Classifications of various materials and features

Table 1: Suggested classification of rockmass strength (from Palmström, 1995)

CHARACTERIZATION		Rockmass compr. strength (approx.. RMi value)
Term related to rock mass strength	Term for RMi	(MPa)
Extremely weak	Extremely low	< 0.001
Very weak	Very low	0.001 - 0.01
Weak	Low	0.01 - 0.1
Moderately strong	Moderately high	0.1 - 1
Strong	High	1 - 10
Very strong	Very high	10 - 100
Extremely strong	Extremely high	> 100

Table 2: Main types of coating and filling materials in joints and seams

FILLING MATERIALS IN JOINTS		PROPERTIES
FRICTIONAL MATERIALS	Calcite	May dissolve, particularly when being porous or flaky.
	Gypsum	May dissolve.
	Epidote, quartz	May cause healing or welding of the joint.
	Zeolite	May slake.
	Sandy or silty materials	Cohesionless, friction materials.
COHESIVE MATERIALS	Chlorite, talc, graphite	Very low friction materials, in particular when wet.
	Inactive clay materials	Weak, cohesion materials with low friction properties.
	Swelling clay	Exhibits a very low friction and loss of strength together with high swelling pressure.

Rock spalling/slabbing and rock burst

(from W.D. *Ortlepp* Rockbursts in tunnels */ Tunnelling and Underground Space Technology 16 (2001) 41 -48)*

The term 'rockburst' is widely used throughout the mining world and is well known to tunnellers in some countries particularly in Scandinavia. Unfortunately, it also has some wide range of meanings and there does not appear to be a broadly recognised definition of the term.

Definition (from South African hard rock mining): a rockburst is a 'seismic event' which causes violent and significant damage to a tunnel or the excavations of a mine. 'Seismic event' is understood to be an incident resulting from some failure or slip in the rockmass, which causes significant vibrations to radiate outward from the source to be felt as a distinct shock or severe tremor.

Table 3: Simplified classification of seismic event types (from Ortlepp, 2001)

Seismic event	Postulated source mechanism	First motion from seismic records	Richter magnitude M_L
Strain-burst	Superficial spalling with violent ejection of fragments	Usually undetected, could be implosive	-0.2 - 0
Buckling	Outward expulsion of large slabs pre-existing parallel to surface of opening	Implosive	0 - 1.5
Face crush/ pillar burst	Violent expulsion of rock from stope face or pillar sides	Mostly implosive, complex	1 - 2.5
Shear rupture	Violent propagation of shear fracture through intact rock mass	Double-couple shear	2.0 - 3.5
Fault-slip	Sudden, renewed movement on existing fault or dyke contact	Double-couple shear	2.5 - 5.0

Russenes (1974) has shown the relations between rock burst activity, tangential stress on in the tunnel surface and the point load strength of the rock (Figure 1).

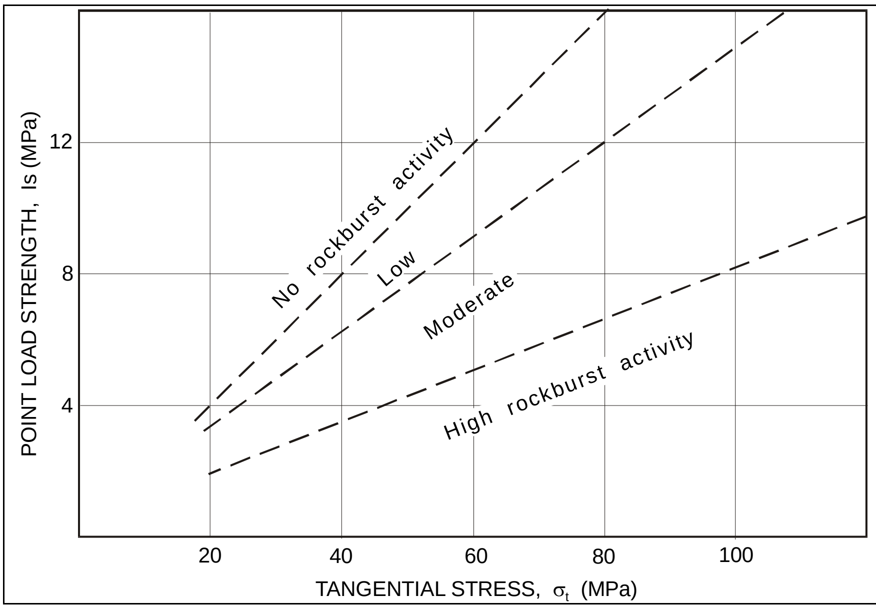

Figure 1:
The level of rock burst related to point load strength of the rock and the tangential stress ($\sigma_t = \sigma_\theta$) in the tunnel surface calculated from Kirsch's equations (from Russenes, 1974).

Table 4: Classification of slabbing and rock burst

σ_c/σ_θ	RMi / σ_θ	Stress mode (in massive rock)
> 4	2	Stable
4 - 2	2 - 1	Low rock slabbing/spalling activity
2 - 1	1 – 0.5	Moderate slabbing after few hour
< 1	< 0.5	High rock bursting activity (within few minutes)
In massive rock, RMi ≈ $0.5\sigma_c$		
σ_θ = tangential stress; σ_c = uniaxial strength; RMi = rock mass index		

Swelling minerals

Table 5: Classification of free swell and of swelling pressure as suggested by NBG, 1985

Parameter	Classification				Comment
	low or small	moderate	high	very high	
Free swell	< 100%	100 – 140%	140 – 200%	> 200%	Measured on dry powder < 20 μm
Swelling pressure	< 0.1 MPa	0.1 – 0.3 MPa	0.3 – 0.75 MPa	> 0.75 MPa	With 0.2 MPa pre-consolidation

Karstification

Suggested classification of the karstification (chemical solution of rock from water) of limestone and marble in underground excavations:

none	no visible signs of karst development along joints or fissures;
very small	mm sized opening(s) along fissures or joints from initial karst activity;
small	channels of cm size have been developed;
moderate	openings of dm thickness;
strong to very strong	development of large caves in the metre range.

Water inflow to underground excavations

Suggested classification of the inflow of water into underground excavations:

seepage	inflow volumes < dm^3/day;
dripping	inflow volumes of dm^3/day to m^3/hour;
flowing	inflow volumes of m^3/hour to several m^3/min;
water in-burst	inflow volumes of several m^3/s.

Orientation of joints related to the axis of the tunnel or cavern

Table 6: Classification of the effect of joints, according to Bieniawski, 1984

Strike perpendicular to tunnel axis			
Drive with dip		Drive against dip	
Dip 45° – 90°	Dip 20° – 45°	Dip 45° – 90°	Dip 20° – 45°
Very favourable	**Favourable**	**Fair**	**Unfavourable**

Strike parallel to tunnel axis	
Dip 20° – 45°	Dip 45° – 90°
Fair	**Very unfavourable**

Irrespective of strike
Dip 0° – 20°
Fair

Table 7: Classification of the effect of joints in roof and walls, as suggested by Palmström, 2014

<table>
<tr><th rowspan="2">TERM</th><th colspan="2">In one WALL</th><th colspan="2">In opposite WALL</th><th colspan="2">In ROOF</th></tr>
<tr><th>strike (°)</th><th>dip (°)</th><th>strike (°)</th><th>dip (°)</th><th>strike</th><th>dip (°)</th></tr>
<tr><td>Very favourable</td><td>> 70</td><td>all</td><td>> 70</td><td>all</td><td rowspan="6">all strikes</td><td>> 60</td></tr>
<tr><td>Favourable</td><td rowspan="2">< 20</td><td>< 20</td><td rowspan="2">< 20</td><td>< 20</td><td>45 - 60</td></tr>
<tr><td rowspan="2">Fair</td><td>20 - 45</td><td>≤60</td><td rowspan="2">30 - 45</td></tr>
<tr><td rowspan="2">20 - 70</td><td>< 45</td><td>20 - 70</td><td>all</td></tr>
<tr><td>Unfavourable</td><td rowspan="2">45 - 90</td><td>< 20</td><td>> 60</td><td>15 - 30</td></tr>
<tr><td>Very unfavourable</td><td>< 20</td><td>-</td><td>-</td><td>< 15</td></tr>
</table>

References

Russenes B.F. (1974): Analysis of rock spalling for tunnels in steep valley sides (in Norwegian). M.Sc. thesis, Norwegian Institute of Technology, Dept. of Geology, 247 p.

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Palmström A., 2014, in the spreadsheet 'Geo-calculations'.