THESIS SUMMARY

A MATHEMATICAL MODEL OF ROCK BREAKAGE BY BLASTING

T.H. Kleine

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Approach

The problem of predicting the fragmentation and damage caused by blasting is well recognised and continues to receive much attention. The key elements are understood to be the rock (structure and geometry), the explosive (dynamic properties) and the blast design (geometric and dynamic description). Most fundamental research on the problem has focussed on discovering the detailed and intimate interactions between the rock and the explosive. Conversely most practical research on the problem has focussed on linking blast designs to observed fragmentation.

There is clearly a middle ground which includes rock structure, dynamic explosive behaviour, full production blast design and observed blast products. It includes mathematical models which are more practical than implementing the fundamental discoveries and more widely applicable than the simple but practical links to observation. The central purpose of the model presented in the thesis is to be both practical and realistic. It was developed through research conducted in producing stopes at two large underground mines (Figures 1 and 2). The model of blast induced rock breakage predicts both fragmentation and damage, is fully three dimensional, has modest calculation requirements and each component uses observations as directly as possible.

Data

The components of the model are the rock (before and after blasting), the blast design (the geometry and composition of individual decks of explosive) and the dynamic rock-explosive interaction. Each of these is measured independently. Six data collection techniques (Table 1) were used to provide fundamental evidence for the model but only three of these are needed for practical application (Table 2).

Although the cross hole seismics and photographic fragmentation assessment are recommended after each blast they are only needed for verification of the predictions.

Typical data are shown in Figures 3-7 and Tables 3 and 4 which were extracted from the thesis. They show a fracture mapping log and its analysis, cross hole seismic data, vibration records and their analysis, a fragmentation photograph and its analysis and hole charging and location data.

LOG LINE: 20
LOGGED BY: M.C.BRIDGES, T.KLEINE
DATE: 7.3.85
LEVEL: 18B
BEARING, DIP: 90. 0.
COMMENT:

DIST. FROM	TO	ROCK TYPE	FEA-TURE	ORIENT. D.D.	DIP	EXTENT LENGTH	WIDTH	FILL	LINEAR	COMMENT
3.2		BD								START 13:44
4.6			F	024.	70.	+0.8	1.2			
5.2			F	013.	81.	+0.4	0.6			
5.95			F	212.	85.	+0.5	0.5			
12.35			F	022.	90.	+0.3	0.6			
12.35		RS	R9							
13.8			B9	259.	44.					
13.95			F	306.	58.	+0.4	0.6			
14.3	15.25		SH							
14.35			B9	263.	47.					
14.8			F	225.	46.	+0.4	0.8			
14.8			F	314.	52.	+0.3				
[illegible]			F	221.	46.					
		BD	R9					SEP		14:0[illegible]
32.6										
34.5				[illegible].	41.					
38.9			F	198.	87.	+0.3	0.6			14:11
39.4			F	168.	73.	0.5	0.6			
39.55			B9	259.	46.					
40.3		BD	R9							
41.25			F	020.	73.	+0.2	0.6			
41.55			F	009.	87.	+0.4	0.8			
42.1			F	004.	83.	+1.2	+0.6			
47.1			F	264.	69.	+0.4	2.5			
59.3			B9	270.	44.					
61.4			F	283.	89.	+0.1	0.5			14:22
66.35			F	037.	90.	+0.3	0.8			
67.05			F	229.	88.	+0.4	2.0			
67.2										END 14:24
69.9										X/CUT

Figure 3 Extract from a fracture mapping log

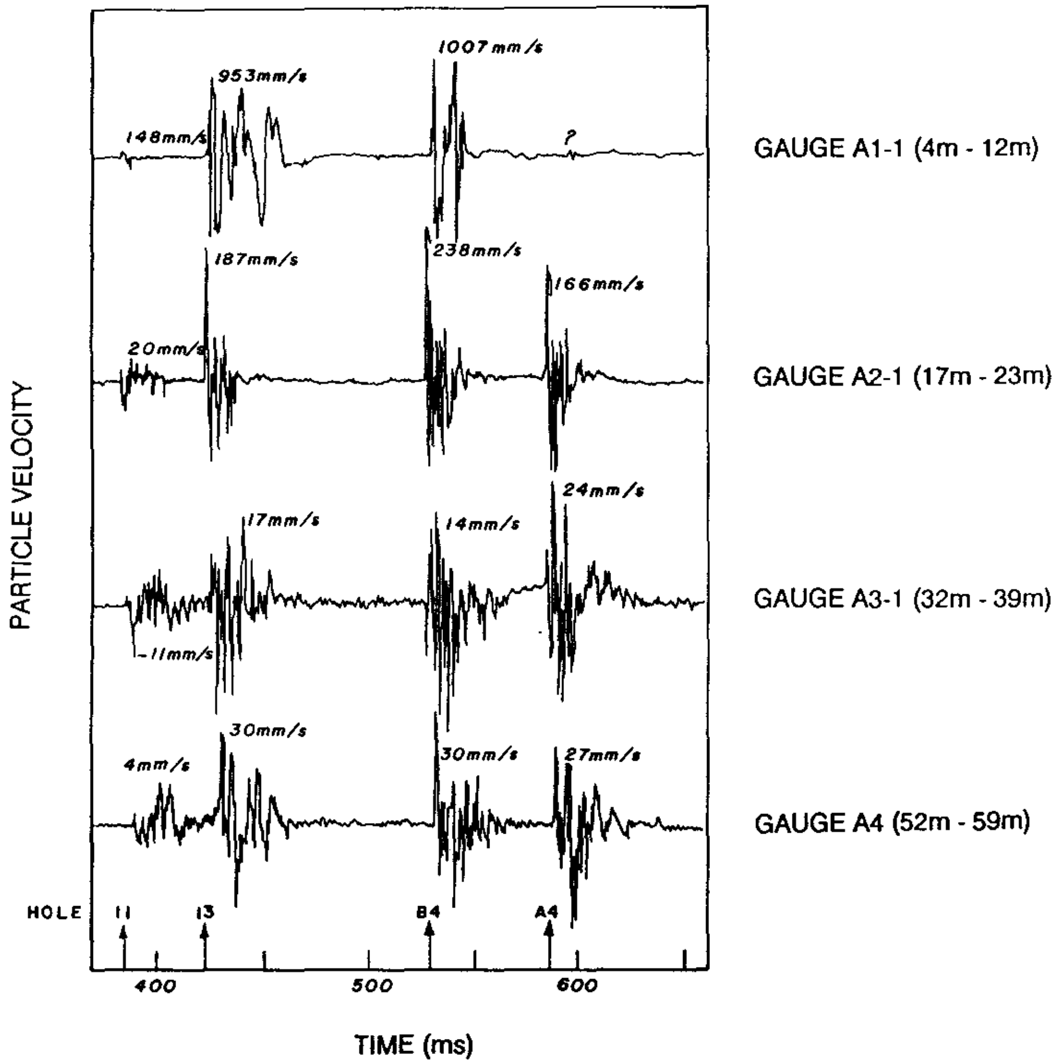

Figure 6 Typical vibration records

Table 3 TYPICAL VIBRATION PARAMETERS

PARAMETER	*ANFO (#7)*	*TOVAN (#6)*	*TOVAN (#11)*	*AVERAGE*[1]
Q	25.4	21.3	23.8	23.5
c	0.297	0.249	0.279	0.275
τ_o (μs)	106.	106.	106.	106.
A_o (m/s)	34.0	58.1	76.9	34.0
K_o	4.55	4.55	4.55	4.55
V_p (m/s)	6800.	6800.	6800.	6800.

1 The average A_o value is for ANFO. The relative vibration strength of TOVAN to ANFO is: 1.98

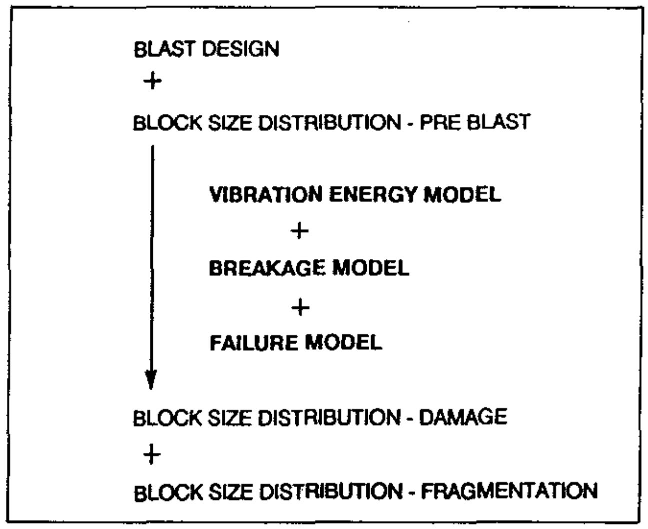

Figure 8 Framework of the blast breakage model

The key to the framework is the separation of breakage and failure shown in Figure 9. The treatment of rock as a two phase medium in which each phase may have the same block size distribution conveniently simplifies the blasting process but retains sufficient complexity to simulate damage and fragmentation.

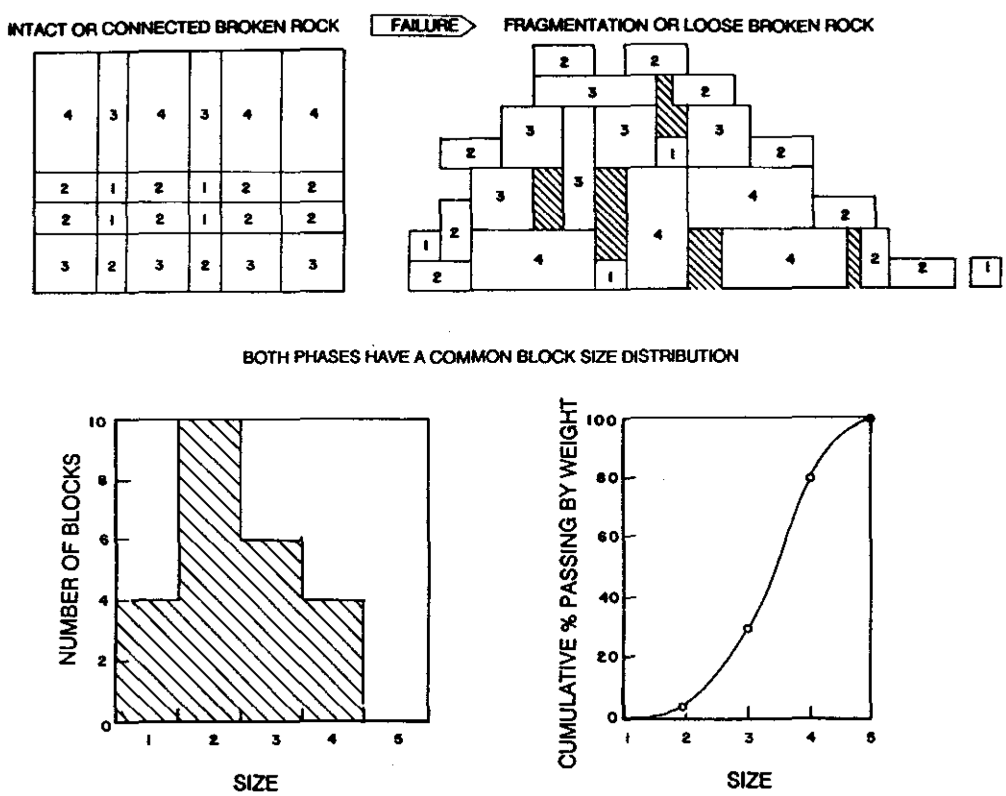

Figure 9 Separation of breakage and failure

The definitions and assumptions of the technique are presented in Table 5. The key assumption is that the mean spacing between fractures is the same as the mean block size. The simplification allows joints to be treated independently and allows straightforward statistical analyses of joints to be applied to determine the size distribution of blocks by frequency. The global mean joint spacing is calculated for an even and fine distribution in three dimensions to ensure an unbiased result. An assumption of block shape yields a distribution by volume or weight.

Table 5 DEFINITIONS AND ASSUMPTIONS OF THE FRACTURE ANALYSIS

	DEFINITIONS
FRACTURE	Fractures are thin flaws or surfaces of weakness in intact rock and may be measured by fracture mapping. Fractures are measured in terms of their volume density.
BLOCK	The inverse of the volume fracture density is the mean unfractured volume. A volume of rock with a defined though not necessarily complete boundary is a block. The block's size is described by a single number representing its width. The weight of the block is proportional to a power of its width. A cube, for instance, requires a power of 3.
INTACT ROCK	Intact rock is composed of connected blocks of various sizes. It is possible to define and measure the size distribution of blocks in intact rock.
DAMAGE	The block size distribution of connected blocks, intact rock, is damage. It is possible to quantify the significance of the damage by comparing the size distribution after blasting with either or both a reference distribution which represents virgin ground or a reference distribution which represents critical damage.
	ASSUMPTIONS
BLOCK SIZE	Fracture spacing is related to block size.
POPULATION DISTRIBUTION	Fracture spacing has a known population distribution whose form is the same in every direction.
UNBIASED DIRECTION	No direction is favoured. Fractures are considered equally in all directions.
BLOCK OCCURRENCE	The number of blocks in a size range is proportional to the number of intact straight line segments (in the same length range) which can be drawn between successive fractures.

Line mapping data consisting only of the orientation of each observation and the length and orientation of the scan line are used. The intact block size distribution is simply calculated in a few minutes (1 to 5 minutes) using common desktop computers.

block size distribution and is applied only at points of interest, say, to calculate the damage in a sensitive structure. There is no need to calculate the entire blast outcome.

Because direct measurement of damage is difficult an indirect technique was developed. It is a correlation between observed seismic results and the degree of fracturing.

Impact

The result when the components of the model are combined is a practical three dimensional approach to fragmentation and damage modelling which uses common engineering inputs as well as allowing for arbitrary blast design changes including individual blast hole locations and explosive types.

On a different level the impact of each component can be seen in the individual advances made to three dimensional fracture analysis, vibration attenuation, simple three dimensional blast energy estimates, damage assessment and comminution modelling.

Finally by bringing the diverse models together each was forced into a framework which clearly points out their shortcomings and leads to further refinements. To quote from the thesis,

> *... the main achievment was the renewed emphasis placed on the originally separate observation techniques of fracture mapping, cross hole seismic scanning, fragmentation assessment and vibration monitoring. Clear directions have emerged for further development of data collection and model mechanisms, which will provide more flexibility, accuracy and practicality to the practicing blasting engineer.*
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