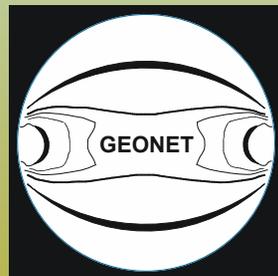


SIMULATION OF ROCKMASS STRENGTH USING UBIQUITOUS JOINTS

Ian H.Clark



GEONET Consulting Group

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?

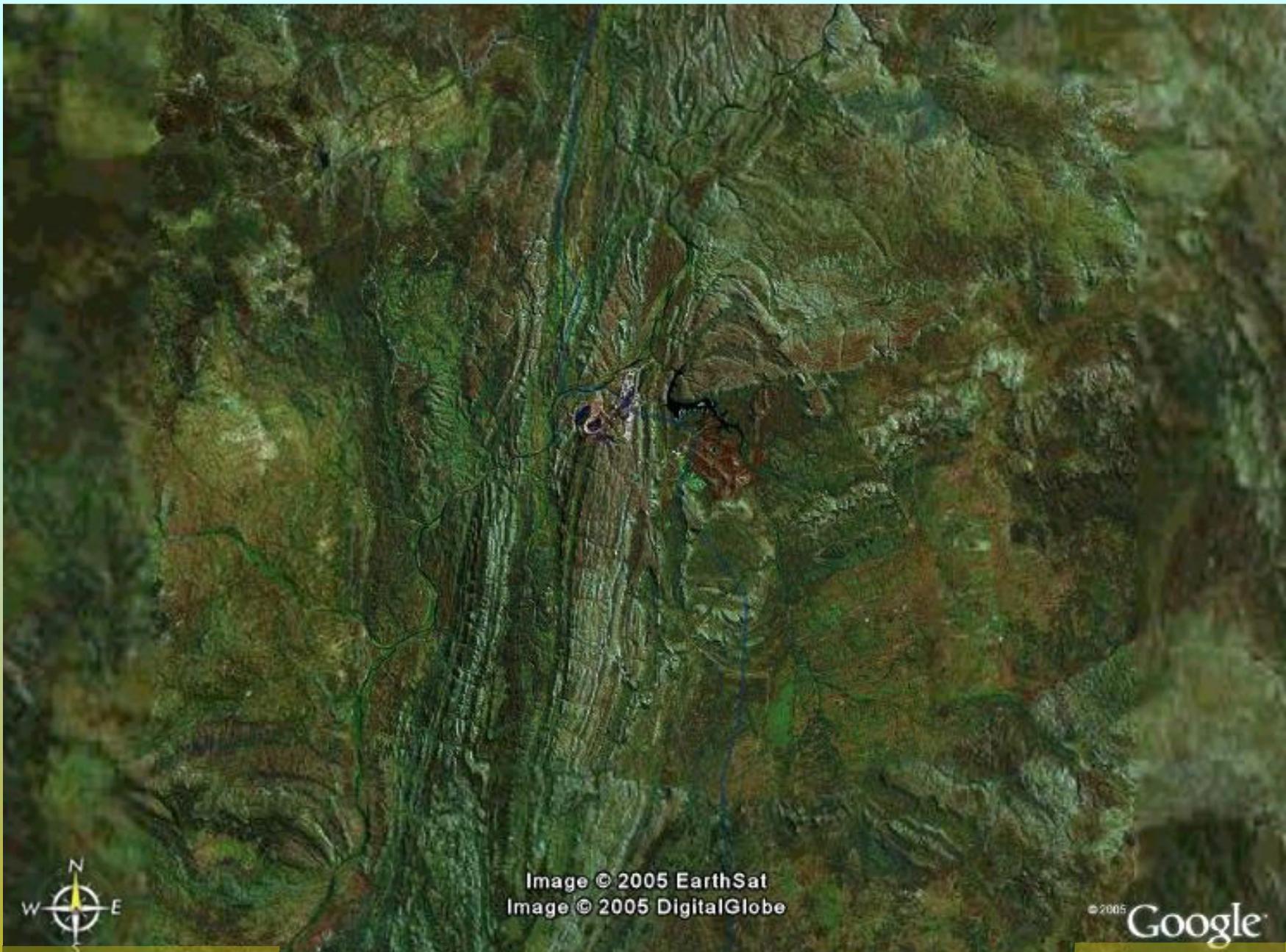


Image © 2005 EarthSat
Image © 2005 DigitalGlobe

©2005 Google

FLAC SYMPOSIUM
MADRID 2006

Point 19°40'21.88" S 139°22'23.45" E elev 1091 ft

Streaming ||||| 100%

Eye alt. 22.31 km

GEONET



FLAC SYMPOSIUM
MADRID 2006

GEONET



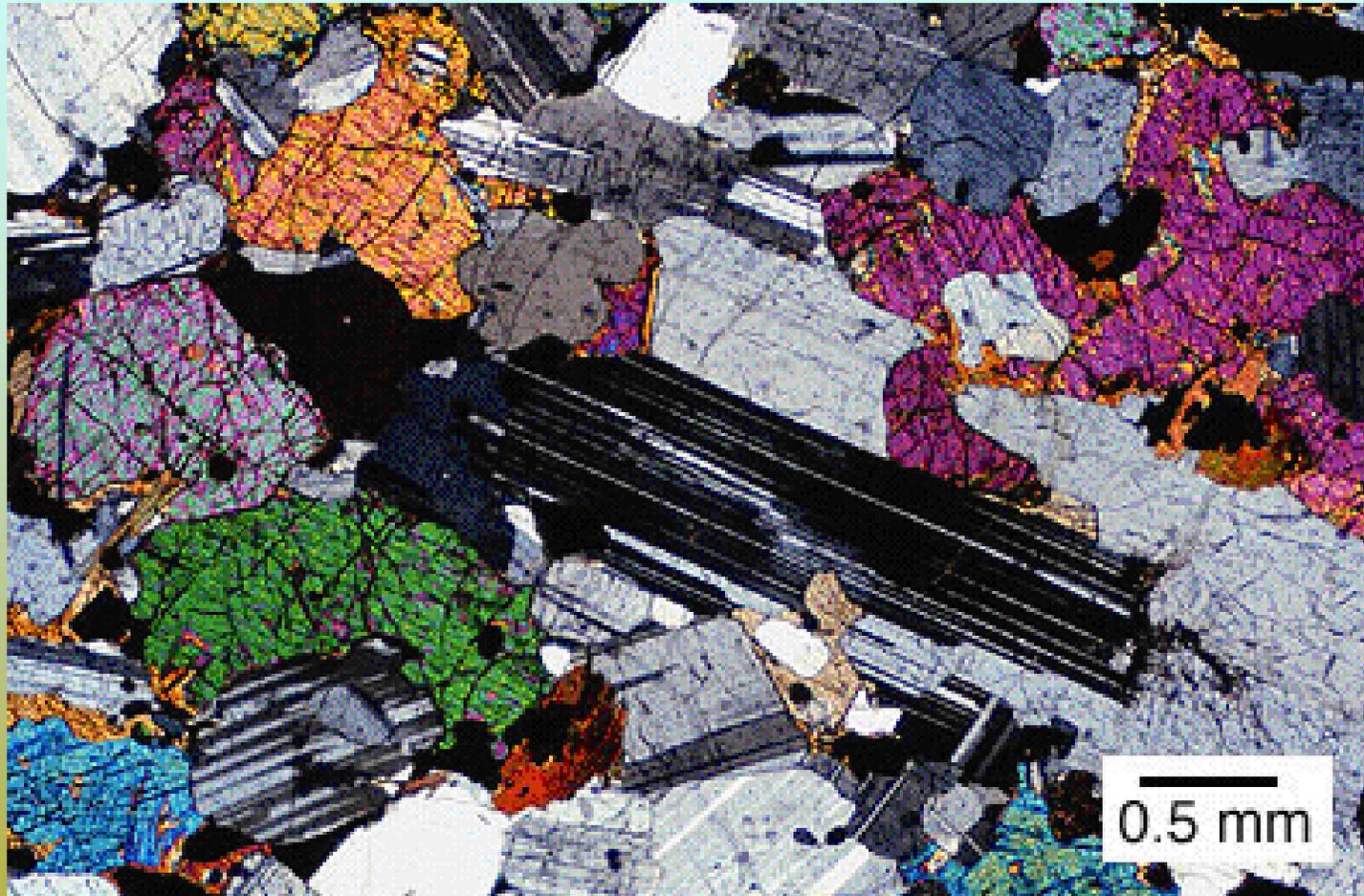
FLAC SYMPOSIUM
MADRID 2006

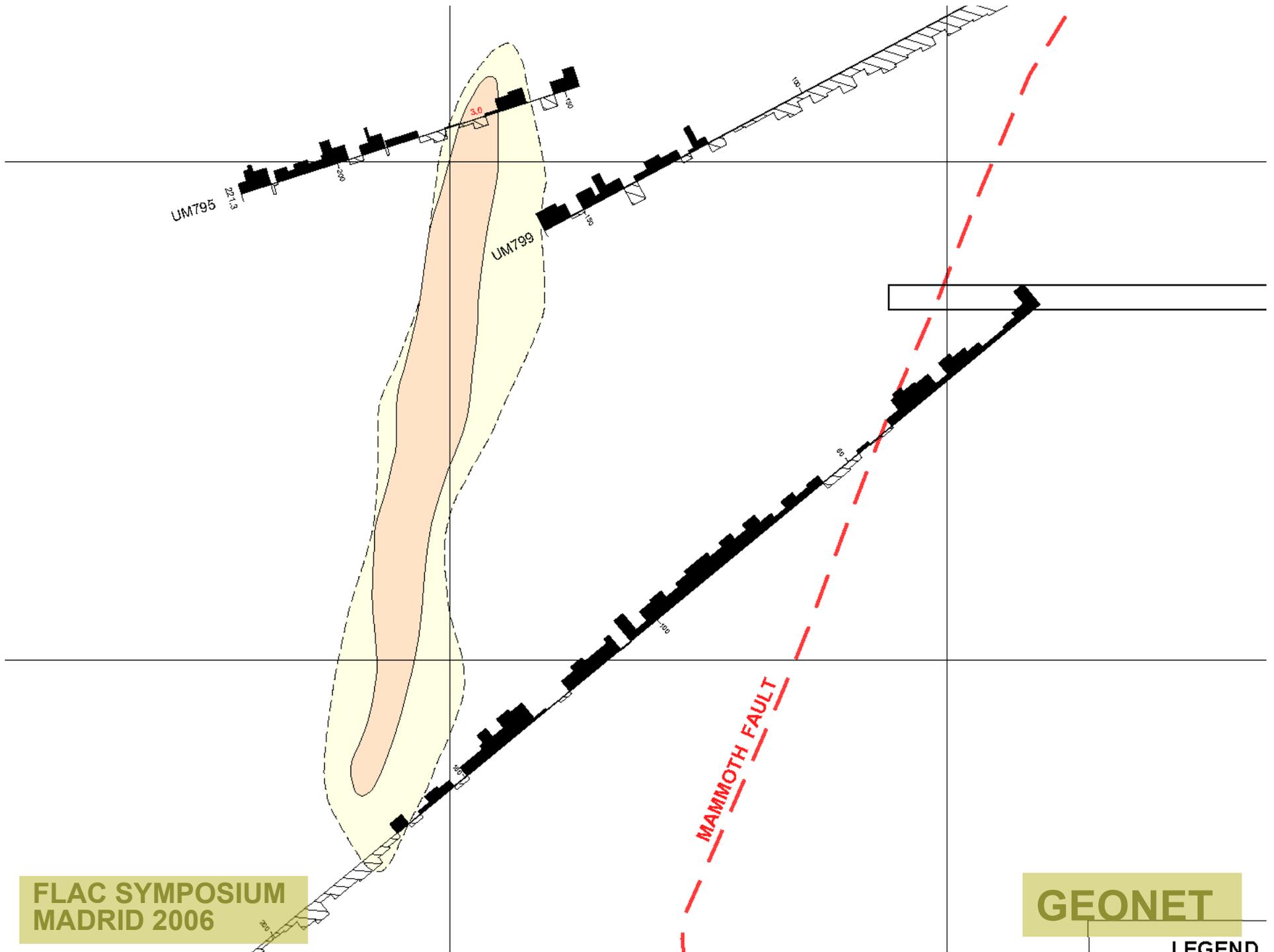
GEONET

Insitu Rockmass



Microstructure





FLAC SYMPOSIUM
MADRID 2006

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LEGEND

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.

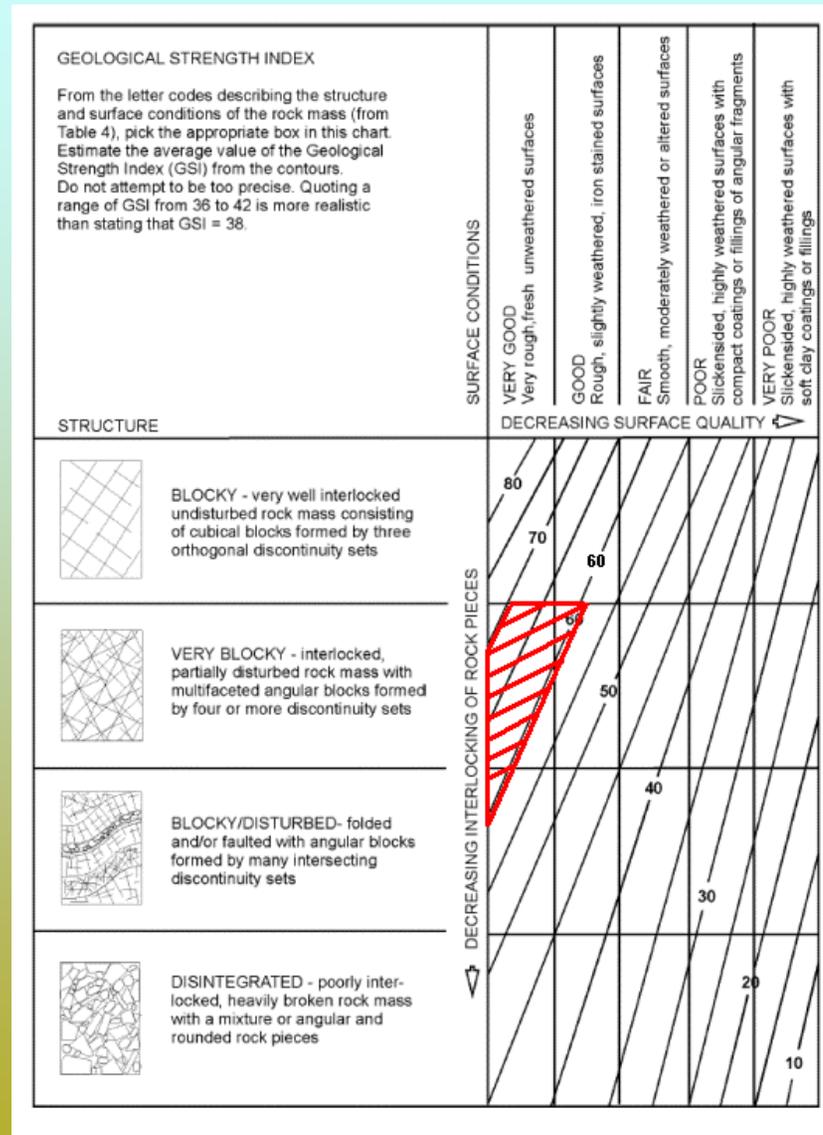
Rockmass Jointing

Joint Set	Angle (o)	Proportion (%)
J1	0	20
J2	124	30
J3	54	20
J4	84	30

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)

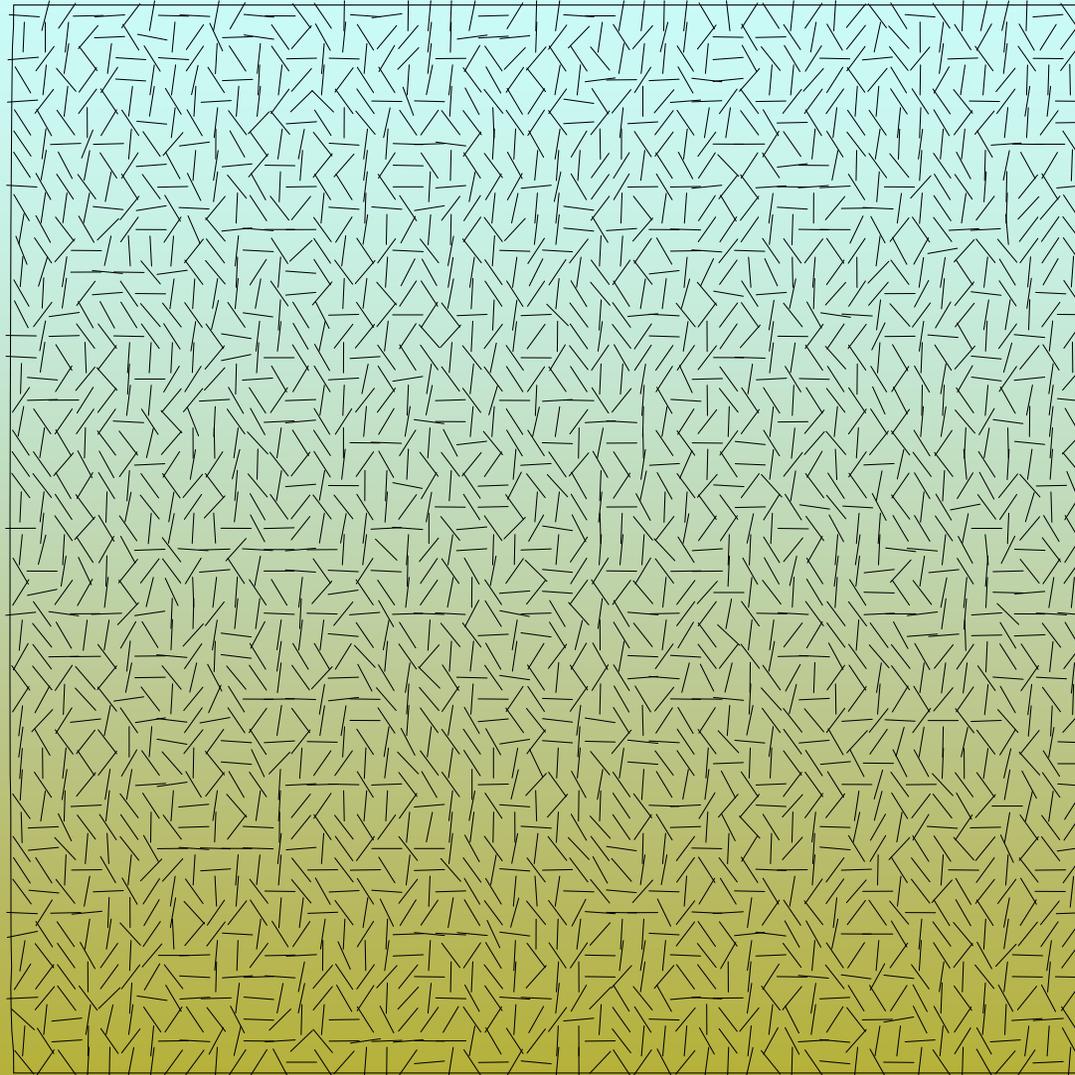


Area in red is $60 < \text{GSI} < 70$.

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

	Intact Rock	Joints
Bulk Modulus (Pa)	18.8e9	-
Shear Modulus (Pa)	13.0e9	-
Cohesion (Pa)	15.7e6	1.5e6
Friction (°)	35	32
Tension (Pa)	1.5e6	0.15e6
Dilation (°)	2	3
Density (kg/m ³)	2830	-

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:

$$UCS_{\text{rock mass}} = UCS_{\text{intact}} * s^{0.5}$$

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

$$c = \frac{UCS_{\text{rockmass}} (1 - \sin \phi)}{2 \cos \phi}$$

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:

$$\nu = 0.32 - 0.0015 \text{ GSI} = 0.22$$

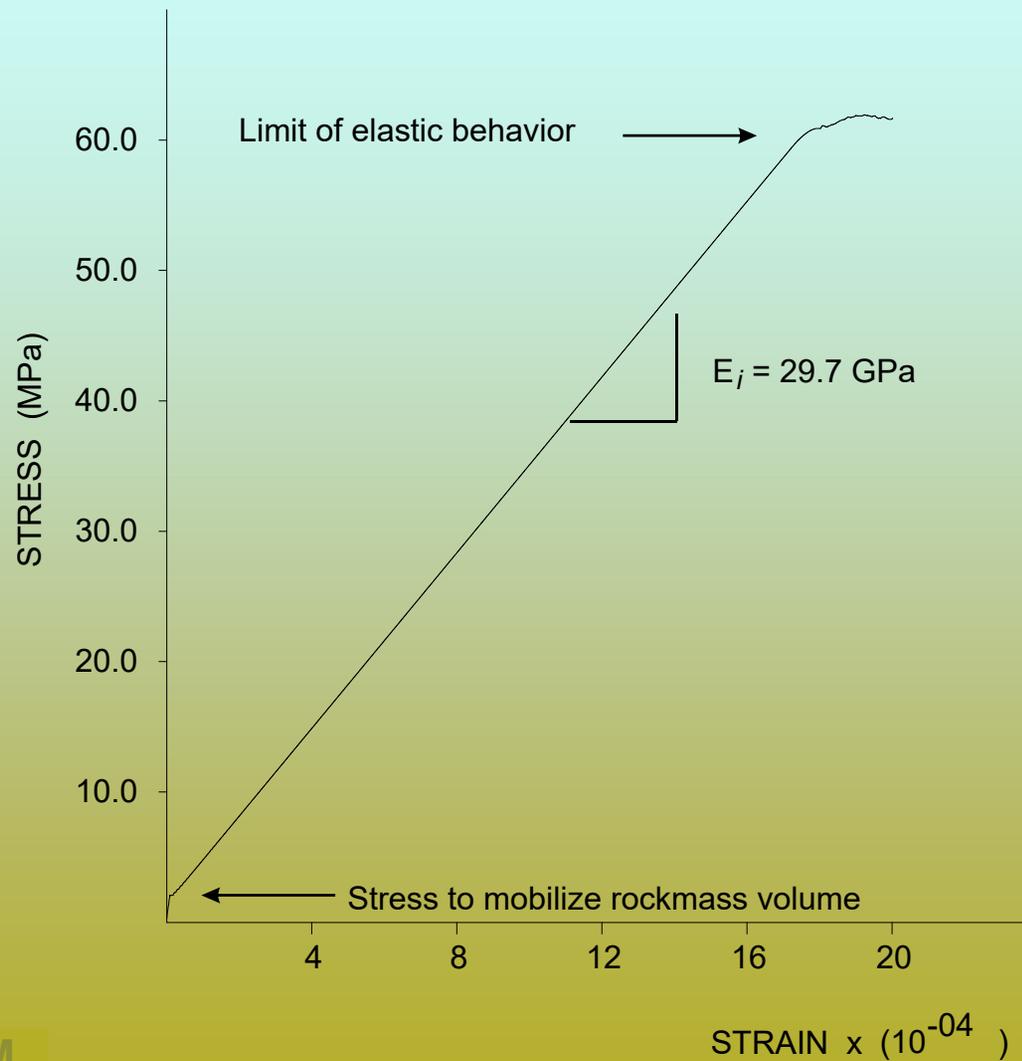
Rockmass Properties

	Intact	Rockmass
GSI		70
s		0.0357
E (GPa)	31.7	31.62
ν	0.22	0.22
UCS (MPa)	61.8	11.68
Cohesion (MPa)	15.7	3.23
Tension (MPa)	1.5	0.32
Friction ($^{\circ}$)	35	32

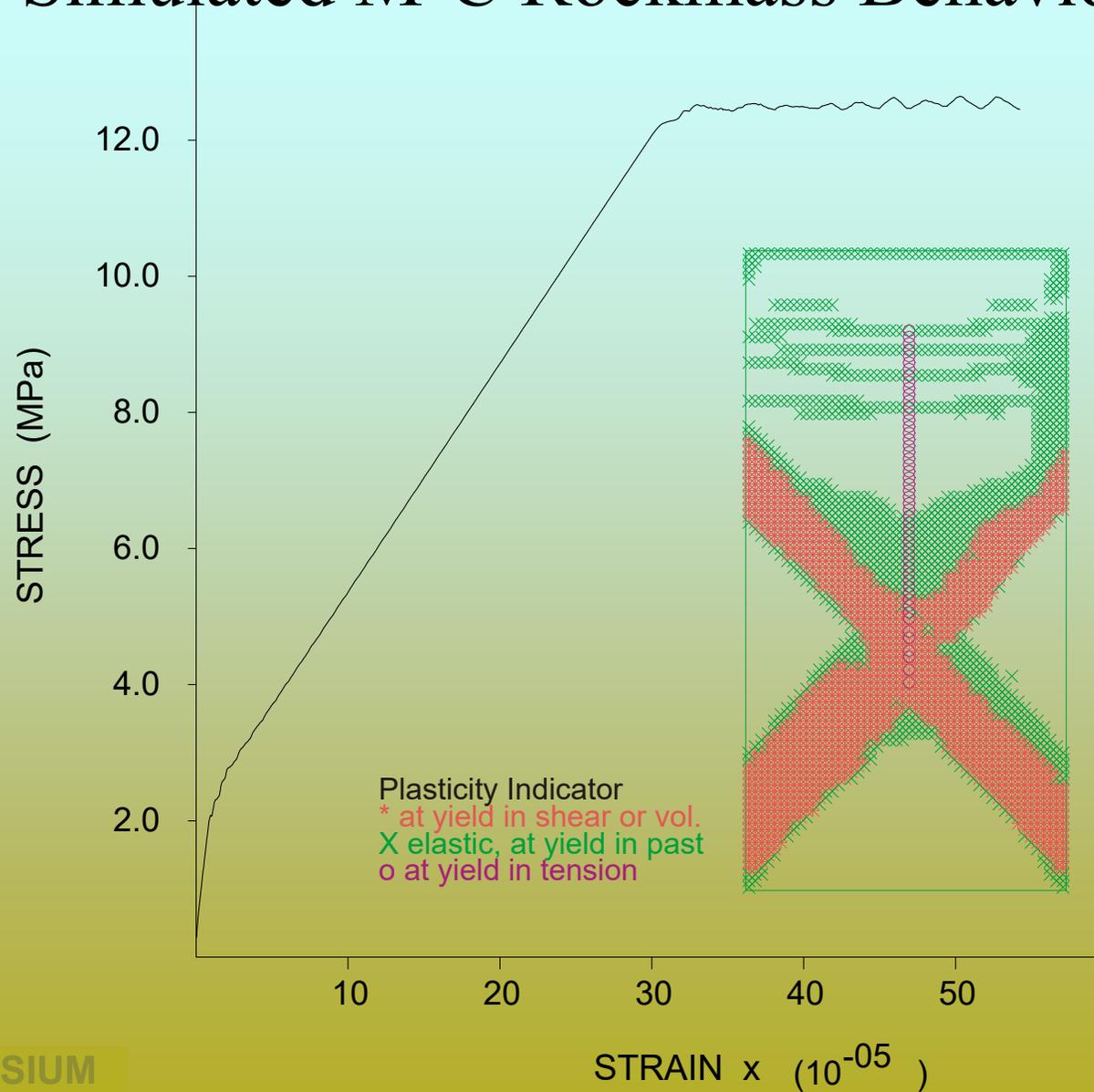
Simulated Mechanical Behavior

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

Simulated Intact Rock Strength



Simulated M-C Rockmass Behavior



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

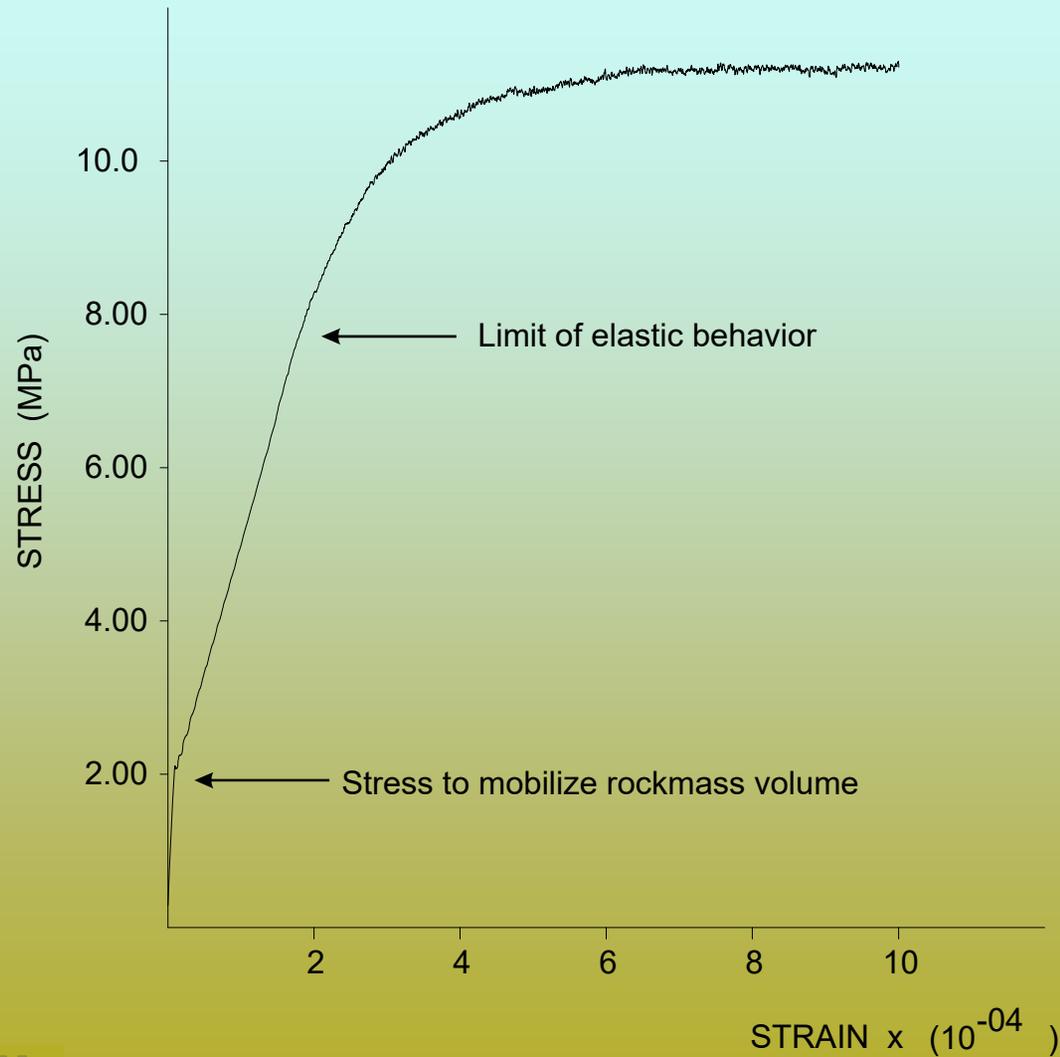
However,

- By using the UJ model these limitations can be overcome.

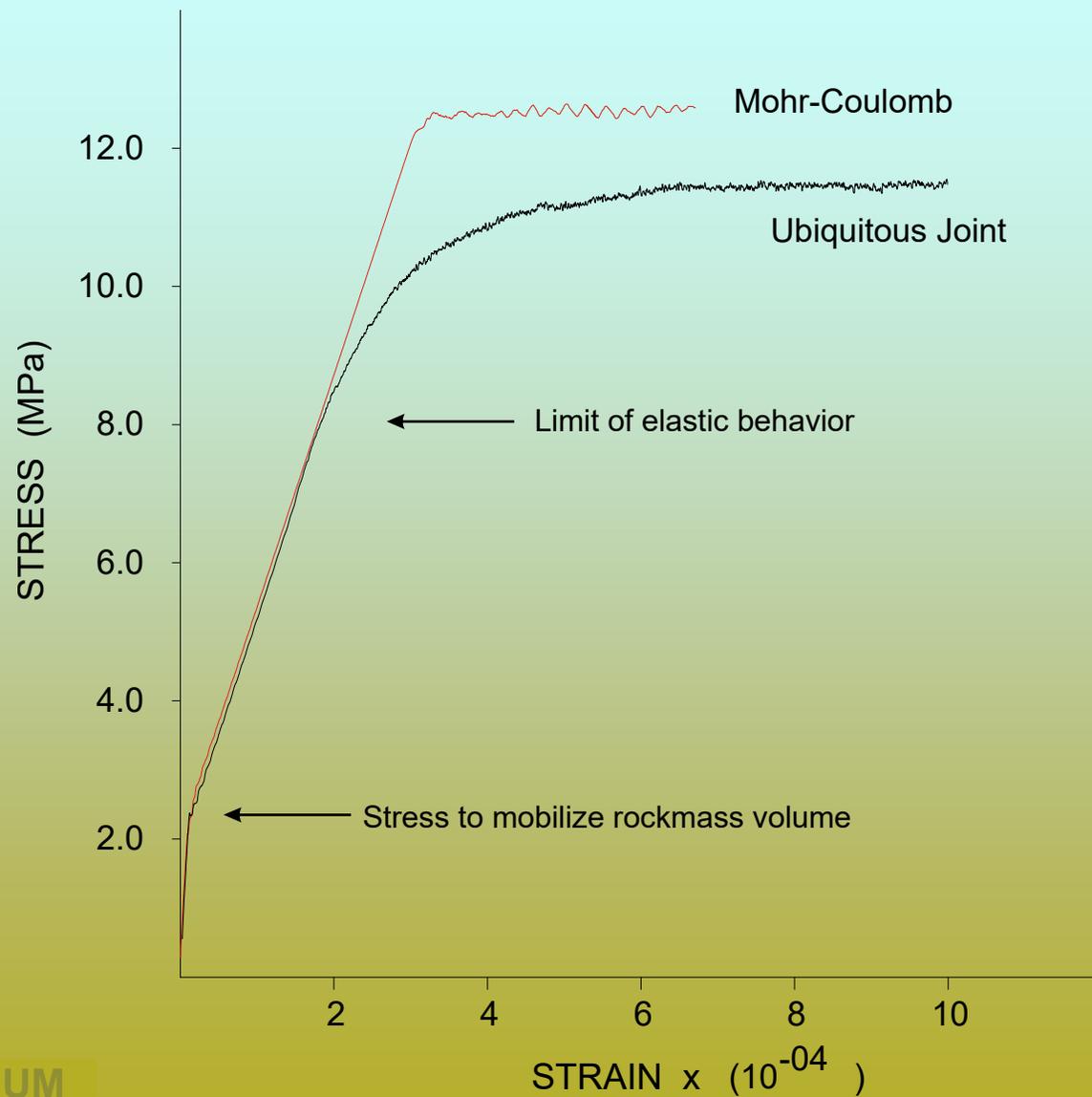
Material Properties

	Intact Rock	M-C Rockmass	Ubiquitous Joints
Bulk Modulus (Pa)	18.8e9	18.8e9	-
Shear Modulus (Pa)	13.0e9	13.0e9	-
Cohesion (Pa)	15.7e6	3.23e6	1.5e6
Friction (°)	35	32	32
Tension (Pa)	1.5e6	0.32e6	0.15e6
Dilation (°)	2	2	3
Density (kg/m ³)	2830	2830	-

Simulated Behavior of Jointed Rockmass



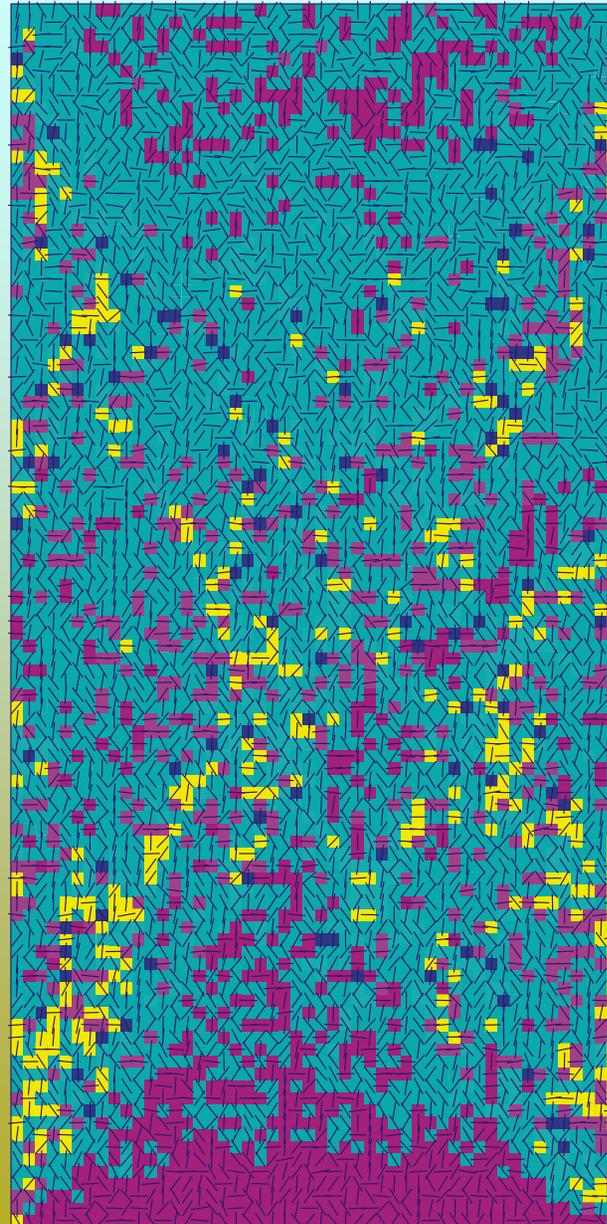
Comparison of UJ and M-C Rockmass Behavior



Stress Damage in Failed Rockmass Sample

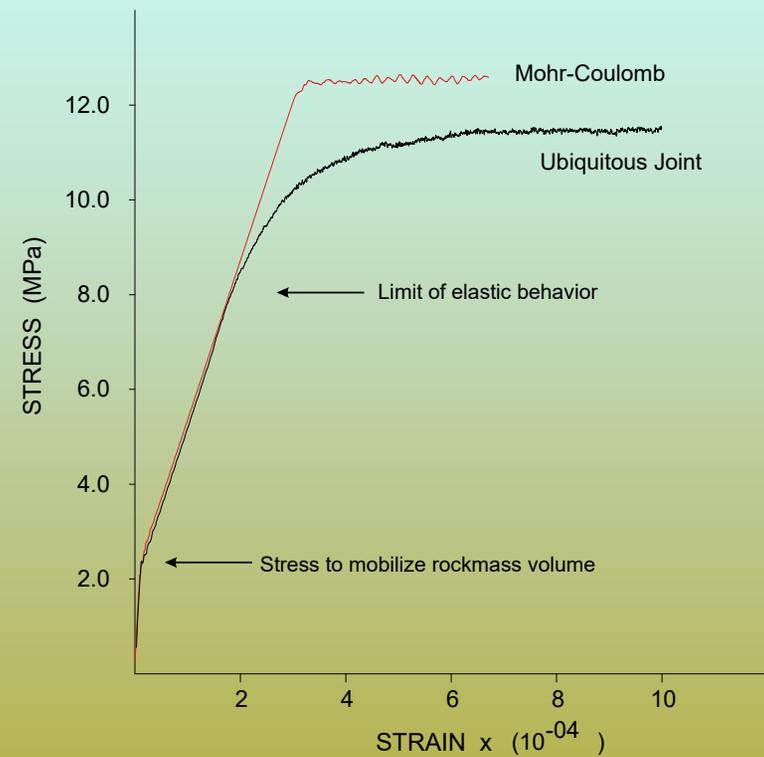
Plasticity Indicator

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

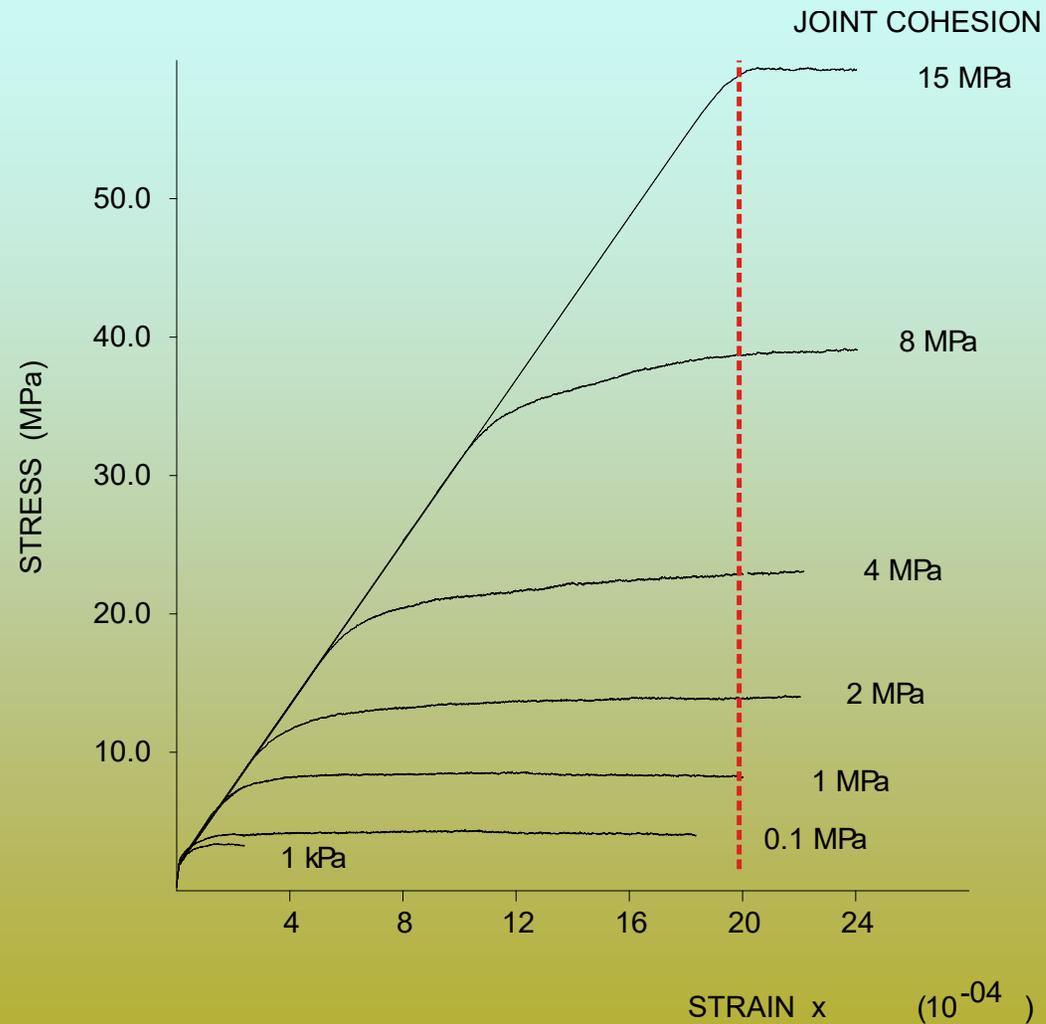


Factors Affecting UJ Rockmass Strength

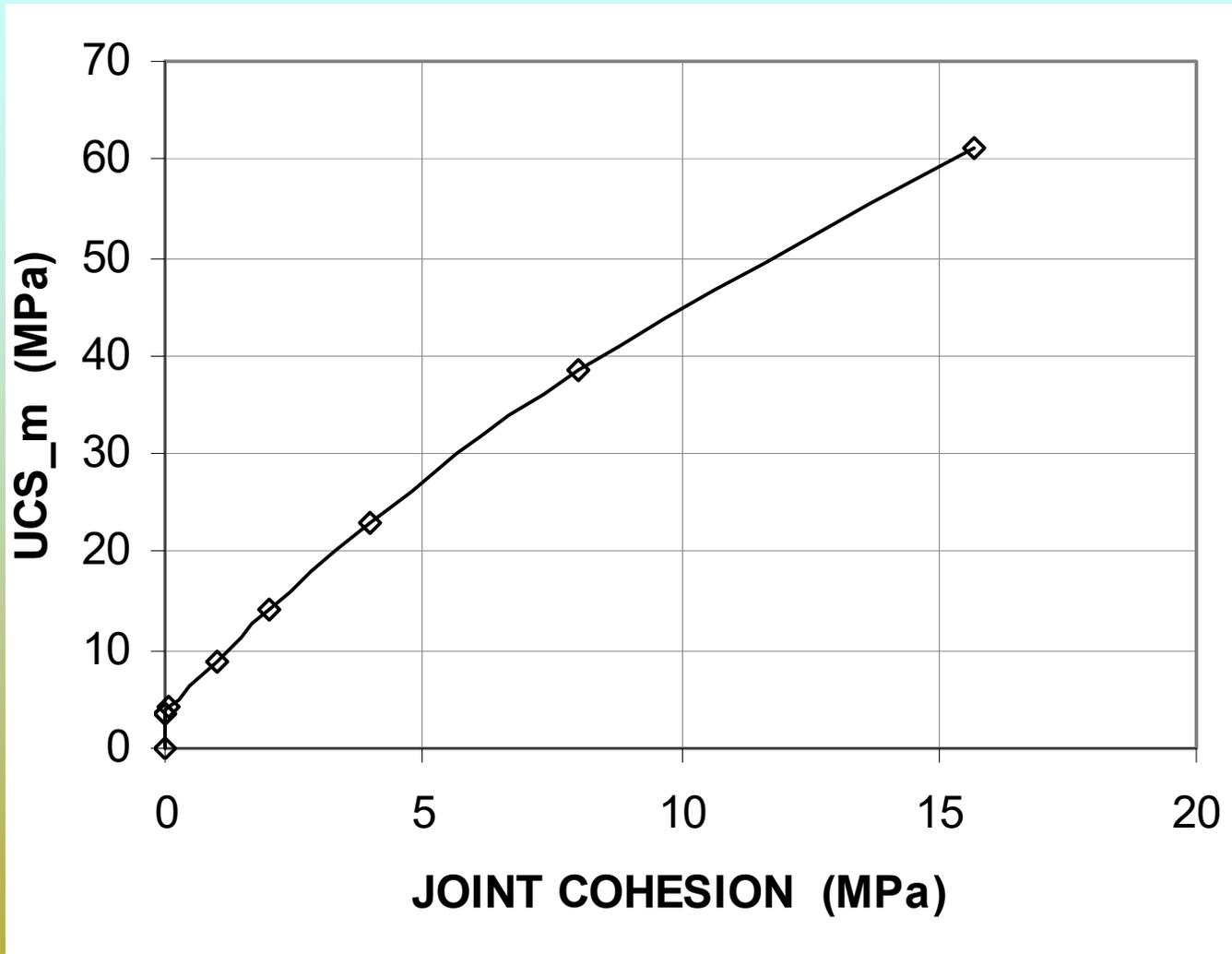
- Friction on Joints
- Cohesion on Joints
- Tensile Strength of Joints



Effect of UJ Cohesion on Rockmass Strength

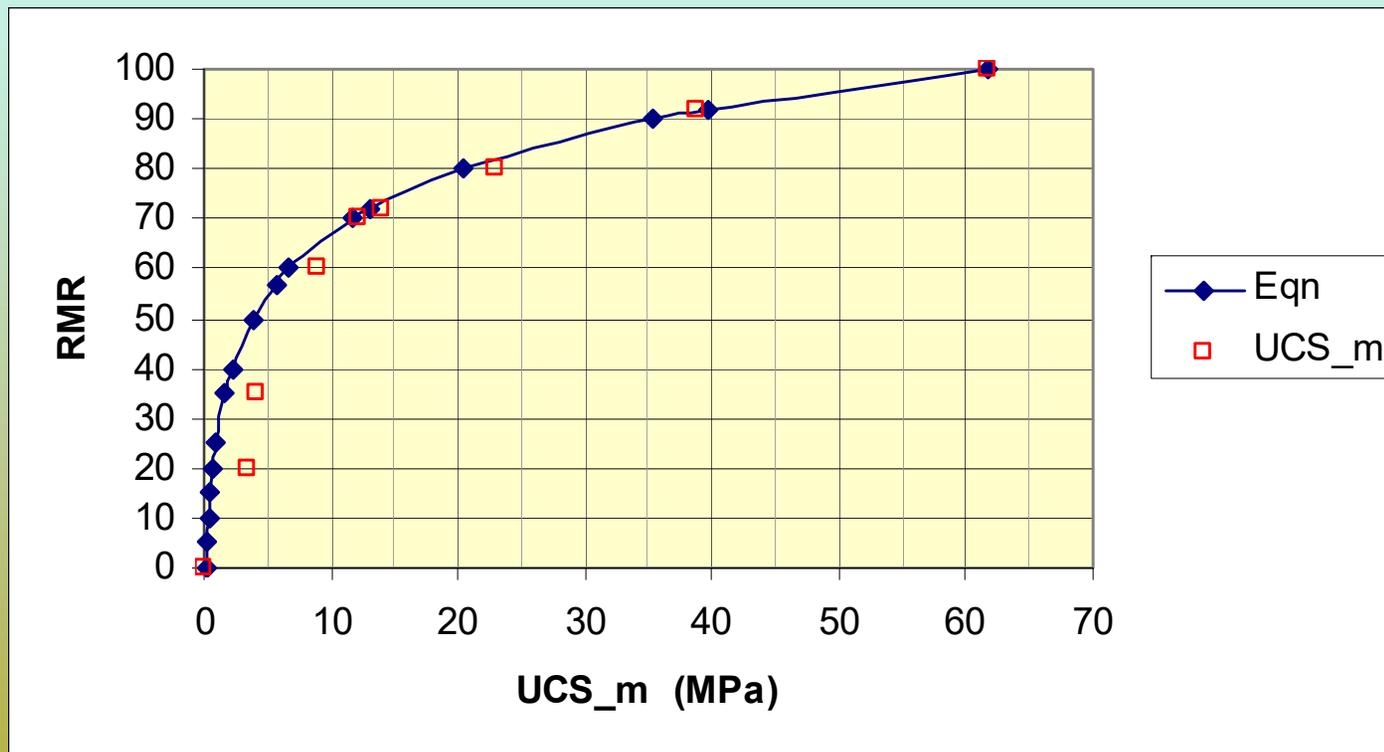


Effect of Joint Cohesion on Rockmass Strength

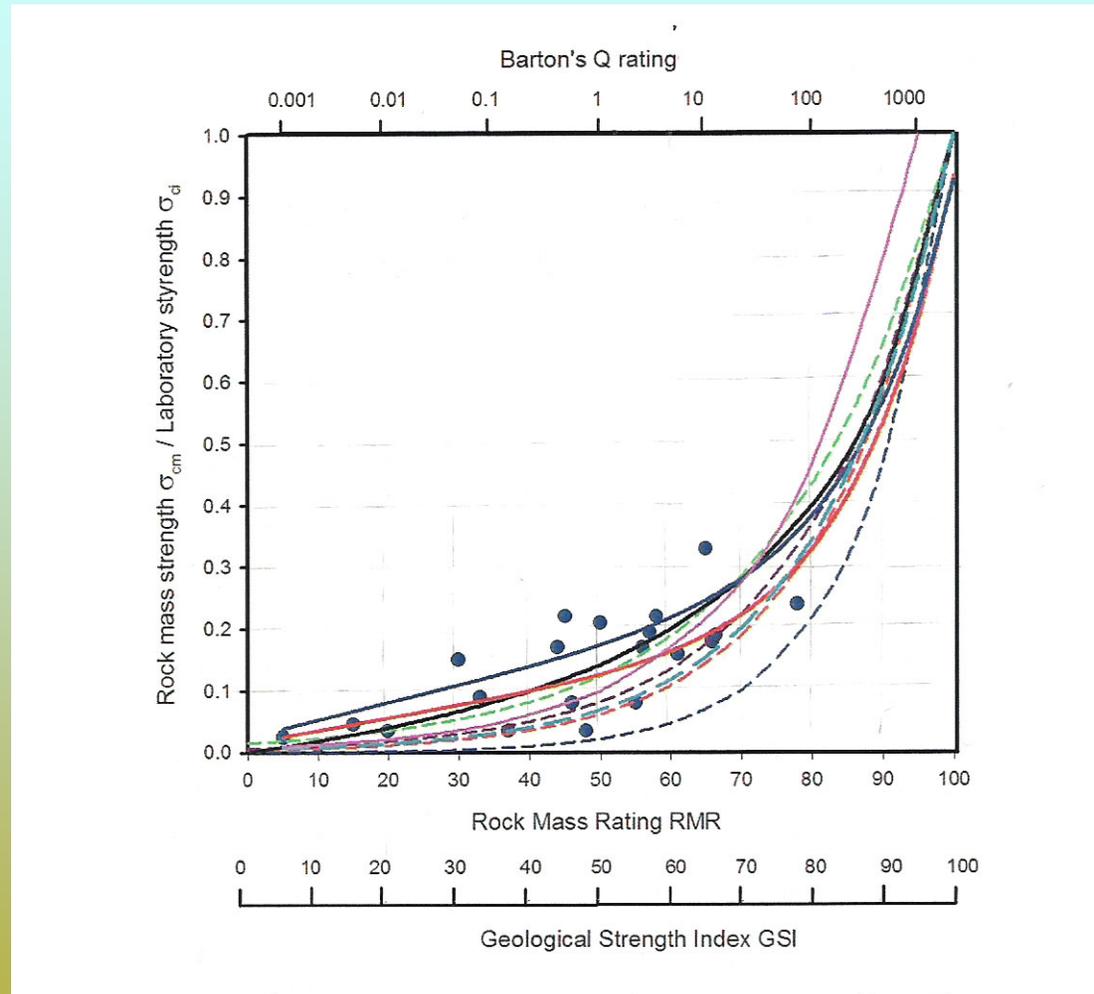


Estimate of Equivalent Rockmass Rating

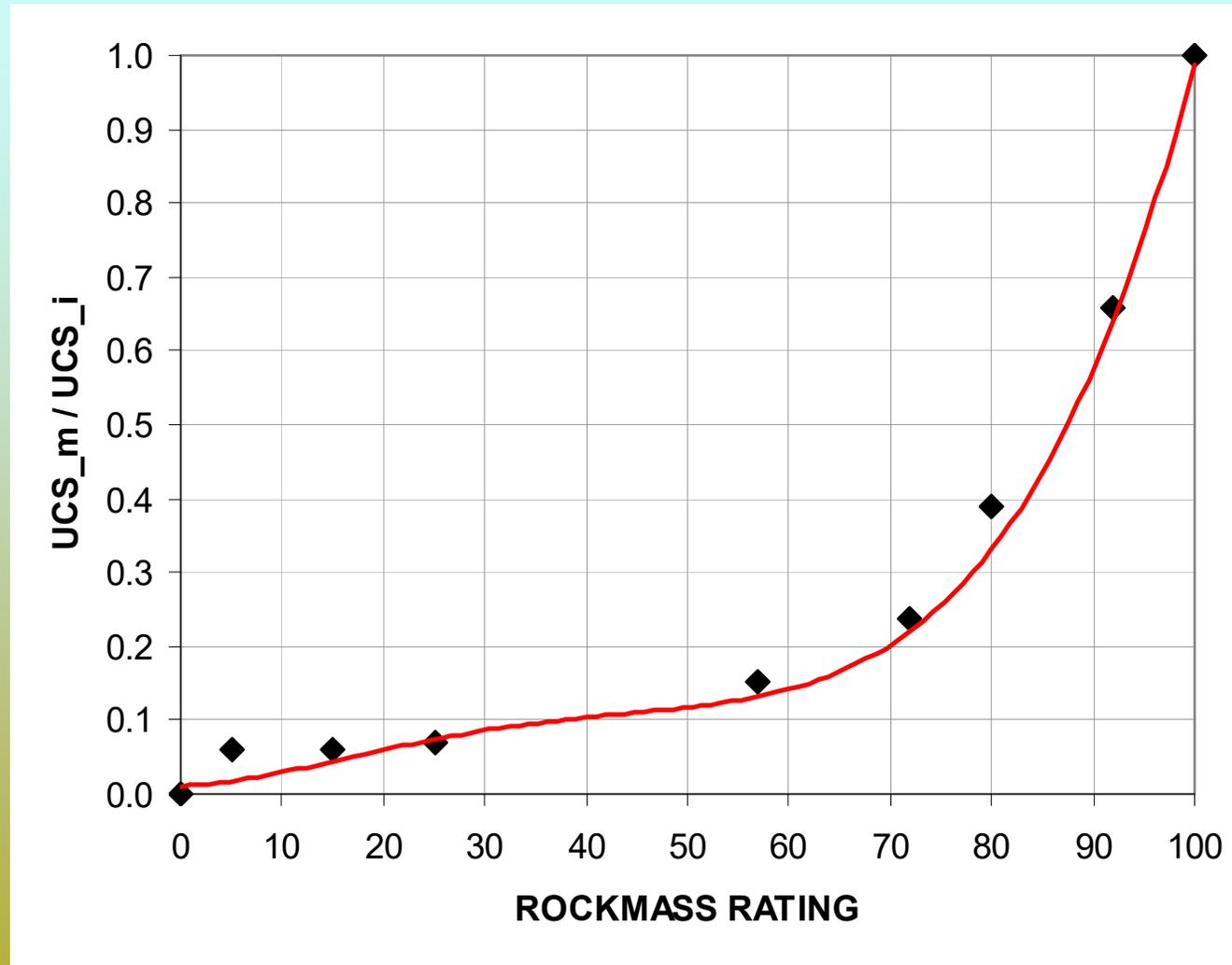
$$s = e^{\left(\frac{GSI-100}{9}\right)} \quad UCS_{\text{rock mass}} = UCS_{\text{intact}} * s^{0.5}$$



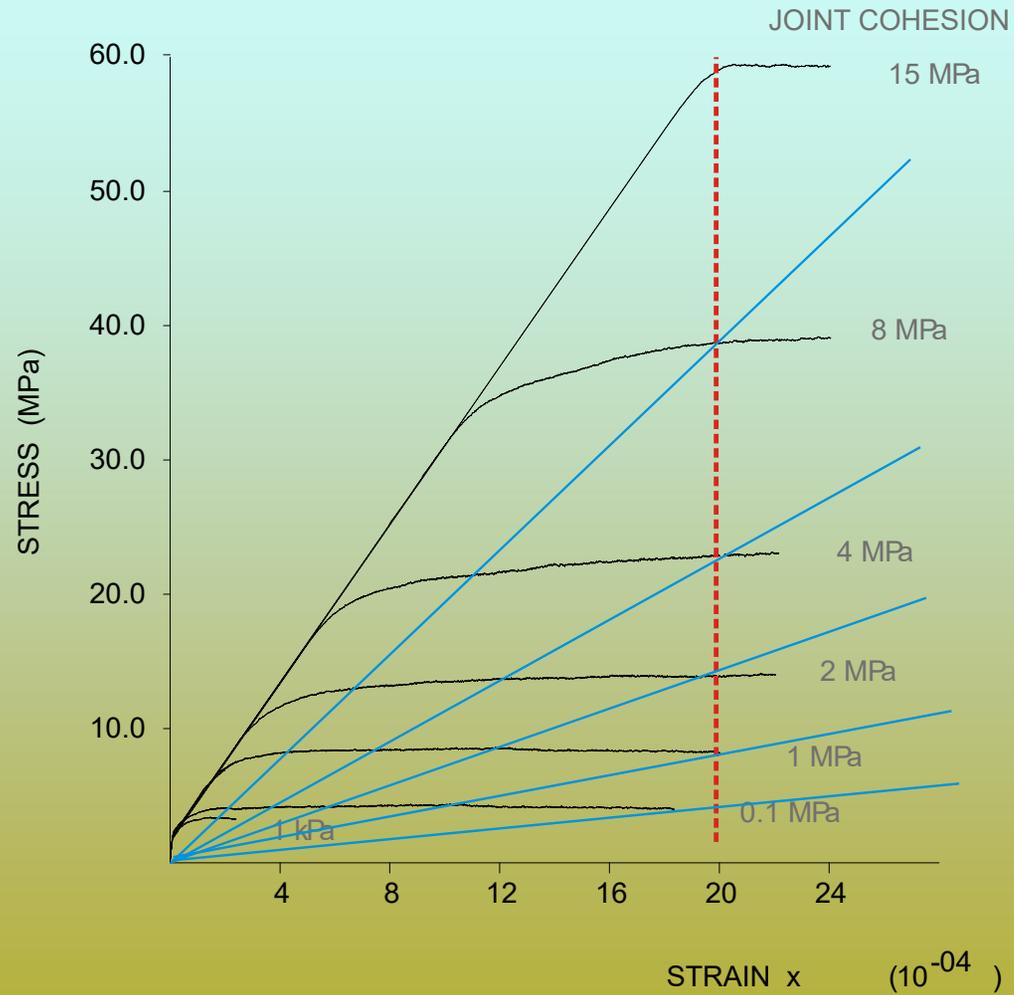
Estimates of Rockmass Strength [Hoek, 2004]



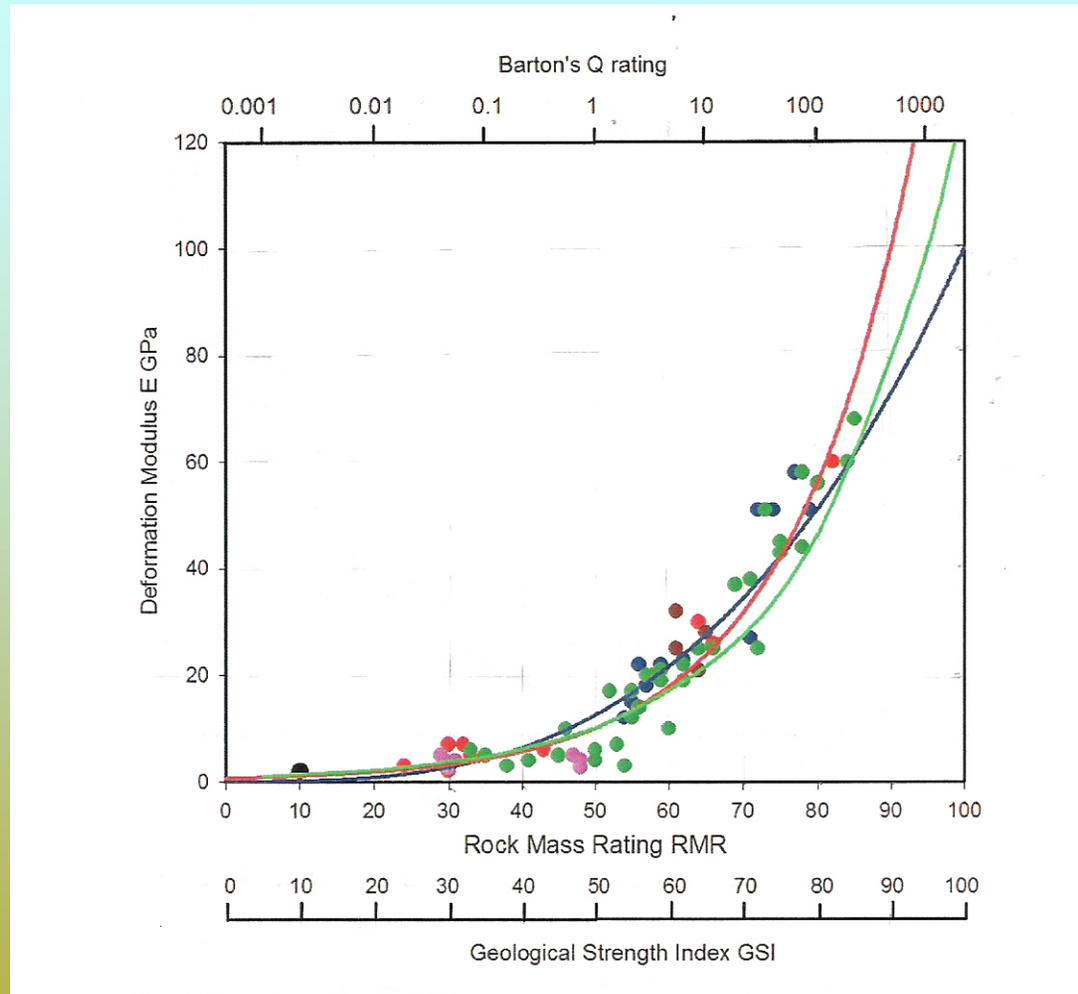
Rockmass Strength: UJ Simulated vs Empirical



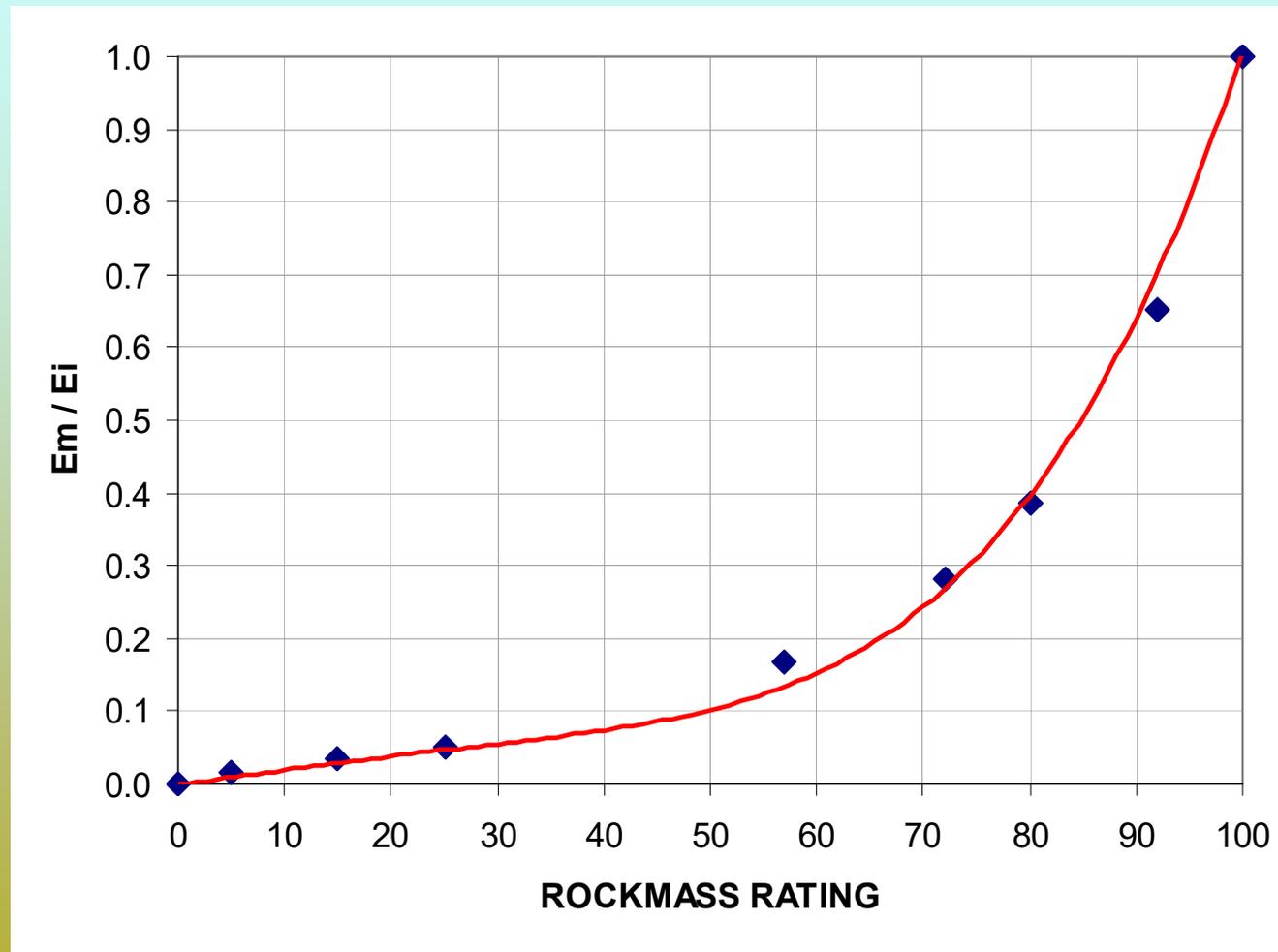
Simulated Estimation of Secant Modulus



Estimates of Rockmass Modulus [Hoek, 2004]



Rockmass Secant Modulus: UJ Simulated vs Empirical



Practical Applications

JOB TITLE :

- B-B' West=40 East =46.5 [BB2.s16]

(*10³)

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

state

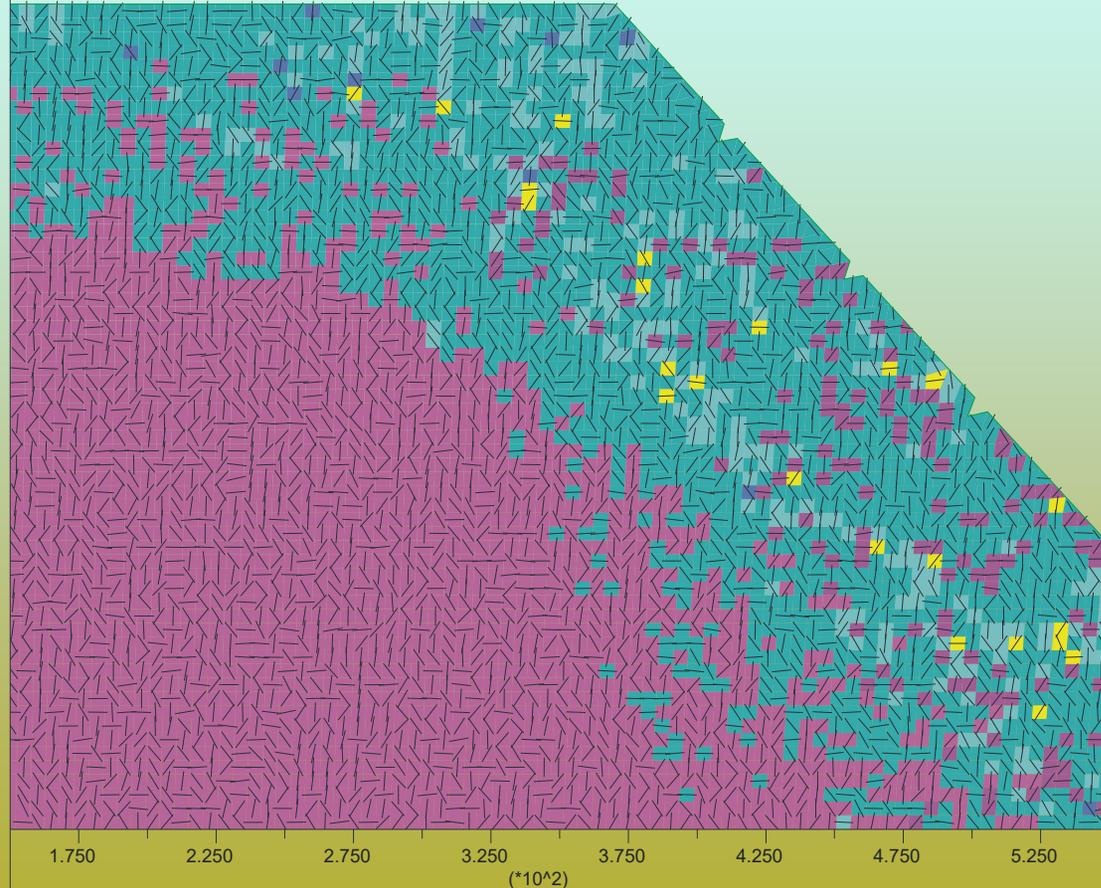
- Elastic
- At Yield in Shear or Vol.
- Elastic, Yield in Past
- At Yield in Tension
- Slip Along Ubiq. Joints
- Ubiq. Jnts. Fail Past
- Tens. Fail. Ubiq. Joint

jangle

Boundary plot



GEONET Consulting Group
Brisbane, Australia



JOB TITLE :

- B-B' West=40 East =46.5 [BB2.s16]

(*10^3)

FLAC (Version 4.00)

LEGEND

5-Apr-05 3:24

step 95000

1.500E+02 <x< 5.500E+02

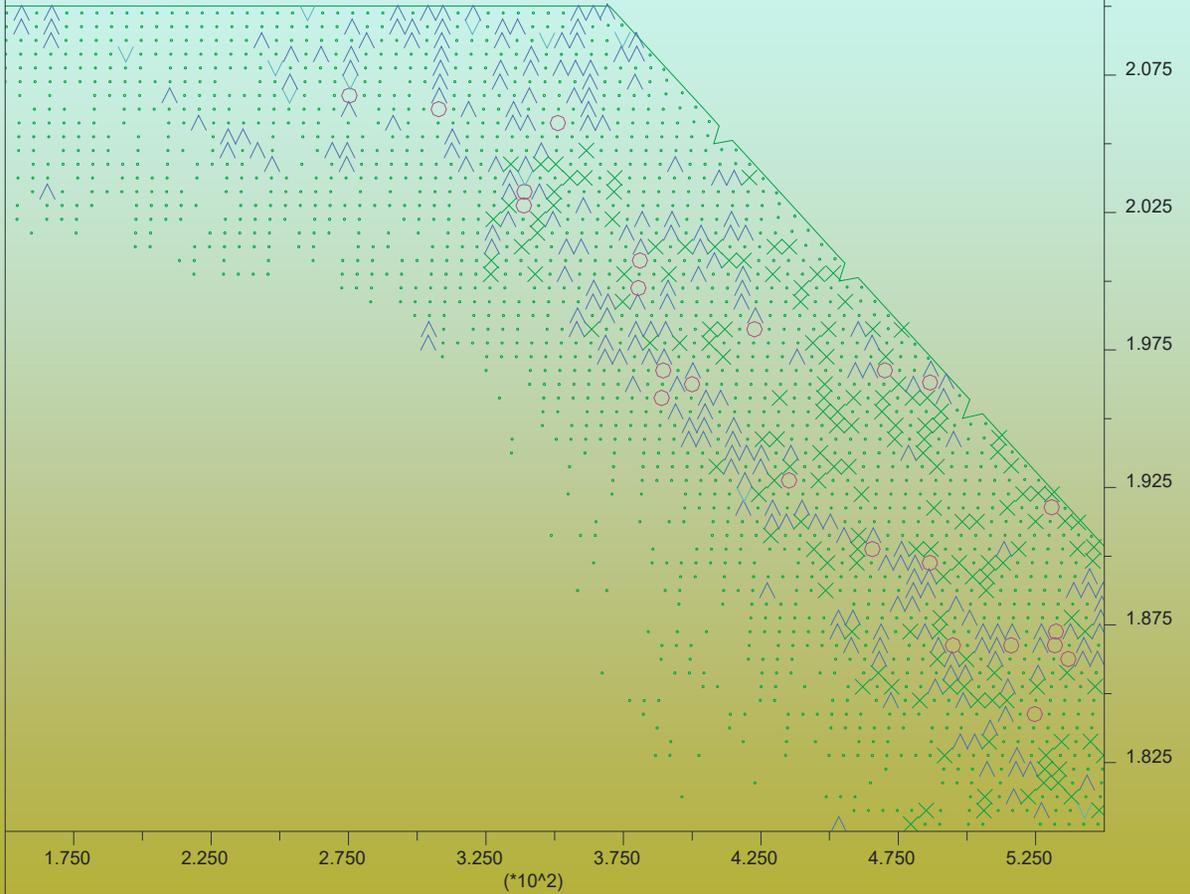
1.800E+03 <y< 2.200E+03

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

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Brisbane, Australia



JOB TITLE :

- D-D' Pit Slope=47

[DD2.s17]

(*10^3)

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

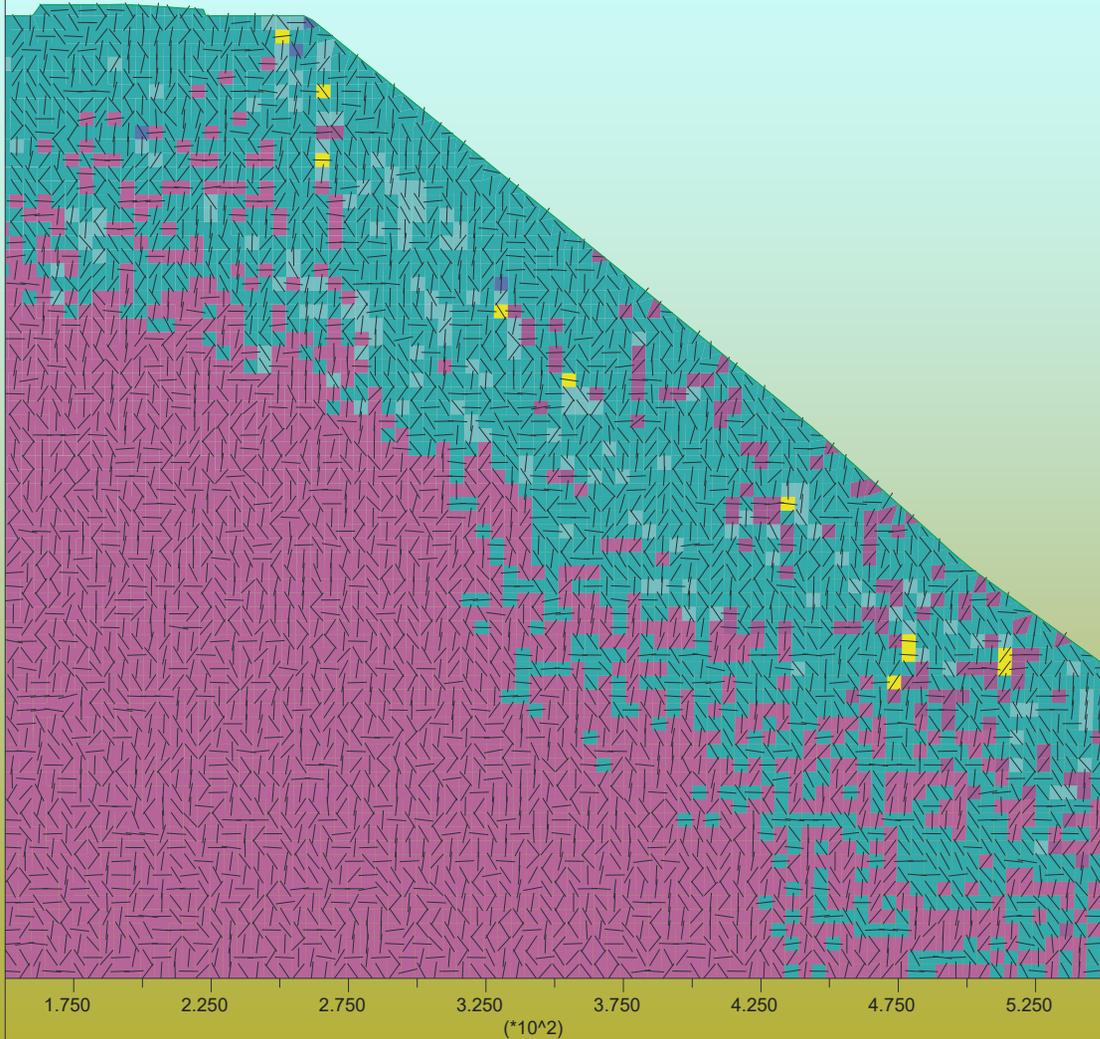
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- Tens. Fail. Ubiq. Joint

jangle

Boundary plot



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JOB TITLE :

- D-D' Pit Slope=47

[DD2.s17]

(*10^3)

FLAC (Version 4.00)

LEGEND

5-Apr-05 3:26

step 75000

1.500E+02 <x< 5.500E+02

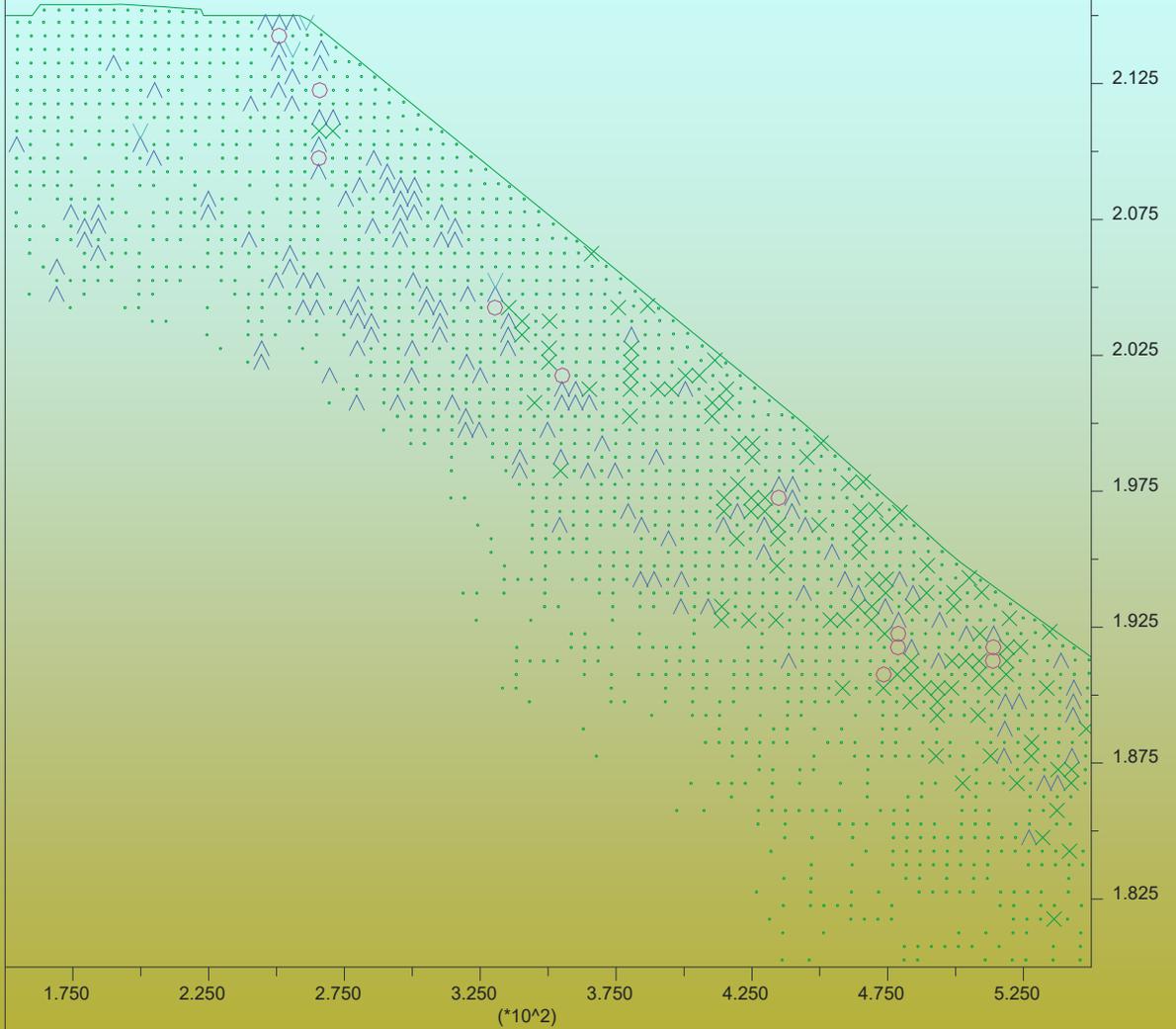
1.800E+03 <y< 2.200E+03

Boundary plot



Plasticity Indicator
X elastic, at yield in past
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JOB TITLE :

- D-D' Pit Slope=47

[DD2.s17]

(*10^3)

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

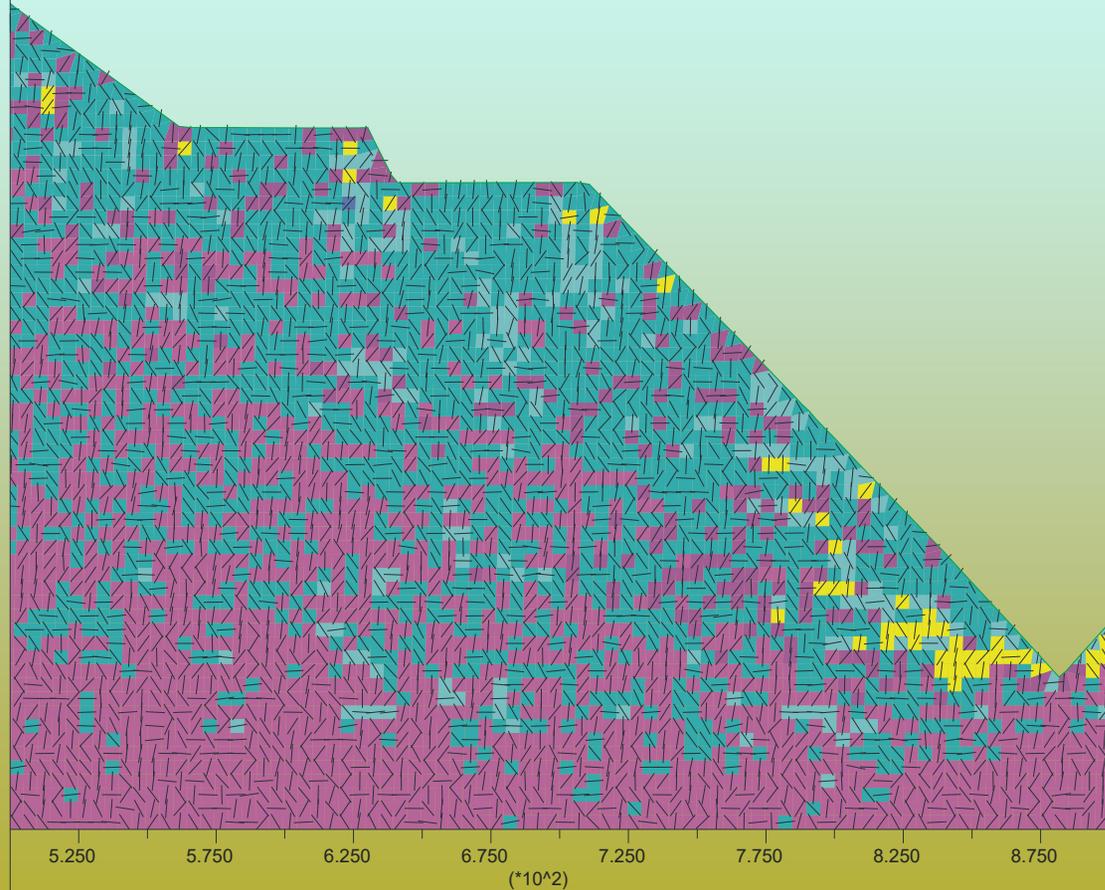
- Elastic
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jangle

Boundary plot



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JOB TITLE :

- D-D' Pit Slope=47

[DD2.s17]

(*10³)

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

Boundary plot



Plasticity Indicator

X elastic, at yield in past

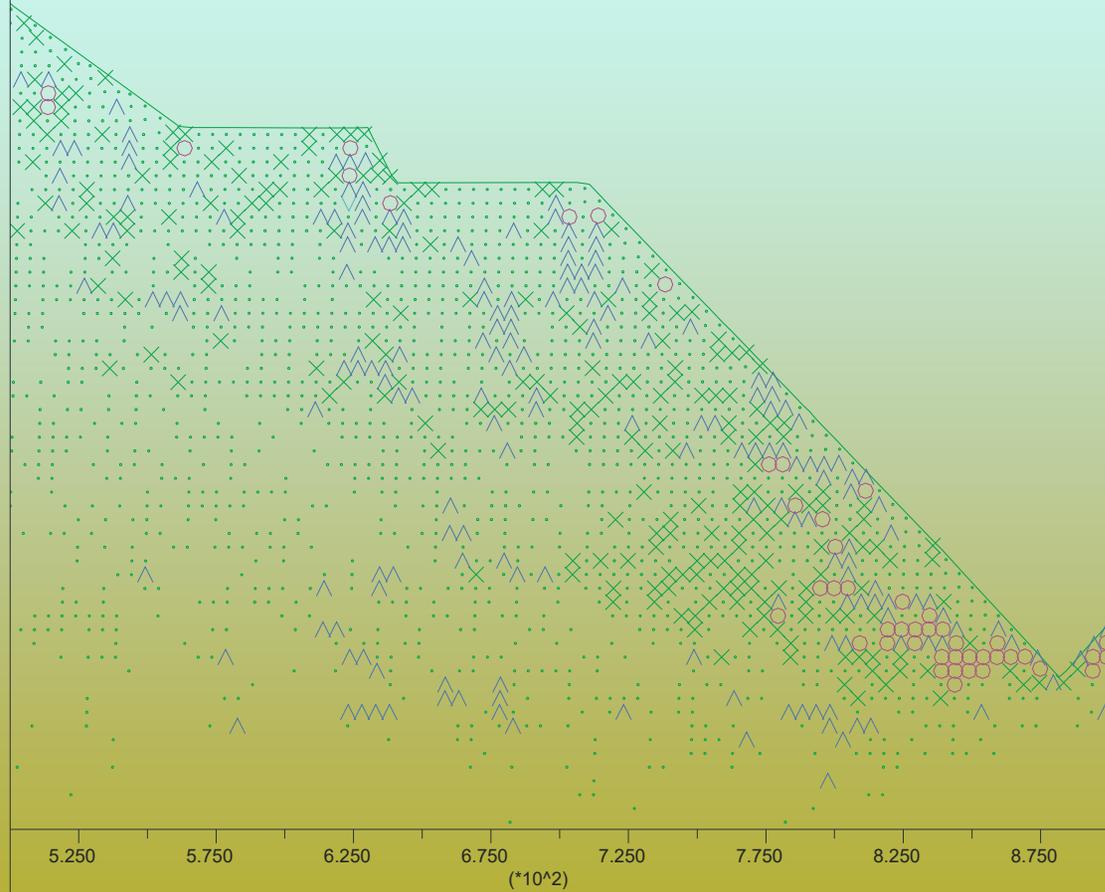
o at yield in tension

^ slip along ubiq. joints

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v tens. fail. ubiq. joints

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JOB TITLE :

B-B' Pit Slope=47

[BB-F01.sv8]

(*10^3)

FLAC (Version 4.00)

LEGEND

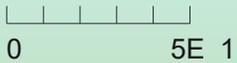
1-Mar-05 1:23

step 60000

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1.900E+03 <y< 2.200E+03

Boundary plot



Joint Angle

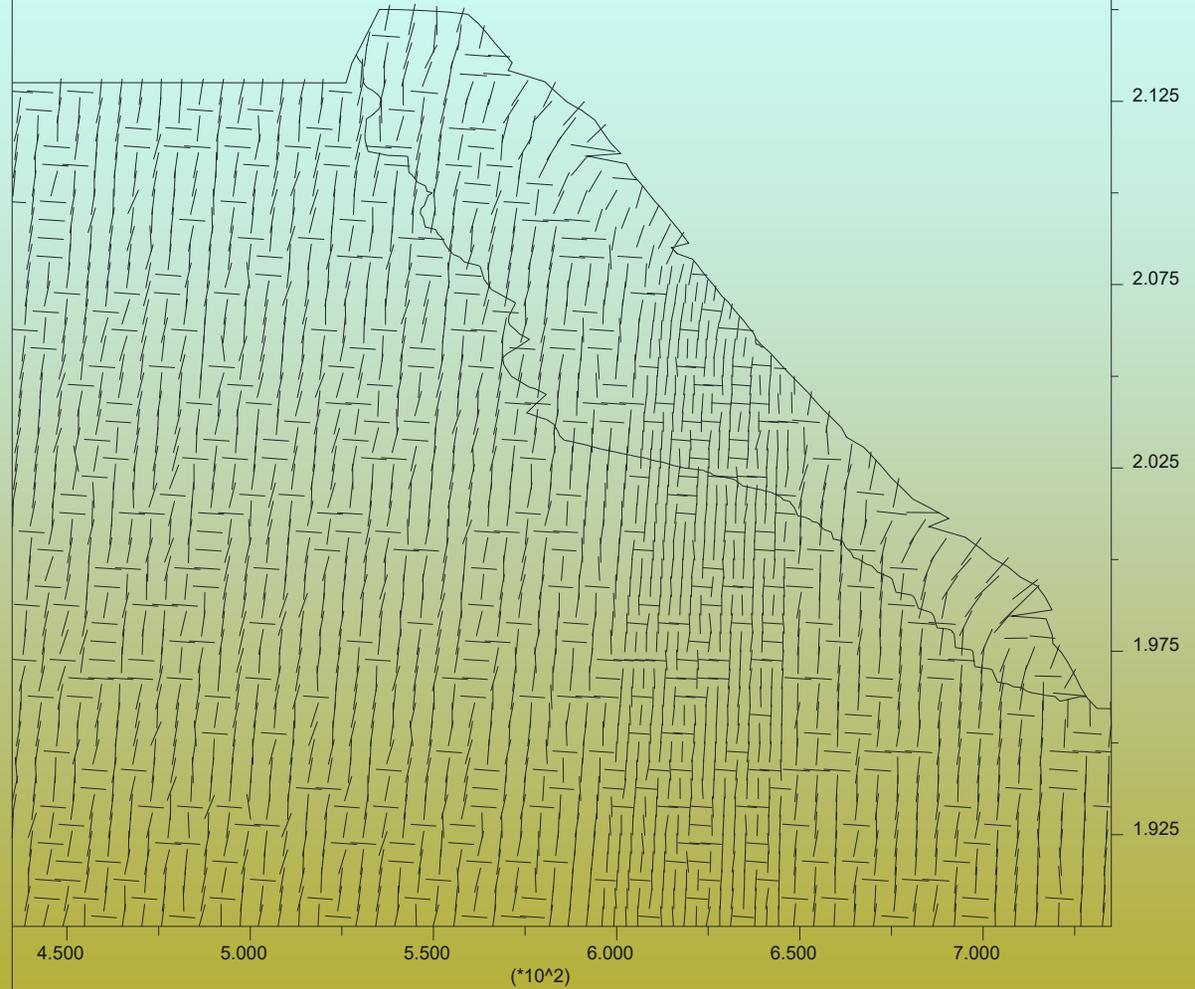
X-displacement contours

Contour interval= 1.00E-01

Minimum: 0.00E+00

Maximum: 1.00E-01

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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.

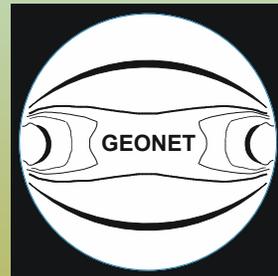
Future Considerations

- 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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