GEOTECHNICAL ENGINEERING CHALLENGES FOR HIGHWAY DESIGN AND CONSTRUCTION ON SOFT GROUND

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CHALLENGES FOR GEOTECHNICAL ENGINEERS ON SOFT GROUND

Consolidation
Settlement

Bearing Capacity
and Consolidation Settlement
Two drowned after road collapses

By Roy Cohn and Julia Chan

PAPAR: A man and his son drowned while a university student is missing after a 20m stretch of road collapsed into a river yesterday.

The man and his son were travelling in a Proton Kancil which plunged two metres into the Mandahan river about 8am.

The university student, meanwhile, had wanted to cross to the other side of the river later in the afternoon but was unable to do so due to the road collapse.

The student, who was riding a motorcycle, then tried to use a nearby railway bridge but lost his balance and fell into the river.

The road at Kilometre 16 Papar-Beaufort had caved in after floodwaters eroded the soil covering three box culverts placed across the river.

The culverts had been chocked with debris for several days, causing the water to seep through the soil at the side.

The victims were identified as Husin Mustapha, 50, a religious teacher from Skim Kejang, Kuala Penyu, and his son, Razali Husin, 22, a Universiti Malaysia Sabah undergraduate.

The missing university student is Zubairi Abdul Wahab, in his 20s, from Kuchare, Beaufort.

The road collapse cut off links to Kuching, Penyu, Mentakut, Bongawan, Beaufort, Memenulok and Simpang.

The damaged road was also used by those travelling from Sarawak and Brunei.
Bridge and water woes leave 800 families dry

KANOWIT: Some 800 families have been left dry after a major water main burst as a concrete bridge across Sungai Menyan here collapsed.

The families were from several villages and longhouse settlements in Pidai, Nibong, Tada, Sedaya and nearby areas.

Nobody was injured as the bridge, which was built in 1997, collapsed at about 3am on Saturday.

Villagers said they heard a loud sound and thought it was an explosion. They went to check and found that the bridge had given way.

State Assistant Minister for Housing Dr Soon Choon Teck, who carried out a site inspection, said a notice board was placed near the bridge, warning drivers of heavy vehicles against crossing it, when the bridge was found to be unstable a month ago.

The Public Works Department had planned to close the bridge to facilitate remedial works after discovering defects in one of the bridge's foundations.

A temporary bridge was under construction when the incident happened.

Dr Soon said the temporary bridge was expected to be ready by today.

The Sibu Water Board would lay a new water pipe to restore supply to the affected residents.

WRECKED: Residents inspecting the site of the broken bridge across Sungai Menyan in Kanowit yesterday.
FAILURE EVENT IN MALAYSIA

Bumpy journey

The new road linking Malacca and Johor only opened three months ago, but two major cave-ins had already occurred. The road is a short-cut to Sungai Rambai, Malacca, from Sungai Mati and links to the second Muar bridge. Heavy vehicles and bad weather have been blamed for the cave-ins. A Public Works Department spokesman said once the extent of the damage had been ascertained, repairs would begin. — NST picture by Chong Chee Seong
FAILURE EVENT IN MALAYSIA
FAILURE EVENT IN MALAYSIA
FAILURE EVENT IN SINGAPORE
IDENTITY OF SOFT GROUND
IDENTITY OF SOFT GROUND

- $S_u < 10\text{kPa}$
- $S_u > 10\text{kPa}$
IDENTITY OF SOFT GROUND

Picture courtesy of TenCate Geosynthetics
IDENTITY OF SOFT GROUND

Picture courtesy of TenCate Geosynthetics
VEGETATION
VEGETATION
Alluvial Deposits

Soft Ground in Malaysia
Embankment Failure
Embankment Treated with Vacuum Preloading with Vertical Drains

Embankment Fill (Failed Area) (Vacuum Preloading with Vertical Drains)

Embankment Fill (Without Vacuum Preloading)

Liner and Sand Layer for Vacuum System

Very Loose Clayey SAND

Very Soft Silty CLAY

Soft Sandy CLAY

Very Loose Clayey SAND

Medium to Stiff Silty CLAY and Clayey SILT

(After Gue et al. 2001)
Embankment Failure

- Embankment failed = Fill height of 5.5m
- After Failure of Vacuum Preloading → Remedial with Stone Columns.
- Embankment Failed Again at 3.2m
Undrained Shear Strength Profile

![Undrained Shear Strength Profile]

- **Su = 10 kPa**
- **Su = 8 kPa**
- **Su = 13 kPa**
- **Su = 17 kPa**
- **Su = 19 kPa**

Legend:
- □ Su-Undisturbed from VS-A
- ■ Su-Remolded from VS-A
- ○ Su-Undisturbed from VS-B
- ● Su-Remolded from VS-B

**Sensitivity, St**

- **In-Situ Vane Shear Test**
  - □ VS-A
  - ○ VS-B
Monitored Pore Water Pressures

Excess Pore Water Pressure generated at PZ-A3,
$\Delta U = + ve$

Excess Pore Water Pressure generated at PZ-A2,
$\Delta U = + ve$

Designed Water Head is 3m at PZ-A1

Designed Water Head is 6m at PZ-A2.

Designed Water Head is 8m at PZ-A3

Piezometers at Location A
- at 3.0m depth
- at 6.0m depth
- at 8.0m depth

Fist Crack Observed on Day 162
Failure of Embankment treated with Stone Columns

- Only Priebe’s Method was used
- Bulging & General Shear Failures not checked
- Independent review shows inadequate General Shear Capacity
Methods of Estimating Ultimate Bearing Capacity

Table 3: Methods for Estimation of Ultimate Bearing Capacity of Stone Columns

<table>
<thead>
<tr>
<th>Mode of Failures</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulging</td>
<td>Greenwood (1970); Vesic (1972); Datye &amp; Nagaraju (1975); Hughes and Withers (1974); Madhav et al. (1979).</td>
</tr>
<tr>
<td>General Shear</td>
<td>Madhav &amp; Vitkar (1978); Wong (1975); Barksdale and Bachus (1983).</td>
</tr>
</tbody>
</table>

- Large range of possible Ultimate Bearing Capacity
- Attention when using stone columns in very soft ground (e.g. $s_u < 15\text{kPa}$)
Lessons Learned

• Vacuum Preloading Method shall be closely monitored

• Remedial design for failed embankment shall use "disturbed" soil strength

• Stone columns design shall check for all modes of failure
  + Observational Method (recommended)

• Understand the Limitation of Software used → It may not check all the required modes of failures
Stone Column
Stone Column

The Principle

- Stone Columns = Granular Pile = Vibro Replacement
- Involves partial replacement of unsuitable subsoil with compacted column of stones or aggregates
- Usually completely penetrates the weak strata
Stone Column

Sand Platform

Compressible Layer

Firm Strata
Stone Column

**Function**

- Provide bearing capacity / strengthening immediately upon installation
- Reduce settlement
- Increase the rate of consolidation
- Facilitate subsoil drainage

- Diameter: 0.6m - 1.2m
Other Available Option for Ground Improvement
Surcharging

- Temporarily compress the subsoil with higher pressure than permanent load

- Achieve higher initial rate of settlement + reduce long term settlement

- Larger portion of fill left behind

- If fill material is available
Surcharging

Finished Level

Embarkment

Soft Soil
Surcharge

- Filling
- Rest Period
- With Surcharge
- Without Surcharge
- Settling Time
- Faster
Settlement
Service Life of Embankment
Permanent Loading
Service Life of Embankment
Primary Consolidation
Secondary Consolidation
Permanent & Surcharge Loading
Service Life Settlement without Surcharge
Vertical Pressure from Embankment Loading
Log Time
Log Time
Settlement
Construction
Surcharge Duration
Permanent Loading Only
Temporary Surcharge

Earthwork Surcharge in Progress
VERTICAL DRAINS
Functions

• Provide **shorter** drainage path

• **Accelerate** dissipation of excess pore water pressure
Without inserting PVD, dissipation of excess pore pressure is a slow process.
With VERTICAL DRAINS

Surcharge
Drainage Blanket
Fill

Preload

With PVD the excess pore pressure dissipates quickly through shorter drainage paths.
Drainage Path for Consolidation

1. **Thick Clay Layer**
   - Embankment
   - Clay
   - Sand
   - $H_D$

2. **Intermediate Sand Layer**
   - Embankment
   - Clay
   - Sand
   - $H_D$

3. **Vertical Drains**
   - Embankment
   - Clay
   - Sand
   - $H_D$
Consolidation Theory

\[ c_v = T_v \frac{H_D^2}{t} \]

Where

- \( c_v \) = coefficient of consolidation in vertical direction (m\(^2\)/year)
- \( T_v \) = Time factor (dimensionless)
- \( H_D \) = Drainage path length (m)
- \( t \) = Time application of loading (year)
Rearrange...

t = T_v H_D^2 / c_v

Therefore

t \propto H_D^2

<table>
<thead>
<tr>
<th>H_D</th>
<th>1m</th>
<th>10m</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>1</td>
<td>100</td>
</tr>
</tbody>
</table>
INSTALLED PVD
Failure of Bridge
Foundations and Approach
Embankment
Overview
Overview

Abutment I

Pier I

Pier II

Abutment II
Subsoil Condition

25m coastal & alluvium CLAY
Sheer Drop

Pilecaps
Slip Failure
Tilted Abutment & Gap between Bridge Decks

Tilt from Vertical

Opening between bridge
Pier II
Slip Failure of Embankment

• At 25m behind Abutment II

• Abutment II:
  - Tilted 550mm on top
  - Angular distortion of 1/6

• 300mm gap between bridge decks
Geotechnical Investigation

- $H_{\text{failure}} \@ 3\text{m}$
- $H_{\text{Design}} \@ 5.5\text{m}$

$\Rightarrow$ NOT SAFE

HOW TO CHECK?
What Is The Critical Height?

Simple Calculation

\[ H_{\text{failure}} = \frac{(N_c \times Su)}{\gamma_{\text{fill}}} \]

\[ N_c \approx 5 \]

\[ H_{\text{failure}} = \frac{(5 \times Su)}{\gamma_{\text{fill}}} \]

e.g.:

When \( Su = 10 \text{ kPa} \); \( \gamma_{\text{fill}} = 18 \text{ kN/m}^3 \)

\[ H_{\text{failure}} = \frac{(5 \times 10)}{18} = 2.8 \text{ m} \]
Lessons Learned

• Failures ← (temporary works)
  - Inadequate geotechnical design
  - Subsoil Condition (Lack of understanding)
  - Lack of construction control & supervision
Preventive Measures

• Proper design and review
• Stability check of embankment & abutment
• Most critical :-
  *During construction*
  *(must check temporary works)*
• Proper full-time supervision
  *(with relevant experience & understand design assumptions)*
SETTLEMENT OF APPROACHES BRIDGES
Typical Cross-Section

Final Profile

Long Term Profile

Abutment

O.G.L.

Pile
SOME SOLUTIONS TO THE PROBLEM
USE OF LIGHT WEIGHT MATERIAL
USE OF TRANSITION EMBANKMENT PILES

Abutment

O.G.L.

Pile

Final Profile

Long Term Profile

Approach Slab

Transition Embankment

Piles

USE OF TRANSITION EMBANKMENT PILES
EXAMPLE (BERNAM JAYA)
Transition Piles + Surcharging = Fewer Piles + Cost Saving

DESIGN SURCHARGE
DESIGN ROAD LEVEL
SURCHARGE
EXISTING GROUND LEVEL
3m SOFT SOIL REPLACEMENT OR AS SPECIFIED BY DESIGN ENGINEER

RL.63.5m
RL.63.0m
RL.62.0m
350mm THK. R.C. SLAB

R.C. WALL

PILE TO SET (ESTIMATED LENGTH=18m)
SETTLEMENT OF APPROACHES TO CULVERTS
SOME SOLUTIONS TO THE PROBLEM
ENLARGED CULVERT

Final Profile

Long Term Profile

O.G.L.

Silt
Guidance Notes on Subsoil Investigation
Guidance Notes on Subsoil Investigation

• Collect **UD** from BH

• Laboratory Test: **UCT & 1-D Consolidation Test**

• **Piezocone:**
  – To detect presence of **sand lenses**
  – $q_u$
  – Especially for surcharge design with or without **PVD**
Localised Weak Zone
Localised Weak Zone

- Generalised moderately conservative design line (MCL)
Localised Weak Zone

- If not identified, likely to cause failure
- **Surcharge + PVD**
  \[ \Rightarrow \text{Piled Embankment} \]
- Further verify by Vane Shear Tests, Piezocones & MPs
Conclusion
Conclusions:

- Important:
  - Bearing Capacity assessment by CRUDE check
  - SYSTEMATIC check & review process (review by experienced engineers)
  - STRUCTURED training programmes (enhance technical knowledge & share lessons learned)
  - Full-time SUPERVISION with team of suitable experience
  - Extra Care on TEMPORARY WORKS
CONCLUSION

• DO NOT
  ▪ Abuse **geotechnical design**, detailed analysis
  ▪ Overlook localised **weak zones**
  ▪ Overlook structural **detailing**
Thank You for Your Attention

G&P Geotechnics Sdn Bhd (www.gnpgroup.com.my)