GEOTECHNICAL PROPERTY TOOL ON NASA AMES K-10 ROVER.

leag-ilewg-srr
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Kris Zacny, zacny@honeybeerobotics.com

Co-Authors:
Honeybee Robotics: J. Wilson, A. Ashley, and C. Santoro
NASA Ames: T. Fong, S. Lee, and L. Kobayashi
why measure soil mechanical (strength) properties?
When you want to build a house, road etc. you call geotechnical engineer first...
but is it important for the space exploration?
yes
Surface operations require geotech data

- excavation forces and energy
  - size of an excavator
- traction requirements
  - mass, wheel design
- radiation protection (density)
- road/landing pad conditions
what has been done so far
Methods of in-situ soil testing

- Cone Penetrometer
- Vane Cone
- Cohron Sheargraph
- DCP
- Bevameter

S. Shoop, 1993
Space Heritage

Soviet Lunokhod: Cone-Vane (>100 tests)

- Bearing capacity & Shear resistance
- Surface measurements only

- Findings
  - Greatest strength was found in the level areas between craters, the least in the circular embankments around craters.
  - The bearing capacity for the cone ranged from 0.2 to 1.0 kg/cm^2, with a most probable value of 0.34 kg/cm^2.
  - The most probable value of shear strength (according to vane test) is \( \sim 0.048 \) kg/cm^2, with a range from 0.03 to 0.09 kg/cm^2.

Cherkasov, 1973
what about greater depths?
Use Dynamic Cone Penetrometer

- Rate of penetration per impact is converted to
  - **California Bearing Ratio (CBR).**
- $1 < CBR < 100$
  - CBR=1 (weak soils); CBR=100 (strong soils)
And we can get other soil properties

- Additional correlations developed over the years
- Example: DCP test (in situ) vs. Tri-axial in lab on same soil (undisturbed)

<table>
<thead>
<tr>
<th>Geotechnical parameter</th>
<th>What it describes</th>
<th>Relationship to CBR</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing Capacity, q</td>
<td>A parameter used in the design of shallow foundations</td>
<td>$q(kPa) = 26.16 * CBR^{0.64}$</td>
<td>Portland Cement Association (PCA)</td>
</tr>
<tr>
<td>Dynamic Modulus (E)</td>
<td>Characterizes soil under a variety of temperatures and stress states that simulate the conditions in a soil subjected to moving wheel loads. Dynamic Modulus: if loading is continuous (e.g. constant traffic). Resilient Modulus: if loading has a rest period (e.g. intermittent traffic)</td>
<td>$E(MPa) = 10.34 * CBR$</td>
<td>Huekelom and Klomp, 1962</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$E(MPa) = 17.58 * CBR^{0.64}$</td>
<td>Powel et al., 1984</td>
</tr>
<tr>
<td>The Modulus of Subgrade Reaction, k,</td>
<td>Used during the design and later in evaluation of rigid pavements</td>
<td>$k(M/m) = 65.91 - 1.49 * CBR + 35.23 * CBR$</td>
<td>Department of Defense Unified Facilities Criteria Manual, 2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For CBR &lt; 20</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$k(M/m) = -3.05 - 0.59 * CBR + 16.34 * CBR^{0.5}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>For CBR &gt; 20</td>
<td></td>
</tr>
</tbody>
</table>
DoD has been using it for over 30 years...

but...

they needed something ‘more’ man portable and easier to use...
Percussive DCP: Concept for DoD

- Drop hammer -> Percussive hammer
- Lighter, 1 operator, more accurate, Less noise
- Quick soil assessment for trafficability, airfields construction, etc.
Percussive DCP in operation
Side-By-Side Field Tests

Smaller data spread!!!
Correlations: PDCP->DCP->CBR

CBR (for DCP) or Blows/mm x 2.6 (for PDCP)

Depth, in.

Weak

Strong

Depth, mm

DCP

PDCP
what about space application?
Percussive DCP: Concept for NASA

Change outfit (and planet)
but....

astronauts don't want to drill any more
Final Concept: Auto operation

NASA Ames K-10 rover
- 80 kg
- 90 cm/s
- 40 kg payload
Final Product

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass in kg (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percussion System</td>
<td>3.2 (7.0)</td>
</tr>
<tr>
<td>Deployment System</td>
<td>4.2 (9.2)</td>
</tr>
<tr>
<td>Battery &amp; Electronics</td>
<td>2.7 (6.0)</td>
</tr>
<tr>
<td>Framing &amp; Support</td>
<td>3.0 (6.7)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13.1 (28.9)</strong></td>
</tr>
</tbody>
</table>
Lab Data (at Honeybee Facility)

Soil Type
Sandy Clay
~ 20% wt. H2O

8/04/2008 - Column D

CBR for DCP (Actual) and PDCP (Estimate)

Depth (mm)
Field Data (at NASA Ames “Marscape”)
the issue of lunar regolith
Luna regolith

- Regolith becomes very dense very quickly
  - $1.9 \text{g/cc}$
- Relative density >90%
Apollo Core Tubes -> PDCP

Apollo Experience

- Apollo Astronauts managed to hammer core tubes into the regolith
- It was a tough job, but doable
- A17: core tube to 68 cm in 50 hammer blows
  - (that`s 2 sec with PDCP)

PDCP

- No sleeve friction
- Cone can be smaller diameter
- High energy and frequency percussion
- And, if you can't get any deeper:
  - it's hard enough for construction
  - too hard for excavation
PDCP tests in compacted JSC1a

- Yes, it's not lunar regolith, but we don't have anything better right now (MSFC simulant not available yet)

- Resistance is a function of a cone diameter and rod diameter

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![Image: Drill and test setup]

### Depth (m) vs. Elapsed Time (s)

- Test 9: Cone 25 mm, Rod 22.2 mm
- Test 10: Cone 10 mm, Rod 8 mm
- Test 11: Cone 25 mm, Rod 22.2 mm
- Test 12: Cone 25 mm, Rod 22.2 mm
- Test 13: Cone 25 mm, Rod 14.3 mm
- Test 14: Cone 10 mm, Rod 8 mm
- Test 15: Cone 25 mm, Rod 14.3 mm
- Test 16: Cone 10 mm, Rod 8 mm
- Test 17: Cone 25 mm, Rod 21.3 mm
- Test 18: Cone 25 mm, Rod 21.3 mm
Acknowledgements

1. Army: ERDC
2. NASA Ames
PDCP on K10 rover at NASA Ames Marscape

contact: kris zacny, zacny@honeybeerobotics.com