Lunar Regolith and Structure Mechanics

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LUNAR REGOLITH AND STRUCTURE MECHANICS

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• MODELING OF REGOLITH-STRUCTURE INTERACTION IN EXTRATERRESTRIAL CONSTRUCTED FACILITIES

• DENSIFICATION OF LUNAR SOIL SIMULANT

• VIBRATION-ASSISTED PENETRATION OF LUNAR SOIL SIMULANT

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MINERALOGY AND PHYSICAL PROPERTIES
OF LUNAR REGOLITH AND MLS ARE VERY CLOSE

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

Maximum and Minimum Void Ratio for Lunar Soil and Simulants

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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
TENSION-SHEAR DEVICE

DIRECT SHEAR DEVICE
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

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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)

<table>
<thead>
<tr>
<th></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 ($c$, $kN/m^2$)</td>
<td>0</td>
<td>0.05-4.50</td>
</tr>
<tr>
<td>Specific Mass of Solids ($\rho_s$, $g/cm^3$)</td>
<td>2.7</td>
<td>3.1</td>
</tr>
<tr>
<td>Mass Density of Particulate Void-Solids Composite ($\rho$, $g/cm^3$)</td>
<td>1.4-1.9</td>
<td>1.8-2.2</td>
</tr>
<tr>
<td>Unit Weight ($\gamma$, $kN/m^3$)</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 ($q_f$, $kN/m^2$)</td>
<td>8.45</td>
<td>27-1810</td>
</tr>
<tr>
<td>Modulus of Subgrade Reaction (est.) ($k_s$, $MN/m^3$)</td>
<td>0.5-15</td>
<td>1-10$^1$</td>
</tr>
</tbody>
</table>

- ADVANTAGES
  - Increased Strength
  - Increased Stiffness
  - Subsurface Homogeneity

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

### Slope Angle

<table>
<thead>
<tr>
<th>Slope Angle</th>
<th>Volume [m$^3$]</th>
</tr>
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<tbody>
<tr>
<td>30°</td>
<td>1,245</td>
</tr>
<tr>
<td>55°</td>
<td>705</td>
</tr>
<tr>
<td>90°</td>
<td>690</td>
</tr>
</tbody>
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**Lunar Prototype II.III.M. Dimensions**

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PHYSICAL PROPERTIES OF LUNAR REGOLITH

APOLLO 15 CORE TUBE SITES
LUNAR CRANE CAN PROVIDE EXCAVATING CAPABILITY USING A VIBRATING EXCAVATOR

(After Martin Mikulas)
CENTRIFUGE MODELING OF PENETRATOR PERFORMANCE

PENETRATOR

SPECMEN
(REGOLITH)

ACTUATOR

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Static Vs. Vibration Assisted Penetration

Static

5 & 120 Hz

10 & 40 Hz

20-30 Hz

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Average Depth - 9" Steel Tip Rod

Depth (in)

Time (sec)

Legend

10 Hz
15 Hz
20 Hz
30 Hz
40 Hz
50 Hz
70 Hz
120 Hz
RESPONSE OF 6 IN. STEEL PENETRATOR

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RESPONSE OF 9 IN. STEEL PENETRATOR

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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)