THE RED POCKET BOOK

O-PITBLAST

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THE LATEST INNOVATION IN BLAST DESIGN

(EN) O-Pitblast assumes no responsibility for any physical injury or loss of material resulting from natural causes, follow-up procedures in the recommendations presented here or for any physical injury or loss of material resulting from forgetting any information here. The recommendations issued by O-Pitblast refer to the best practices identified based on scientific data.

CONTENT

GLOSSARY

Back break: broken rock and damage beyond the limits of the last row.

Bench: horizontal surface in an excavation or mining operation along which holes are drilled vertically.

Blast Area: area that is expected to be affected by flyrock, dust and toxic gases.

Blast: act of fragmenting and moving rock material using explosives.

Blasting vibration: seismic manifestation of the releasing of energy during the blast in the ground, atmosphere or underwater environments.

Booster: explosive charge used to initiate less sensitive explosive materials.

Burden theoretical: unit of measurement in meters that represents the distance between different rows of holes and from the first row to the free face.

Critical diameter: minimum diameter that allows the explosive to have a stable detonation.

Delay: timing difference, at the predetermined time intervals, in the initiation of individual explosive decks, boreholes, or rows of boreholes using delay detonators.

Explosive: chemical or set of chemicals that can react to produce an explosion or detonation.

Flyrock: undesired flying of rock and/or debris when blasting is executed.

Fragmentation: fragment size distribution of blasted rock material.

Free Face: exposed surface in the vicinity of a shothole where the rock is free to move under the force of the explosion.

Maximum Instantaneous Charge (MIC): mass of explosive that will be detonated in a defined time window, which is usually 8 milliseconds. Often used to ensure reduced damage.

Misfire: complete or partial failure of a blasting charge to detonate as planned during a mine blast. Usually caused by bad drilling control or bad control in the connecting process.

Overbreak: excessive breakage or damage beyond the desired excavation limit.

Powder factor: ratio between the explosive mass and the volume of rock to be blasted.

Pre-Split: controlled blasting technique in which charges are fired in holes on the perimeter of the excavation prior to the initiation of the rest of the blast in order to preserve the slope.

Relative Weight Strength (RWS): energy per mass of explosive relative to ANFO.

Spacing: distance between holes in the same row.

Stemming: superior portion of the hole, not loaded with explosives and ideally filled with inert material, intended to confine the charge.

Subdrilling: extra length of hole drilled below the target excavation level to achieve the desired floor grade.

Velocity of Detonation (VoD): speed at which the detonation front travels throught the explosive.

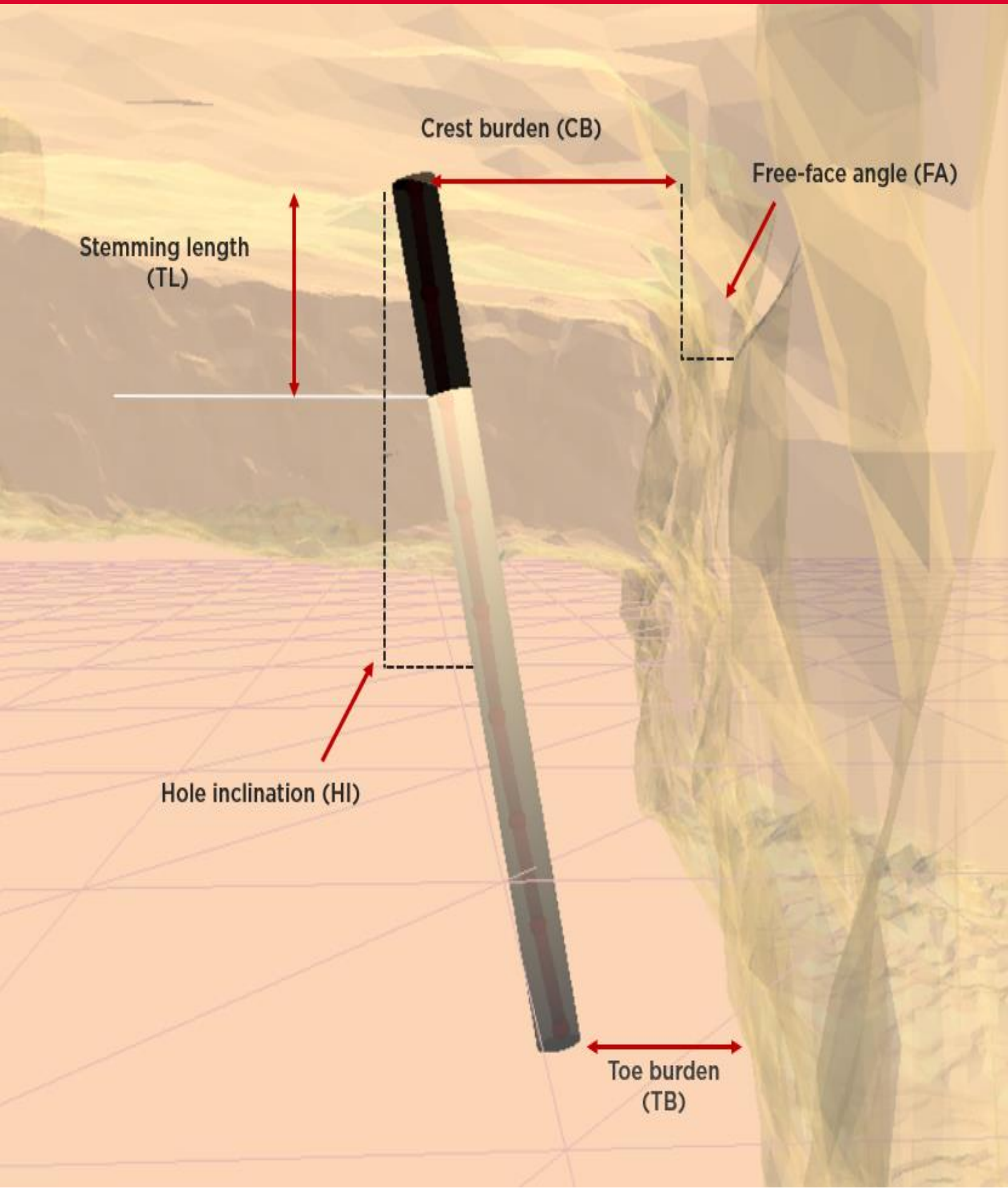
BLAST DESIGN - TERMINOLOGY

Charge column (C) =	L – T
Hole length (L) =	H + J
Blast volume (BV) =	B x S x H x N
Blast tons (BT) =	BV x Density of rock in g/cm^3
Volume of blasthole (VB) =	$\pi \times \frac{D^2}{4000} \times L$
Mass of explosive per hole (Kg) =	$\left(\pi \times \frac{D^2}{4000}\right) \times (L-T) \times \rho$
PF =	$\frac{TE}{BV}$
RWS =	$\frac{\text{AWS of explosive}}{\text{AWS of ANFO}} \times 100$
RBS =	$\frac{\text{RWS explosive} \times \rho}{\text{ANFO density}}$
Vertical length of angled hole =	Mensured length x cos ∝

Where:

∝ =	Angle subtended from vertical by the inclined hole (°)
AWS =	Absolute Weight Strength
B =	Burden (m)
BT =	Blast tons
BV =	Blast volume (m^3)
C =	Charge column (m)
D =	Hole diameter (mm)
H =	Bench height (m)
J =	Subdrilling (m)
L =	Hole length (m)
N =	Number of holes in a blast
PF =	Powder factor (kg/m^3)
RBS =	Relative bulk strength
S =	Spacing (m)
T =	Stemming (m)
TE =	Total explosives in the blast (kg)
π =	3.1416 (the ratio of the circumference of a circle to its diameter)
ρ =	Explosive density (g/cm^3)
RWS =	Relative Weight Strength

ANGULAR FACED HOLES



Crest burden (CB) =	Distance of blasthole collar from crest
Hole length (L) =	Measured stemming length x cos (HI)
Toe burden (TB) =	Burden at a floor level ([tan(FA) x H] + CB − [tan(HI) x H])

Where:

H = Bench height (m)

RULES OF THUMB

Empirical rules are used in the estimation of geometric parameters when optimum data is not available

Bench height maximum (m) or **Bench height minimum (m)**	= 0,12 x D = 0,06 x D
Burden (m)	= 25 to 40 x $\frac{D}{1000}$
Spacing (m)	= 1 to 1,15 x Burden
Subdrilling (m)	=0,3 to 0,5 x Burden
Stemming (m)	= 0,7 to 1 x Burden
Stiffness ratio = $\frac{\text{bench heigth}}{\text{burden}}$	: 2 to 3,5 good fragmentation : > 3,5 very good fragmentation
Stemming material size (mm)	= $\frac{D}{10}$ to $\frac{D}{25}$ (with minimum fines)

Where:

D = Diameter (mm)

POWDER FACTOR

Typical Powder Factor used in production blast

ROCK TYPE	UCS (MPa)	PF (kg/m3)
Very low strength	1 – 5	0,15 - 0,25
Low strength	5 – 25	0,25 - 0,35
Medium strength	25 – 30	0,4 - 0,5
High	50 – 100	0,7 - 0,8
Very strength	100 – 250	-
Extremely high strength	> 250	-

PRE-SPLIT AND SMOOTH BLASTING

PRE-SPLIT BLASTING

Uncharged length at top	= 10 x D
Burden (m)	= 0,5 x Production blast burden
Spacing (m)	= D x 12
Powder factor (kg/m^3)	= 0,5 Kg per square metre of face

It is recommended to fire all holes with the same delay, or in sets of 5 or more holes.

SMOOTH BLASTING

Burden (m)	= 1,25 x Spacing
Spacing (m)	= 15 x D (hard rock) = 20 x D (soft rock)

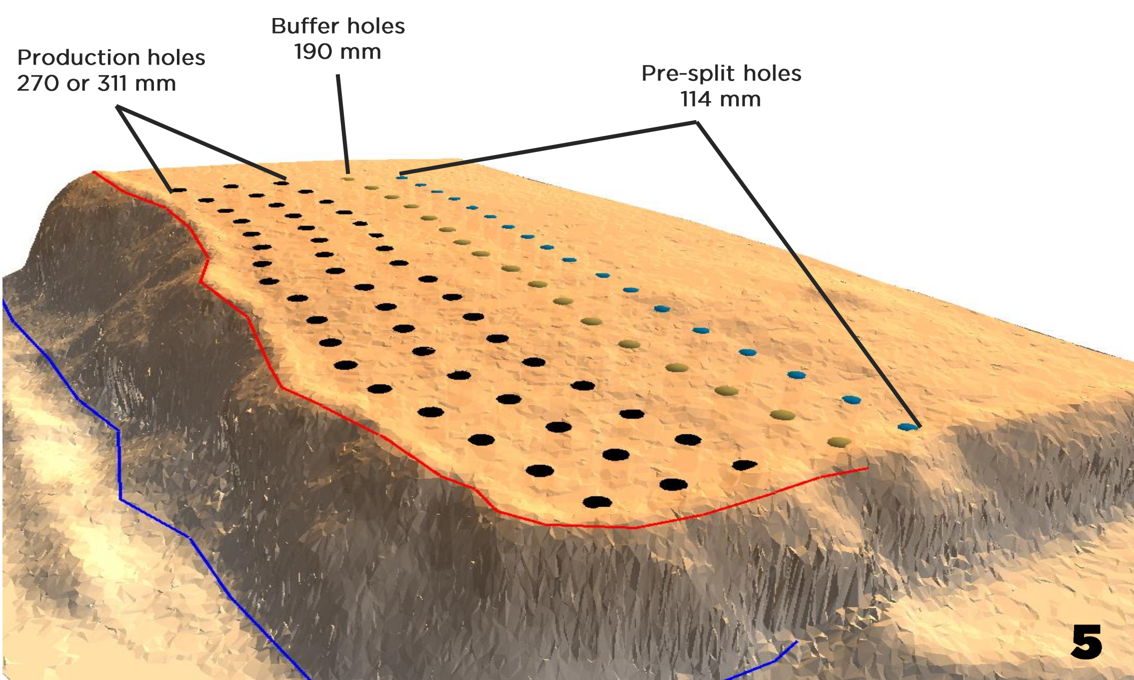
It is recommended to fire as many holes as possible with one delay.

Where:

D = Diameter (m)

Typical Powder Factor used in presplit and smooth blasting

ROCK TYPE	PF (kg/m3)
Soft rock	0,2 – 0,3
Medium rock	0,4 – 0,5
Hard rock	0,6 – 0,9



PERIMETER CONTROL

This technique is used to decrease overbreak and/or backbreak of blasts in open-pit. It normally uses charges in closely spaced holes. The formula used to evaluate the distance from center to the center of the cartridges for pre-splitting is shown below:

$$PF = \frac{L \times S}{0{,}5}$$

Where:

L = Hole length (m)

S = Spacing (m)

PF = Powder Factor

Please note that usually the required powder factor is between 0.3 and 0.6 Kg/m^2

$$D = \frac{L \times Lc}{B \times S \times PF}$$

Where:

D = Center-center distance between cartridges (mm)

Lc = Linear charge (kg/m)

B = Burden (m)

AIR BLAST

Airblasts are shock waves caused by the blast. The severity of the airblast depends on the explosive confinement, explosive mass and distance. The formula used to estimate this is shown below:

$$P = K \times \left(\frac{D}{Q^{1/3}}\right)^{-1,2}$$

Where:

P = Pressure (kPa)
K = State of confinement
Q = Maximum Instantaneous Charge (kg)
D = Blasting distance from the observation point (m)

STATE	TYPICAL VALUES FOR K
Fully confined	3,3
Unconfined	185

EXPECTED DAMAGE POST BLASTING	
	Kpa
Windows rattle	0,1
1% of windows break	0,7
Most windows break, plaster cracks	7

MINIMUM LEVELS QUOTED AS 2187.2 - 1993	
	Db (lin.)
Human Discomfort	120
Beginning of structural damage or historic buildings, where there are no specific limits	130

GROUND VIBRATIONS

The detonation of a confined explosive charge generates a considerable amount of energy to the ground. This, in turn, propagates as concentric shock waves from the blasthole, attenuating their intensities with the distance. These waves create the vibration phenomena. To calculate the maximum vibration generated on the ground to far field, the following formula is used:

$$PPV = K \times \left(\frac{D}{Q^{1/2}}\right)^{B}$$

Where:

PPV = Peak Particle Velocity (mm/s)
K = Fitting parameter influenced by the ground and blasting conditions
Q = Maximum Instantaneous Charge (kg)
D = Blasting distance from the observation point (m)
B = Fitting parameter that express how quickly the vibration attenuates with the distance (generally -1.6)

STATE	TYPICAL VALUES FOR K
Free face hard rock	500
Free face soft/medium rock	1140
Fully confined	5000
RECOMMENDED MAXIMUM PPV (AS 2187.2 - 1993)	
	mm/s
For high rises, hospitals, long floor spans, dams or historic buildings where no specified limit exists	5
Housing and low rise residential buildings (commercial buildings not included below)	10
Commercial and industrial buildings, structures of reinforced concrete or steel constructions	25
EXPECTED DAMAGE POST BLASTING	
	mm/s
Lower limit for damage to plaster walls	13
Lower limit for dry wall structures	19
Minor damage	70
> 50% chance of minor damage to structures	140
50% chance of major damage	190

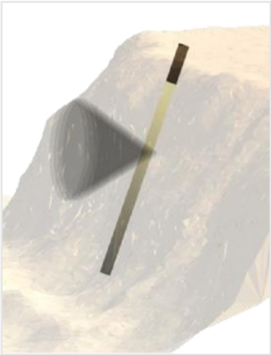
SAFETY DISTANCES

In blasting operations flyrock can occur due to the explosive column not being confined enough, resulting in energy loss.

The most common cases in which flyrock is generated are the result of three key mechanisms that occur because there is inadequate burden for the hole diameter or the face contains a zone of weak rock.

These mechanisms are shown below (Moore and Richards, 2005):

FACE BURST



CRATERING

RIFLING

Some equations can be used to help calculate the clearance distance design and to predict and establish which is the maximum flyrock throw during a blast. Each of the mechanisms and their respective equations are described below:

- **Face burst:** burden conditions usually control flyrock distances in front of the face.

$$L_{max} = \frac{k^2}{g} \times \left(\frac{\sqrt{m}}{B}\right)^{2.6}$$

- **Cratering:** if the stemming height to hole diameter ratio is too small or the collar rock is weak, it can be projected in any direction from a crater at the hole's collar.

$$L_{max} = \frac{k^2}{g} \times \left(\frac{\sqrt{m}}{JH}\right)^{2.6}$$

- **Rifling (Stemming Ejection):** if the stemming length is adequate to prevent cratering, flyrock at a high trajectory can result from riling - the ejection of stemming material and loose rocks from the collar if there is insufficient stemming height or inapropprieate material is used.

$$L_{max} = \frac{k^2}{g} \times \left(\frac{\sqrt{m}}{JH}\right)^{2.6} \sin 2\theta$$

Where:

θ = Drillhole angle
L = Maximum throw (m)
M = Charge mass/m (kg/m)
B = Burden (m)
JH = Stemming height (m)
g = Gravitational constant

ROCK TYPE	TYPICAL VALUES FOR K
Soft rock	13.5
Medium rock	20.3
Hard rock	27.0

Clearance distance for equipment = $2 \times l_{max}$
Clearance distance for personnel = $4 \times l_{max}$

FRAGMENTATION PREDICTION

To predict the degree of fragmentation prior to a blast, an empirical model was proposed by Cunningham – The Kuz-Ram model is one of the most used prediction tools in rock fragmentation prediction due to its easy parametrization. This model is based in three main equations:

The Kuznetsov Equation (Equation 1), presented by Kuznetsov, determines the blast fragments' mean particle size based on explosives quantities, blasted volumes, explosive strength and a Rock Factor.

$$X_m = A \times K^{-0.8} \times Q^{\frac{1}{6}} \times \left(\frac{115}{RWS}\right)^{\frac{19}{30}} \qquad \text{(Eq. 1)}$$

Where:

X_m or X_{50} =	Mean size of fragments (cm)
A =	Rock factor
Q =	Quantity of explosive per hole (kg)
115 =	Relative Weight Strength (RWS) of TNT compared to ANFO
RWS =	Relative Weight Strength of the used explosive compared to ANFO

The Rosin-Rammler Equation (Equation 2), represents the size distribution of the fragmented rock. It does a very good job of characterizing natural rock breakage in a particle size distribution between 10 and 1000 mm.

$$R(x) = 100 \times [1 - e^{\left(-0.693 \times \left(\frac{X}{X_m}\right)^{n}\right)}] \qquad \text{(Eq. 2)}$$

Where:

R(x) =	Fraction of mass passed on a screen opening of size "X" (%)
X =	Mesh size correspondent to a screen opening (mm)
X_m or X_{50} =	The median or the size for 50% cumulative passing fragments
n =	Uniformity Index

The Uniformity Index Equation (Equation 3), determines a constant that represents the uniformity of blasted fragments based on the design parameters.

$$n = \left[2{,}2 - 14 \times \left(\frac{B}{D}\right)\right] \times \left[\frac{1 + \frac{S}{B}}{2}\right]^{0.5} \times \left(1 - \frac{W}{B}\right) \times \left(\frac{|L_B - L_C|}{L} + 0{,}1\right)^{0{,}1} \times \frac{L}{H} \qquad \text{(Eq. 3)}$$

Where:

n =	Uniformity Index		
B =	Burden (m)	**LB =**	Bottom charge length (m)
S =	Spacing (m)	**LC =**	Column charge length (m)
D =	Drill diameter (mm)	**L =**	Charge Length (m)
W =	Standard deviation of drilling precision (m)	**H =**	Bench height (m)

LOADING DENSITY

Kg OF EXPLOSIVE PER METER OF COLUMN FOR GIVEN DENSITY (g/cm3) ►

◄HOLE DIAMETER

mm	pol	0,80	0,85	0,90	0,95	1,00	1,05	1,10	1,15	1,20	1,25	1,30	1,35	1,40
38	1 ½	0,91	0,97	1,03	1 018	1,14	1,20	1,25	1,31	1,37	1,43	1,48	1,54	1,60
44	1 ¾	1,24	1,32	1,40	1,47	1,55	1,63	1,71	1,78	1,86	1,94	2,02	2,09	2,17
51	2	1,62	1,72	1,82	1,93	2,03	2,13	2,23	2,33	2,43	2,53	2,63	2,74	2,84
57	2 ¼	2,05	2,18	2,31	2,44	2,57	2,69	2,82	2,95	3,08	3,21	3,33	3,46	3,59
64	2 ½	2,53	2,69	2,85	3,01	3,17	3,33	3,48	3,64	3,80	3,96	4,12	4,28	4,43
70	2 ¾	3,07	3,26	3,45	3,64	3,83	4,02	4,22	4,41	4,60	4,79	4,98	5,17	5,36
76	3	3,65	3,88	4,10	4,33	4,56	4,79	5,02	5,24	5,47	5,70	5,93	6,16	6,38
83	3 ¼	4,28	4,55	4,82	5,08	5,35	5,62	5,89	6,15	6,42	6,69	6,96	7,23	7,49
89	3 ½	4,97	5,28	5,56	5,90	6,21	6,52	6,83	7,14	7,45	7,76	8,07	8,38	8,69
102	4	6,49	6,89	7,30	7,70	8,11	8,51	8,92	9,32	9,73	10,13	10,54	10,94	11,35
114	4 ½	8,21	8,72	9,23	9,75	10,26	10,77	11,29	11,80	12,31	12,83	13,34	13,85	14,37
127	5	10,13	10,77	11,40	12,03	12,67	13,30	13,93	14,57	15,20	15,83	16,47	17,10	17,73
140	5 ½	12,26	13,03	13,80	14,56	15,33	16,09	16,86	17,63	18,39	19,16	19,93	20,69	21,46
152	6	14,59	15,51	16,42	17,33	18,24	19,15	20,07	20,98	21,89	22,80	23,71	24,63	25,54
165	6 ½	17,13	18,20	19,27	20,34	21,41	22,48	23,55	24,62	25,69	26,76	27,83	28,90	29,97
229	9	32,83	34,89	36,94	38,99	41,04	43,10	45,15	47,20	49,25	51,30	53,36	55,41	57,46
251	9 ½	39,53	42,00	44,47	46,94	49,41	51,88	54,35	56,82	59,29	61,76	64,24	66,71	69,18
254	10	40,54	43,07	45,60	48,14	50,67	53,20	55,74	58,27	60,80	63,34	65,87	68,41	70,94
279	11	49,05	52,11	55,18	58,25	61,31	64,38	67,44	70,51	73,57	76,64	79,71	82,77	85,84
305	12	58,37	62,02	65,67	69,32	72,97	76,61	80,26	83,91	87,56	91,21	94,86	98,50	102,15
311	12 ¼	60,83	64,63	68,43	72,24	76,04	79,84	83,64	87,44	91,25	95,05	98,85	102,65	106,45
330	13	68,50	72,78	77,07	81,35	85,63	89,91	94,19	98,47	102,76	107,04	111,32	115,60	119,88
349	13 ¾	76,64	81,43	86,22	91,01	95,80	100,59	105,38	110,17	114,96	119,75	124,54	129,33	134,12

Being:

For non-gassed products only

$$\text{Kg of Explosive per meter} = \frac{\pi \text{ x } D^2}{4000} \text{ x } \rho$$

Where:

D = Diameter (mm)

ρ = Explosive Density (g/cm^3)

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CONVERSION TABLE

THIS UNIT ►	X BY THIS VALUE ►	CONVERTS TO
Energy		
Joule	0.24	calorie
	0.74	ft-lb
Calorie	3.09	ft-lb
Kilowatt	1.34	horsepower
Volume		
Cubic centimetres (cm^3 or cc)	0.06	in^3
Cubic metres (m^3)	1.31	yd^3
Cubic feet (ft^3)	0.03	m^3
US gallon	3.79	Litres (l)
Ounces (US fluid)	29.57	cm^3
Length		
Metres (m)	3.280	Feet (ft)
	38.370	Inches (in)
Inches (in)	25.400	Milimetres (mm)
Kilometres (km)	0.621	Miles
Mass		
Kilogram (kg)	2.20	lb
Metric ton (t)	1.10	short tons
Ounce Avoirdupois (oz)	28.35	grams (g)
Ounce troy (oz)	31.10	grams (g)
Grains	0.06	grams (g)
CONVERTS TO ►	**÷ BY THIS VALUE ►**	**THIS UNIT**

THIS UNIT ►	X BY THIS VALUE ►	CONVERTS TO
Pressure		
psi	6.89	kPa
atmosphere (atm)	14.70	psi
bar	14.50	psi
bar	100	kPa
Density		
lbs/ft^3	16.02	kg/m^3
gm/cm^3	62.43	lbs/ft^3
Powder Factor		
kg/m^3	1.69	lb/yd^3
Area		
cm^2	0.16	in^2
m^2	1550.00	in^2
ft^2	0.09	m^2
Temperature		
ºF – 32	0.56	Centigrade
ºC + 17.78	1.8	Fahrenheit
Speed		
m/s	3.28	ft/s
in/s	25.4	mm/s
km/h	0.62	miles/h
CONVERTS TO ►	**÷ BY THIS VALUE ►**	**THIS UNIT**

PROPERTIES OF ROCK MASSES

ROCK MASSES / PROPERTIES	ρ	UCS	E	ν
Basalt	3.00	78 - 412	20 - 100	0.14 - 0.25
Bauxite	2.05			
Clay - dense, wet	1.70			
Coal, Anthracite	1.60	8 - 50		
Coal, Bituminous	1.36			
Dolerite	2.80	290 - 500		
Dolomite	2.96	15 - 118	20 - 84	0.1 - 0.2
Earth, moist	1.80			
Gneiss	2.88	78 - 240	25 - 60	0.1 - 0.19
Granite	2,72	100 - 275	25 - 70	0.15 - 0.34
Gypsum	2.80			
Iron ore	4.89			
Limestone	2.64	10 - 245	10-80	0.1 - 0.23
Limonite	3.76			
Magnetite	5.05			
Marble	2.48	50 - 200	60 - 90	0.2 - 0.35
Mica-Schist	2.70			
Porphory	2.56			
Quartzite	2.50	85 - 350	26 - 100	0.15 - 0.20
Sandstone	2.40	50 - 160	5 - 86	0.1 - 0.3
Shale	2.58	20 - 150	8 - 30	0.1 - 0.3
Silica Sand	2.56			
Siltstone	2.25			
Slate	2.72	98 - 196	30 - 90	0.1 - 0.44
Talc	2.64			

Where:

ρ = Rock Density (g/cm^3)

UCS = Unconfined Compressive Strength (MPa)

E = Young´s Modulus (GPa)

ν = Poisson´s Ration

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