Celebrating Houston
Part 2 of 4
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Frederic Masse
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Lessons learned from Ground Improvement projects Around the World

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Around the world, Geotechnical Engineers face many of the same challenges.

Principle 1:
Owners don’t want to pay for a thorough geotechnical investigation incl. Lab testing -> There’s never enough information.
Principle 2: Terzaghi is our god

\[ \sigma = \sigma' + u \]
Principle 3:

- The three main issues that may lead to the use of deep foundations or ground improvement are:

  - SETTLEMENT / HEAVE
  - BEARING CAPACITY
  - LIQUEFACTION
To deal with these three issues, there are basically three ways:

**CONSOLIDATE**
- Vacuum consolidation
- Vertical drains

**DENSIFY**
- Rapid impact compaction
- Dynamic compaction
- Vibroflotation

**STRENGTHEN**
- Deep soil mixing
- Rigid inclusions
- Stone columns
- Bi-modulus columns
- Dynamic replacement
WICK DRAINS

- Band-Shaped plastic strip – Accelerate consolidation of compressible soils
The Art of Wick Cutting
with Jonah
US Wick Drain
Charleston 2016
VACUUM CONSOLIDATION

- Use of atmospheric pressure to simulate surcharge and accelerate consolidation
DYNAMIC COMPACTION

- Free fall of 12-20 tons weights from 50-100 ft for compaction of granular soils
RAPID IMPACT COMPACTION (RIC)

- High Frequency tamping using a 9-12 tons weight
VIBROFLOTTATION

- High energy vibratory probe using water jets to densify clean sands
CONTROLLED MODULUS COLUMNS (CMC)

- Grouted Rigid Inclusions installed with a displacement tool
STONE COLUMNS / AGGREGATE PIERS

Columns of Vibrated Compacted Crushed Stone – Seismic mitigation
BI-MODULUS COLUMNS

- Combination of a Stone Column Installed Directly Above a Rigid Inclusion
Influence of local conditions: Depth

- Excavate
- RIC / DR
- DC / RAP
- VSC
- Vibro / DSM
- CMC / WD / Vac

Depth in feet:
- 5 ft
- 15 ft
- 30 ft
- 60 ft
- 90 ft
- 150 ft
### Influence of Local Conditions: Soil Type

<table>
<thead>
<tr>
<th></th>
<th>Peat / Soft Organic Clays</th>
<th>Stiff Clays / Silts</th>
<th>Silty Sands / Sandy Silts</th>
<th>Sand / Gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum / Wick Drains</td>
<td></td>
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<tr>
<td>Stone Columns / Aggregate Piers</td>
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<tr>
<td>Dynamic Replacement</td>
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<td>DC / RIC</td>
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<td>Vibroflottation</td>
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<tr>
<td>CMC Rigid Inclusions / DSM</td>
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</tbody>
</table>
Project: Kimhae & Jangyoo Sewage Treatment Plant
Country: South Korea (Busan)
Summary: New plant in Greenfield with final grade raised several meters and large net new loads

Main Issues to Solve:

- Local condition: deep very soft young deposits (>45M) from NakDong River Valley
- Settlement: predicted long term settlement > 6M over 20 years due to deep soft clays
- Construction period – Fast schedule
- Lack of availability of fill material
GENERAL DATA ON PROJECT:

- 160,000 m2 (1.7M ft²)
- 2 Water Sewage Treatment plant to meet the growing demand of the boom of population of Kimhae and Jangyoo township, suburbs of Busan, 2nd largest city in South Korea
Silty Sand to Sandy Silt – 5m (17 ft)

Weathered Rock

Soft Organic clay – 40m (130 ft)
<table>
<thead>
<tr>
<th>Layer</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silty Sand to Sandy Silt – 5m</td>
<td>normally Consolidated</td>
</tr>
<tr>
<td>(17 ft)</td>
<td>Water content average 75%</td>
</tr>
<tr>
<td></td>
<td>$N(SPT ) = 0$ to $1$</td>
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<tr>
<td></td>
<td>$Cc = 1.21$</td>
</tr>
<tr>
<td></td>
<td>$eo = 2.012$</td>
</tr>
<tr>
<td></td>
<td>$Cv = 1.32 \text{ m}^2/\text{y}$</td>
</tr>
<tr>
<td></td>
<td>Thickness between 25 and 40m (85ft to 130 ft)</td>
</tr>
<tr>
<td></td>
<td>Expected max settlement &gt; 6m (15% of clay thickness)</td>
</tr>
</tbody>
</table>
SAND DRAINING LAYER
FILL LAYER
HORIZONTAL VACUUM PIPES
VERTICAL DRAINS
ISOTROPIC VACUUM CONSOLIDATION
VACUUM
ATMOSPHERIC PRESSURE
MEMBRANE
SEALING TRENCH
SATURATED SOFT CLAY
BEFORE VACUUM APPLICATION:

\[ \sigma_T = \gamma z + \gamma_f h + P_a = \sigma_t + P_a \]
\[ u_T = \gamma_w z + P_a = u_t + P_a \]
\[ \sigma_i' = \sigma_T - u_T = \sigma_t - u_t \]
\[ = \gamma' z + \gamma_f h \]

AFTER VACUUM APPLICATION:

\[ \sigma_T = \gamma z + \gamma_f h + P_a = \sigma_t + P_a \]
\[ u_T = \gamma_w z + P_a - P_a \]
\[ \sigma_f' = \sigma_T - u_T \]
\[ = \sigma_i' + P_a \]

\[ \Delta \sigma' = \eta P_a \quad \text{Where } \eta \approx 0.7 - 0.8 \]
Value are average between 7:30 and 13:30 CPV readings
SETTLEMENT ANALYSIS & VACUUM STOP DECISION PROCESS

1D consolidation theory

\[ \Delta \sigma'(z) = \gamma H \text{fill} + \sigma_o + \gamma' \Delta H_{\text{primarysettlement}} \]

\[ \Delta H_{\text{primarysettlement}} = \frac{C_c H \log(\frac{\sigma_o + \Delta \sigma'(z)}{\sigma_o})}{1 + e_o} \]

Calibration Coefficient

\[ \beta = \frac{\Delta H_{\text{asaoka}}}{\Delta H_{\text{theory}}} = \frac{(\frac{C_c}{1 + e_o})_{\text{actual}}}{(\frac{C_c}{1 + e_o})_{\text{soilinvestigation}}} \]

Asaoka Analysis of monitoring results

SETTLEMENT TARGET

Target reached? Yes -> Stop vacuum
Target reached? No -> Continue analysis
Project: Airbus A380 Assembly Plant  
Country: Germany (Hamburg)  
Summary: New Assembly plant on Elbe River for Airbus A380 – extension of runway  

Main Issues to Solve:  
- Local condition: underconsolidated river tidal deposits (Elbe River)  
- Settlement: predicted long term settlement > 2M over 20 years due to very compressible deposits (Muck)  
- Bearing capacity / Slope Stability at edge
- Reclaimed Area = 170 ha
  (about 1.9m ft²)
- Final Assembly of Airbus A380
- Spare parts delivered by barge, plane or road to the Hamburg plant
- Containment dike on GCC
- Hydraulic sand reclamation
- Wick drains + Vaccum + GEC
DA - Erweiterung - Umschließung

Konzept der Ausschreibung:
Deich im Schutz einer temporären Spundwand
Fertigstellung des Deiches und Beseitigung der Spundwand i.J. 2005

Konzept Möbius:
Deich auf GSM - Gründung
Fertigstellung des Deiches Anf. 2002

ORIGINAL DESIGN OF DIKE

VALUE ENGINEERING DIKE
Solution:
Installing a „corset“

$\eta \ll 1.3$

$\gamma + 2.5 \text{ mNN}$

$\gamma + 6.5 \text{ mNN}$

Stability problem
Celebrating Houston

March 31 at Rice University