SIMULATION OF ROCKMASS STRENGTH USING UBIQUITOUS JOINTS

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Introduction

• Estimate rock mass properties from uniaxial compressive strength (UCS) and a listing of the rock mass joint sets interpreted from drill-logs or field mapping.
• Empirical estimates of rock mass strength and deformation modulus based on rock mass classification systems.
• Data may then be used directly in a continuum model.
• Mohr-Coulomb criterion limits the range of potential rockmass failure mechanisms.
• Critical conditions are related to local geology, e.g. joints, faults, and rock fabric (schistosity).
Introduction

• In this paper a method is described to determine input properties from minimal data.
• The ubiquitous joint model is used to describe the rockmass fabric and to capture the structurally controlled softening of the rockmass.
• Results from numerical experiments to simulate the rockmass strength are then correlated with the strength estimates obtained from the rockmass classification systems.
• Conclude paper with some examples of the application of the method.
ROCKMASS

• At what scale is a rock a rockmass?
Insitu Rockmass
Microstructure
MATERIAL PROPERTIES
Rockmass

• Intact rock has a UCS value of 60 MPa
• Four major joint sets
• Rockmass GSI value of 70
• Simulated rockmass showing the random distribution of joint sets at angles in the assigned proportions.
## Rockmass Jointing

<table>
<thead>
<tr>
<th>Joint Set</th>
<th>Angle (°)</th>
<th>Proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>J2</td>
<td>124</td>
<td>30</td>
</tr>
<tr>
<td>J3</td>
<td>54</td>
<td>20</td>
</tr>
<tr>
<td>J4</td>
<td>84</td>
<td>30</td>
</tr>
</tbody>
</table>
Rockmass

- Intact rock has a UCS value of 60 MPa
- Four major joint sets
- Rockmass GSI value of 70
- Simulated rockmass showing the random distribution of joint sets at angles in the assigned proportions.
Geological Strength Index (GSI)

Area in red is 60<\text{GSI}<70.
Rockmass

- Intact rock has a UCS value of 60 MPa
- Four major joint sets
- Rockmass GSI value of 70
- Simulated rockmass showing the random distribution of joint sets at angles in the assigned proportions.
Simulated Rockmass with 4 Joint Sets
Material Properties

<table>
<thead>
<tr>
<th></th>
<th>Intact Rock</th>
<th>Joints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Modulus (Pa)</td>
<td>18.8e9</td>
<td></td>
</tr>
<tr>
<td>Shear Modulus (Pa)</td>
<td>13.0e9</td>
<td></td>
</tr>
<tr>
<td>Cohesion (Pa)</td>
<td>15.7e6</td>
<td>1.5e6</td>
</tr>
<tr>
<td>Friction (°)</td>
<td>35</td>
<td>32</td>
</tr>
<tr>
<td>Tension (Pa)</td>
<td>1.5e6</td>
<td>0.15e6</td>
</tr>
<tr>
<td>Dilation (°)</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>2830</td>
<td></td>
</tr>
</tbody>
</table>
ROCK-MASS STRENGTH

Estimates of rock mass strength for *in situ* rock mass, GSI used to estimate the Hoek-Brown parameter \( s \) as follows.

\[
s = e^{\left(\frac{GSI-100}{9}\right)}
\]

For good-quality rock masses, GSI is equivalent to RMR (1976). The unconfined rock mass strength is then estimated from:

\[
UCS_{\text{rock mass}} = UCS_{\text{intact}} \times s^{0.5}
\]

Rockmass friction angle for all units is assumed to be 45 degrees. Rockmass cohesion is calculated from the following relation:

\[
c = \frac{UCS_{\text{rock mass}} (1 - \sin \phi)}{2 \cos \phi}
\]

Rockmass tensile strength is 10% of rockmass cohesion.
ROCK-MASS MODULUS

Estimate of the *in situ* rock mass modulus is calculated as follows.

\[
E_m = 10 \left( \frac{GSI - 100}{9} \right) = 31.6 \text{ GPa}
\]

Poisson’s Ratio is estimated from:

\[
\nu = 0.32 - 0.0015 \text{ GSI} = 0.22
\]
## Rockmass Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Intact</th>
<th>Rockmass</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSI</td>
<td>0.0357E</td>
<td>70</td>
</tr>
<tr>
<td>s</td>
<td>0.0357</td>
<td>0.0357</td>
</tr>
<tr>
<td>E (GPa)</td>
<td>31.7</td>
<td>31.62</td>
</tr>
<tr>
<td>ν</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td>UCS (MPa)</td>
<td>61.8</td>
<td>11.68</td>
</tr>
<tr>
<td>Cohesion (MPa)</td>
<td>15.7</td>
<td>3.23</td>
</tr>
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Simulated Mechanical Behavior

- Sample size is width 50m and height 100m
- 2D Plane Strain conditions
- Compressed between rigid platens and
- No lateral confinement
Simulated Intact Rock Strength

Limit of elastic behavior

E_i = 29.7 GPa

Stress to mobilize rockmass volume

STRESS (MPa)

STRAIN \times (10^{-04})
Simulated M-C Rockmass Behavior

Stress (MPa)

Strain $\times (10^{-05})$

Plasticity Indicator:
- * at yield in shear or vol.
- X elastic, at yield in past
- o at yield in tension
Limitations of M-C Model

• Elastic perfectly plastic model may over estimate strength of rockmass (particularly at high stress)
• It provides limited indication of possible structural failure mechanism(s)
• Does not provide stress limits that may be used to identify potential for time dependent behavior

However,
• By using the UJ model these limitations can be overcome.
## Material Properties

<table>
<thead>
<tr>
<th></th>
<th>Intact Rock</th>
<th>M-C Rockmass</th>
<th>Ubiquitous Joints</th>
</tr>
</thead>
<tbody>
<tr>
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<td>18.8e9</td>
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<td>-</td>
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<td>2830</td>
<td>-</td>
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</table>
Simulated Behavior of Jointed Rockmass

- Limit of elastic behavior
- Stress to mobilize rockmass volume
Comparison of UJ and M-C Rockmass Behavior

Mohr-Coulomb
Ubiquitous Joint

Limit of elastic behavior
Stress to mobilize rockmass volume
Stress Damage in Failed Rockmass Sample

Plasticity Indicator:
- Elastic
- Elastic, Yield in Past
- At Yield in Tension
- Slip Along Ubiq. Joints
- Ubiq. Jnts. Fail Past
- Tens. Fail. Ubiq. Joint
Factors Affecting UJ Rockmass Strength

• Friction on Joints
• Cohesion on Joints
• Tensile Strength of Joints
Effect of UJ Cohesion on Rockmass Strength

![Effect of UJ Cohesion on Rockmass Strength](image)

- Joint cohesion: 15 MPa
- Joint cohesion: 8 MPa
- Joint cohesion: 4 MPa
- Joint cohesion: 2 MPa
- Joint cohesion: 1 MPa
- Joint cohesion: 0.1 MPa

**Stress (MPa)** vs **Strain x (10^-4)**
Effect of Joint Cohesion on Rockmass Strength
Estimate of Equivalent Rockmass Rating

\[ s = e^{\left(\frac{GSI-100}{9}\right)} \quad \text{UCS}_{\text{rock mass}} = \text{UCS}_{\text{intact}} \times s^{0.5} \]
Estimates of Rockmass Strength [Hoek, 2004]
Rockmass Strength: UJ Simulated vs Empirical
Simulated Estimation of Secant Modulus

![Graph showing simulated estimation of secant modulus](image)
Estimates of Rockmass Modulus [Hoek, 2004]
Rockmass Secant Modulus: UJ Simulated vs Empirical
Practical Applications
FLAC (Version 4.00)

**LEGEND**

5-Apr-05 3:24
step 95000
1.500E+02 < x < 5.500E+02
1.800E+03 < y < 2.200E+03

Boundary plot

Plasticity Indicator
X elastic, at yield in past
o at yield in tension
^ slip along ubiq. joints
. ubiq. joints fail in past
v tens. fail. ubiq. joints

GEONET Consulting Group
Brisbane, Australia
JOB TITLE: D-D' Pit Slope=47 [DD2.s17]

**FLAC (Version 4.00)**

**LEGEND**

- 5-Apr-05 3:26
- step 75000
- 1.500E+02 < x < 5.500E+02
- 1.800E+03 < y < 2.200E+03

- state
  - Elastic
  - At Yield in Shear or Vol.
  - Elastic, Yield in Past
  - At Yield in Tension
  - Slip Along Ubiq. Joints
  - Ubiq. Jnts. Fail Past
  - Tens. Fail. Ubiq. Joint

- jangle

- Boundary plot

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FLAC (Version 4.00)

LEGEND

5-Apr-05  3:26
step    75000
5.000E+02 <x<  9.000E+02
1.650E+03 <y<  2.050E+03

state
- Elastic
- At Yield in Shear or Vol.
- Elastic, Yield in Past
- At Yield in Tension
- Slip Along Ubiq. Joints
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jangle

Boundary plot

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**FLAC (Version 4.00)**

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- $5.000E+02 < x < 9.000E+02$
- $1.650E+03 < y < 2.050E+03$

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- X elastic, at yield in past
- o at yield in tension
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- . ubiq. joints fail in past
- v tens. fail. ubiq. joints

**JOB TITLE:** - D-D’ Pit Slope=47 [DD2.s17]

GEONET Consulting Group
Brisbane, Australia
JOB TITLE: B-B' Pit Slope=47 [BB-F01.sv8]

**FLAC (Version 4.00)**

**LEGEND**

1-Mar-05 1:23
step 60000
4.350E+02 < x < 7.350E+02
1.900E+03 < y < 2.200E+03

Boundary plot

0 5E 1

Joint Angle

X-displacement contours
Contour interval= 1.00E-01
Minimum: 0.00E+00
Maximum: 1.00E-01

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Brisbane, Australia
Conclusions

- U-J model provides an excellent method for modeling specific local rockmass conditions rather than the standard softened rockmass properties in a continuum M-C analysis.

Advantages of using the ubiquitous joint model are:
- Geological fabric clearly controls the failure mechanism.
- The onset of failure on critically orientated joint sets defines the progressive softening behavior of the rockmass beyond the elastic limit.
- By identifying the elastic limit of the rockmass it is possible to specify relevant support strategies and even design limits which should minimize the onset of time dependent behavior.
Future Considerations

• It is now possible to reconsider the general application of elastic and continuum models (MC, HB, etc.) of rockmass behavior in favour of models which include the fundamental rockmass structure (fabric, joint/bedding planes, etc.).

Next stage is to:
• Consider the effect of strain softening on joints using the SSUJ model
• Extend modelling to represent the 3D joint orientation (dip / dip direction).
THANK YOU FOR YOUR ATTENTION

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