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Concept of Blastability – An Update

Kaushik Dey & Phalguni Sen
Dept. of Mining Engg. Indian School of Mines, Dhanbad – 826 004, India E-mail: kausdey@yahoo.co.uk

Abstract

The main objective of fragmentation by blasting is to achieve the optimum powder factor, which may be defined as the powder factor required for the optimum fragmentation, throw, ground vibration, etc. for a specified blast condition to minimize the overall mining cost. Presently, the powder factor is established through the trial blasts. However, powder factor may be approximated using rock, design and explosive parameters. The term blastability is used to indicate the susceptibility of the rock mass to blasting and is closely related with the powder factor. This paper presents a review of some of the important studies made on blastability and powder factor determination using rock and design parameters.

1. Introduction: -

Rockmass comprises several different rock types and is affected by different degrees of fracturing in varying stress condition. A number of rockmass classification or rating have been developed for Geo-technical purposes like Rock Quality Designation (RQD; Deere et al 1963), Q-Index (NGIQ; Barton et al 1974), Rock Mass Rating (RMR; Bieniawski et al 1974), etc. In the context of drilling and blasting, these rockmass classifications are mainly useful for assessing the drilling affectivity, but are not of very much use in defining the blastability of the rock and rockmass. Blastability can be defined as the blasting characteristics of the rockmass subjected to a specified blast design, explosive characteristics and specified legislative constraints depending on the site specifics. In other words, blastability indicates how easy to blast a rockmass under a specified condition. To determine the blastability several approaches have been made by different researchers and a review of the same has been aimed at in this paper.

2. Blastability - Different Approaches: -

Several approaches have been used for estimating blastability. While some researchers tried to correlate it with the data available from laboratory and field testing of rock parameters, some others have related it with rock and blast design parameters, and yet some others have tried to estimate blastability through approaches based on the drilling rates and/or blast performances in the field. The latest improvements in computer methods have also opened up new vistas to the researchers to use various artificial intelligence algorithms for determination of blastability.

2.1 Hino (1959): - Hino proposed that blastability (named as Blasting Coefficient (BC) by him) is the ratio of compressive strength (CS) to tensile strength (TS) of rockmass, which may be given as follows.

$$BC = CS / TS$$

In case of blasting in presence of a free face in the vicinity, compressive stress waves travel from the blast hole towards the free face and reflected back as tensile stress waves. When the tensile stress exceeds tensile strength of rock, rock fractures in tension and this fracturing (or slabbing) process of rock continues till the residual compressive stress becomes too weak. The extent of tensile fractures and the number of slabs so produced depends on the tensile strength of rock (σ_t), and amplitude (σ_a) and length (L) of compressive wave. It has been found by him that the number of slabs (n) produced by tensile slabbing due to reflected shock waves may be given by

$$n \leq \sigma_a/\sigma_t \quad \text{or} \quad n \leq L/2t \qquad \text{Where, t = thickness of slab}$$

Hino also found that a linear relationship exists between the compressive strength of rock (σ_c) and the amplitude of the compressive stress wave (σ_a) propagated through the rock, which implies that $\sigma_a \propto \sigma_c$ and hence, $n \propto \sigma_c/\sigma_t$

He named $(\sigma_c) / (\sigma_t)$ as blasting coefficient.

2.2 Langefors (1978): - Langefors proposed a factor to represent the influence of rock and defined it by C_0, when it refers to a limit charge (zero throw condition). C indicates the value of the factor including a technical margin for satisfactory breakage, and is given by $C=1.2 \times C_0$. C_0 has a value of 0.17kg/m^3 for crystalline granite (found from a number of trial blasts in brittle crystalline granite) and has value between 0.18 to 0.35 kg/m^3 for other rocks. For blast designs, C = 0.4 kg/m^3 is considered directly and with the incorporation of desired tendency for breakage and throw based on geological and design parameters alteration in powder factor is required. This alteration factor may be regarded as geometric or fixation factor. Fraenkel (1954) proposed that "for practical use the blastability of rock, C (kg/m^3), can be determined by test blasting with one single vertical hole with 33mm bottom diameter, hole depth 1.33m and with that charge which is needed to give a 1m high vertical bench and 1m burden a breakage and throw of maximum 1m". Larson (1974) proposed that normally rock constant value (0.4 kg/m^3) might vary upto ± 25%.

2.3 Borquez (1981): - Borquez determined blastability factor (K_v) from the Pierce equation for calculation of burden using RQD Index, corrected by a coefficient of alteration. This coefficient of alteration has taken into account the joint strength as a function of their tightness and type of filling. Table-1 gives the alteration factor with respect to joint strength. Figure-1 shows the Borquez blastability factor with respect to Equivalent Rock Quality Designation (ERQD).

Table-1: Alteration factor

Joint Strength	Alteration Factor
Strong	1.0
Medium	0.9
Weak	0.8
Very Weak	0.7

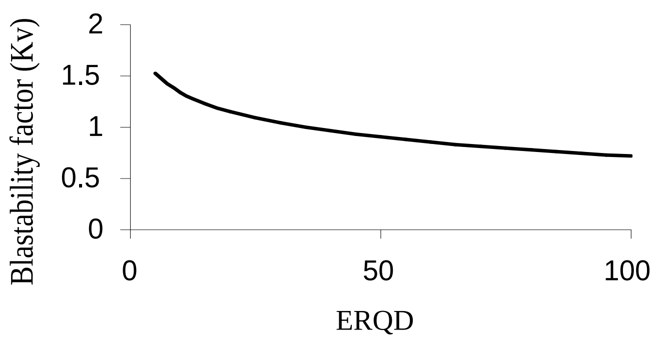

Figure-1: Borquez Blastability Factor

Where, $K_V = a + b \times \ln(ERQD)$,

ERQD = RQD × alteration factor

a & b are constant

2. 4 Fraenkel (1954): - Fraenkel proposed the following empirical relationship between the height and diameter of the charge, hole depth, maximum burden and blastability.

$$S = \frac{(50 \times V_{max})}{h^{0.3} \times H^{0.3} \times d^{0.8}} = \frac{(50 \times V_{max})}{Q^{0.3} \times H^{0.3} \times d^{0.2}}$$

Where,

S = Blastability V_{max} = Maximum Burden (m) H = Depth of hole (m)

h = Charge height (m) d = Charge diameter (mm)

Q (charge in g) can be used to replace h as h × d^2 = Q (charge in g) when degree of packing (P) = 1.27 g/cm^3.

2. 5 Hansen (1968): -

Hansen suggested the following equation to estimate the quantity of explosive required for optimum fragmentation at Marrow Point Dam and Power Plant Project.

$$Q = B^2 \left\{ 0.0236 \times \left(\frac{h}{B} + 1.5 \right) + 0.1984 \times C \times \left(\frac{h}{B} + 1.5 \right) \right\}$$

Where,

Q = total charge in a single hole with free burden (kg)

B = burden (m)

H = height of free face (m)

C = rock constant which will be estimated from trial blast.

The computed total charge weight Q is then corrected for the influence of the deviation of bore hole, explosive strength, drill pattern and influence of other charge blasted in the same delay.

$$\text{Total Charge} = \frac{F}{E} \times \frac{S}{B} \times 0.80$$

Where,

F = Fixation factor = 1.0 (vertical hole) to 0.75 (free breakage at the bottom of hole)

E = Explosive factor = 0.9 (30% dynamite) to 1.3 (60% dynamite)

S/B = Spacing/Burden

2. 6 Sassa & Ito (1974): - This method is established on the basis of blastability studies conducted in tunneling operation. They proposed RBFI (Rock Breakage Field Index) and later on developed RBLI (Rock Breakage Laboratory Index), by regression analysis of mechanical properties of rock measured in the laboratory and crack frequency studies at blast site in the field.

2. 7 Heinen & Dimock (1976): - They proposed a method for describing blastability of rockmass based on the field experience at a copper mine in Navada (USA). They relate the average powder factor with seismic propagation velocity in rockmass and found that powder factor increases with the increased rock propagation velocity. They proposed a graph (Figure-2) based on the correlation study in the field.

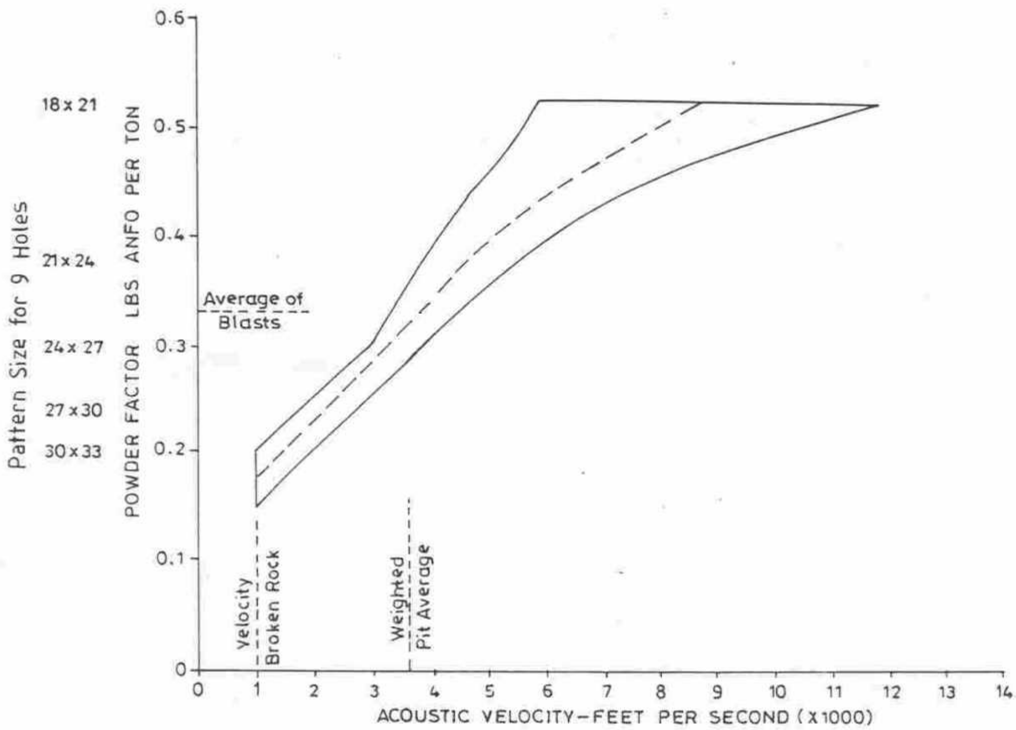

Figure - 2 : Heinen & Dimock's correlation between fragmentation Vs powder factor, pattern size, and velocity

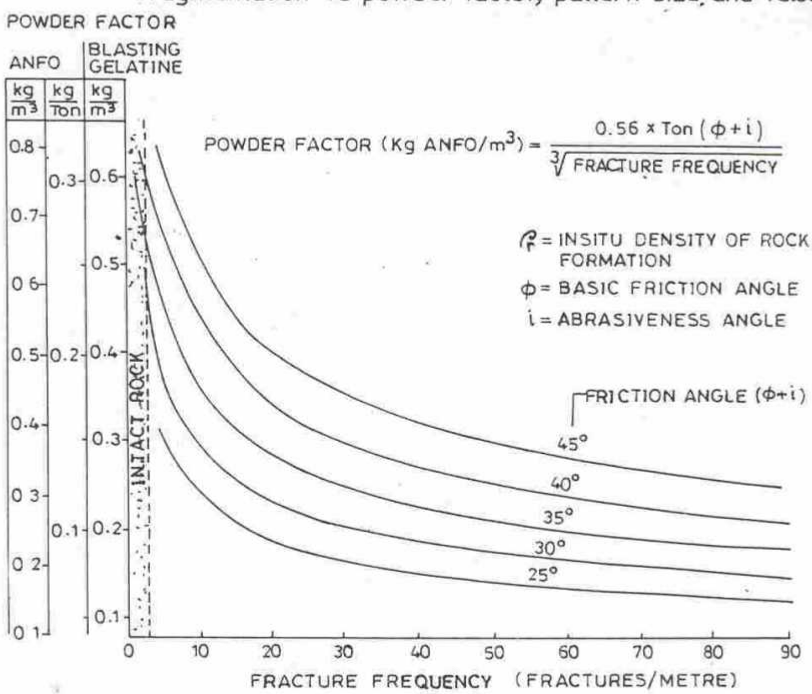

Figure - 3: Empirical relationship between powder factor. fracture frequency and joint shear strength. as proposed by Ashby

2. 8 Ashby (1977): - Ashby developed an empirical relationship to describe the powder factor required for adequate blast (in Bougainville Copper Mine) based on the fracture frequency representing the density of fracturing and effective friction angle representing the strength of structured rockmass. According to Ashby the powder factor of rock with ANFO may be determined either from the graph (Figure-3) drawn for the purpose or from the following equation—

$$\text{Powder Factor} = \frac{0.56 \times \text{Tan}\,(\phi + i)}{\sqrt[3]{\text{fracture/meter}}}\ \text{kg/cu.m.}$$

Where,

ϕ = Friction angle i = Roughness angle

Fracture/meter represents the fracture frequency.

2. 9 Praillet R. (1980): - R. Praillet calculates the compressive strength of the rock from the penetration rate, pull down weight, rotary speed & diameter and after words, by using a third degree equation, he determines the burden value as a function of –

- **i.** Bench height, charge density.
- **ii.** Detonation velocity
- **iii.** Stemming height
- **iv.** Compressive strength
- **v.** Components that depends upon the loading equipment size.

The advantage of the system is that it calculates the drilling pattern as a function of parameters known beforehand except compressive strength which is to be known from the drilling parameters. So it required few test holes or test blasts.

2. 10 Leighton (1982): - Leighton correlates RQI with the Powder factor of ANFO for perimeter blasting with correlation coefficient R=0.98 as shown in Figure-4. RQI is determined from the rotary drill using the following equation—

$$\text{RQI} = E_h \frac{t}{L}$$

Where,

E_h = Hydraulic pressure of the drill (in kPa)

t = Drilling time (in min)

L = Length of the blast hole (in m)

RQI may be correlated by using the following equation –

$$\ln(CE) = \frac{RQI - 25.000}{7.2000}$$

The limitations of using RQI are –

- As only hydraulic pressure of drilling is used data obtained depends on type & model of the rig.
- Drill diameter is not considered in RQI calculation.
- Rotation speed is not considered.

The main problem of Leighton's approach is that it is only applicable for drilling rig of B.E. 40-R drill with diameter of 229 mm for rotary drilling.

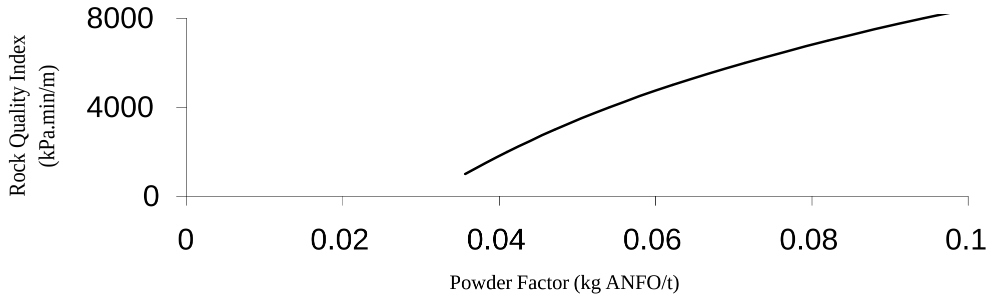

Figure-4: Leighton's Correlation between RQI & Powder Factor

2. 11 Rakishev (1982): - Rakishev expressed blastability, resistance to fracture by a blast, as a function of rock density (ρ_0; kg/m^3), longitudinal wave velocity (c; m/s), Poisson's ratio, elastic modulus (kN/m^2), compressive(σ_c) and tensile (σ_t) strength (kN/m^2)of rockmass, mean dimension of a natural structure unit (d_n) and a coefficient representing the properties of filling of the fracture and their degree of opening (k). He defined a critical fracture velocity using the above parameters and then categorised the blastability in five categories (Table-2) corresponding to different values of critical fracture velocity. Critical fracture velocity (V_{cr}) can be found out from the following formula -

$$V_{cr} = k\sqrt{g \times d_n} + \frac{\sigma_{cor}}{\rho_0 \times c}$$

Where, g= gravitational acceleration (m/s^2)

and $\sigma_{cor} = 0.1\, \sigma_c + \sigma_t$

Table-2: - Correlation of blastability with critical fracture velocity

Critical fracture velocity (m/s^2)	Blastability
3.6 > V_{cr}	EB (Easily blasted)
3.6 V_{cr} < 4.5	MB (Moderately easily blasted)
4.5 V_{cr} < 5.4	DB (Difficult to blast)
5.4 V_{cr} < 6.3	VDB (Very difficult to blast)
6.3 V_{cr}	EDB (Exceptionally difficult to blast)

2. 12 Lopez Jimeno (1984): - E. L. Jemino has taken into account the limitations of RQI and has proposed a rock characterization drilling index based on penetration rate, drilling diameter etc as per following formula.

$$\text{Ip drilling index} = \frac{VP}{\dfrac{E \times N_r}{D^2}}$$

Where,

VP = Penetration rate in (m/hour)

E = Pull down weight on the tricon bit in (1000 lb)

N_r = Drilling Speed in (rpm)

D = Diameter of drilling in (inch)

This equation valids subjected to the following conditions –

⇒ Drilling bit used must be the best for the type of formation.

⇒ Air flow must be sufficient to sweep away drill cuttings

⇒ Only net penetration rate to be counted (not bit changing, positioning time).

The charge factor is correlated with the Ip drilling index by statistical regression analysis of the data from various mines and represented by the Figure-5 and by the following equation established –

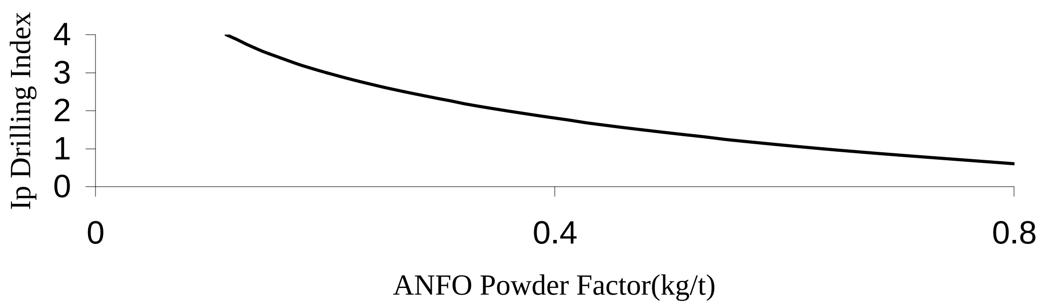

Figure-5: - Correlation between Ip drilling index and Powder factor

$$\text{Charge Factor} = \text{CE (kg of ANFO/m}^3) = 1.124 \times e^{-0.5727\, Ip}$$

2. 13 Lilly (1986): - Lilly developed a blasting index based on rockmass description, Joint density & orientation, specific gravity and hardness. This index can closely be related with powder factor. To use Lilly's blastability Index it is required to establish a site specific relationship between this Blastability Index and the Powder Factor. This can be established either with the help of historical blast records or from trial blast results. Lilly proposed the following formula –

$$BI = 0.5 \times (RMD + JPS + JPO + SGI + H)$$

Where, BI = Blasting Index

RMD (Rockmass Description) = 10 , for Powdery/Friable rockmass
= 20 , for Blocky rockmass
= 50 , for Totally Massive rockmass
JPS (Joint Plan Spacing) = 10 , for Closely Spacing (<0.1m)
= 20 , for Intermediate (0.1 – 1.0 m)
= 50 , for Widely Spacing (>1.0m)
JPO (Joint Plane Orientation) = 10 , for Horizontal
= 20 , for Dip out of the Face
= 30 , for Strike Normal to Face
= 40 , for Dip into Face
SGI = Specific Gravity Influence,= 25 × Specific Gravity of rock (t/m^3) – 50
H = Hardness in Mho Scale (1 – 10).

2. 14 Ghose (1988): -

Ghose proposed a geo-mechanic classification system of rockmass in case of coal mine (Table-3) and correlated the powder factor with blastability index (Table-4). However, this blastability index is limited for surface blasting only and is given by –

$$BI = (DR + DSR + PLR + JPO + AF1 + AF2)$$

Where,

BI = Blastability index
DR = Density ratio
DSR = Discontinuity spacing ratio
AF1 = Adjustment factor 1
PLR = Point load strength index ratio
AF2 = Adjustment factor 2
JPO = Joint plane orientation ratio

Table-3: Assigned Ratio for the Parameters of Blastability Index

Parameters	Ranges				
Density (t/m^3) ratio	<1.6	1.6-2.0	2.0-2.3	2.3-2.5	>2.5
	20	15	12	6	4
Discontinuity spacing (m) ratio	<0.2	0.2-0.4	0.4-0.6	0.6-2.0	>2.0
	35	25	20	12	8
Point load strength index (MPa) ratio	<1	1-2	2-4	4-6	>6
	25	20	15	8	5
Joint plane orientation ratio	DIF	SAF	SNF	DOF	HOR
	20	15	12	10	6
Adjustment factor 1	Highly confined Reasonably free				-5 0
Adjustment factor 2	Hole depth/Burden > 2 Hole depth/Burden 1.5 - 2 Hole depth/Burden < 1.5				0 -2 -5

Where,

DIF= Dip into face SNF= Strike normal to face HOR= Horizontal

DOF= Dip out of face SAF= Strike at an angle acute to face

Table-4: Relationship between Blastability Index and Powder Factor

	Value				
Blastability Index	30-40	40-50	50-60	60-70	70-85
Powder Factor (kg/m^3)	0.7-0.8	0.6-0.7	0.5-0.6	0.3-0.5	0.2-0.3

2. 15 Gupta R.N. et al (1990)

Based on a number of field data Gupta et al suggested the following relationship to estimate the charge factor(kg/m^3) for various rock strength.

$$\text{Charge Factor} = 0.278 \times B^{-0.407} \times F^{0.62}$$

Where,

B = Effective burden (m)

F = Protodyakonov strength index = $C^2/1.06 \times E$

Where C = Compressive strength of rock (kg/cm^2)

E = Modulus of elasticity (kg/cm^2).

2. 16 JKMRC (1996): - JKMRC approaches to classify the rockmass according to the properties affect blasting performance and a blastability analysis has been developed for coal measure strata taking the following parameters –

- ⇒ Rockmass – Strength, density, Young's modulus.
- ⇒ Structure – Average insitu block size, ***influence of structure***.
- ⇒ Design – Target fragment size, ***heave desired***, ***confinement provided***, ***scale of operation***.
- ⇒ Environment – Water.

The parameters highlighted (in Bold) above are used as the design modifier factors, which make the blasting easier or difficult. Table–5 gives an example of analysis of powder factor in a surface coal mine of Hunter Valley, New South Wales using ANFO as the explosive. These blasting practices are used to derive the blastability relationship. There are some indices also predicted from the result.

Compressive strength, density and Young's modulus obtained from the laboratory test, are used to described the basic strength and stiffness of rock material. Average insitu block size is estimated from exposed rock surface or from the structural mapping. Influence of structure is taken considering the situation is difficult for blasting or easier for blasting (5 is neutral, 1 is strongly favorable, 9 is strongly difficult). Heave parameter is based on the loading equipment (like FEL needs more spreaded heave and shovel needs high and compact heave). Confinement is based on the free face availability. A blast, having full face available, has confinement <5 and over-confined >5. Scale factor is considered for blasting in same material but separate geometry.

Table-5: A Case Study of Blastability by JKMRC

Parameters	Dragline operation	Dragline operation with cast blasting	Shovel operation	Shovel operation in wet condition	Parting FEL
Rockmass					
Strength (MPa)	60	60	50	50	40
Density (gm/cc)	2.51	2.51	2.47	2.47	2.42
Young's modulus [E] (Gpa)	12	12	10	10	10
Structure					
Block size (m)	2	2	2	2	0.5
Structure (1-9)	5	5	5	5	3
Design					
Target fragment size (m)	0.5	0.5	0.3	0.3	0.15
Heave (1-9)	5	10	5	5	7
Confine (1-9)	5	5	5	5	7
Scale (1-9)	3	3	5	5	7
Environment					
Water (1-9)	1	1	1	5	1
Indices					
Strength	0.30	0.30	0.25	0.25	0.20
Breakage	0.08	0.08	0.13	0.13	0.06
Heave	0.25	0.51	0.26	0.26	0.36
Modifier	-0.02	0.03	0.00	0.08	0.02
Powder Factor Kg/t	0.18	0.24	0.17	0.21	0.16
Powder Factor Kg/m^3	0.44	0.61	0.42	0.52	0.39

Predicted indices are as follows –

- Strength Index → It indicates the compressive strength of rock is proportional to powder factor.
- Breakage Index → The degree of breakage required is the ratio of insitu block size and target fragment size. This is proportional to Young's Modulus.
- Heave Index → The heave energy required is inversely proportional to Young's modulus of rock.
- Modifier Index → This is to adjust powder factor with structure, scale and confinement modifier value. That modifier value of 5 is neutral, >5 is difficult and <5 is easy. Each unit above and below 5 for modifier index increase and decrease respectively powder factor by 1%.

In water parameter dry blasting condition are indicated by 1 and each unit above 1 adds 2% to the powder factor.

2. 17 Jiang Han, Xu Weiya and Xie Shouyi (2000)

They used Artificial Neural Network (ANN) approach to determine rockmass blastability classification. They have designed a back propagation network of 6 inputs, 5 hidden and 1 output processing elements. Computing mode of rockmass blastability classification followed the equation –

$$K = \{L, S, R_{cd}, E_d, P_c, d_{cp}\}$$

Where,

L = Total length of fracture in 2 × 2 m^2 block (m)

S = The mean distance of fractures in 2 × 2 m^2 block (m)

R_{cd} = Dynamic compressive strength of rock (MPa)

E_d = Dynamic elastic modulus of rock (Gpa)

P_c =Percentage of unqualified block (%)

d_{cp} =Mean fragment size (mm)

K = Output parameter of network

88 datasets representing different blasting conditions were used to construct the vector space of the network among which 44 sets were training data, 22 sets were validating data and 22 sets were testing data. Output result gives accuracy within 10%.

3. Conclusion: -

Table-6 gives a concise look on the discussed blastability study. There are a lot more approaches to determine the blastability. It has been tried to define blastability a no of way. But still now a well defined single universal blastability scheme, which will define blast design and performance effectively, is yet to achieve. Fundamental research on blast design and to describe the rockmass viewing the blasting operation is going on. It is believed that it may be possible to get a universal methodology to determine the blastability, which will incorporate blast outcomes and be able to relate closely with the powder factor for different geo-mining condition. Viewing this, till now the JKMRC methodology may be accepted as the best approach.

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Table-6: A Comparative Look on Blastability

Year	Proposed by	Formula	Inputs	Special Features
1954	Fraenkel	$h \times d^2 = \frac{(50 \times V_{max})^{3.3}}{S^{3.3} \times H \times d^{2/3}}$	Burden, hole depth, hole diameter, charge length	Relationship between charge with blastability
1959	Hino	BC = CS/TS	Compressive and tensile strength	Powder factor correlated with blastability
1968	Hansen	$Q = B^2 \left\{0.0236 \times \left(\frac{h}{B} + 1.5\right) + 0.1984 \times C \times \left(\frac{h}{B} + 1.5\right)\right\}$	Burden and height of free face	Relate total charge with rock constant
1970	Sassa & Ito		Mechanical properties of rock and crack frequency	RBFI and RBLI found by regression analysis
1976	Heinen & Dimock		Seismic propagation velocity of rock	Powder factor is correlated to seismic velocity
1977	Ashby	$\text{Powder Factor} = \frac{0.56 \times \text{Tan}(\phi + i)}{\sqrt[3]{\text{fracture/meter}}}$ kg/cu.m.	Fracture frequency, friction angle and roughness angle	Powder factor of ANFO is determined based on fracture frequency
1978	Langefors			Correlation between powder factor and rock constant established
1980	Praillet		Penetration rate, bench height, burden and detonation velocity	Charge density is a function of input parameters
1981	Borquez	$K_V = a + b \times \ln(ERQD)$	RQD	Use alteration factor for joint strength.
1982	Rakishev	$V_{cr} = k\sqrt{g \times d_n} + \frac{\sigma_{cor}}{\rho_0 \times c}$	Rock density, elastic modulus, compressive and tensile strength and degree of opening etc.	Correlate fracture velocity with blastability
1982	Leighton	$\ln(CE) = \frac{RQI - 25.000}{7.2000}$	RQI	Correlate RQI with powder factor
1986	Lilly	BI = 0.5 × (RMD + JPS + JPO + SGI + H)	Rockmass description, joint spacing, joint orientation, Sp. Gravity hardness etc.	Relationship expressed between blastability and powder factor
1987	Rusten & Lin		Critical burden, angle of breakage, fragmentation, throw, back break, vibration results etc.	
1988	Ghose	BI = (DR + DSR + PLR + JPO + AF1 + AF2)	Density, discontinuity spacing, joint orientation, point load index.	Powder factor relates with rated blastability for coal mines
1989	Jimeno	$CE\,(\text{kg of ANFO/m}^3) = 1.124 \times e^{-0.5727\,Ip}$	I_p drilling index	Correlate charge factor with I_p drilling index
1990	Gupta	$\text{Charge Factor} = 0.278 \times B^{-0.407} \times F^{0.62}$	Burden and Protodyakonov index	Relate charge factor to rock constant
1996	JKMRC		Rockmass design, structure, environment characteristics	Incorporate blast outcomes for coal mines
2000	Jiang Han	$K = \{L, S, R_{cd}, E_d, P_c, d_{cp}\}$	Fracture length and distance, elastic modulus, fragment size, dynamic compressive strength.	Relate blastability using back propagation technique from a dataset.