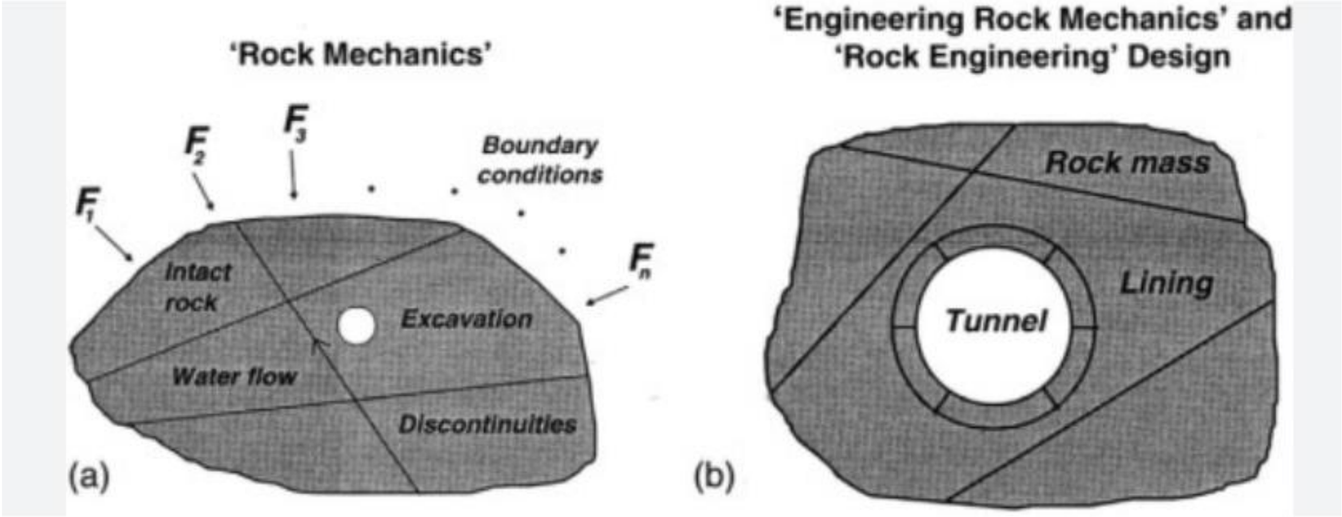
How to Calculate Rock Mass Properties

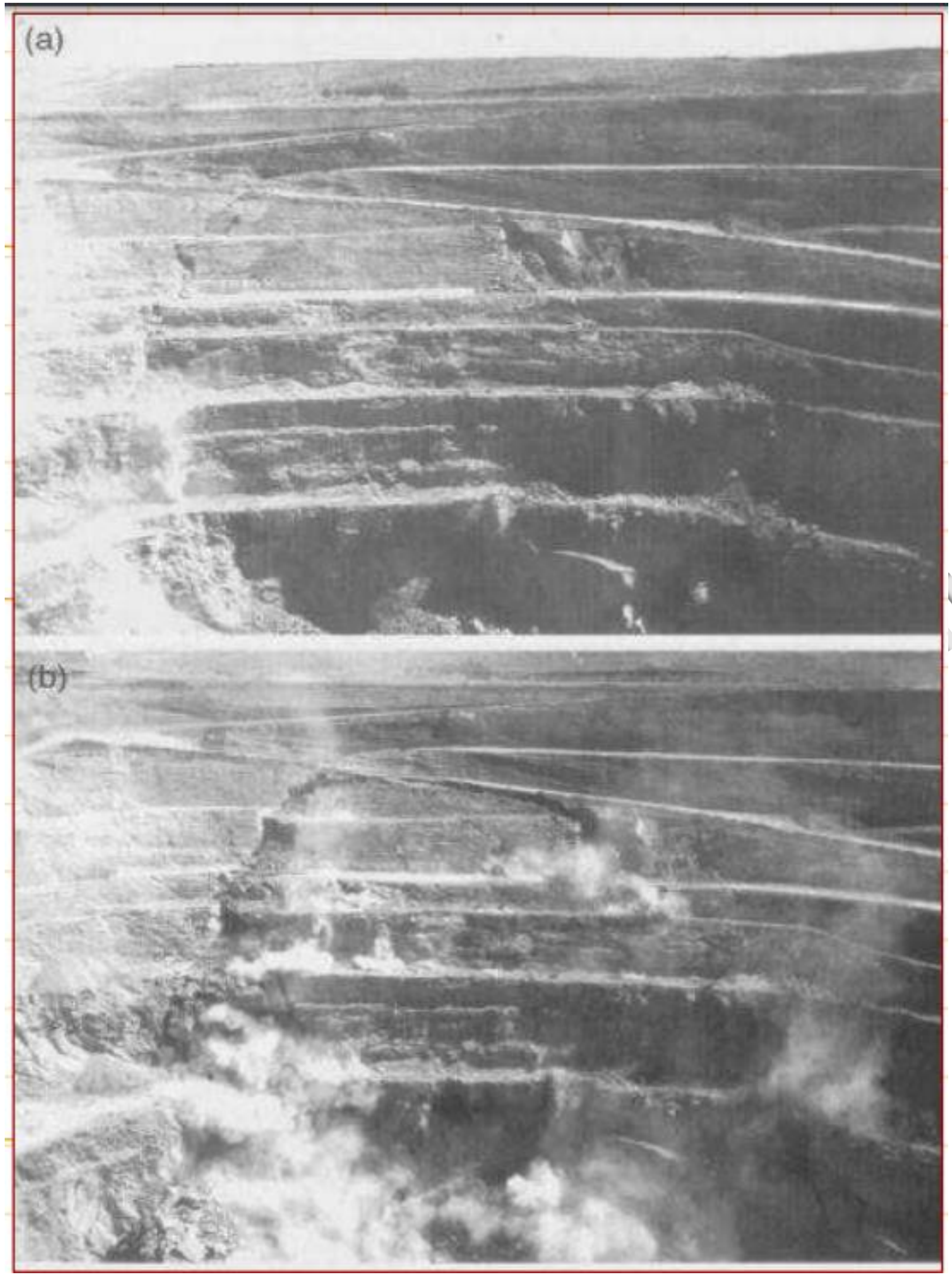
Introduction About - Rock Mechanics

Rock mechanics is the theoretical and applied science of the mechanical behaviour of rock and rock masses. Rock mechanics deals with the mechanical properties of rock and the related methodologies required for engineering design.



Rock mechanics involves characterizing the intact strength and the geometry and mechanical properties of the natural fractures of the rock mass.

Rock engineering is concerned with specific engineering circumstances, for example, how much load will the rock support and whether reinforcement is necessary.



For Example –
There is a failure in this mine pit. It is all about these forces (sliding or failure forces) to determine in the rock mass, to design support system which could take this load.

Nature of Rock

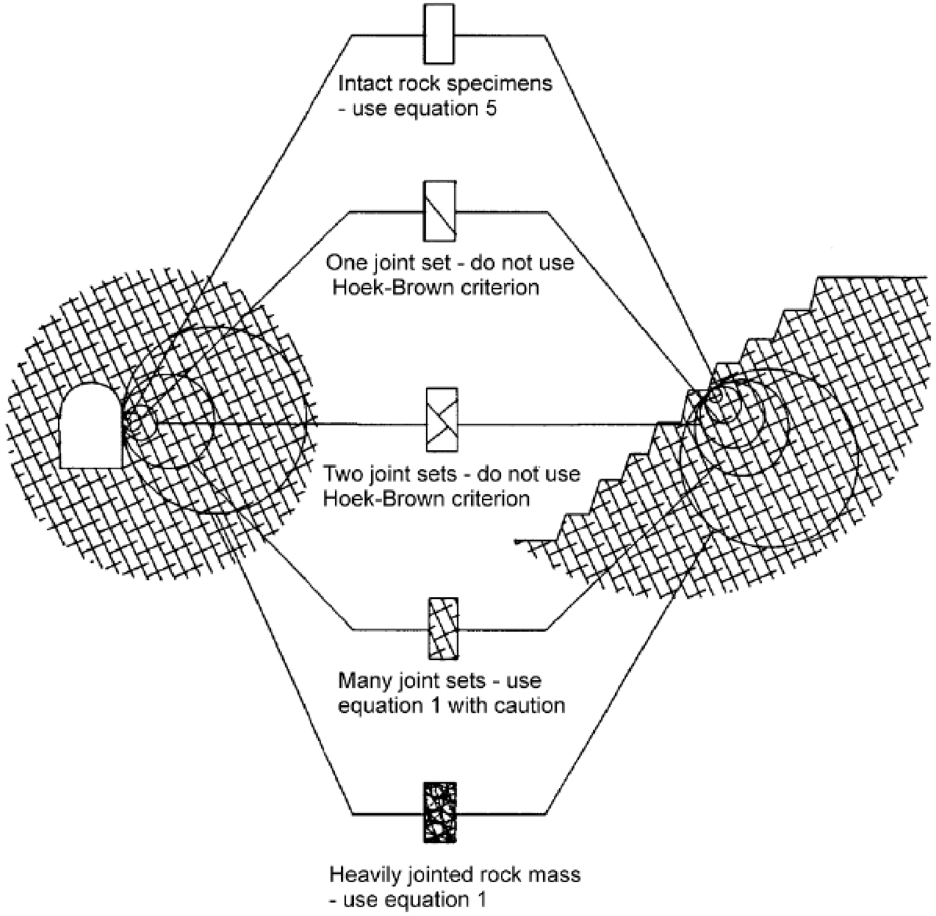
A common assumption when dealing with the mechanical behavior of solids is that they are:

- homogeneous
- continuous
- isotropic

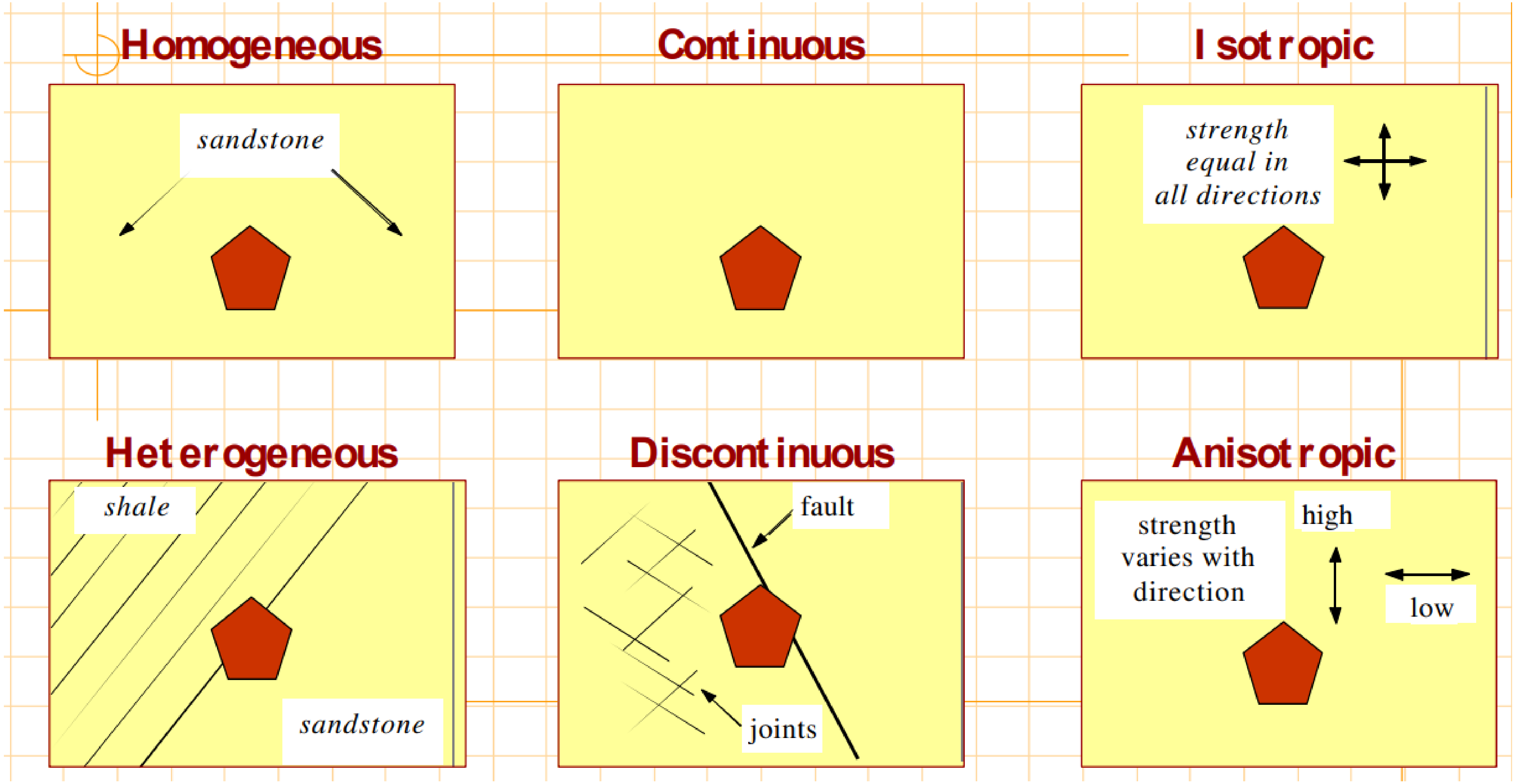
Solids in this case are cement concrete, metals

However, rocks are much more complex than this and their physical and mechanical properties vary according to scale. As a solid material, rock is of ten:

heterogeneous · discontinuous · anisotropic



Nature of Rock



Influence of Geological Factors

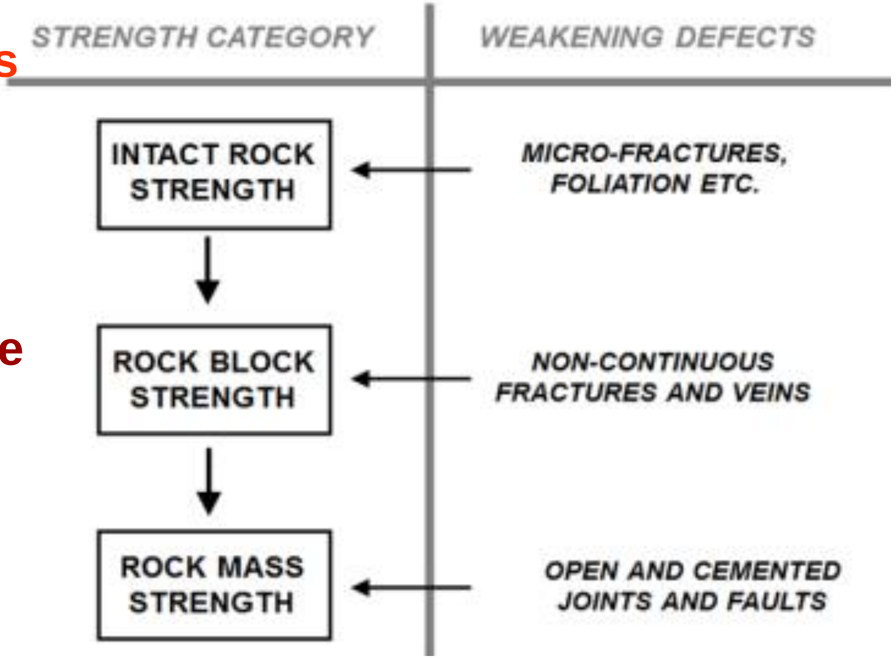
Five primary geological factors can be viewed as influencing a rock mass. In the context of the mechanics problem, we should consider the material and the forces applied to it .

1. We have the intact rock which is itself divided by discontinuities to form the rock structure.

2. We find then the rock is already subjected to an *in-situ* stress.

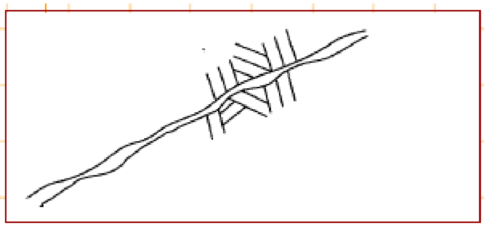
3. Superimposed on this fundamental mechanics circumstance are the influence of pore fluid/ water flow and time.

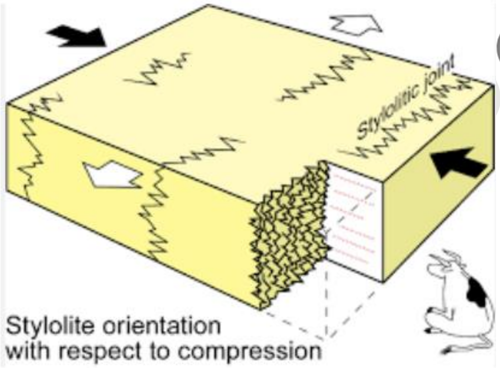
In all these subjects, the geological history has played its part ,altering the rock and the applied forces.

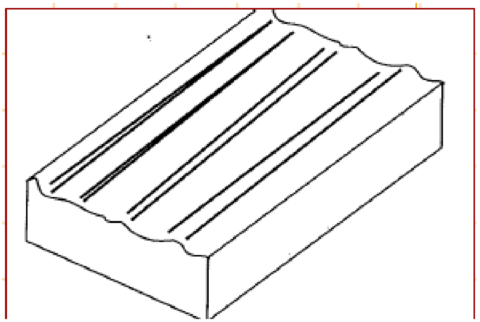


Influence of Geological Factors – Discontinuities and Rock Structure

In practice, failure is most of ten associated with discontinuities which act as pre- existing planes of weakness. Some examples of the way in which the discontinuity genesis leads to differing mechanical properties are:







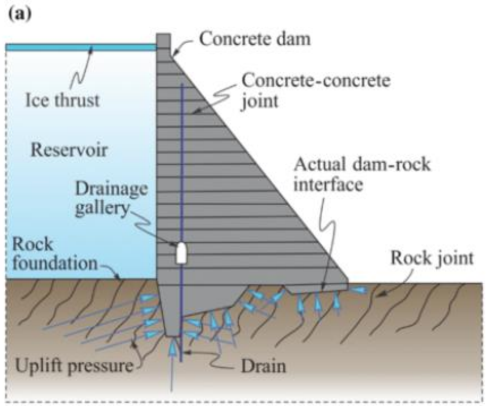
Open joint which will allow free flow of water

Stylolitic discontinuity with high shear resistance

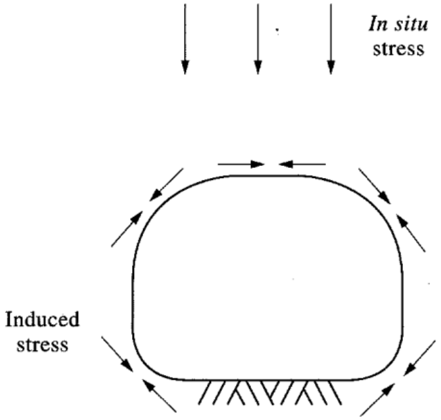
Slickensided fault surface with low shear resistance

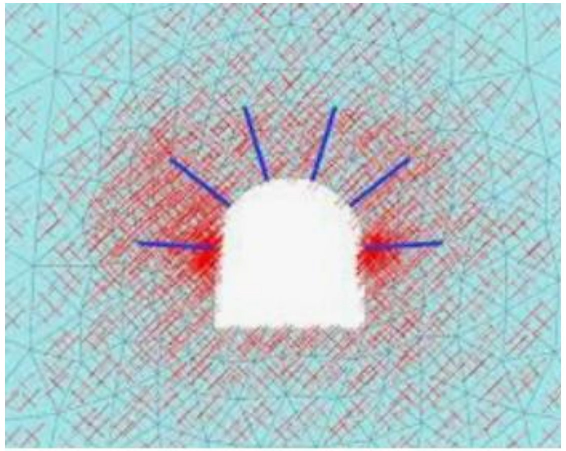
Influence of Geological Factors – Pre- Existing In-Situ Rock Stress

When considering the loading conditions imposed on the rock structure, it must be recognized that an *in situ* pre- existing state of stress already exists in the rock.



In some cases, such as a dam or nuclear power stat ion foundation, the load is applied to this.

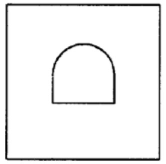
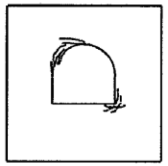
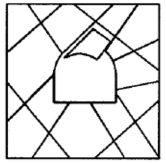
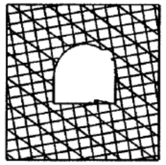
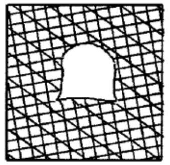




In other cases, such as the excavation of a mine or tunnel, no new loads are applied but the pre- existIng stresses are redistributed.

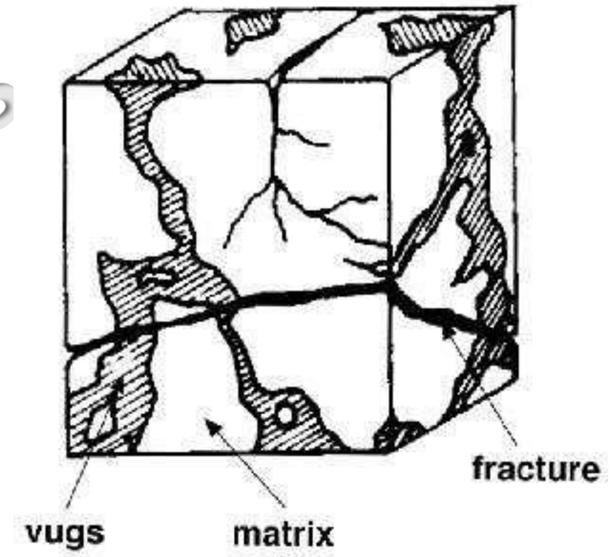
Influence of Structure & In Situ Rock Stress Together

Types of failure which occur in different rock masses under low and high *in situ* stress levels.

	Low stress levels	High stress levels
Massive rock	 Massive rock subjected to low in situ stress levels. Linear elastic response with little or no rock failure.	 Massive rock subjected to high in situ stress levels. Spalling, slabbing and crushing initiates at high stress concentration points on the boundary and propagates into the surrounding rock mass.
Jointed rock	 Massive rock, with relatively few discontinuities, subjected to low in situ stress conditions. Blocks or wedges, released by intersecting discontinuities, fall or slide due to gravity loading.	 Massive rock, with relatively few discontinuities, subjected to high in situ stress conditions. Failure occurs as a result of sliding on discontinuity surfaces and also by crushing and splitting of rock blocks.
Heavily jointed rock	 Heavily jointed rock subjected to low in situ stress conditions. The opening surface fails as a result of unravelling of small interlocking blocks and wedges. Failure can propagate a long way into the rock mass if it is not controlled.	 Heavily jointed rock subjected to high in situ stress conditions. The rock mass surrounding the opening fails by sliding on discontinuities and crushing of rock pieces. Floor heave and sidewall closure are typical results of this type of failure.

Influence of Geological Factors – Pore Fluids and Water Flow

Many rocks in their int act state have a very low permeability compared to the duration of the engineering construct ion, but the main wat er flow is usually via secondary permeability, (i. e. pre- existing fractures). Thus, the study of flow in rock masses will generally be a function of the discontinuities, their connectivity and the hydrogeological environment .



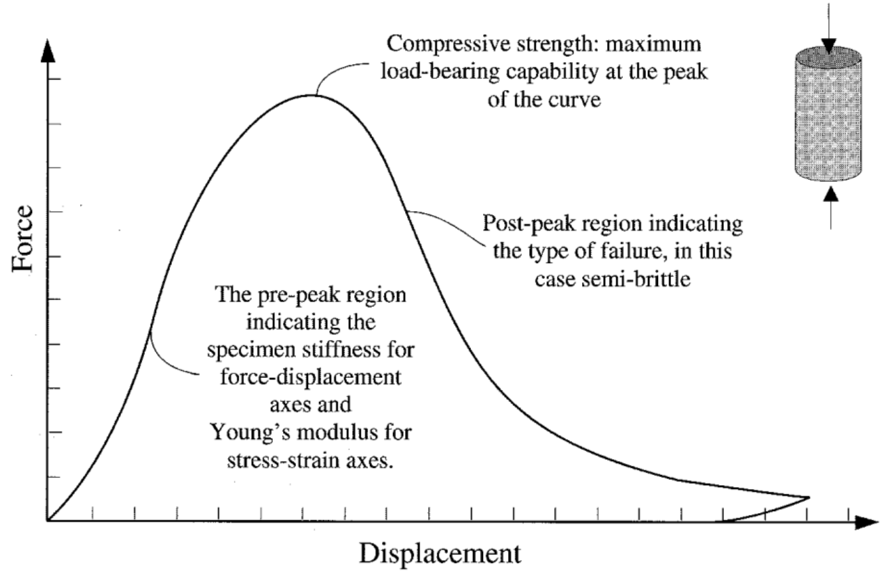
A primary concern is when the water is under pressure, which in turn act s to reduce the effective stress and/ or induce instabilities.
Other aspects, such as groundwater chemistry and the alteration of rock and fracture surf aces by fluid movement may also be of concern.

Intact Rock

Uniaxial Compression Strength of Intact Rock

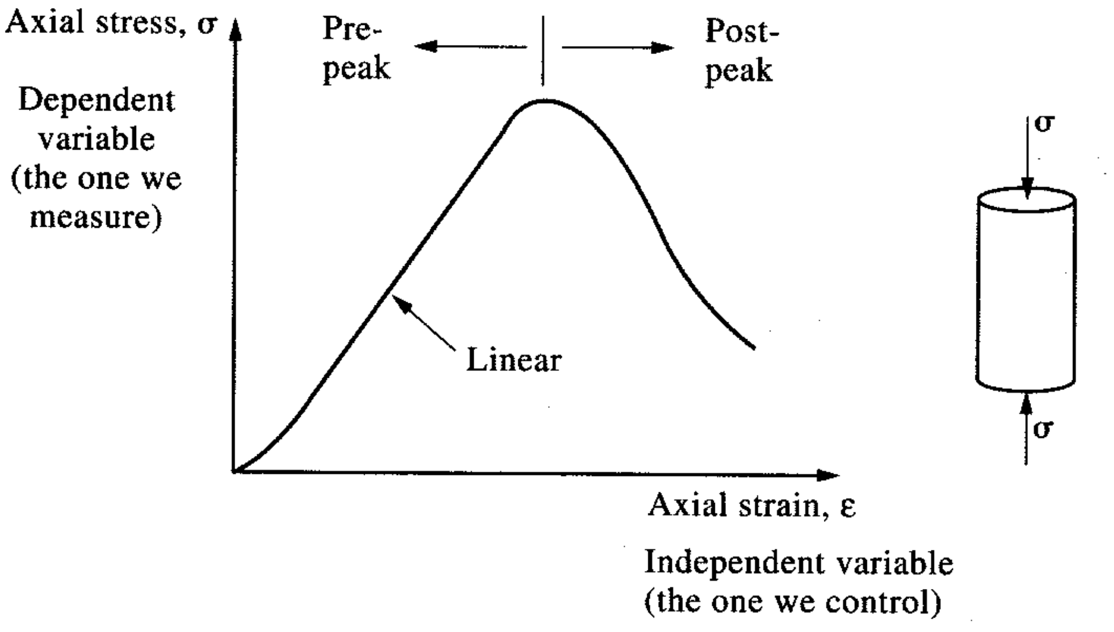
Uniaxial Compression test

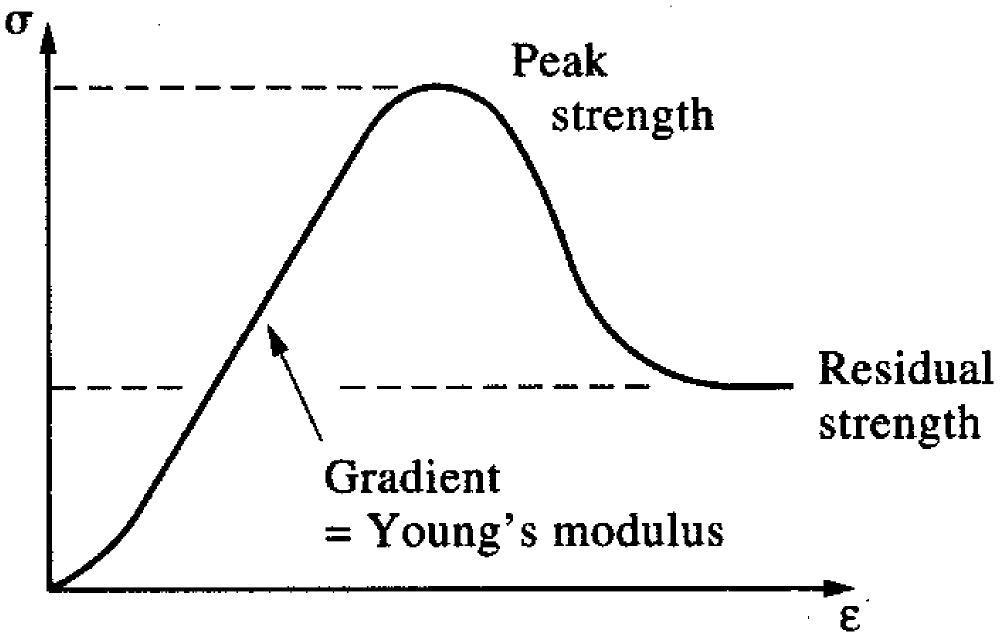
Important parameter in the uniaxial compression test is the maximum stress that the test sample can sustain. Under uniaxial loading conditions, the peak stress is referred to as the uniaxial compressive strength, σ_c.



Compressive Strength

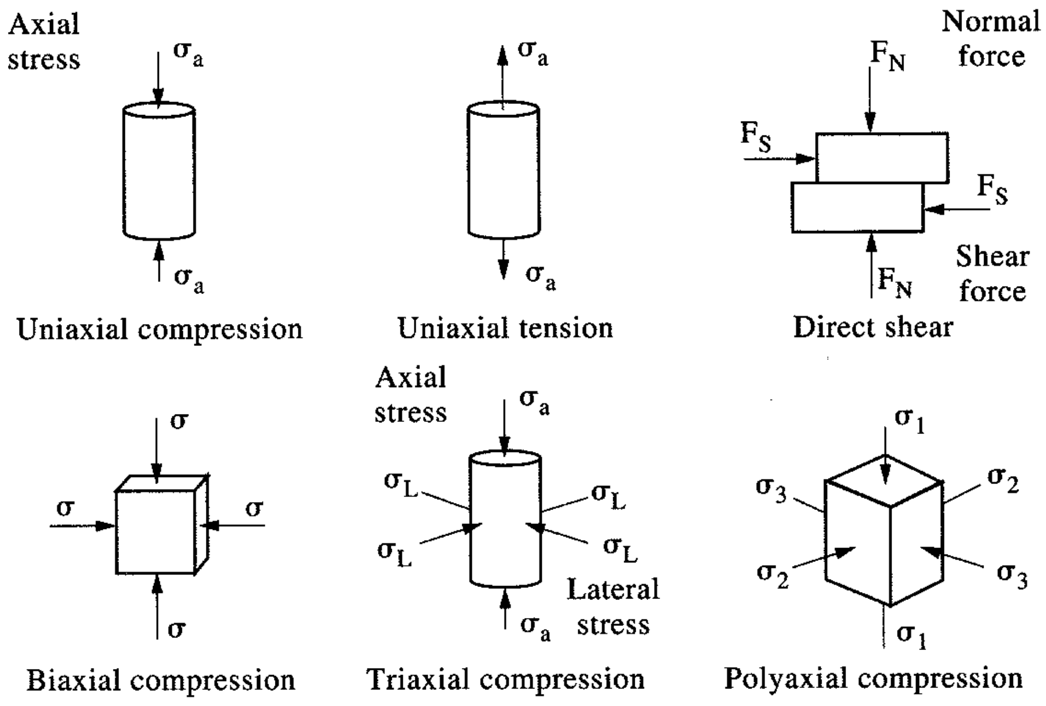
The compressive strength is probably the most widely used and quoted rock engineering parameter and therefore it is crucial to understand its nature. In other forms of engineering, if the applied stress reaches σ_c, there can be catastrophic consequences.
This is not always the case in rock engineering as rock often retains some load bearing capacity in the post peak region of the σ- ε curve.
Whether failure beyond σ_c is to be avoided at all costs, or to be encouraged, is a function of the engineering objective, the form of the complete stress- strain curve f or the rock (or rock mass), and the characteristics of the loading conditions. These features are crucial in the design and analysis of underground excavations.





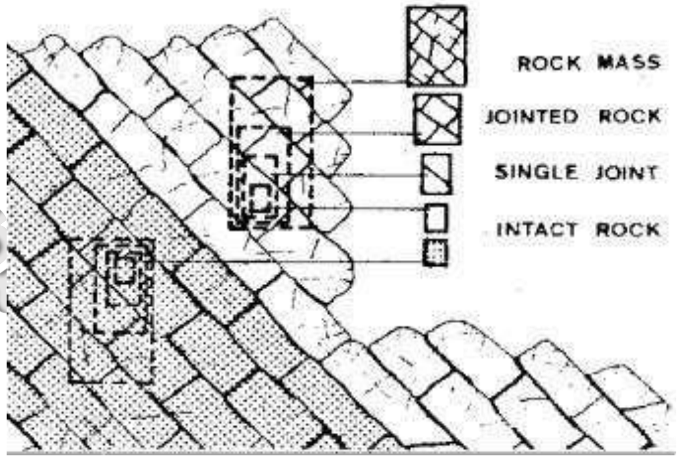
Effects of Loading Conditions

These different strengths may be tested either directly (e.g. uniaxial tension test , direct shear test , etc.) or indirectly (e.g. Brazilian tensile test , triaxial compression test , etc.).

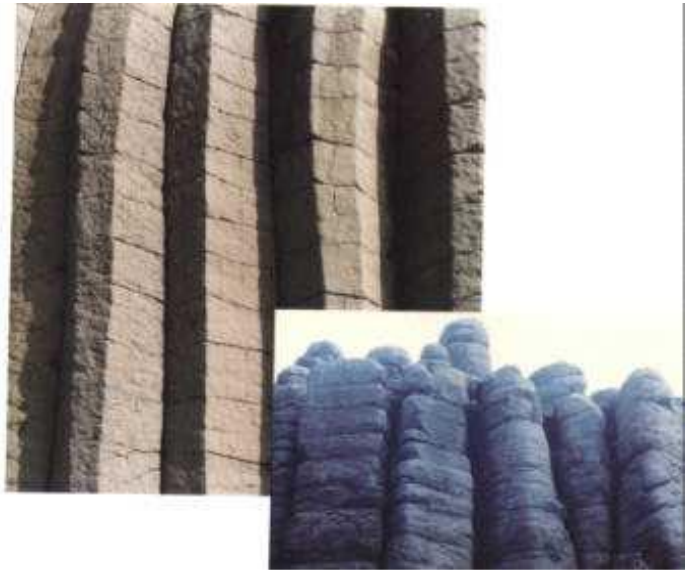


Discontinuities

It is the existence of discontinuities in a rock mass that makes rock mechanics a unique subject . The word ‘discontinuity’ denotes any separation in the rock continuum having effectively zero tensile strength and is used without any generic connotation (e. g. joints and faults are types of discontinuities formed indifferent ways).

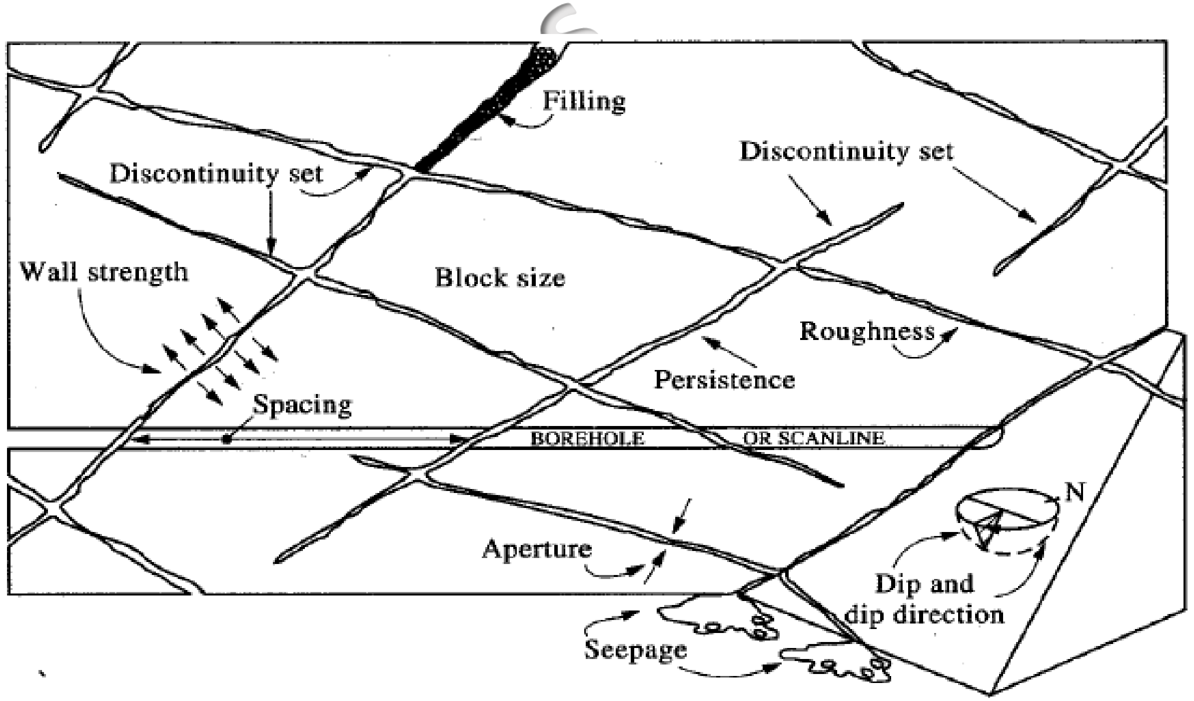


Discontinuities have been introduced into the rock by geological events, at different times and as a result of different stress states. Very of ten, the process by which a discontinuity has been formed may have implications f or its geometrical and mechanical properties.



Geometrical Properties of Discontinuity

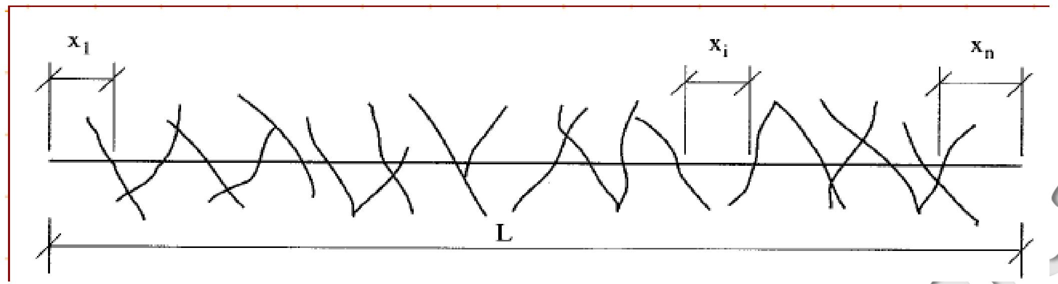
The main features of rock mass geometry include spacing and frequency, orientation (dip direct ion/ dip angle), persistence (size and shape), roughness, aperture, clustering and block size.

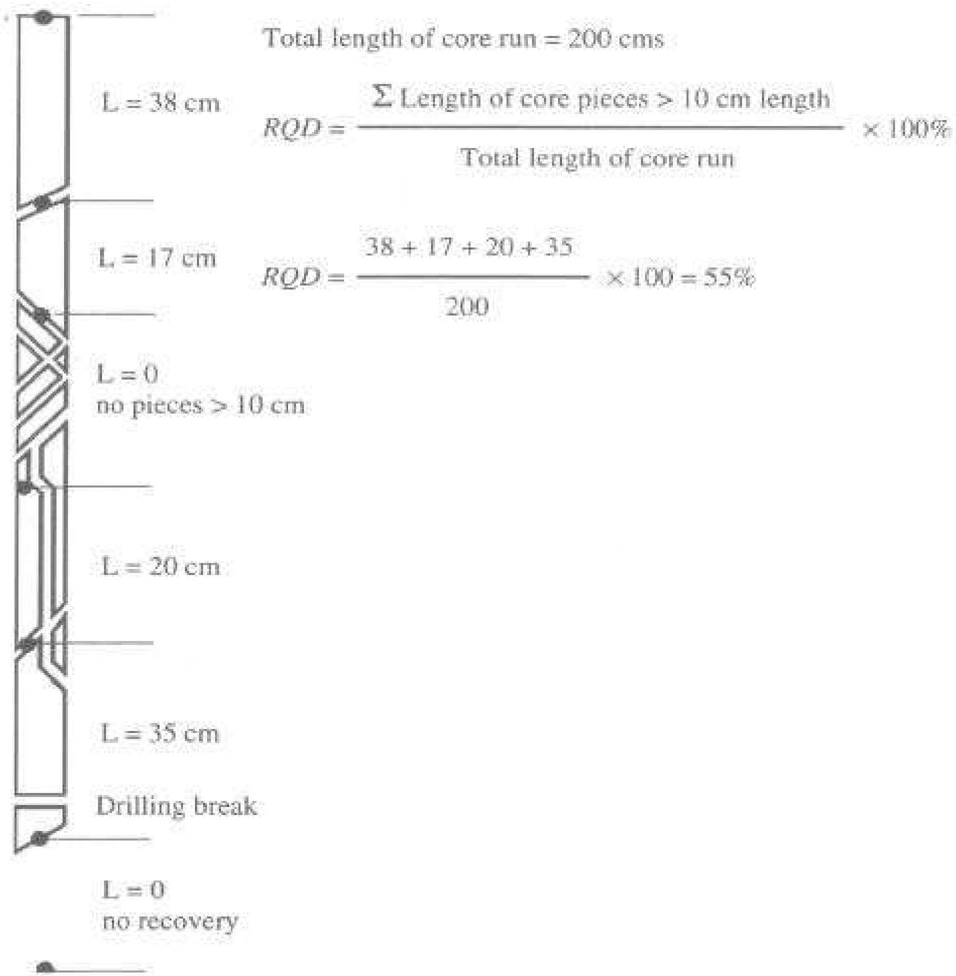


There is, however, no standardized method of measuring and characterizing rock structure geometry, because the emphasis and accuracy with which the separate parameters are specified will depend on the engineering objectives.

Discontinuity Spacing and Frequency

Spacing is the distance between adjacent discontinuity intersections with the measuring scanline. Frequency (i. e. the number per unit distance) is the reciprocal of spacing (i.e. the mean of these intersect ion distances).



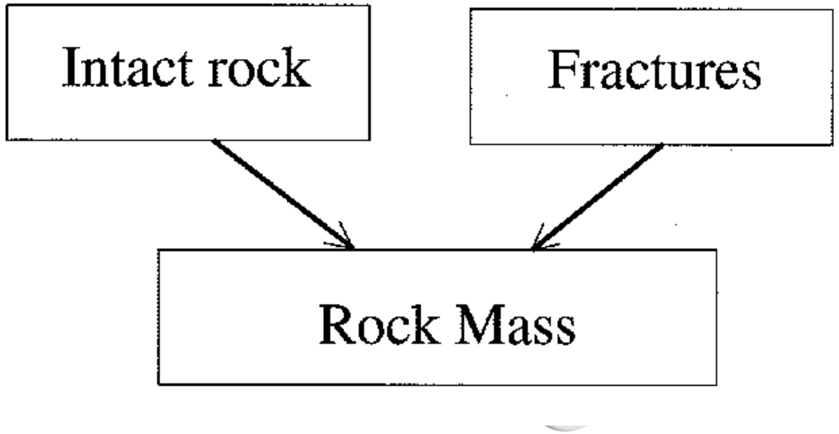


Rock Quality Designation

An important feature for engineering is the overall quality of the rock mass cut by fracture systems. For this reason, the concept of the RQD was developed.

Rock Masses

Building on our examination of first intact rock behaviour and then discontinuity behaviour, we can now concentrate on extending these ideas to provide a predictive modelf or the deformability and strength of rock masses.



Rock Mass Properties

Content

- Introduction
- Rock Mass Properties
- Generalized Hoek-Brown failure criterion
- Input Parameters

Introduction

In this presentation, I will introduce you how to determine Rock Mass Properties through Generalized Hoek-Brown failure criterion.

For analyzing underground problems, to design cut slopes and to determine ground behavior around tunnels, it has become important to determine

I determine rock mass properties through the excel file which I have prepared for tunnels and rock slopes.

I will compare the values determined through excel file with Roclab (Rocscience software) for validation.

What are Rock mass Properties?

First of all, we shall know what is Rock Mass?

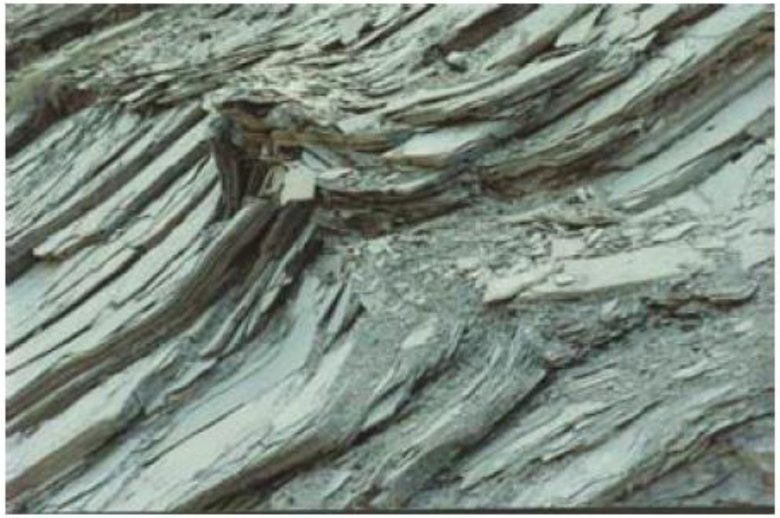
Rock mass is a matrix consisting of rock material and rock discontinuities.

Secondly it usually come to our mind when we see any fractured rock mass,what are their properties?

- How to determine and characterize their strength and deformation?
- The fact that fractures control the mechanical response of rock masses makes the determination of their mechanical behavior difficult..

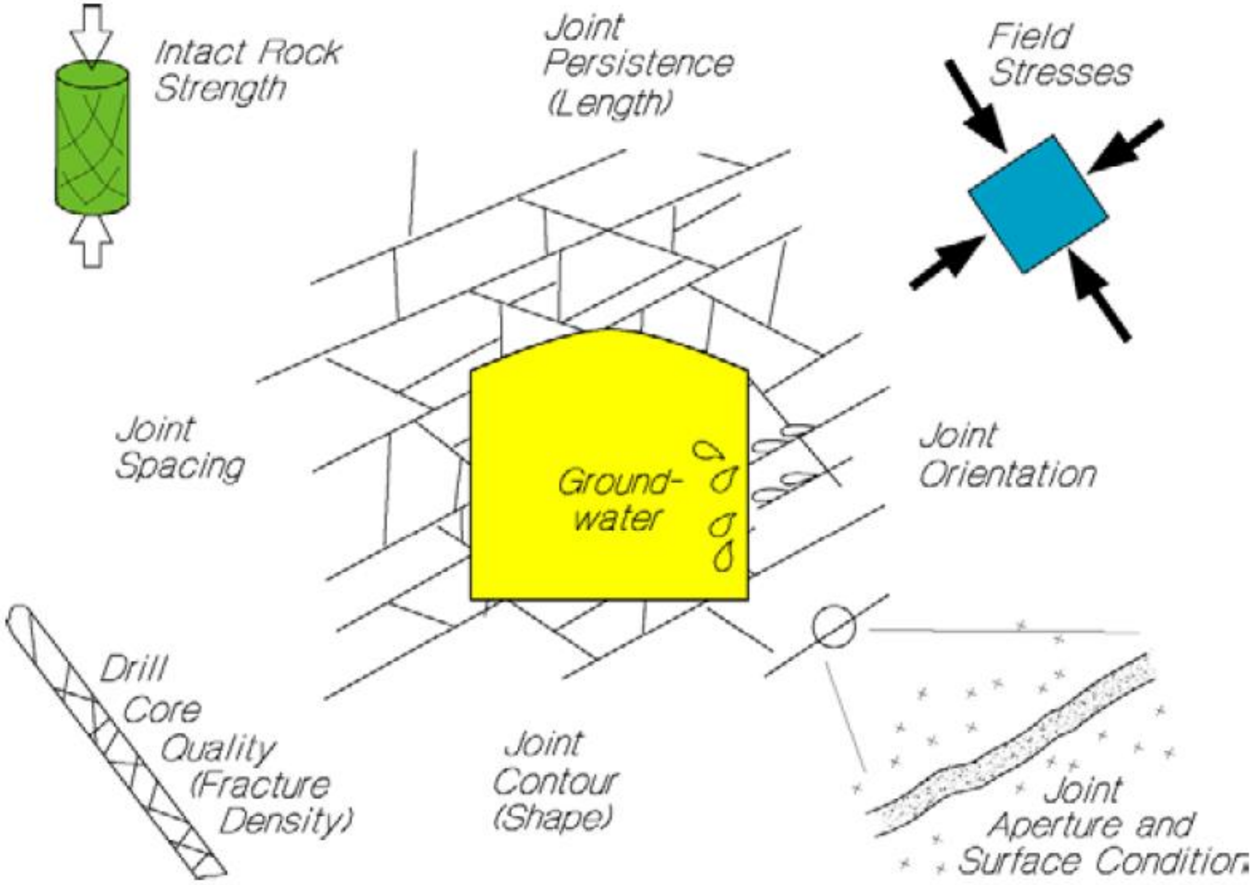
Rock Mass Properties

Rock masses




Rock Mass Properties

By taking strength and deformability parameters of intact rock, rock fractures parameters like spacing; orientation; width; roughness; weathering and in-situ stresses, we can determine Rock mass properties.

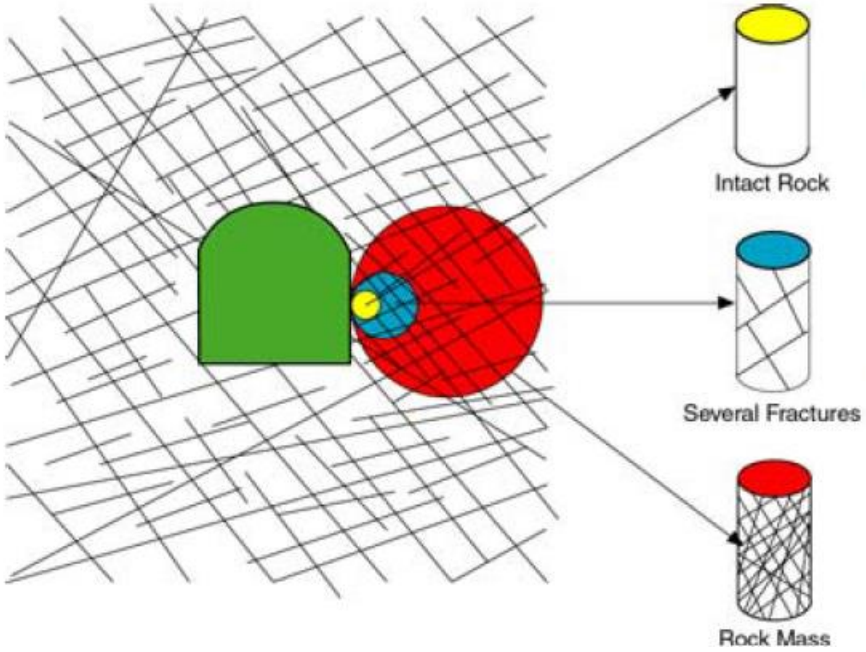


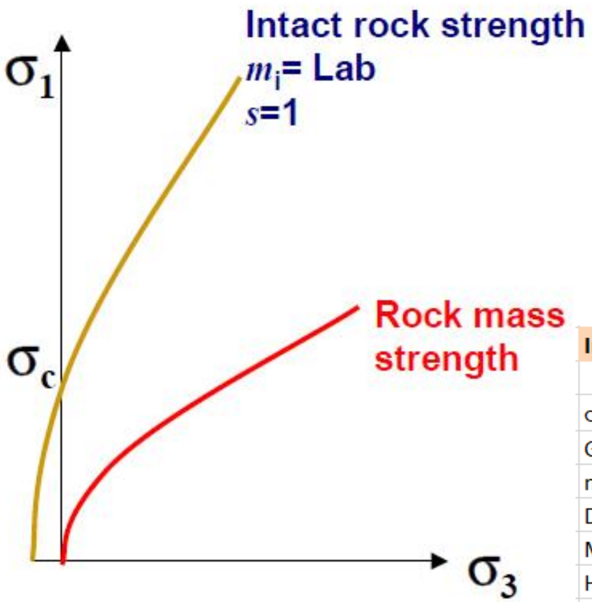
Rock Mass Properties

For determining rock mass properties or we can say **rock mass strength**, we usually adopt Generalized **Hoek-Brown failure criterion as shown in below equation.**

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b \frac{\sigma_3'}{\sigma_{ci}} + s\right)^a$$

- Uniaxial compressive strength **σc** of the **intact rock pieces,**
- Value of the Hoek-Brown constant **mi** for these intact rock pieces, and
- Value of the Geological Strength Index **GSI** for the rock mass.





Inputs					
σ_{ci}	=	Uniaxial Compressive Strength	=	75	Mpa
GSI	=	Geoloquical Strength Index	=	55	
mi	=	Constant for Intact Rock	=	17	
D	=	Disturbance Factor	=	0	
MR	=	Modular Ratio	=	275	
H	=	Depth of Tunnel/Slope Height	=	100	m
γ	=	Unit wieght of Rock	=	0.027	KN/m3

Generalized Hoek-Brown Failure Criterion

This failure criteria helps in determining the rock mass properties for analyzing underground tunnels and for slope stabilization.

Generalized Hoek-Brown Criterion expressed as

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b \frac{\sigma_3'}{\sigma_{ci}} + s\right)^a$$ ....Equation 1

σ_1 – Maximum principal stress at the time of failure
σ_3 – Minimum principal stress at the time of failure
m_b – is the reduced Value material constant mi
σ_{ci} – Uniaxial compressive strength of the intact rock
s and a – Constant which depends upon the rock mass characteristics

To determine the above failure criteria following parameters need to be determined.
mb is determined

$$m_b = m_i \exp\left(\frac{GSI - 100}{28 - 14D}\right)$$ ....Equation 2

Generalized Hoek-Brown Failure Criterion

$$s = \exp\left(\frac{GSI - 100}{9 - 3D}\right)$$ …………Equation 3

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right)$$ …………Equation 4

In equation 2 to 4 there are many input parameters like GSI, D, mi, σci, which I will show you in next slide how we could determine them.

Generalized Hoek-Brown Failure Criterion- Rock mass Properties

Uniaxial Compressive strength of Rock mass

UCS of rock mass is obtained by keeping σ3 = 0 in Equation 1 . It is stress where there is initiation of failure of rock mass. (It is not rock mass compressive strength)

$$\sigma_c = \sigma_{ci} . s^a$$

Tensile Strength of Rock mass obtained by keeping σ1 =σ3=σt in Equation 1

$$\sigma_t = -\frac{s\sigma_{ci}}{m_b}$$

Modulus of deformation E_m

$$E_m(GPa) = \left(1 - \frac{D}{2}\right)\sqrt{\frac{\sigma_{ci}}{100}} \cdot 10^{((GSI-10)/40)}$$

Mohr Coulomb Failure Criteria for Rock Mass – Friction Parameters

Mohr Coulomb determines equivalent angles of **friction** and **cohesive strengths** for each rock mass and stress range.
c and ϕ for rock mass has been determined for numerical software where the rock mass properties determined through H&B criteria can not be incorporated.

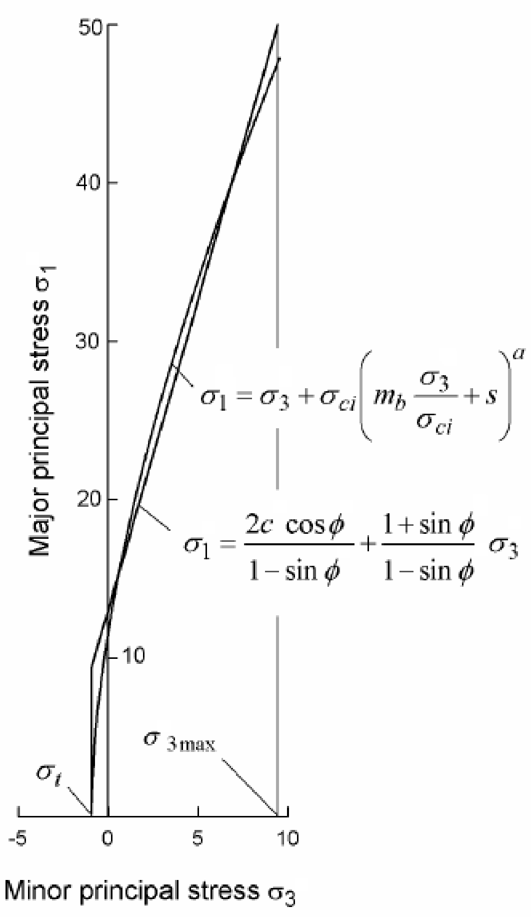
$$\phi = \sin^{-1}\left[\frac{6am_b(s+m_b\sigma_{3n})^{a-1}}{2(1+a)(2+a)+6am_b(s+m_b\sigma_{3n})^{a-1}}\right]$$

$$c = \frac{\sigma_{ci}\left[(1+2a)s+(1-a)m_b\sigma_{3n}\right](s+m_b\sigma_{3n})^{a-1}}{(1+a)(2+a)\sqrt{1+\left(6am_b(s+m_b\sigma_{3n})^{a-1}\right)/((1+a)(2+a))}}$$

where $\sigma_{3n} = \sigma_{3\max}/\sigma_{ci}$

This co-relation is valid only for $\sigma_t < \sigma_3 < \sigma_{3max}$

Where σ_{3max} is maximum confinement Stress, beyond which this co-relation does not applies.



Hoek & Brown Criteria

Mohr & Coulomb Criteria

Rock Mass Properties

Compressive Strength of Rock Mass

$$\sigma_{cm} = \frac{2c\ \cos\phi}{1-\sin\phi}$$

$$\sigma_{cm} = \sigma_{ci} \cdot \frac{(m_b + 4s - a(m_b - 8s))(m_b/4 + s)^{a-1}}{2(1+a)(2+a)}$$

γ - Unit weight of rock
H - depth of tunnel below surface

Determination of σ_{3max} for Tunnels and Slopes

Tunnels

$$\frac{\sigma_{3\max}}{\sigma_{cm}} = 0.47\left(\frac{\sigma_{cm}}{\gamma H}\right)^{-0.94}$$

If Horizontal Stresses > Vertical stresses use horizontal stress instead of γH

Slopes

$$\frac{\sigma_{3\max}}{\sigma_{cm}} = 0.72\left(\frac{\sigma_{cm}}{\gamma H}\right)^{-0.91}$$

Input Parameters Required

Input parameters for determining Rock mass properties are the parameters which **we determine through geotechnical investigation** like

- **Intact Rock Uniaxial Compressive Strength** which we determine through UCS Tests
- **Modulus of elasticity** which is determined through same UCS tests
- **GSI Geological Strength Index** – Determined on the site, borehole data and also during excavation.
- **Overburden Cover** over Tunnel – Which we could determine engineering drawings.
- **Unit weight** of the intact rock through lab test.

(In the starting of the project, input parameters are determined through the Geotechnical Investigation, which is the very important stage to get all the rock & soil parameters, in-situ stresses of the area, Ground water levels).

Input Parameters – UCS & Rock Cover

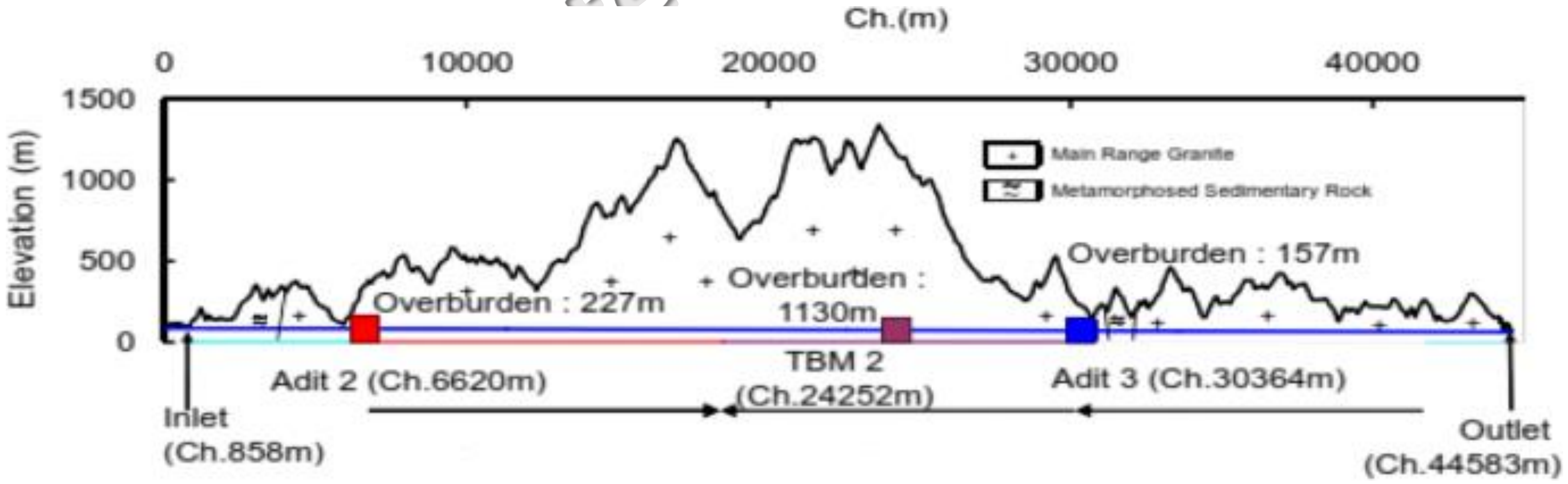
Uniaxial Compressive Strength

UCS is Uniaxial compressive Strength test where we determine the Intact rock uniaxial strength.

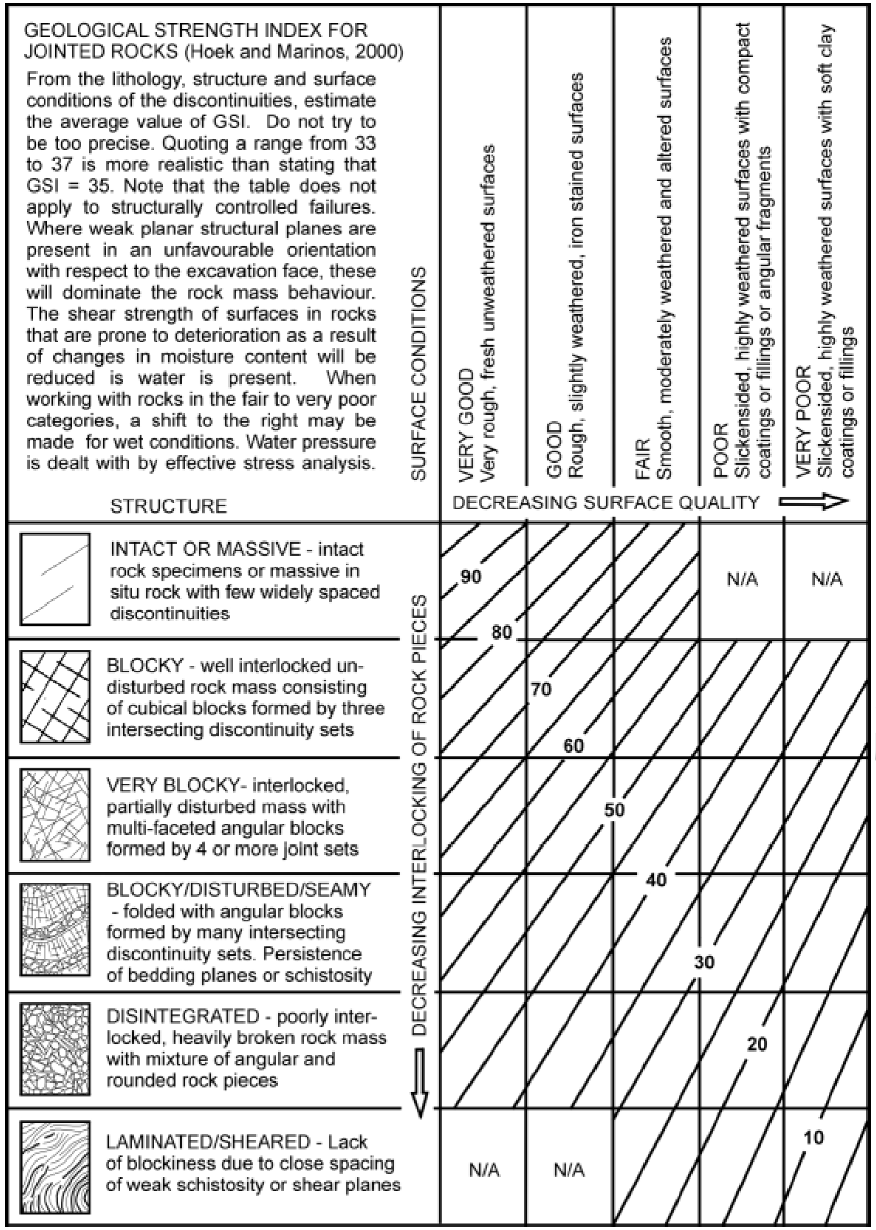
- **BS EN 1926 -** specifies a method for determining the uniaxial compressive strength of natural stones.
- **AS AS-4133-4.2.2** - Methods of testing rocks for engineering purposes - Rock strength tests - Determination of uniaxial compressive strength - Rock strength less than 50 Mpa
- **AS 4133.4.2.1-2007-** Methods of testing rocks for engineering purposes Rock strength tests - Determination of uniaxial compressive strength of 50 MPa and greater.

Rock Cover over the tunnel

This is the depth of rock over the tunnel crown as shown in the below Figure.



Input Parameter - GSI



GSI is the rock mass characterization through visual inspection and comparing the data through this chart and determine the value of GSI.

Determining GSI is not in the scope of this presentation. It is more for geologist who are more expert of geological field.

Input Parameter – mi for Intact Rock

Rock type	Class	Group	Texture			
			Coarse	Medium	Fine	Very fine
SEDIMENTARY	Clastic		Conglomerates* (21 ± 3) Breccias (19 ± 5)	Sandstones 17 ± 4	Siltstones 7 ± 2 Greywackes (18 ± 3)	Claystones 4 ± 2 Shales (6 ± 2) Marls (7 ± 2)
	Non-Clastic	Carbonates	Crystalline Limestone (12 ± 3)	Sparitic Limestones (10 ± 2)	Micritic Limestones (9 ± 2)	Dolomites (9 ± 3)
		Evaporites		Gypsum 8 ± 2	Anhydrite 12 ± 2	
		Organic				Chalk 7 ± 2
METAMORPHIC	Non Foliated		Marble 9 ± 3	Hornfels (19 ± 4) Metasandstone (19 ± 3)	Quartzites 20 ± 3	
	Slightly foliated		Migmatite (29 ± 3)	Amphibolites 26 ± 6		
	Foliated**		Gneiss 28 ± 5	Schists 12 ± 3	Phyllites (7 ± 3)	Slates 7 ± 4
IGNEOUS	Plutonic	Light	Granite 32 ± 3 Diorite 25 ± 5 Granodiorite (29 ± 3)			
		Dark	Gabbro 27 ± 3 Norite 20 ± 5	Dolerite (16 ± 5)		
	Hypabyssal		Porphyries (20 ± 5)		Diabase (15 ± 5)	Peridotite (25 ± 5)
	Volcanic	Lava		Rhyolite (25 ± 5) Andesite 25 ± 5	Dacite (25 ± 3) Basalt (25 ± 5)	Obsidian (19 ± 3)
		Pyroclastic	Agglomerate (19 ± 3) Breccia (19 ± 5)		Tuff (13 ± 5)	

* Conglomerates and breccias may present a wide range of m_i values depending on the nature of the cementing material and the degree of cementation, so they may range from values similar to sandstone to values used for fine grained sediments.
* *These values are for intact rock specimens tested normal to bedding or foliation. The value of m_i will be significantly different if failure occurs along a weakness plane.

Constant mi is for Intact rock, can be determine from the given rock type, Class of rock, group and texture of the rock present in the area of project.

Otherwise, mi also determined through Triaxial testing of Intact rock sample. (not included in this presentation)

Input Parameter – Disturbance Factor

Table 1: Guidelines for estimating disturbance factor *D*

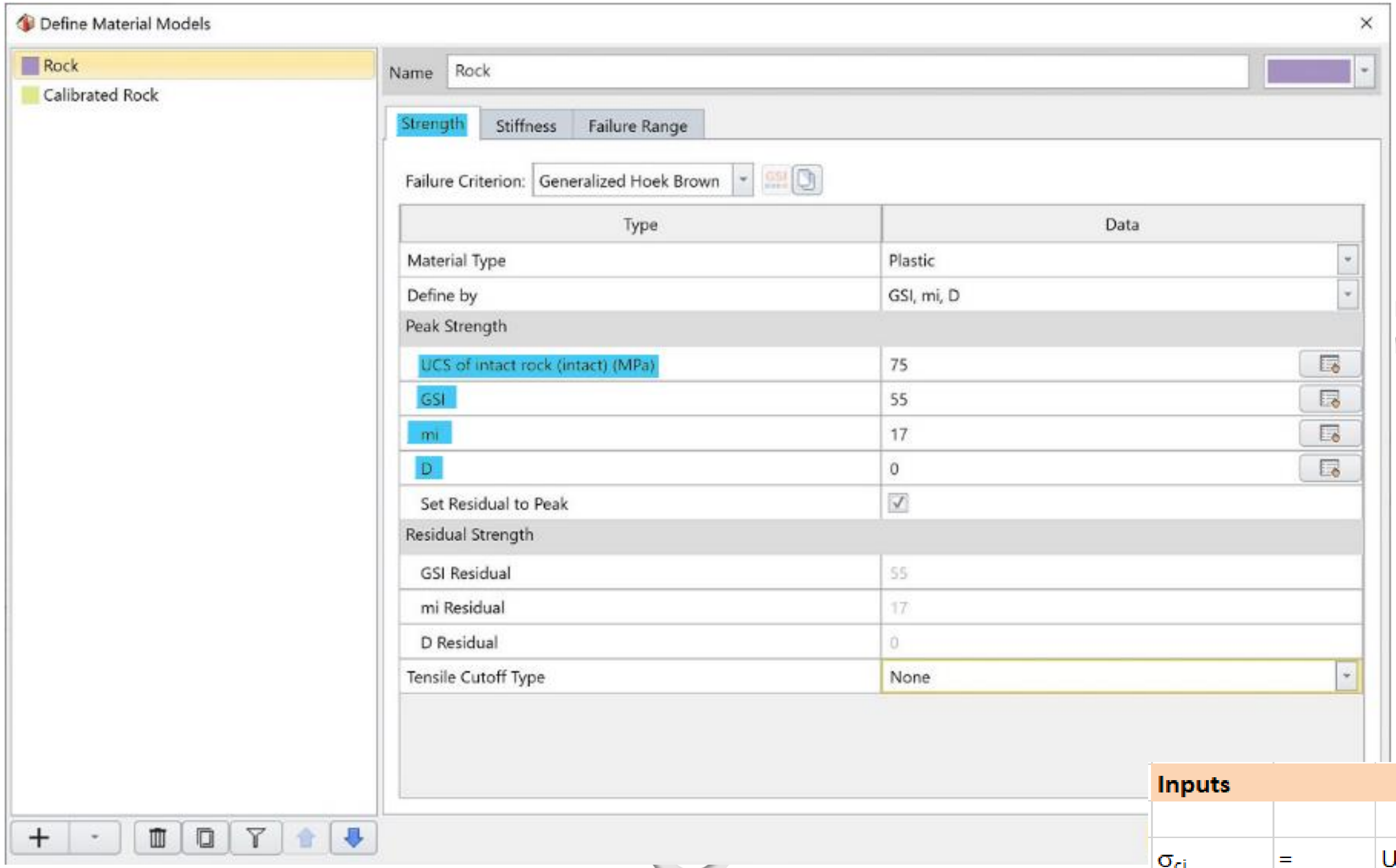
Appearance of rock mass	Description of rock mass	Suggested value of *D*
	Excellent quality controlled blasting or excavation by Tunnel Boring Machine results in minimal disturbance to the confined rock mass surrounding a tunnel.	$D = 0$
	Mechanical or hand excavation in poor quality rock masses (no blasting) 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.	$D = 0.8$
	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 depends on the disturbance of rock mass while blasting as shown in the Figure.

D-Disturbance Factor is used for determining **mb** and **s** for equation 2 and 3, respectively.
Where :

m_b is the reduced Value material constant mi
s is constant which depends upon the rock mass characteristics

Comparison of RocData Vs GDs Design Sheet



Here I will provide the comparison between Rocscience software Rocdata and GDs Excel Sheet for determining Rock mass properties.

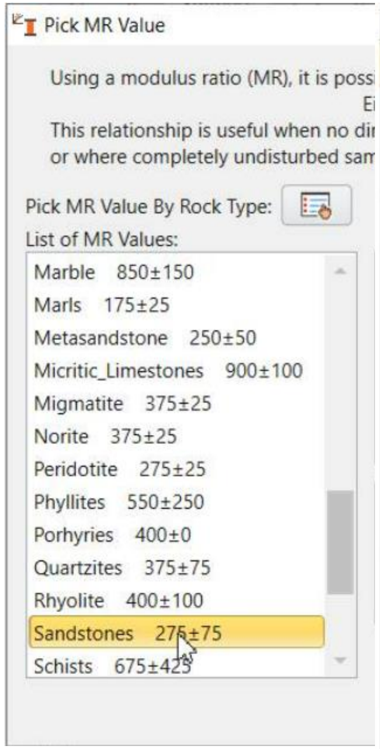
Both will give the same results as the same equations has been used.

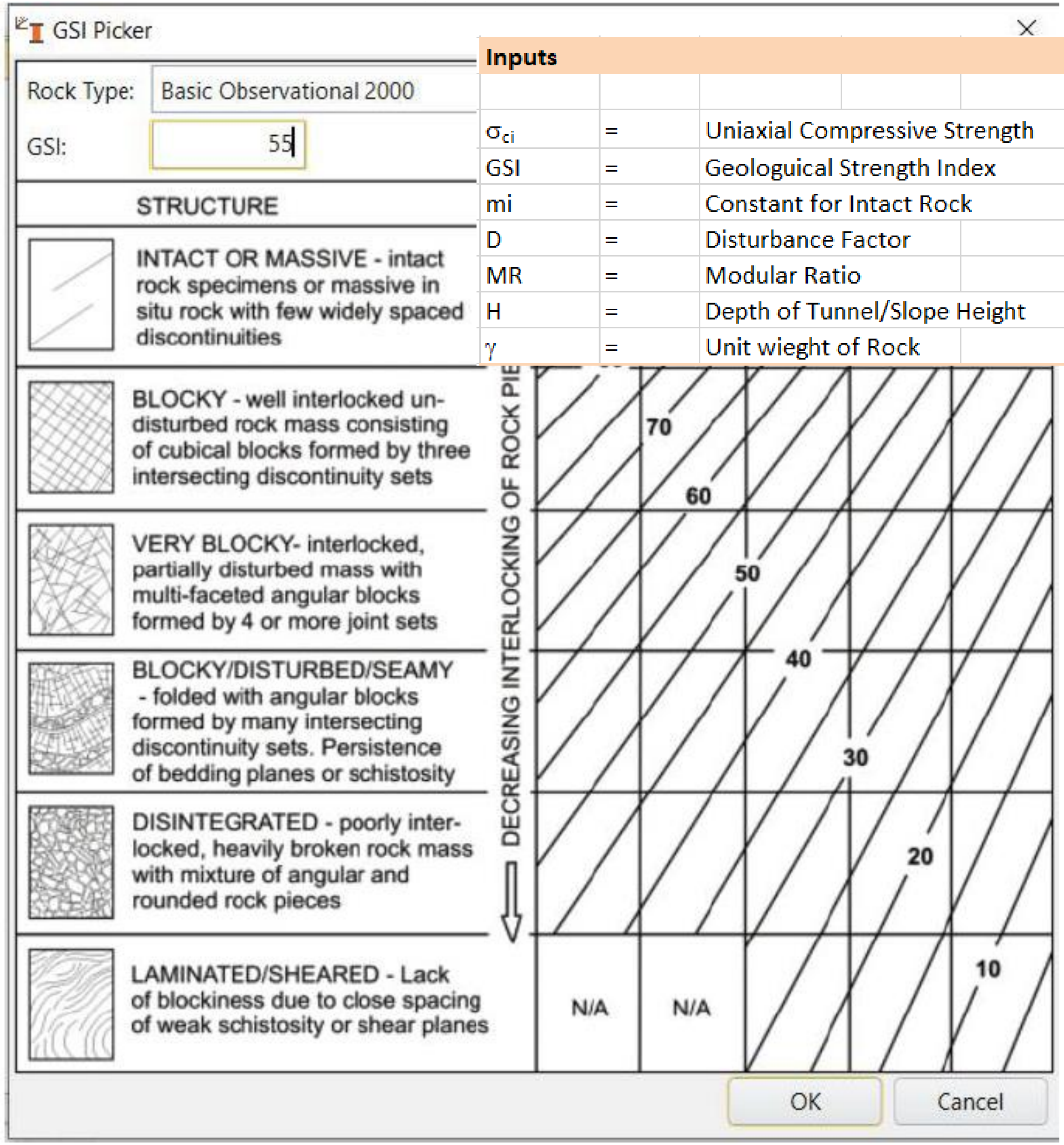
Inputs

σ_{ci}	=	Uniaxial Compressive Strength	=	75	Mpa
GSI	=	Geologuical Strength Index	=	55	
mi	=	Constant for Intact Rock	=	17	
D	=	Disturbance Factor	=	0	
MR	=	Modular Ratio	=	275	
H	=	Depth of Tunnel/Slope Height	=	100	m
γ	=	Unit wieght of Rock	=	0.027	KN/m3

RocData Comparison Example - https://www.rocscience.com/help/rsdata/tutorials/rock-strength-tutorials/hoek-brown-strength-envelope-for-a-tunnel-in-undisturbed-rock-d-0

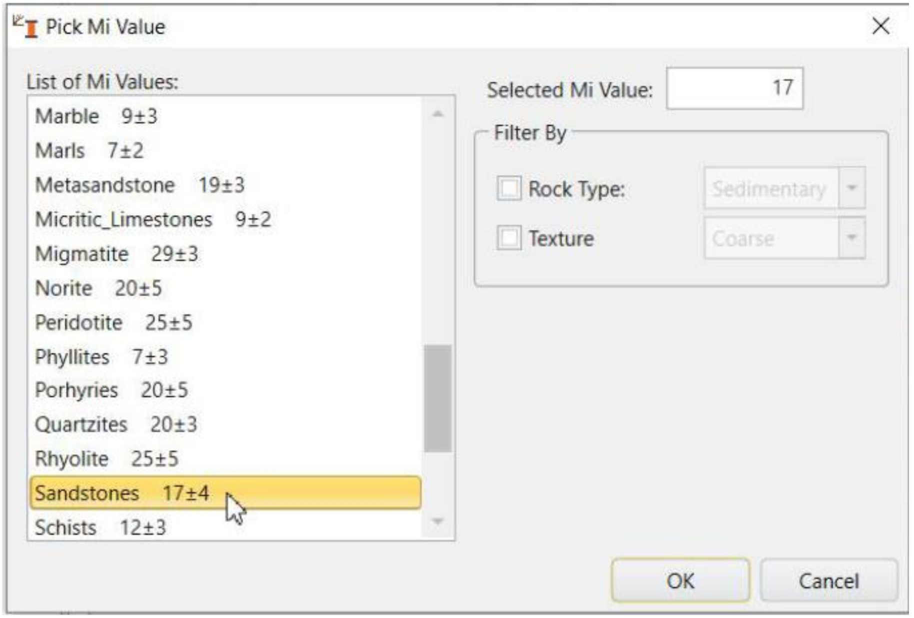
Comparison of RocData Vs GDs Design Sheet





Inputs

σ_{ci}	=	Uniaxial Compressive Strength	=	75	Mpa
GSI	=	Geoloeuical Strength Index	=	55	
mi	=	Constant for Intact Rock	=	17	
D	=	Disturbance Factor	=	0	
MR	=	Modular Ratio	=	275	
H	=	Depth of Tunnel/Slope Height	=	100	m
γ	=	Unit wieght of Rock	=	0.027	KN/m3



Result from RocData Vs GDs Design Sheet

Rock	
Hoek Brown Classification	
UCS of intact rock (MPa)	75
GSI	55
mi	17
disturbance factor	0
Intact Modulus (MPa)	20625
Hoek Brown Criterion	
mb	3.408
s	0.00674
a	0.504
Rock Mass Parameters	
tensile strength (MPa)	-0.148
uniaxial compressive strength (MPa)	6.033
global strength (MPa)	18.73
modulus of deformation (MPa)	8420.787
Failure Range Envelope	
application	Tunnels
sig3max (MPa)	1.425
Mohr Coulomb Fit	
cohesion (MPa)	1.008
friction angle (°)	56.621

Results				
Rock Mass Properties				
mb	=	Hoek's Constant	3.408	
s	=	Hoek's Constant	0.00674	
a	=	Hoek's Constant	0.504	
Ei	=	Modulus of elasticity of intact rock	20625	MPa
Ed	=	Modulus of Deformation	8420.8	Mpa
σ_c	=	UCS of Rockmass	6.033	MPa
σ_t	=	Tensile strength of the rock mass	-0.1483	MPa
σ_{cm}	=	Global Rock Mass Strength	18.73	MPa
σ'_{3max}	=	Maximum horizontal Stress	1.425	MPa
ϕ	=	Friction Angle of Rockmass	56.62	°
c'				

Results				
Rock Mass Properties				
mb	=	Hoek's Constant	3.408	
s	=	Hoek's Constant	0.00674	
a	=	Hoek's Constant	0.504	
Ei	=	Modulus of elasticity of intact rock	20625	MPa
Ed	=	Modulus of Deformation	8420.79	Mpa
σ_c	=	UCS of Rockmass	6.033	MPa
σ_t	=	Tensile strength of the rock mass	-0.1483	MPa
σ_{cm}	=	Global Rock Mass Strength	18.73	MPa
σ'_{3max}	=	Maximum horizontal Stress	1.425	MPa
ϕ	=	Friction Angle of Rockmass	56.62	°
c'	=	Cohesion of Rockmass	1.008	Mpa

Both R … o not
have R … ck
mass F

Thank You