Lunar Regolith and Structure Mechanics

Stein Sture

Third Annual Symposium
November 21 & 22, 1991
LUNAR REGOLITH AND STRUCTURE MECHANICS

Frank Barnes
Hon-Yim Ko
Stein Sture

Tyrone R. Carter
Kraig A. Evenson
Mark P. Nathan
Steve W. Perkins

- MODELING OF REGOLITH-STRUCTURE INTERACTION IN EXTRATERRESTRIAL CONSTRUCTED FACILITIES

- DENSIFICATION OF LUNAR SOIL SIMULANT

- VIBRATION-ASSISTED PENETRATION OF LUNAR SOIL SIMULANT

A NASA Space Engineering Research Center at the University of Colorado
MINERALOGY AND PHYSICAL PROPERTIES OF LUNAR REGOLITH AND MLS ARE VERY CLOSE

Grain Size Distribution Curves for Apollo Samples and Recombined MLS-1

A NASA Space Engineering Research Center at the University of Colorado
Best Estimates of Lunar Soil In Situ Density Versus Depth (data after Carrier, 1990)

Best Estimates of Lunar Soil Friction Angle Versus Depth (data after Carrier, 1990)
Best Estimates of Lunar Soil Cohesion Versus Depth (data after Carrier, 1990)

Mohr-Coulomb Peak Strength Envelopes for Lunar Regolith and MLS-1 (after Carrier et al., 1991)
MECHANICAL PROPERTIES OF A SIMULATED LUNAR SOIL

TRIAXIAL COMPRESSION EXPERIMENTS (MLS)

Schematic Diagram of the Triaxial Testing System

A NASA Space Engineering Research Center at the University of Colorado
CTC Experimental Results and Predictions For "High" Confining Stress Levels (Dense)
CTC Experimental Results and Predictions For "low" Confining Stress Levels (Dense)
MRS-Lade Prediction for Unconfined Compression Test From Calibration at Ultra-Low Stress Levels
TENSILE STRENGTH EXPERIMENT

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH
MRS-Lade Prediction for Unconfined Tension From Calibration at Ultra-Low Stress Levels

ULTIMATE STRENGTH ENVELOPE FOR MLS-1
TYPICAL RANGES OF ENGINEERING PROPERTIES FOR DRY TERRESTRIAL COHESIONLESS SOILS AND LUNAR REGOLITH (REAL AND SIMULATED)

- **ADVANTAGES**
  
  - Increased Strength
  
  - Increased Stiffness
  
  - Subsurface Homogeneity

- **DISADVANTAGES**
  
  - Electrostatic Attraction To All Non-Geologic Matter
  
  - Difficult To Excavate

<table>
<thead>
<tr>
<th>Property</th>
<th>Terrestrial Soils</th>
<th>Lunar Regolith and MLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction Angle ($\phi,^\circ$)</td>
<td>30-38</td>
<td>44-66</td>
</tr>
<tr>
<td>Cohesion/Adhesion ($c, \frac{kN}{m^2}$)</td>
<td>0</td>
<td>0.05-4.50</td>
</tr>
<tr>
<td>Specific Mass of Solids ($\rho_s, \frac{g}{cm^3}$)</td>
<td>2.7</td>
<td>3.1</td>
</tr>
<tr>
<td>Mass Density of Particulate Void-Solids Composite ($\rho, \frac{g}{cm^3}$)</td>
<td>1.4-1.9</td>
<td>1.8-2.2</td>
</tr>
<tr>
<td>Unit Weight ($\gamma, \frac{kN}{m^3}$)</td>
<td>14-19</td>
<td>2.9-3.6</td>
</tr>
<tr>
<td>Bearing Capacity of a 0.10 m by 0.10 m Footing on Level Ground ($q_f, \frac{kN}{m^2}$)</td>
<td>8.45</td>
<td>27-1810</td>
</tr>
<tr>
<td>Modulus of Subgrade Reaction (est.) ($k_s, \frac{MN}{m^3}$)</td>
<td>0.5-15</td>
<td>1-10$^t$</td>
</tr>
</tbody>
</table>

A NASA Space Engineering Research Center at the University of Colorado
CENTRIFUGE MODELING OF REGOLITH-STRUCTURE INTERACTION

Longitudinal Stringers
Solid PVC Cylinder

50.8 cm
21.6 cm
68.6 cm

90°
angle of repose

55°

A NASA Space Engineering Research Center at the University of Colorado
MODEL

SLOPE ANGLE  VOLUME [m^3]
30°          1,245
55°          705
90°          690

Lunar Prototype II.II.M. Dimensions
Comparison of Conventional Slope Stability Solutions To Centrifuge model

A NASA Space Engineering Research Center at the University of Colorado
PHYSICAL PROPERTIES OF LUNAR REGOLITH

APOLLO 15 CORE TUBE SITES


A NASA Space Engineering Research Center at the University of Colorado
LUNAR CRANE CAN PROVIDE EXCAVATING CAPABILITY USING A VIBRATING EXCAVATOR

(After Martin Mikulas)

ANCORS
(VIBRATING PENETRATORS/AUGERS)

Vibrating Bucket
CENTRIFUGE MODELING OF PENETRATOR PERFORMANCE

PENETRATOR

GUIDING ROSES

SPECIMEN
(REGOLITH)

ACTUATOR

A NASA Space Engineering Research Center at the University of Colorado
Static Vs. Vibration Assisted Penetration

**PENETRATOR RESISTANCE**

- Static
- 5 & 120 Hz
- 10 & 40 Hz
- 20-30 Hz

**PENETRATOR DISPLACEMENT**
RESPONSE OF 6 IN. STEEL PENETRATOR

A NASA Space Engineering Research Center at the University of Colorado
RESPONSE OF 9 IN. STEEL PENETRATOR

A NASA Space Engineering Research Center at the University of Colorado
Power Input - 6" Steel Tip Rod

Power (Watt) vs Frequency (Hz)
PENETRATION vs TIME
Testbeds One & Two

Depth of Penetration (in.)

Time (seconds)

- - Tst 2-1(NoVib)  - - Tst 2-2(Vibr)  - - Tst 2-3(Vibr)
- - Tst 1-4(Vibr)  - - Tst 2-5(Vibr)  - - Tst 2-6(Vibr)
PENETRATION vs TIME
TESTBED 3

Depth of Penetration (in.)

Time (seconds)

- Tst 3-1 (No Vib)  - Tst 3-2 (Vibr)  - Tst 3-3 (Vibr)
- Tst 3-4 (Vibr)  - Tst 3-5 (Vibr)  - Tst 3-6 (Vibr)