BAMBOO PILE-MATTRESS SYSTEM AS AN ALTERNATIVE OF 
SOFT GROUND IMPROVEMENT 
FOR COASTAL EMBANKMENT IN INDONESIA

Masyhur Irsyam* 
*President - Indonesian Society for Geotechnical Engineering 
*Member - Indonesian Academy of Sciences 
*Chair - Team for Revision of Seismic Hazard Maps of Indonesia 2010 and 2017

Acknowledgement:
On behalf of: 
The Indonesian Society for Geotechnical Engineering (HATTI)
The Organizing Committee

Part of this material has been presented in:

Indonesian Plaxis User Meeting
The Application of Plaxis in Solving Various Geotechnical Problems in Indonesia

Plaxis User Meeting
The Application of Plaxis in Solving Various Geotechnical Problems in Indonesia

INTERNATIONAL CONFERENCE ON GEOTECHNICS
Yogyakarta, Indonesia
July 24 - 26, 2018

Content:
1. Ground Improvement Methods for Recent Major Infrastructure Projects in Indonesia
2. Previous Experiences Using the Bamboo Pile-Mattress System
3. Utilization of Bamboo Pile-Mattress System for Soil Improvement: 
   a. For Railway Embankment
   b. For Container Yard
4. Modelling of Load Transfer Mechanism in Bamboo Pile-Mattress System
5. Conclusions
Prof. Dr. Ir. Masyhur Irsyam, MSE. (ITB - HATTI)

5 November 2018

Workshop HATTI 2018
VACUUM PRELOADING
- Negative pressure from vacuum will generates negative pore water pressure, increase effective stress in the soils, and results in accelerating consolidation process
- Much smaller amount of fill material that is needed
- There is no slope instability problem because the soil is in isotropic consolidation condition
- Shorter time for construction

Comparison: Soil Preloading and Vacuum Preloading
- Wide ROW
- High soil surcharge
- Need thick horizontal drain
- Lower Stability
- Greater Lateral Movement
- Longer Construction Time
- Narrow ROW
- Lower or no soil surcharge
- Relatively thin horizontal drain
- Better Control of Stability
- Lesser Lateral Movement
- Shorter Construction Time
Map of Earthquake Sources for Indonesia 2017

Subduction Megathrust

Earthquake Hazard:
- Tsunami
- Ground Shaking
- Liquefaction

TYPICAL SOIL PROFILE

- 0 – 3 m = Very Loose to Loose SAND
- 3 – 7 m = Loose to Medium SAND
- > 7 m = Dense to V Dense SAND
PAVEMENT FOR AIR SIDE AREA

Design Criteria:

• Safety Factor for Liquefaction > 1.3 based on NCEER method with PGA 0.4g.
• Settlement < 10cm in future 10 years
• Post Improvement requirements:

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>N-SPT</th>
<th>q (Mpa)</th>
<th>Dr (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>16</td>
<td>7</td>
<td>&gt;70</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>9</td>
<td>&gt;70</td>
</tr>
<tr>
<td>6</td>
<td>26</td>
<td>13</td>
<td>&gt;70</td>
</tr>
<tr>
<td>8</td>
<td>30</td>
<td>15</td>
<td>&gt;70</td>
</tr>
</tbody>
</table>

Dynamic Compaction for Counter Measure of Liquefaction

Liquefaction Susceptibility

Historical Criteria

Relationship between limiting epicentral distance of sites at which liquefaction has been observed and moment magnitude for shallow earthquakes (Ambrasey, 1988)

Liquefaction Susceptibility

Compositional criteria

1. Sands (and Silty Sands and Clayey Sands), if fine content ≤ 15%
2. Silt:
   - Low Plasticity (PI ≤ 15%)
   - Higher Plasticity
3. Clays:
   - Fraction finer than 0.005 mm ≤ 15%
   - Liquid limit, LL ≤ 35%
   - Natural water content ≥ 0.9 LL

Necessary Conditions:

1. Potentially liquefiable soil (soil type, condition)
2. Saturation
3. Undrained loading:
   - Earthquake
   - Blasting
   - Pile driving
   - Trains, etc
Gradation Range for Potentially Liquefiable Sand (Hatanaka et al., 1997)

Corrected SPT Blow Counts, \((N_{60})_{60} \text{ or } (N_{60})_{70}\)

Correction Due to Fine Content (Seed et al., 1985 and Youd et al., 2001)

\[
\text{CSR} = \frac{\tau}{\sigma_n}
\]

Percepatan gempa
Muka air tanah
Kedalaman yg ditinjau

CSR
Liquefied
Non-Liquefied

N-SPT

Correction Due to Fine Content

Magnitude gempa
Kandungan butir halus

Gradation

Range for Potentially Liquefiable Sand

Most liquefiable soils

Likely to be liquefied

Most likely to be liquefied

Cyclic Stress Ratio, \((CSR_{7.5})\) or Cyclic Resistance Ratio \((CRR_{7.5})\)

Correction Due to Fine Content

\((N_{60})_{60} \text{ or } (N_{60})_{70}\)
Trial Test of Dynamic Compaction

Pelaksanaan dilakukan dengan menentukan konfigurasi jumlah pukulan yang harus dilakukan melalui tahapan percobaan.

Dari proses tersebut, jumlah pukulan jika diperlukan dapat dibagi menjadi beberapa tahap pemukulan dan fase ironing.

DC Phase 1
DC Phase 2
(if necessary)
VC Ironing

Result of Dynamic Compaction

Proses Trial (Percobaan) menghasilkan konfigurasi pemukulan sebagai berikut:
1. Berat tamper: 17 Ton
2. Tinggi jatuh: 15 m
3. Jumlah pukulan: 6 pukulan

New Yogyakarta International Airport
Rapid Impulse Compaction for Land Site Area, 2018
Impulse Compaction for Land Site Area
New Yogyakarta International Airport

Depth effect

Liquefaction → Stone Column
Consolidation → PVD

CONSTRUCTION OF RUNWAY 3
SOEKARNO – HATTI INTERNATIONAL AIRPORT SECTION 1
JAKARTA 2018

KETERANGAN
Jalan Perimeter  Jalan Inspeksi  Saluran  Gardu Catu daya listrik

TYPICAL POTONGAN  LAPISAN PERKERASAN

TYPICAL POTONGAN SOIL IMPROVEMENT

Workshop HATTI 2018
Application of Full Displacement Column 632 cm for solving Bearing Capacity and Consolidation problems.
**DETAIL PROJECT LOCATION**

**LONG SECTION PROFILE OF CONSTRUCTION HEIGHT**

**SEQUENCE OF WORK**

**Pembebanan berdasarkan Spesifikasi Teknis dan Gambar Rencana Pekerjaan Perbaikan Tanah**

**FDC = Full Displacement Column**

**KGM = Kolom Grout Modular**

**Design Criteria:**
- Minimal Subgrade CBR 6%
- Settlement post construction < 100mm
- FS static > 1.5 and FS earthquake > 1.0

**Step 1:** Positioning of FDC rig

**Step 2:** Lowering the displacement tool into the ground by rotating and pushing. Soil is loosen by the auger starter and the pushed into the surrounding soil by the displacement body.

**Step 3:** Installation to required founding depth

**Step 4:** Once the displacement tool reached the required depth, simultaneously it will extract and pump in-situ fill material (mortar) through the hollow rod. The tool is rotated in the same direction during installation phase.
Full Displacement Column (FDC)

Konsep Desain

1. Pemasangan FDC dan LTP
2. Pembebanan dan distribusi tegangan oleh LTP ke FDC dan tanah sekitarnya
3. Selama proses konsolidasi, Pada saat displacement tanah terjadi lebih besar dari pada displacement FDC, sebagian tegangan pada tanah tertransfer pada FDC akibat negative skin friction pada bagian atas FDC
4. Pada saat tercapai kondisi displacement tanah mengecil sehingga kurang dari displacement FDC, pada kedalaman tertentu, terjadi transfer tegangan kembali dari FDC ke tanah sekitarnya. Hal ini memobilisir positive skin friction dan tahanan ujung bawah FDC
5. FDC dan tanah sekelilingnya bersama-sama menahan beban secara komposit
Map of Earthquake Sources for Indonesia 2017
Subduction Megathrust

Earthquake Hazard:
- Liquefaction

Working Progress
Assembly and testing of Vibro-Flotation Equipment

Content:
1. Ground Improvement Methods for Recent Infrastructure Projects in Indonesia
2. Previous Experiences Using the Bamboo Pile-Mattress System
3. Utilization of Bamboo Pile-Mattress System for Soil Improvement:
   a. For Railway Embankment
   b. For Container Yard
4. Modelling of Load Transfer Mechanism in Bamboo Pile-Mattress System
5. Conclusions
Embankment on Soft Soils

- Low bearing capacity
- Limited Height
- Very soft soil

Large and Uneven settlement

- Very soft soil

For:
- Embankment with limited height
- Embankment in submerge area
- Embankment with tolerable settlement
- Embankment in remote area

BAMBOO PILE-MATTRESS SYSTEM

Stability of Embankment Without Reinforcement

- Critical height $h_c$
- Soft Soil
Stability of Embankment With Geotextile

It enforces the failure surface not to pass through middle of the embankment

Stability of Embankment With Bamboo Mattress

Distribute embankment load more uniformly
Reduce differential settlement due to it stiffness
Provides buoyancy

Stability of Embankment With Bamboo Pile-Mattress

Increase resistance due to side friction from bamboo piles

Consolidation Settlement

However, embankment is still subjected to consolidation settlement!!!
Durability?

Bamboo is durable as long as it is always saturated

Appropriate for embankment in coastal and swampy area where it is always saturated
Utilization of Bamboo Mattress for Coastal Embankment at Tambaklorok - Semarang

Laboratorium Geoteknik
Pusat Penelitian Antar Universitas, PPAU
Institut Teknologi Bandung

Embarkment for Land Reclamation on Very Soft Soil Morokrembangan-Surabaya 1999
Dermaga dan Breakwater, Muara Angke 2003

Tipikal Potongan

Seabed 1:1
Quarry run/kerikil/sand bags
2%
2%
Pas ir
Matras Bamboo 5 lapis
Cerucuk Bamboo
L = 6 m
Woven Geotextile
Armor: Ruble mount
W50 = 400 Kg
Seabed
W50 = 370 Kg, Ø59 - 70 cm
Filter: W50 = 37 Kg
Armor: Ruble mount
Ø27 - 33 cm
Tipikal Potongan Melintang
Quarry run/kerikil/sand bags
Seabed
Cerucuk Bamboo
Matras Bamboo 5 lapis
Spasi = 1 m, L = 6 m
Seabed
Prefabricated Segmental Raft

Content:
1. Ground Improvement Methods for Recent Infrastructure Projects in Indonesia
2. Previous Experiences Using the Bamboo Pile-Mattress System
3. Utilization of Bamboo Pile-Mattress System for Soil Improvement:
   a. For Railway Embankment
   b. For Container Yard
4. Modelling of Load Transfer Mechanism in Bamboo Pile-Mattress System
5. Conclusions
UTILIZATION OF BAMBOO PILE-MATTRESS SYSTEM FOR RAILWAY EMBANKMENT ON VERY SOFT SOIL CONDITION SEMARANG – TAWANG, 2012-2013
Cara Meletakkan Bambu Pada Matras
Untuk 5 lapis
Prof. Dr. Ir. Masyur Irsyam, MSE. (ITB - HATTI)

5 November 2018

Workshop HATTI 2018
Loading Test Cargo Train

UTILIZATION OF BAMBOO PILE-MATTRESS SYSTEM FOR CONTAINER YARD ON VERY SOFT SOIL CONDITION
JAKARTA PORT TERMINAL, KALIBARU, 2013

Masyhur Irsyam
Ketua - Himpunan Ahli Teknik Tanah Indonesia
Ketua - Pusat Penelitian Mitigasi Bencana ITB
Ketua - Tim Penasehat Konstruksi Bangunan DKI

Bangun Sucipto
PT. Pembangunan Perumahan

Andi Kartawiria
PT. Promisco

Surabaya, 4 Juli 2013

New Priok Port Project:

FERIALDY NOERLAN – Direktur Teknik PT PELABUHAN INDONESIA II (Persero)
Seminar HATTI, Desember 2012
Owner: PT PELABUHAN INDONESIA II (Persero)
Konsultan: direncanakan oleh PT LAPI ITB
Kontraktor: PT Pembangunan Perumahan
(Penulis terlibat sbg Geotechnical Expert PT PP)

Reklamasi:
- Sebagian besar area yang tersedia untuk reklamasi berada di atas tanah lunak → complicated design (matras bambu untuk pondasi revetment);
- Permasalahan ketersediaan pasir untuk material reklamasi;

Panjang daerah yang diperkuat dng cerucuk matras bambu > 5.0 km
Jumlah matras > 360 ribu
Alat pancang cerucuk cluster bambu dipatenkan oleh PT. PP
INUNDATION DURING HIGH TIDE

Luas genangan ROB ± 4,500 ha (2007), dan akan meningkat terus Penyebab: penurunan muka tanah (land subsidence); abrasi pantai; dan kenaikan muka air laut (SLR).
Sea Dyke

- **Tahapan**:
  - Urug pasir 1 m
  - Pasang cerucuk cluster bamboo L = 10 m, spasi 1.0 m
  - Pasang matras bambu 14 lapis
  - Pasang PVD L = 20 m
  - Timbunan bertahap 1 m (termasuk batu dan tetrapod) dengan waktu konsolidasi 14 hari per tahap hingga elevasi + 5.70 (as). Pada tahap akhir hingga elevasi + 7.20 as, waktu konsolidasi selama 90 hari sebelum pelaksanaan perkerasan fleksibel.

Content:

1. Ground Improvement Methods for Recent Infrastructure Projects in Indonesia
2. Previous Experiences Using the Bamboo Pile-Mattress System
3. Utilization of Bamboo Pile-Mattress System for Soil Improvement:
   - a. For Railway Embankment
   - b. For Container Yard
4. Modelling of Load Transfer Mechanism in Bamboo Pile-Mattress System
5. Conclusions

How to calculate?

Conceptually, it is similar with pile-raft system for high rise buildings
FEM Modelling

Very Soft Soil

Node-to-Node Spring

Embankment soil

Beam

Beam with interface

FEM 3D

FEM 2D

Configuration of bamboo cluster pile

Beam
dng interface element

Very Soft Soil

FEM 2D

Configuration of bamboo cluster pile

L=10 m

1.0 m

1.0 m

1.0 m

1.0 m

θ = 7 to 10 cm

Workshop HATTI 2018
**Matt and Pile Properties**

- Beam Element
- \( K = \text{Node to Node Spring/ Anchor} \)
- FEM 2D

---

**Verification and Numerical Modeling**

By Using Instrumented Trial Embankment at Tambak Oso Surabaya

- Pemancangan Cerucuk Bambu
- Pembuatan Matras bambu
Pemasangan Instrumentasi di lapangan:

Pemasangan Settlement Plate

Pemasangan Instrumentasi di lapangan:

Pemasangan Piezometer dan tipe alat baca

Grafik Penurunan-Waktu pada Settlement Plate 4

Elastic settlement = 48 cm
Consolidation settlement = 17 cm

Grafik Penurunan-Waktu pada Settlement Plate 4

Elastic settlement
Consolidation settlement

Tinggi Timbunan (m)

Hari Pengamatan
Penurunan (cm)
Analisis Stabilitas Timbunan Double Track Tawang, Semarang
### Content:

1. Ground Improvement Methods for Recent Infrastructure Projects in Indonesia
2. Previous Experiences Using the Bamboo Pile-Mattress System
3. Utilization of Bamboo Pile-Mattress System for Soil Improvement:
   a. For Railway Embankment
   b. For Container Yard
4. Modelling of Load Transfer Mechanism in Bamboo Pile-Mattress System
5. Conclusions

### Conclusions

- Recent major infrastructure projects in Indonesia used Vacuum Consolidation, Dynamic Compaction, Rapid Impulse Compaction, Stone Column, and Full Displacement Column etc.
- Bamboo pile-mattress system is proven to be reliable, and therefore, can be used as ground reinforcement for coastal/ swampy embankment on soft soil layer.
- Performance of the system can be predicted accurately as long as it is modeled correctly.
- Consolidation settlement has to be accounted for during the design life.
Thank You