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Influence of lithophysae geometry on mechanical properties of Hydro-Stone®

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Influence of Lithophysae Geometry on Mechanical Properties of Hydro-Stone®

Task: ORD-FY04-013

Co-op Briefing to the U.S. Department of Energy

Presented by:
Moses Karakouzian and Doug Rigby

January 11, 2007 – Harry Reid Center Auditorium
Outline

1. Background
2. Purpose
3. Methodology
4. Results
5. Future Work
1. Background

- 85 percent of YM drift tunnels will be constructed in lithophysal volcanic tuff
- Rock behavior depends on porosity
- Limited experimental data exists to characterize rock porosity and dependencies on properties such as $\sigma_c$, $E$, and $n$. 
Lithophysal Rock

Lithophysal Cavities

Random shapes, sizes, and locations

Uncertain lithophysal porosity
Properties of Lithophysal Rock

Continuous Matrix
(intact rock)

Solid with Holes
(lithophysal rock)

$E_0$, $\nu_0$, $\sigma_{co}$

introduce
holes

$E$, $\sigma_c$
Previous Project (Task 27)

Analog Rock (Plaster of Paris) Testing
Previous Project (Task 27)

Plaster of Paris

Deformation Modulus, E

Graph showing the relationship between porosity (%) and deformation modulus (E, ksi) for plaster of Paris. Points indicate different porosity levels, with some showing uniform distribution and others showing random distribution.
Previous Project (Task 27)

Plaster of Paris

Compressive Strength

![Graph showing the relationship between porosity and compressive strength for Plaster of Paris. The graph includes data points for uniform and random distributions of compressive strength.]
Previous Project (Task 27)

- Results of Specimen Tests
Yucca Mountain Tests

- Deformation Modulus

\[
y = 20.245e^{-4.1815x} \\
R^2 = 0.9779
\]

\[
y = 17.866e^{-3.457x} \\
R^2 = 0.9981
\]

\[
y = 19.684e^{-3.1677x} \\
R^2 = 0.9938
\]

- 10.5 and 11.5-in lithophysal tuff lab tests, room dry
- PFC2D (AR=2:1, Davg=17.1 mm, 166-mm circles)
- PFC3D (AR=2:1 cyl, Davg=52.3 mm, 166-mm spheres)
- UDEC (AR=1:1, Davg=17 mm, 90-mm circles)
- PFC2D (Stenciled lithophysae from panel maps, 1m X 1m)
- 10.5 and 11.5-in lithophysal tuff lab tests, saturated
Yucca Mountain Tests

Uniaxial Compressive Strength

- 10.5 and 11.5-in lithophysal tuff lab tests, room dry
- PFC2D (AR=2:1, Davg=17.1 mm, 166-mm circles)
- PFC3D (AR=2:1 cyl, Davg=52.3 mm, 166-mm spheres)
- UDEC (AR=1:1, Davg=17 mm, 90-mm circles)
- PFC2D (Stenciled lithophysae from panel maps, 1m X 1m)
- 10.5 and 11.5-in lithophysal tuff lab tests, saturated

Equations:

\[ y = 52.167e^{-6.9159x} \]
\[ R^2 = 0.9434 \]

\[ y = 38.467e^{-4.792x} \]
\[ R^2 = 0.9898 \]

\[ y = 51.648e^{-6.202x} \]
\[ R^2 = 0.9344 \]

Graph:

- X-axis: Fractional Lithophysal Porosity
- Y-axis: Uniaxial Compressive Strength (MPa)
2. Purpose

- Find an analog rock similar to YM tuff
- Carry out a systematic experimental study to determine the affects of lithophysal geometry on the properties of a strong analog rock.
- Obtain data to help validate YM numerical models and assumptions

* Details of task plan worked out with DOE, BSC, and UNLV personnel
3. Methodology

- Task 1: Experimental Test Plan
- Task 2: Analog Rock Material Scoping
- Task 3: QA Specimen Preparation
- Task 4: QA Uniaxial Compressive Testing
- Task 5: Analysis of Results including some numerical modeling
Experimental Test Plan

- Material Selection: Hydro-StoneTB®
  - YM Solid Rock $\Rightarrow$ $E = 20$ GPa, $\sigma_c = 60$ MPa
  - Plaster of Paris $\Rightarrow$ $E = 0.34$ GPa, $\sigma_c = 11.7$ MPa
  - Hydro-StoneTB Ave. $E = 16$ GPa ($2.3 \times 10^6$ psi)
  - Hydro-StoneTB Ave. $\sigma_c = 55.0$ MPa ($8000$ psi)

- Hole patterns
  - Circular, Square, Diamond
  - Random locations to mimic actual rock
Experimental Test Plan
### Experimental Test Plan

<table>
<thead>
<tr>
<th>Hole Shape</th>
<th>Starting Hole Location</th>
<th>Hole Size</th>
<th>Number of Holes</th>
<th>Porosity (%)</th>
<th>Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circle</td>
<td>at center (0,0)</td>
<td>1.226&quot; (L)</td>
<td>2</td>
<td>6.56</td>
<td>1</td>
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<tr>
<td></td>
<td></td>
<td>4</td>
<td>13.12</td>
<td>2</td>
<td></td>
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<td></td>
<td></td>
<td>6</td>
<td>19.68</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.870&quot; (M)</td>
<td>4</td>
<td>6.61</td>
<td>4</td>
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<tr>
<td></td>
<td></td>
<td>8</td>
<td>13.22</td>
<td>5</td>
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<td></td>
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<td>12</td>
<td>19.82</td>
<td>6</td>
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<tr>
<td></td>
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<td>0.503&quot; (S)</td>
<td>11</td>
<td>6.07</td>
<td>7</td>
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<td>22</td>
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<td></td>
<td>33</td>
<td>18.22</td>
<td>9</td>
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</tr>
</tbody>
</table>

**Circular Hole**

- **Pattern A Set**
  - 12 x 3 = 36 blocks
- **Pattern B**: 36 blocks
- **Pattern C**: 36 blocks

**Circular total**: 108

- **Square hole blocks**: 24
- **Diamond blocks**: 24
- **Solid blocks**: min 7
QA Uniaxial Compression Tests

- NDOT Test Facility
4. Experimental Results
QA Uniaxial Compression Tests

- Progressive Failure, Repeatability

\[ E \rightarrow 9.95 \text{ GPa} \quad 7.40 \quad 8.58 \]
\[ \sigma_c \rightarrow 11.4 \text{ MPa} \quad 11.6 \quad 13.2 \]
QA Uniaxial Compression Tests
Results

Best Fit Young's Modulus (25-50%) vs Void Porosity
Results

UCS vs Void Porosity

Uniaxial Compressive Strength (UCS) (MPa)

Circular Pattern A
Circular Pattern B
Circular Pattern C
Diamond Pattern A
Diamond Pattern B
Square Pattern A
Square Pattern B
QA Uniaxial Compression Tests
Helps Validate YM Model?

\[ y = 53.585e^{-7.1352x} \quad R^2 = 0.9409 \]

\[ y = 54.737e^{-11.579x} \quad R^2 = 0.8927 \]

\[ y = 52.482e^{-5.1493x} \quad R^2 = 0.9434 \]
Helps Validate YM Model?

\[ y = 10.004e^{0.0579x} \quad R^2 = 0.6479 \]

\[ y = 5.9043e^{0.1225x} \quad R^2 = 0.9635 \]

\[ y = 6.3088e^{0.1171x} \quad R^2 = 0.9548 \]

\[ y = 6.3234e^{0.1159x} \quad R^2 = 0.9258 \]
Results

UCS vs Best fit curve (25-50%)

- Circular Pattern A
- Circular Pattern B
- Circular Pattern C
- Diamond Pattern A
- Diamond Pattern B
- Square Pattern A
- Square Pattern B

Uniaxial Compressive Strength (UCS) (MPa) vs Best fit modulus (25-50%) (GPa)
5. Future Work
Future Work – This Task

- **For Task 13:**
  - Submission of Data (Electronic)
  - Some numerical modeling
  - Final Report

- **Future study as part of UNLV Theses:**
  - Seek understanding! Bridge length analysis
  - Explore problems with YM numerical model
  - Study progressive cracking (stress redistribution modeling and significance)
Future Work – New

- **Tensile** Hydro-StoneTB Tests:
  - No tests exist for lithophysal rock
  - Needed to produce Rock Failure Criterion for lithophysal rock (none exist)
  - Needed to carry out applications in analog rock

- **Confined Tests** of Hydro-StoneTB

- **Rock Bolt Performance** in Lithophysal Rock

- **Characterization of Ballast/Fill Material** Derived from Lithophysal Rock
Reference Slides
Drift Proportions

- Lithophysal Rock comprises 85%
Hoek-Brown Failure Criterion

- Non-lithophysal Rock (Tptmn, Tptln)
Reliance on Numerical Modeling

- Tensile, Triaxial Tests are numerical only

Solid Rock

Lithophysal Rock
Numerical Rock Criterion

- Hoek-Brown Criterion: Lithophysal Rock