INFLUENCE OF AIR-DECK LENGTH ON FRAGMENTATION IN QUARRY BLASTING

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Abstract

An air gap in the explosive column known as an air deck has been applied in open-pit blasting as a means to reduce explosive charge, vibration, fly rock, and improve fragmentation and controlled blasting in some situations. Determining the appropriate air-deck length and optimum fragmentation is still in question despite many applications and studies. In this research, a total of 30 air-deck blasts with air-deck lengths between 15-65% of the charge length were tested while also considering two other important parameters: maximum joint spacing and blasting direction. Average fragmentation size was obtained from image processing analysis and used as an indicator of blasting performance. Results indicate that the average fragmentation size increases relative to the higher percent air-deck length and maximum joint spacing. In addition, an unfavorable blasting direction also increases average fragmentation size. The relationship between average fragmentation size and an air-deck length is displayed on a graph for simplicity of uses. The small to medium opening feed size of a normal primary crusher may vary between 93cm (37 inches) to 112cm (44 inches) so an air-deck length between 20-30% of the charge length can be used with a high possibility that the average fragmentation size will be less than 100cm. With favorable parameters, an air-deck length of up to 40% is worth testing in the quarry mines; however, other uncontrollable parameters exist and may also affect blast fragmentation.

Keywords: Air-deck, blasting, fragmentation, quarry

1. Introduction

Since Melnikov and Marchenko (1971) proposed the air-deck theory of how one or more air gaps used in the explosive column called air deck can improve fragmentation, the technique has been studied and increasingly applied in presplit and also production blasting in open-pit mines. Despite numerous practical applications and research into air-deck blasting, improvements in fragmentation do not always occur and questions remain regarding the optimum length of the air gap to be used. Two main factors affect blast results, which can be generally separated into controllable and uncontrollable factors. Examples of controllable factors are the types of explosive used and geometry of the blast pattern, while uncontrollable factors relate primarily to geological structure. This paper discusses the results of experimental blasts conducted in two quarry mines to evaluate the relationship between the length of the air deck (as a percentage of charge length in the blast hole) and the required fragmentation size. The maximum spacing of discontinuity and the angle between the direction of the strata and the blast break were also considered.

2.Theory of air-decking

The theory was first proposed by Melnikov and Marchenko (1971), and Melnikov et al. (1979), who postulated that when shock waves reflect from the boundary between the stemming bed and an air gap, a secondary shock wave is generated that extends the network of fractures prior to gas pressurisation. The degree of fracture is increased by the second shock wave and the duration of the shock wave action on the rock surrounding the hole is also prolonged. Consequently, the crack network within the rock mass is increased when using air-deck blasting techniques.

Moxon et al. (1993) indicated that if the air deck is placed in the middle of the explosive column, the pressure front will collide at the centre of the air deck. This interaction should develop a reinforced stress field and result in a more radial crack pattern than if an air deck was kept on the top of the charge.

3. Blasting experimentation

The experiments were conducted in two quarry mines. One is located in northern Thailand and known as Lampang qurry mine, while the other is located in central Thailand and is known as Supan quarry mine. Limestone productions from the Lampang mine are mostly used for flue gas desulfurization (FGD) processing to capture sulfur dioxide gas released from coal-fired power plants. Productions from the Supan mine are used only for cement production.

Blast performance, particularly the fragmentation size of the rock, was observed and analyzed, using Spilt Desktop (demo version) image processing software. In order to isolate and evaluate the effect of air-deck length, other blast design parameters, such as hole diameter, bench height, burden and spacing were kept similar. The number of holes varied between 20-30 per blast. However, the two mines have more than one production area and also have different blasting directions. For this reason, the direction of the strata (bedding) and the blast break were observed in the fields and represented as a controllable parameter. In addition, geotechnical information was collected in all 30 experimental blasts to determine different rock masses and rock mass quality at the different locations. An air deck (A) was placed on top of the charge as shown in Figure 1. Detailed geological investigations are presented in Section 4, while Tables 1 and 2 shows details of all blasting patterns and air deck lengths, which varied from approximately 15-65% of the charge length in the charge column of both mines.

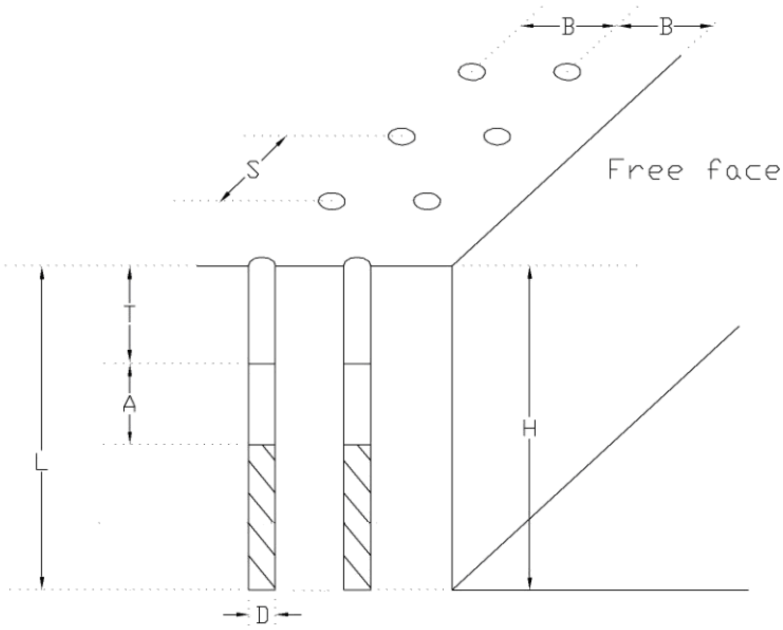

Figure 1 Air deck position (A) placed between stemming (T) and explosive charge

Table 1 Blast pattern and air deck length in Lampang mine

Blast No.	Burden (m.)	Spacing (m.)	Stemming (m.)	Air deck (m.)	Total hole length (m.)	Charge length (m.)	% of air deck compared to charge length
1	3.00	3.00	2.00	0.80	8.50	5.70	14.04
2	3.00	3.00	2.00	0.80	8.50	5.70	14.04
3	3.00	3.00	2.00	0.80	8.50	5.70	14.04
4	3.00	3.00	2.00	1.20	8.50	5.30	22.66
5	3.00	3.00	2.00	1.20	8.50	5.30	22.66
6	3.00	3.00	2.00	1.20	8.50	5.30	22.66
7	3.00	3.00	2.00	1.50	8.50	5.00	30.00
8	3.00	3.00	2.00	1.50	8.50	5.00	30.00
9	3.00	3.00	2.00	1.50	8.50	5.00	30.00
10	3.00	3.00	2.00	1.80	8.50	4.70	38.30
11	3.00	3.00	2.00	1.80	8.50	4.70	38.30
12	3.00	3.00	2.00	1.80	8.50	4.70	38.30
13	3.00	3.00	2.00	2.00	8.50	4.50	44.44
14	3.00	3.00	2.00	2.00	8.50	4.50	44.44
15	3.00	3.00	2.00	2.00	8.50	4.50	44.44

Table 2 Blast pattern and air-deck length in Supan mine

Blast No.	Burden (m.)	Spacing (m.)	Stemming (m.)	Air deck (m.)	Total hole Length (m.)	Charge length (m.)	% of air deck compared to charge length
1	2.60	3.50	2.00	2.00	8.50	4.50	44.44
2	2.60	3.50	2.00	2.00	8.50	4.50	44.44
3	2.60	3.50	2.00	2.00	8.50	4.50	44.44
4	2.60	3.50	2.40	1.50	11.50	7.60	19.74
5	2.60	3.50	2.40	1.50	11.50	7.60	19.74
6	2.60	3.50	2.40	1.50	11.50	7.60	19.74
7	2.20	2.50	2.00	1.40	7.50	4.10	34.15
8	2.20	2.50	2.00	1.40	7.50	4.10	34.15
9	2.20	2.50	2.00	1.40	7.50	4.10	34.15
10	2.20	2.50	2.00	2.20	7.50	3.30	66.67
11	2.20	2.50	2.00	2.20	7.50	3.30	66.67
12	2.20	2.50	2.00	2.20	7.50	3.30	66.67
13	2.50	2.50	2.40	3.20	11.50	5.90	54.24
14	2.50	2.50	2.40	3.20	11.50	5.90	54.24
15	2.50	2.50	2.40	3.20	11.50	5.90	54.24

4. Geotechnical investigations

Preliminary geotechnical investigations for both mines were conducted by considering several rock mass parameters such as uniaxial compressive strength, rock quality designation index (RQD), spacing of discontinuity, and conditions of discontinuity, which comprises discontinuity length (persistence), deparation (aperture), roughness, infilling (gouge) and weathering. The conditions of these parameters are shown in Table 3 and 4 for the Lampang and Supan mine, respectively. A total of 30 blast experiments were conducted: 15 blasts in both the Lampang and Supan mines. Bieniawski's rock mass rating (RMR) was determined to compare rock mass quality in both quarry mines. The RMR at both locations varies from 64-81, indicating there is not much difference in RMR between the two mines. However, the joint spacing parameter is significantly different so the maximum joint spacing was collected and used as as an uncontrolled parameter.

Table 3 Bieniawski's RMR at Lampang mine

Blast No.	Value (rating)									RMR[2]
	UCS (MPa)	RQD (%)	Joint spacing (m)	Ground water	Joint conditions					
					Discontinuity Length (m.)	Aperture (mm.)	Roughness[1]	Infilling	Weathering	
1	8.00	100	0.5	dry	7	0.3	6-8	none	slightly	75
2	5.31	100	1.35	dry	6	0.2	8-10	none	moderately	80
3	9.27	100	1.125	dry	12	0.1	2-4	none	slightly	81
4	4.82	97	1.2	dry	17	0.3	6-8	none	slightly	79
5	7.17	100	1.65	dry	6	0.2	8-10	none	unweathered	78
6	5.38	100	0.75	dry	12	0.5	2-4	none	slightly	78
7	8.32	90	1.05	dry	22	0.4	4-6	none	moderately	76
8	9.73	100	1.625	dry	15	0.1	2-4	none	slightly	81
9	6.34	100	0.9	damp	13	0.2	2-4	none	unweathered	74
10	4.16	100	1.1	damp	11	0.1	2-4	none	unweathered	74
11	6.30	100	0.575	damp	12	0.2	4-6	none	slightly	69
12	7.57	100	1.05	damp	15	0.2	2-4	none	unweathered	79
13	6.04	93	1.25	damp	25	0.3	4-6	none	slightly	73
14	6.89	100	0.5	dry	20	0.3	2-4	none	slightly	72
15	9.13	100	0.825	dry	23	0.2	4-6	none	slightly	81

[1] Joint Roughness Coefficient (JRC) using Barton and Choubey's Table
[2] Bieniawski's RMR

Table 4 Bieniawski's RMR at Supan mine

Blast No.	Value (rating)									RMR[2]
	UCS (MPa)	RQD (%)	Joint spacing (m)	Ground water	Joint conditions					
					Discontinuity Length (m.)	Aperture (mm.)	Roughness[1]	Infilling	Weathering	
1	5.78	100	0.65	dry	20	0.3	4-6	none	unweathered	77
2	13.17	100	0.73	dry	20	0.2	4-6	none	unweathered	80
3	8.49	100	0.74	dry	21	0.5	4-6	none	unweathered	77
4	4.35	100	0.93	dry	20	0.3	4-6	none	unweathered	77
5	4.27	100	1.13	dry	20	0.4	4-6	none	unweathered	77
6	6.47	97	1.13	dry	20	0.4	4-6	none	unweathered	77
7	7.77	100	0.78	damp	20	0.2	4-6	none	unweathered	72
8	9.38	100	0.60	damp	20	0.7	4-6	none	slightly	71
9	10.01	100	0.70	dry	20	0.5	4-6	none	slightly	79
10	10.41	97	0.80	damp	20	0.6	4-6	none	moderately	72
11	4.55	98	0.63	damp	20	0.3	4-6	none	moderately	69
12	7.46	100	0.43	damp	20	0.5	4-6	none	moderately	64
13	7.06	100	0.65	dry	20	0.4	4-6	none	moderately	74
14	7.76	100	0.70	damp	20	0.3	4-6	none	moderately	69
15	6.10	100	0.68	dry	20	0.7	4-6	none	moderately	74

[1] Joint Roughness Coefficient (JRC) using Barton and Choubey's Table
[2] Bieniawski's RMR

As mentioned above, the inclination of the strata was recorded in every blast to determine the angle between the direction of the strata and blast direction in order to ascertain whether or not the blast directions are in favorable, acceptable or unfavorable directions based on the information presented in Figure 2 (Jimeno, et al., 1995)

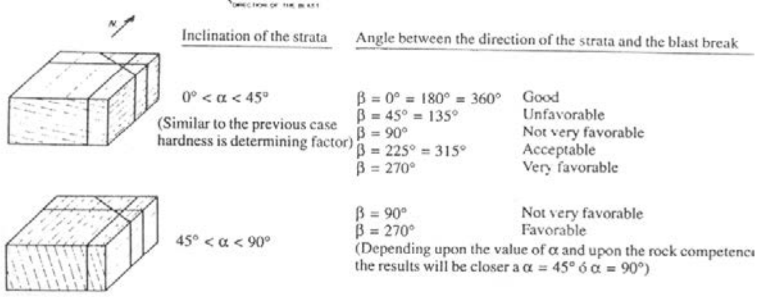

Figure 2 Fragmentation results in different directions compared to strata (Jimeno,et al., 1995)

5. Assessment of fragmentation

Photographs of the muck pile were taken, including 4 10-inch balls, which were used for scale references, as exemplified in Figure 3. Each of the 4 balls was placed separately on the rock muck pile. The example photograph in Figure 3 is furthur divided into 4 small photographs, with each one containing one ball for reference. The small photographs were then processed with Split Desktop (demo version) to provide the results of cumulative size distribution as shown in Figure 4. The results from the 4 small photographs were averaged to obtain the cumulative size distribution of the whole muck pile. The 80% passing size is used to indicate blast performance in this study.

Figure 3 An example photo with the reference balls

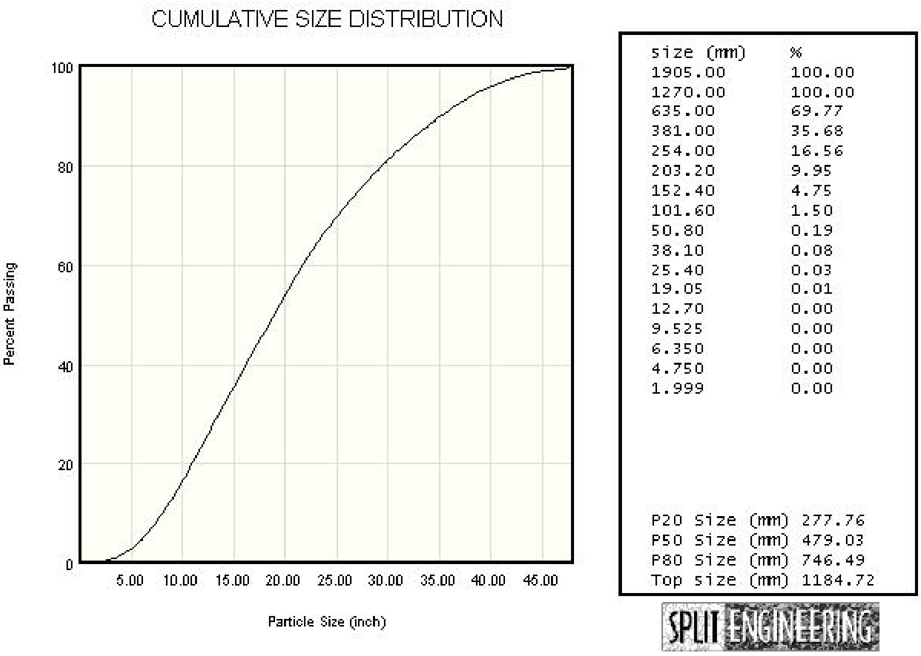

Figure 4 Cumulative size distribution obtained from the Split-Desktop program

6. Impact of air-deck length and designed parameters on fragmentation

The influence of air-deck length on fragmentation was evaluated in term of average (80%) passing size while considering two other parameters: maximum joint spacing and blasting direction results compared to the dip strata. Table 5 summarizes the results from both mines.

The average passing size and percent air-deck length of all blasts in Table 5 were plotted in one graph, as shown in Figure 5. When maximum joint spacing data were applied, the data points can be roughly categorized into 2 range bands: less than 200cm and between 200-300cm, as presented in Figure 6 and 7. In addition, blast directions are also provided and shown along with the data points.

Table 5 Details of air-deck blast results at Lampang and Supan mines

Blast No.	Lampang mine				Supan mine			
	80% passing size (cm)	Max. Joint Spacing (cm)	Blast Direction	% of Air deck length	80% passing size (cm)	Max. Joint Spacing (cm)	Blast Direction	% of Air deck length
1	56.17	80	favorable	14.04	51.25	125	acceptable	44.44
2	87.21	250	acceptable	14.04	48.40	140	acceptable	44.44
3	72.57	210	acceptable	14.04	48.56	138	acceptable	44.44
4	73.85	230	favorable	22.66	43.18	180	acceptable	19.74
5	81.00	300	acceptable	22.66	43.10	220	acceptable	19.74
6	59.16	140	acceptable	22.66	35.51	220	acceptable	19.74
7	110.09	200	unfavorable	30.00	44.61	150	acceptable	34.15
8	77.10	300	acceptable	30.00	47.44	110	acceptable	34.15
9	66.00	150	acceptable	30.00	48.42	130	acceptable	34.15
10	90.14	200	unfavorable	38.30	63.02	150	unfavorable	66.67
11	103.77	100	unfavorable	38.30	63.18	120	unfavorable	66.67
12	72.54	200	favorable	38.30	62.26	80	acceptable	66.67
13	92.39	240	unfavorable	44.44	52.44	120	unfavorable	54.24
14	91.48	90	unfavorable	44.44	52.45	130	unfavorable	54.24
15	76.64	150	acceptable	44.44	59.96	130	unfavorable	54.24

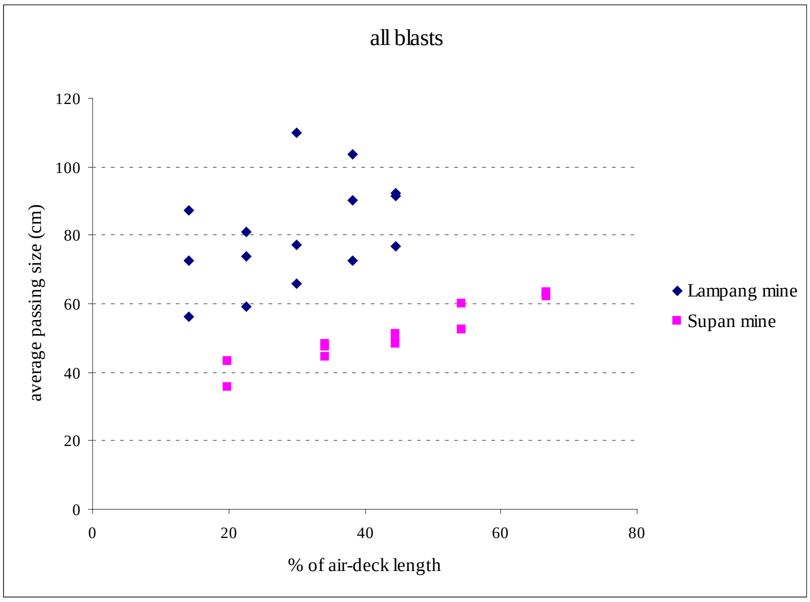

Figure 5 Fragmentation from all air-deck blasts

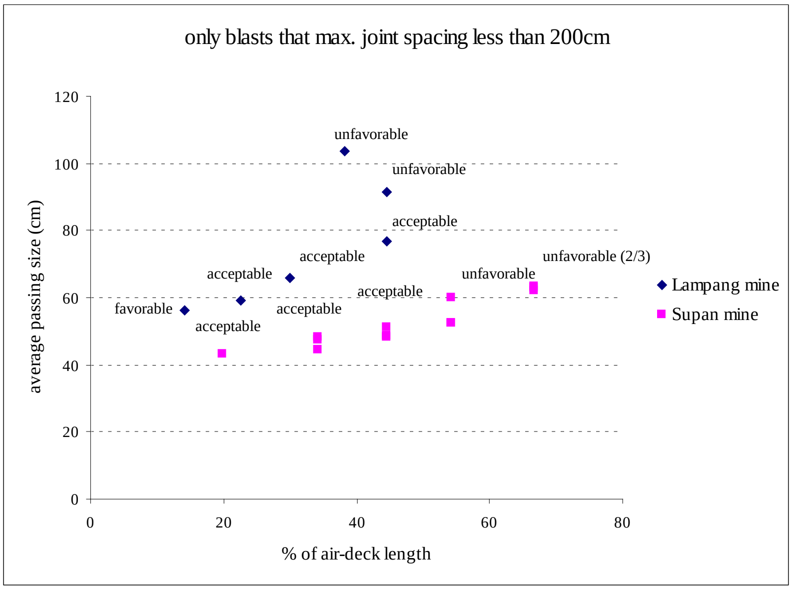

Figure 6 Blast with maximum joint spacing less than 200cm

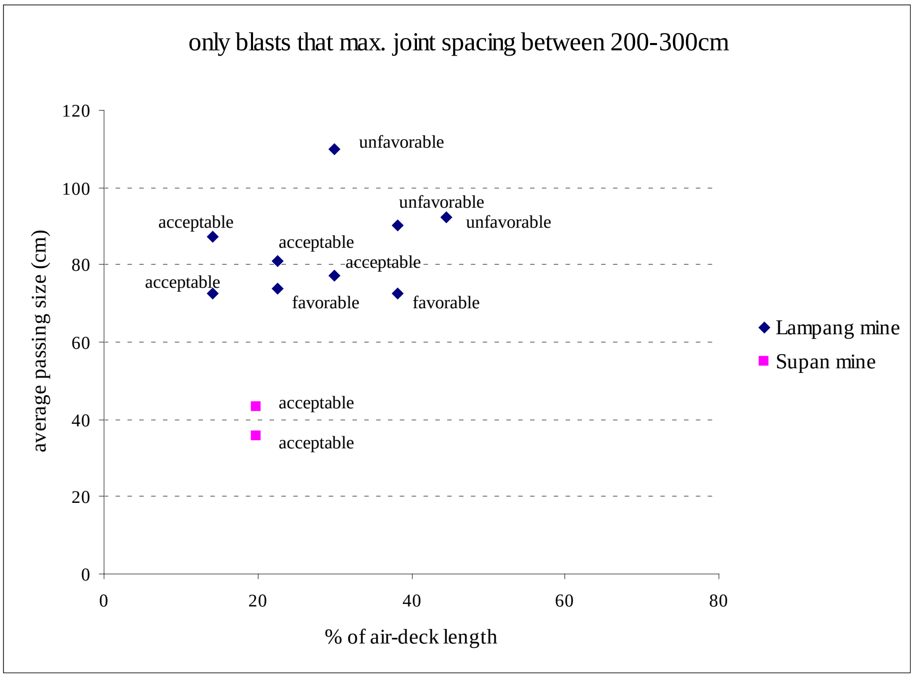

Figure 7 Blast with maximum joint spacing between 200-300cm

7. Analysis and conclusion

The average passing size tends to steadily increase with a higher percentage air-deck length. This is clearly seen in the blasts at both mines, where maximum joint spacing is less than 200cm and in mostly acceptable blast direction (Figure 6). With the unfavorable blast directions, the average passing size suddenly increases. Blasts that have a maximum joint spacing of between 200-300cm give average passing size clustering at bigger sizes compared to the maximum joint spacing of less than 200cm (Figure 7). It is evident that when joint spacing is longer (rock is more massive), the average 80% passing size is expected to be bigger.

Figure 8 shows that trend lines can be drawn to provide the possible area (between trend line 1 and 2,) of average passing size with maximum joint spacing of less than 200cm. The enclosed line (line 3) in Figure 8 is drawn to indicate the possible area (between trend line 2 and 3) of the average passing size with maximum joint spacing of between 200-300cm and also the possible area of the average passing size with maximum joint spacing of more than 300cm. In addition, blasts with unfavorable directions also result in a bigger average passing size compared to acceptable directions. One hypothesis line (a line with arrowheads) is also drawn to indicate the possible area where blasts with unfavorable directions appear, which is mostly in upper areas. The complete graph in Figure 8 summarizes the relationship between the average passing size and percent air-deck length along with the other two parameters.

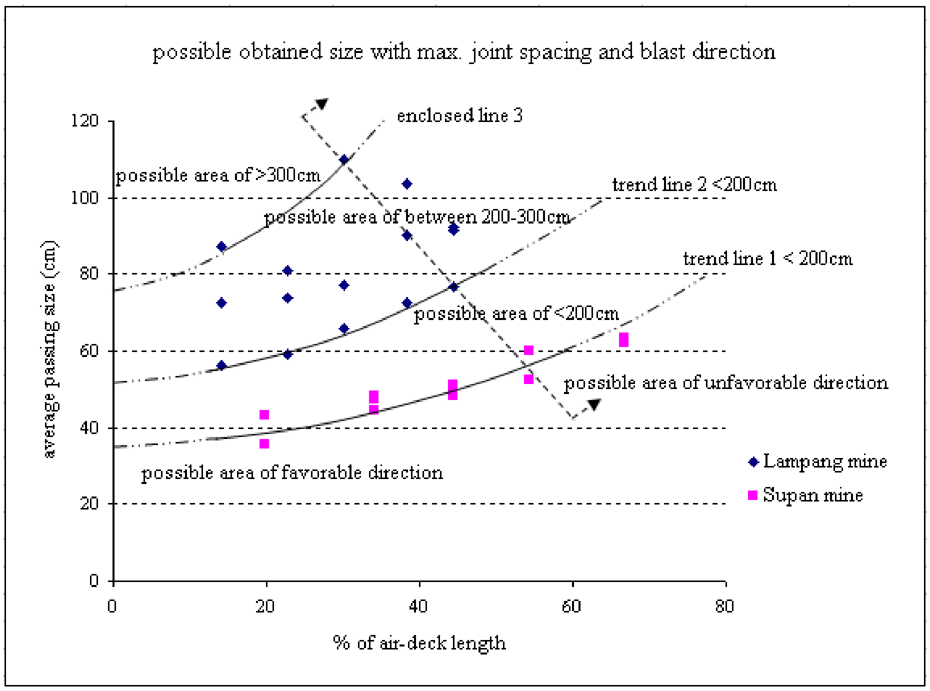

Figure 8 Areas of possible obtained an average 80% passing size from various air-deck lengths

By categorizing the data points and considering the parameters, possible areas of the average passing size can be obtained for different air-deck lengths as shown in Figure 8. For example, using an air-deck length of 20% can result in an average passing size of between 40-60cm if the maximum joint spacing is less than 200cm, or between 60-90cm if maximum joint spacing is more than 200cm. With the maximum joint spacing more than 300cm, an average passing size more than 90cm can be obtained. Unfavorable blasting directions will increase the average passing size clearly seen in an air-deck length of 40%, while the increasing of an average passing size obtained from using an air-deck length more than 50% is unclear. The small to medium opening size may vary from between 93cm (37 inches) to 112cm (44 inches), so an air-deck length of between 20-30% gives a high possibility that the average passing size will be less than 100cm. With favorable parameters, an air-deck size of up to 40% is worth testing in the quarry mines. However, other uncontrollable parameters still exist and may affect the blast fragmentation

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