td>
<td>China</td>
<td>Vacuum Preloading + HVDM</td>
<td>Completed</td>
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<tr>
<td></td>
<td>changhe south road, heping south road soft ground improvement project</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Yunlong Road (W Binhe Road-Huayuan Road), Wufang Road (W Binhe Road-Huayuan Road), Xingchuanhe Road (Yunlong-Nanliu Road), Shengxin Road (Xingchuanhe Road-S Zhongshan Road), Zhilu 3 (Yunlong Road-Wufang Road) Ground Improvement</td>
<td>2013</td>
<td>189,137</td>
<td>China</td>
<td>Vacuum Preloading + HVDM</td>
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<td>7</td>
<td>Municipal Road Phase 4 Ground Improvement</td>
<td>2013</td>
<td>332,059</td>
<td>China</td>
<td>Vacuum Preloading + HVDM</td>
<td>Completed</td>
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<tr>
<td>8</td>
<td>Formosa Ha Tinh Steel Mill E0506 temporary road project</td>
<td>2012</td>
<td>285,719</td>
<td>Vietnam</td>
<td>Vacuum Preloading, HVDM,</td>
<td>Completed</td>
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<td>Dynamic compaction</td>
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<td>Formosa Ha Tinh Steel Mill public road zone 1 ground improvement project</td>
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<td>411,568</td>
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<td>Dynamic compaction</td>
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<td>Fujian pingtan jinjing harbour district ruyi road K0+960-K2+400 soft</td>
<td>2012</td>
<td>113,177</td>
<td>China</td>
<td>Vacuum Preloading</td>
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<td>Formosa Ha Tinh Steel Mill N22 temporary road project</td>
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<tr>
<td>12</td>
<td>North-South Expressway Construction Project</td>
<td>2011</td>
<td>110,000</td>
<td>Vietnam</td>
<td>Vacuum Preloading</td>
<td>Completed</td>
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<td></td>
<td><strong>Total</strong></td>
<td></td>
<td>3,914,373</td>
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</table>
North-South Expressway Construction Project HCMC-DauGiay
（Vietnam, 2011~2013）
Scale: 110,000 m²
Soft Soil Depth: 15-25 m
Method: Vacuum Consolidation Method (VCM)
Nakhon Si Thammarat Airport (Taxiway) (Thailand, 2015~2016)

Scale: 40,000 m²
Soft Soil Depth: 7 m
Method: Vacuum Consolidation Method (VCM)
Palembang-Kayu Agung TOLL ROAD (Indonesia, Under Construction)

Scale: 13 KM
Soft Soil Depth: 10-25 m
Method: Vacuum Consolidation Method (VCM) + Surcharge
5.2 Case Study

PALEMBANG – INDRALAYA TOLL ROAD
(Indonesia, Under Construction)
To be detailed Presentation

Length: 22 KM
Width: 45 – 50 m
Soft Soil: 10-25 m
Method: Vacuum Consolidation Method (VCM) + Surcharge
5.2.1 General information - Location

Palembang City, South Sumatra Province, Indonesia
5.2.1 General information - Layout

- Length: 21.93 km
- Speed: 100 km/hr
- Initial lane: 2x2
- End lane: 2x3
- Traffic path: 3.6 m
- Shoulder: 1.5 m
- Outer shoulder: 3 m
- Interchange: 2 pieces

Numbers of Structures:
- Underbridge: 13 pieces
- Underpass: 3 pieces
- Overpass: 7 pieces
- Box pedestrian: 5 pieces
- Box culvert: 43 pieces
- JPO: 10 pieces
5.2.1 General information - Typical Section
### 5.2.1 General information - Soil Condition

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>BH-01</th>
<th>BH-02</th>
<th>BH-03</th>
<th>BH-04</th>
<th>BH-05</th>
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<th>BH-11</th>
<th>BH-12</th>
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<td>1+000</td>
<td>1+850</td>
<td>3+650</td>
<td>5+900</td>
<td>7+125</td>
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**SPT (N)**

<table>
<thead>
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<th>1</th>
<th>Very soft</th>
<th>&lt; 2</th>
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<tbody>
<tr>
<td>2</td>
<td>No</td>
<td>CONSISTENCY</td>
</tr>
<tr>
<td>3</td>
<td>Medium Stiff</td>
<td>4 - 8</td>
</tr>
<tr>
<td>4</td>
<td>Stiff</td>
<td>8 - 15</td>
</tr>
</tbody>
</table>
5.2.1 General information - Soil Condition

Cone Penetration Test, CPT

Before Soil improvement process:
Use CPT to verify Soft Clay.
Swampy condition, water level about 1.5 – 2.0 m above the ground during rainy season and 17 km of main road area will under water. Under 5 years flood period the water may increase 1 m. more and it may result total 18 km of main road area will be under water. However, at dry season the ground water table is about -1 m below the ground.
5.2.2 VCM Construction - Site Preparation

- Stripping work (Site Cleaning)
- Woven-Geotextile spreading for Working Platform
- Working road as dike (Service Road)
5.2.2 VCM Construction - working Platform by sand or soil
5.2.2 VCM Construction - PVD Installation
5.2.2 VCM Construction - PHS Installation
5.2.2 VCM Construction - 1st Geotextile Installation
5.2.2 VCM Construction - Geomembrane Installation
5.2.2 VCM Construction - Bury Geomembrane (Edge Treatment)
5.2.2 VCM Construction - Monitoring Instrumentation Installation
5.2.2 VCM Construction - Monitoring Instrumentation Installation

Inclinometer - Horizontal Displacement
5.2.2 VCM Construction - Monitoring Instrumentation Installation

Piezometer Reader
- Pore Water Pressure

Extensometer
- Layered settlement
5.2.2 VCM Construction - Installation and Operation of VCM System
5.2.2 VCM Construction - Installation and Operation of VCM System
5.2.2 VCM Construction - Vacuum Consolidation Process

Vacuum Consolidation Process (Before Surcharge)
5.2.2 VCM Construction - 2nd Geotextile Installation
5.2.2 VCM Construction - Filling Surcharge during VCM period
5.2.2 VCM Construction - Filling Surcharge during VCM period
5.2.3 Traffic Operation
5.2.3 Traffic Operation
5.2.4 Monitoring during VCM- Surface Settlement
5.2.4 Monitoring during VCM - Pore Water Pressure
5.2.4 Monitoring during VCM - Layer Settlement
5.2.5 Site in-situ test- CPT result before and after VCM
### 5.2.5 Site in-situ test - Plate Load Test after VCM

<table>
<thead>
<tr>
<th>NO YIELD POINT</th>
<th>TYPE OF PLATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Intensity (Max Load) q' = 1.70 kg/cm²</td>
<td>RECTANGULAR PLATE</td>
</tr>
<tr>
<td>Load Allowable (Design) q = 0.80 kg/cm²</td>
<td></td>
</tr>
<tr>
<td>Settlement at q δ₁ = 4.40 mm</td>
<td></td>
</tr>
<tr>
<td>Zero Correction δ₂ = 0.00 mm</td>
<td></td>
</tr>
<tr>
<td>Corrected Settlement δ = δ₁ - δ₂ = 4.40 mm</td>
<td></td>
</tr>
<tr>
<td>Modulus Subgrade Reaction Kₛ = q/δ</td>
<td></td>
</tr>
<tr>
<td>Soil Description: SANDY</td>
<td></td>
</tr>
<tr>
<td>μ = 0.30</td>
<td></td>
</tr>
</tbody>
</table>

| Size (d)                         | 1.00 m            |
| Area                            | 1550,0 sqin       |
| Area                            | 10000,0 cm²       |

<table>
<thead>
<tr>
<th>Modulus of Elasticity:</th>
</tr>
</thead>
<tbody>
<tr>
<td>E₀ = l₀ (1-μ²) qd/δ Mpa</td>
</tr>
<tr>
<td>E₀ = 14.38 MPa</td>
</tr>
</tbody>
</table>

**ARITHMETIC LOAD SETTLEMENT DIAGRAM**

**Design Load = 0.80 kg/cm²**
5.2.6 Site Condition - in Rainy Season

Water table will be increased to 1.5~2m above ground during rainy season.
5.2.6 Site Condition - in Dry Season

Water table will be decreased to 1m below ground during dry season.
6 Conclusion

6.1 VCM method can effectively improve soft soil itself shorten the soil particle distance, and soil strength increased;

6.2 VCM method is equivalent to Integrity High-Compacted soil, greatly increase the resistance to the external environment, such as underground water level changing;

6.3 VCM method is the technical reliable, quality guaranteed, cost-saving comparing to traditional methods, both construction cost and maintenance cost.

6.4 VCM method has successfully applied in road projects in some countries, such as Indonesia, Vietnam, China, Singapore, etc. Hope this technique can be applied in the Thailand road project, and support the development of Thailand,
In the Future, Together witness

Thank you for your attention ！
ขอบคุณครับ ！

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Add: Oriental Tower, 25/71 Soi Charoenjai, Khwaeng Khlong Tan Nuea, Khet Watthana, Bangkok 10110
- The Following Pages is only Link Page
VCM Construction Sequence

Execute PVD (Prefabricated Vertical Drain)
**VCM Construction Sequence**

Execute PHS (Prefabricated Horizontal System)
VCM Construction Sequence

Execute Geotextile (On Sand Blanket, Under Geomembrane)

- Note: This Geotextile is for protecting Geomembrane
VCM Construction Sequence

Execute Geomembrane

1) The Geo-membrane is prefabricated according to Zone Size, then install at the site immediately, no need connection work;
2) 20~30 labors could finish one zone in one day without machinery;
3) The installation shall proceed daytime with less than force 5 wind power.
VCM Construction Sequence
Execute Edge Treatment : Sealing Trench / Wall

To cut off permeable air layer
**VCM Construction Sequence**

Execute Vacuum Pump
Reference – Nakhon Si Thammarat Airport, Thailand
VCM Construction Sequence

Vacuum Pump Running
VCM Construction Sequence

Vacuum Pressure

80kPa
VCM + Surcharge

Soil Surcharge Fill During VCM
VCM + Surcharge

Water Surcharge Fill During VCM
VCM + Surcharge

Soil + Water Surcharge Fill During VCM