

# RocLab 1.0

# Rock Mass Strength Analysis using the Generalized Hoek-Brown failure criterion

*RocLab* is a software program for determining rock mass strength parameters, based on the latest version of the generalized Hoek-Brown failure criterion. *RocLab* provides a simple and intuitive implementation of the Hoek-Brown failure criterion, allowing users to easily obtain reliable estimates of rock mass properties and to visualize the effects of changing rock mass parameters on the failure envelopes.



The reference is available in PDF format, when you install the program. The rock mass properties determined by *RocLab* can be used as input for numerical analysis programs such as *Phase*<sup>2</sup> (finite element stress analysis and support design for excavations) or *Slide* (limit equilibrium slope stability analysis).

While *RocLab* 1.0 will continue to be offered as a free program, recent improvements and future developments are included in *RocData* 4.0. A comparison chart, *RocLab* 1.0 versus *RocData* 4.0, highlights the features in both programs.

Go to <u>Downloads</u> to get your free copy of *RocLab*. The *RocLab* Manual is available in both <u>English</u> and <u>Spanish</u>.

## Data Input/Output: Hoek-Brown Input and Output Parameters

Using the following Hoek-Brown classification parameters as input:

- the unconfined compressive strength of intact rock sigci
- the geological strength index GSI
- the intact rock parameter m<sub>i</sub> and
- the disturbance factor D

RocLab determines the generalized Hoek-Brown strength parameters of a rock mass:

- mb
- S
- ∎ a

Hoek	Brown Cl	assification	
sigci	30	🕂 MPa	æ
GSI	50	•	Ċ
mi	10	-	œ
D	0	-	œ
Hoek	Brown Cri	iterion	
m	Ь 1.677		
	s 0.003	9	
	a 0.506		

Input sigci, GSI, *m<sub>i</sub>*, and D to calculate the Generalized Hoek-Brown failure envelope parameters *mb*, *s* and a

#### Data Input/Output: Estimation of Input Parameters

Each of the 4 input parameters (sigci, GSI, m<sub>i</sub> and D) can be conveniently estimated from built-in charts and tables, based on rock type, geological conditions, etc.

These charts and tables are accessed by selecting the pick button located beside each of the input parameter edit boxes in the side bar.

-Hoek	-Brown (	Classificatio	n	
sigci	30		a ⁄ 🔁	= = = = = = = = = = = = = = = = =
GSI	50	-	<b>B</b> Pick	from Uniaxial Strength table
mi	10	-	C2	24
D	0	-	œ	23

When you select a "Pick" button, a table or chart will appear, allowing the user to determine a suitable value for the desired parameter. Once a value is selected in the dialog, the value will be automatically loaded into the input data area and the *RocLab* calculation will be carried out automatically.

Intact Uniaxial Compressive Strength					
Field Estimate of Strength	Examples	Strength (MPa)			
Specimen can only be chipped with a geological hammer.	Fresh basalt, chert, diabase, gneiss, granite, quartzite.	>250			
Specimen requires many blows of a geological hammer to fracture it.	Amphibolite, sandstone, basalt, gabbro, gneiss, granodiorite, limestone, marble, rhyolite, tuff.	100-250			
Specimen requires more than one blow of a geological hammer to fracture it.	Limestone, marble, phyllite, sandstone, schist, shale.	50-100			
Cannot be scraped or peeled with a pocket knife, specimen can be fractured with a single blow from a geological hammer.	Claystone, coal, concrete, schist, shale, siltstone.	25-50			
Can be peeled with a pocket knife with difficulty, shallow indentation made by firm blow with point of a geological hammer.	Chalk, rocksalt, potash.	5-25			
Crumbles under firm blows with point of a geological hammer, can be peeled by a pocket knife.	Highly weathered or altered rock.	1-5			
Indented by thumbnail.	Stiff fault gouge.	0.25-1			
Uniaxial Compressive Strength (sigci):	SI 📑 MPa 🛛 OK	Cancel			

Intact Uniaxial Compressive Strength Chart

Pick GSI Value	×
Rock Type: General	SURFACE CONDITIONS
GSI Selection: 50 OK	VERY GOOD GOOD FAIR POOR VERY POOR
STRUCTURE	DECREASING SURFACE QUALITY
INTACT OR MASSIVE - intact rock specimens or massive in situ rock with few widely spaced discontinuities	90 N/A N/A
BLOCKY - well interlocked un- disturbed rock mass consisting of cubical blocks formed by three intersecting discontinuity sets	70
VERY BLOCKY- interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets	50
BLOCKY/DISTURBED/SEAMY - folded with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity	40
DISINTEGRATED - poorly inter- locked, heavily broken rock mass with mixture of angular and rounded rock pieces	20
LAMINATED/SHEARED - Lack of blockiness due to close spacing of weak schistosity or shear planes	

GSI chart for General rock type

Pick GSI Value	<u>&gt;</u>
Rock Tune Fluich 💌 GSI Selection 50 OK	SURFACE CONDITIONS OF DISCONTINUITIES
COMPOSITION AND STRUCTURE	VERY GOOD FAIR POOR VERY GOOD
A. Thick bedded, very blocky sandstone The effect of policic coatings on the bedding planes is minimized by the confinement of the rock mass. In shallow turnels or slopes these bedding planes may cause structurally controlled instability.	70 A
B. Sand- stone with this inter- layers of sitistone and sitistone and sitistone in sitistone and sitistone and sit	
C.D. E and G - may be more or less folded than ilustrated but this does not change the strength. Tectonic deformation, faulting and loss of continuity moves these categories to F and H.	Ny 30 F
G. Undisturbed silly or clayer shale with or without a few very thin sandstone layers	а. — — — — — — — — — — — — — — — — — — —
thin sandstone layers Thin layers of sandstone are transformed into small rock piece Means deformation after tectonic disturbance	n. //////

GSI chart for Flysch rock type

List of Mi Values	Selected Mi Value	
Agglomerate 19±3 Amphibolites 26±6	MiValue: 10	
Andesite 25±5 Anhydrite 12±2	Filter List	
Basalt 25±5 Pressia 19±5	Rock Type	Texture ——
Breccias 20±2	Sedimentary	Coarse
Chaik 7±2 Claystones 4±2		C Medium
Conglomerates 21 ± 3 Crystalline Limestone 12 ± 3	<ul> <li>Igneous</li> </ul>	C Fine
Dacite 25±3 Diabase 15±5	C Metamorphic	C Veru Fine
Diorite 25±5		
Dolerite 16±5 Dolerites 9±2	<b>-</b>	Cancel

Pick Mi Value chart

Disturbance Factor D		×
	Application: 🕑 Tunnels 🔿 Slopes	
	Excellent quality controlled blasting or excavation by Tunnel Boring Machine results in minimal disturbance to the confined rock mass surrounding a tunnel.	D=0
	Mechanical or hand excavation in poor quality rock masses (no blasting) results in minimal disturbance to the surrounding rock mass. Where squeezing problems result in significant floor heave, disturbance can be severe unless a temporary invert, as shown in the photograph, is placed.	D=0 D=0.5 No Invert
	Very poor quality blasting in a hard rock tunnel results in severe local damage, extending 2 or 3 m, in the surrounding rock mass.	D=0.8
	Disturbance Factor: 0 📩 OK	Cancel

Pick Disturbance Factor dialog for both "Tunnels" and "Slopes" applications

Disturbance Factor D		×
	Application: C Tunnels C Slopes	
	Small scale blasting in civil engineering slopes results in modest rock mass damage, particularly if controlled blasting is used as shown on the left hand side of the photograph. However, stress relief results in some disturbance.	D=0.7 Good Blasting D=1.0 Poor Blasting
	Very large open pit mine slopes suffer significant disturbance due to heavy production blasting and also due to stress relief from overburden removal. In some softer rocks excavation can be carried out by ripping and dozing and the degree of damage to the slopes is less.	D=1,0 Production Blasting D=0.7 Mechanical Excavation
	Disturbance Factor: 0 💼 OK	Cancel

Pick Disturbance Factor dialog for both "Tunnels" and "Slopes" applications

#### Data Input/Output: Triaxial Lab Data Input

Another feature of *RocLab* is the ability to input triaxial lab test data (sigma1 / sigma3 data pairs) in order to determine the intact rock parameters sigci and m<sub>i</sub>.

The data can be entered directly into a spreadsheet in the dialog, pasted from the clipboard, or the data can be imported from various file formats, by selecting the Import button.

The parameters sigci and m<sub>i</sub> are obtained by performing a curve fit of the lab data, using the Marquardt-Levenberg fitting technique. Obtaining values of sigci and m<sub>i</sub> from triaxial lab test data is recommended, if such data is available. If triaxial lab data is not available, values of sigci and m<sub>i</sub> can always be estimated in *RocLab*, using the Pick dialogs.

#	sig3 (MPa)	sig1 (MPa)		
1	1.72	78.61	П	
2	3.45	89.33		200 -
3	5.17	99.81		180
4	6.9	123.79		160 1
5	6.9	125.23	11	a the second sec
6	10.34	125.65		
7	10.34	138.37	11	l l20 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
8	13.79	137.38		
9	13.79	146.6		1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
10	17.24	150.77		i i i i i i i i i i i i i i i i i i i
11	17.24	160.76		1 2
12	20.69	173.79		49 t
13	27.59	187.9		20 t
14	34.48	205.99	-	4
10	24.40	212.50	۳	0 20 40 60 80 100 120 140
Ba C	ору 🛍 Ра	aste Import		Minor principal stress (MPa)

Calculating sigci and m<sub>i</sub> from Lab Data

Open							<u>?</u> ×
Look in: 🔂	RocLab 1.0		•	+ 6	È 💣	<b>.</b>	
C Manuals							
File name:						Open	
Files of type:	RocData (*.ro	oc)		-		Cance	<u>ال</u>
Сору 🛍	CSV (comma Text (tab deli RocLab (*.rlb	delimited) (*.cs mited) (*.txt) )	v]		or princij	pal stres	is (MPa)

Import Triaxial lab Data from Microsoft Excel, RocData or RocLab Files

#### Data Input/Output: Equivalent Mohr-Coulomb Parameters

In addition to the Hoek-Brown failure criterion parameters (mb, s and a), *RocLab* always calculates equivalent Mohr-Coulomb parameters (cohesion and friction angle) for the rock mass. The best-fit Mohr-Coulomb strength envelope is determined over a stress range that the user can define based on the application (i.e. tunneling or slope stability).



The calculated Mohr-Coulomb parameters are listed in the sidebar



The corresponding Mohr-Coulomb envelope (the blue curve) can be viewed on the plot as well

#### Data Input/Output: Rock-mass Parameters Calculation

*RocLab* calculates rock-mass parameters such as tensile strength, uniaxial compressive strength, global strength and deformation modulus.



Calculated rock-mass parameters are listed in the sidebar

Rock Mass Parameters
tensile strength = -0.219 MPa
uniaxial compressive strength = 4.956 MPa
global strength = 13.415 MPa
modulus of deformation = 9070.89 MPa

Rock-mass parameters can be listed on the plot by toggling the "display options"

#### Data Input/Output: Metric and Imperial Units

*RocLab* allows the user to work with either Metric or Imperial units. All data entries and calculations will change accordingly once the unit system is switched in the Project Settings Dialog Box. The user can choose between megapascals (MPa, metric), Kilopounds per square foot (ksf, Imperial) and Kilopounds per square inch (ksi, Imperial) unit systems.

Project Settir	igs		×
Project Title:			
Analysis of R	ock Strength using RocLab		
Stress Units:	Megapascals (MPa)	Ŧ	
	Megapascals (MPa) Kilopounds per square foot (ksf) Kilopounds per square inch (ksi)		Cancel
	<u>_</u>		Carloof

Switch the Stress Units in the Project Settings Dialog

### **Display Capabilities: Failure Envelope Plots**

RocLab plots the rock mass failure envelopes in both principal stress space (sigma1 vs. sigma3) and shearnormal stress space (sigma normal vs. Tau). By default, both principal stress and shear-normal plots are displayed, but the user can choose to display either plot type on its own by selecting the desired plot type from the toolbar, the Analysis menu or the right-click pop-up menu.



Both Principal stress and Shear-Normal stress plots are displayed by default

#### **Display Capabilities: Equivalent Mohr-Coulomb Parameters**

In addition to the Hoek-Brown failure criterion parameters (mb, s and a), RocLab always calculates equivalent Mohr-Coulomb parameters (cohesion and friction angle) for the rock mass. The best-fit Mohr-Coulomb strength envelope is determined over a stress range that the user can define based on the application (i.e. tunneling or slope stability).



The calculated Mohr-Coulomb parameters are listed in the sidebar



The corresponding Mohr-Coulomb envelope (the blue curve) can be viewed on the plot as well

#### **Display Capabilities: Interactive Data Input**

If the user click on the arrows with the mouse to change the input data, the *RocLab* calculations are instantly performed. All output data is immediately recalculated, and the failure envelope plots are redrawn each time the mouse is clicked on either the up or the down arrow.

Hoek-Brown Classification				
sigci	16	(∃)Pa		
GSI	33			

Interactive Data Input by clicking on the up/down arrows

This allows the user to interactively observe the effect of parameter changes, on the shape of the failure envelopes, and the output values.

#### **Display Capabilities: Stress Sampler**

The stress sampler option allows the user to graphically obtain the exact stress coordinates at any point along the failure envelopes.



Sample the Hoek-Brown or Mohr-Coulomb failure envelopes

#### **Display Capabilities: Instantaneous MC Sampler**

The Instantaneous Mohr-Coulomb Sampler option allows the user to graphically obtain the instantaneous Mohr-Coulomb parameters (cohesion and friction angle) at any point along the Hoek-Brown failure envelopes.



Instantaneous MC Sampler

#### **Display Capabilities: Export Data/Images**

*RocLab* allows the user to export data for further analysis or report writing. It lets the user copy the data / plots to the clipboard for easy import into Microsoft Word or other word processors or image editing programs.



The Copy option copies the plots and the Copy Data option copies the data to the clipboard



The Copy Data function in the Sidebar

Also, *RocLab* enables the user to export the data / plots directly into Microsoft Excel by clicking the Excel charting button on the toolbar.



#### A Sample Excel chart generated by RocLab

The user can save the plots to a JPEG or BMP image file using the Export Image File option under the File menu or in the right-click pop-up menu.

File	Edit	View	Analysis	Window
D	<u>N</u> ew			Ctrl+N
Ē	Open			Ctrl+O
	⊆lose			
	<u>S</u> ave			Ctrl+S
	Save <u>A</u>	<u>k</u> s		
	Export	Image	File	
	Export	Inage	1 110111	
	Page S	ietyp		
  }  }	Page S Print P	ietyp re <u>v</u> iew		
	Page S Print P Print.	ietyp., re <u>v</u> iew		Ctrl+P
     	Page S Print P Print <u>1</u> RocL	iet <u>u</u> p re <u>v</u> iew ab1.rlb	)	Ctrl+P

The Export Image File option under File menu

#### **Display Capabilities: Display Options**

The appearance of the plots may be customized with Display Options, zooming, and other options. *RocLab* allows the user to change colors, fonts, line thickness of the plots and toggle grid overlay, plot title, input data, bounding box, graph icons, and Mogi's Line.



The Display Options Dialog



The effect of adding grid overlay, bounding boxes, project title, graph icons, and cropping axes

#### Zooming

The Zoom options in the toolbar allow the user to customize the zooming of the plot axes. The Zoom Extents option will automatically scale the axes of the failure envelopes, so that all possible failure envelopes, for the current value of sigci, will be visible on the plot. The Zoom Extents option is useful for interactive demonstration of parameter changes on the failure envelope.



The effect of Zoom Extents

#### **Mogi's Line**

Mogi's Line defines the ratio of major and minor effective principal stresses at which there is a transition from brittle to ductile failure. This line is simply defined by sig1 / sig3 = 3.4, and is plotted as a green line on the principal stress plot, when the Mogi's Line option is selected in the Display Options dialog.

If the principal stress failure envelope lies above Mogi's line, this indicates a brittle failure mode. If the principal stress failure envelope lies below Mogi's line, this indicates a ductile failure mode. This may occur with low values of GSI, for example.



Mogi's line is shown as a green line on the principal stress plot

#### Grayscale

The Grayscale option allows the user to convert the entire view to grayscale (black and white) with a single mouse click. This can be useful when black and white screen captures or printouts are necessary.



Effect of grayscale

## RocLab 1.0 – FAQs

# *I calculate a value of mi to be around 100 yet RocLab limits mi to be between 1 and 50. Why?*

 Your values of mi of around 100 are almost certainly associated with too small a range of confining stresses in your triaxial testing. This is a problem that I come across very frequently. The original definition of mi is based on triaxial tests up to one half of the uniaxial compressive strength of the intact material. The following quote is from Hoek and Brown, 1997, "Practical estimates of rock mass strength" published in the Int. J. Rock. Mech. Min Sci.

"Note that the range of minor principal stress (sig3) values over which these tests are carried out is critical in determining reliable values for the two constants. In deriving the original values of sigci and mi, Hoek and Brown used a range of 0 < sig3 < 0.5\*sigci and, in order to be consistent, it is essential that the same range be used in any laboratory triaxial tests on intact rock specimens."

For example, if you analyze the following data set for Carrara marble using *RocLab* you obtain sigci = 82.28 and mi = 8.68.

1.72	78.61
3.45	89.33
5.17	99.81
6.9	123.79
6.9	125.23
10.34	125.65
10.34	138.37
13.79	137.38
13.79	146.6
17.24	150.77
17.24	160.76
20.69	173.79
27.59	187.9
34.48	205.99
34.48	213.58

Note that the maximum value of sig3 is too low in this case - it should be about 40 MPa but this is a real data set and it is all that I have.

On the other hand, if I analyze only the first 4 data points, up to sig3 = 6.9 MPa, I obtain sigci = 48.92 and mi = 32.13. If this data set was for hard rock I could easily get mi values of over 100 by limiting the range of sig3 values.

All the values quoted in the various Hoek-Brown papers are derived from triaxial test data with the correct range of sig3 values - this was one of the criteria that we set in determining whether or not the data were acceptable. The typical range of mi values if from about 5, for soft ductile rocks, to 35 for very hard brittle rocks. Hence we set the range of 1 < mi < 50 in RockLab to cover this range.

For the three sigma3, sigma1 laboratory strength data (0,16),(5,105.9),(20,161), why does RocLab 1.007, RocLab 1.006 and RocData 2.37 using Linear Regression and Simplex fitting give different values of mi and sigci when fitting the Hoek-Brown envelope?

 RocLab uses the Levenberg-Marquardt method, a robust algorithm that has become the standard for non-linear regression. The method is very reliable in practice, and has the ability to converge promptly from a wider range of initial guesses than other typical methods.

*RocLab* Versions 1.000 to 1.005 used a linearized form of the Hoek-Brown equation that had the effect of reducing the Levenberg-Marquardt method to linear regression. This was modified in Version 1.006 in order to take full advantage of the power of the Levenberg-Marquardt method.

We looked closely at the varying results provided by different regression algorithms, which you sent us. We judged the quality of the results using the 'Sum Square of Errors' (SSE) – the sum of the square of the vertical distances of the given data points from the fitted curve. (In *RocLab* Version 1.006 and up this quantity is referred to as "Residuals"; in some statistical literature it is known as the sum-of-squares.) The analysis indicated the following:

i. The linear regression results (sigci=50.7 MPa and mi=17.8) given by *RocData* Version 2, the published spreadsheet of Hoek and Brown, and *RocLab* Versions 1.000 to 1.005, gave an SSE value of 1490.98

ii. The simplex method in *RocData* that gave sigci=20.47 MPa and mi=55.46 had an SSE of 663.539

iii. *RocLab* Version 1.007 results (sigci=20.998 MPa and mi=49.9) had an SSE of 702.858

These SSEs tell us that *RocData* and *RocLab* 1.007 found curves that better fit the data than the linear regression approaches. It may seem that RocLab 1.007 gave slightly worse results than the simplex method in *RocData*, but this is not so.

*RocLab* 1.007 allows mi only to range between 1 and 50. When we remove the upper limit, the program gives sigci=20.487, mi=55.44 and SSE=663.539, nearly identical to the results of the simplex method.

*RocLab* 1.007 caps the maximum value of mi at 50 because, according to Dr. Evert Hoek, mi values higher than this threshold indicate too small a range of confining stresses in triaxial testing. The following quote is from the paper "Practical Estimates of Rock Mass Strength" by Hoek and Brown (International Journal of Rock Mechanics and Mining Sciences, Vol. 34, No. 8, pp. 1165-1186, 1997):

Note that the range of minor principal stress () values over which these tests are carried out is critical in determining reliable values for the two constants. In deriving the original values of and, Hoek and Brown used a range of and, in order to be consistent, it is essential that the same range be used in any laboratory triaxial tests on intact rock specimens.