AN APPROACH TO DETERMINING AND PREDICTING THE MEAN PARTICLE SIZE OF A MUCK PILE AFTER BLASTING ACCORDING TO SWEBREC PARTICLE SIZE DISTRIBUTION LAW BASED ON THE FORM OF SINGLE SPHERICAL CHARGE IN LABORATORY SCALE

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Abstract

In the manufacturing procedure at open-pit mines, tunnel construction or channel excavation activities, crushing rocks to a suitable grain size is one of the first technological steps, directly affecting the efficiency of the following steps in the overall process of drilling - blasting - loading - transporting. Currently, drilling-blasting is still an effective method in this field. However, controlling the blasting parameters to obtain a suitable mean particle size is still difficult for mining engineers and scientists. Hence, on a laboratory scale, this research carries out 6 blasting experiments based on the form of single spherical charge with a variety of powder factors but the same specimen condition, equations determining directly the Swebrec particle size distributions (PSDs) law are then established with the input data taken from sieve analysis, as a basis for establishing relationships among each pair of parameters such as the exponential coefficient of Swebrec PSD function b, the mean particle size D_{tb}, and the powder factor q. The results show that the obtained PSDs almost completely fit experimental data, coefficients of determination R^2 for the entire data set are greater than 0.99. Each pair of relationships among b, D_{tb}, and q has R^2 values greater than 0.98 with the addition of predictive significance. The calculations are modularized in Python programming language for use as a package. Compared to other existing methods, the final results can help quickly evaluate the quality of an explosion, appropriately calibrating explosion parameters to obtain the desired rock fragmentation without requiring knowledge of machine learning and statistics.

Keywords: *Rock fragmentation; particle size distribution (PSD); Swebrec function; comminution; mean particle size.*

1. Introduction

According to several research and blasting experts, the effective blasting energy to break rocks is only above 20%, and most of them cause negative impacts on the

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surrounding environment. Therefore, studying ways to increase the efficiency of rock breaking and reducing the negative impact of explosions is a regular goal for both mining engineers and scientists in the industry [1, 2].

In studying and controlling the power of blasting energy, besides the famous theoretical studies on the physical nature of an explosion [3, 4], experimental research is also a direction that attracts many researchers. Some studies have effectively extracted information about the explosive load from the shockwave pressure signals of underwater explosions containing much noise [5, 6]. Studies [7, 8] drew the experimental laws of funnel dimensions after an underwater explosion.

In another approach, when using statistical methods to study the blasting nature, the actual nature of the dynamic crushing process is not interesting, considering only the initial and final results of the destruction process [9]. The experimental specimens and powder factors are considered as the initial state of the environment. The rock fragmentation, represented by the particle size distribution after an explosion or the mean fragment size (D_{tb}), is the final state of the environment. Besides, many studies indicate that this is a synthetic crucial parameter, affected by all factors of the breaking dynamics process, it is considered as a fundamental criterion to evaluate the quality of an explosion [9, 10]. Accordingly, an explosion produces too large mean fragment sizes causing a cost increase of secondary fragmentation, while fragments after a blasting are too fine harming valuable minerals in the mining industry.

In Vietnam, there have been studies analysing the influence of various factors on D_{tb} such as the research of V. T. Hieu and D. T. Thang [11] is the number of open surfaces, that of L. V. Quyen and L. T. Hai [12] is specific machines and devices in an open-pit mine, the studies of D. T. Thang *et al*. [13-16] are the shape of a charge, and the distance from the center of an explosive charge [17]. The common point of studies above is that the parameter D_{tb} is calculated from the data taken from sieve analysis [18], this is a discrete analysis method with accuracy depending on the number and the size of sieves.

Other studies consider rock fragmentation in a more general sense when predicting particle sizes comply with certain PSDs such as Rosin-Rammler (RR), Gate-Gaudin-Schumann (GGS), or Swebrec [19-23]. These studies show that RR and GGS functions find it hard to describe the expansion and contraction at different regions in the actual PSD. By contrast, the Swebrec function has a more precise accuracy in reflecting the entire grain size range, from small scale to industry scale, from fine to coarse grain size. However, these studies only show results and analyze the fit of PSDs to experimental data, and lack of interpretation on the way to establishing PSDs and their relationship to D_{tb}.

In addition, advanced applications of artificial intelligence in predicting D_{tb} from discrete input data [24, 25] are undeniable, reaching very high accuracy. However, the type of these studies in addition to requiring extensive specialized knowledge, also requires a significant understanding of machine learning, statistics, and programming techniques, along with financial support to be able to collect enough data to deploy.

With small experiments, combined to inherit a part of the study of V. X. Bang and D. T. Thang [26], this article provides a method to directly determine PSDs as the Swebrec function form and relationships among pairs of parameters such as the exponential coefficient b, the mean particle size D_{tb}, and powder factor q, facilitating to fast evaluate the quality of an explosion and suitable selection of blasting parameters.

2. Experimental study

2.1. Experimental model

The experimental model is a semi-submersible tank with a depth of 300 (mm), sandbags are arranged around the tank wall. The experimental specimen is placed in the center of the tank. To collect rock fragments after an explosion, a corrugated iron panel is arranged around the specimen and a steel cover is placed on the tank top before detonation. The characteristics of the experimental model are as follows:

Experimental specimens are made of cement mortar, cubic form with a shape of 200 × 200 × 200 (mm), reaching grade M100 (B7.5) in the case of this study. TEN is used as explosives, which are placed at the center of specimens and detonated by an equivalent single spherical charge as electrical detonator No. 8, the blasting machine is MFB-200 from China. The equivalent-TNT total mass of both explosives and detonators are 4.8, 7.2, and 12 (g) in 3 new experiments, corresponding to powder factors of 0.6, 0.9, and 1.5 (kg/m^3), respectively.

Inheriting data from the previous study [26], forming a data set of 6 explosions with powder factors are 0.6, 0.9, 1.2, 1.5, 1.8, and 2.1 (kg/m^3), respectively. Three new experiments are for experimental model validity, supplementing photos of muck pile after blasting. The experimental model is illustrated in Fig. 1 as follows:

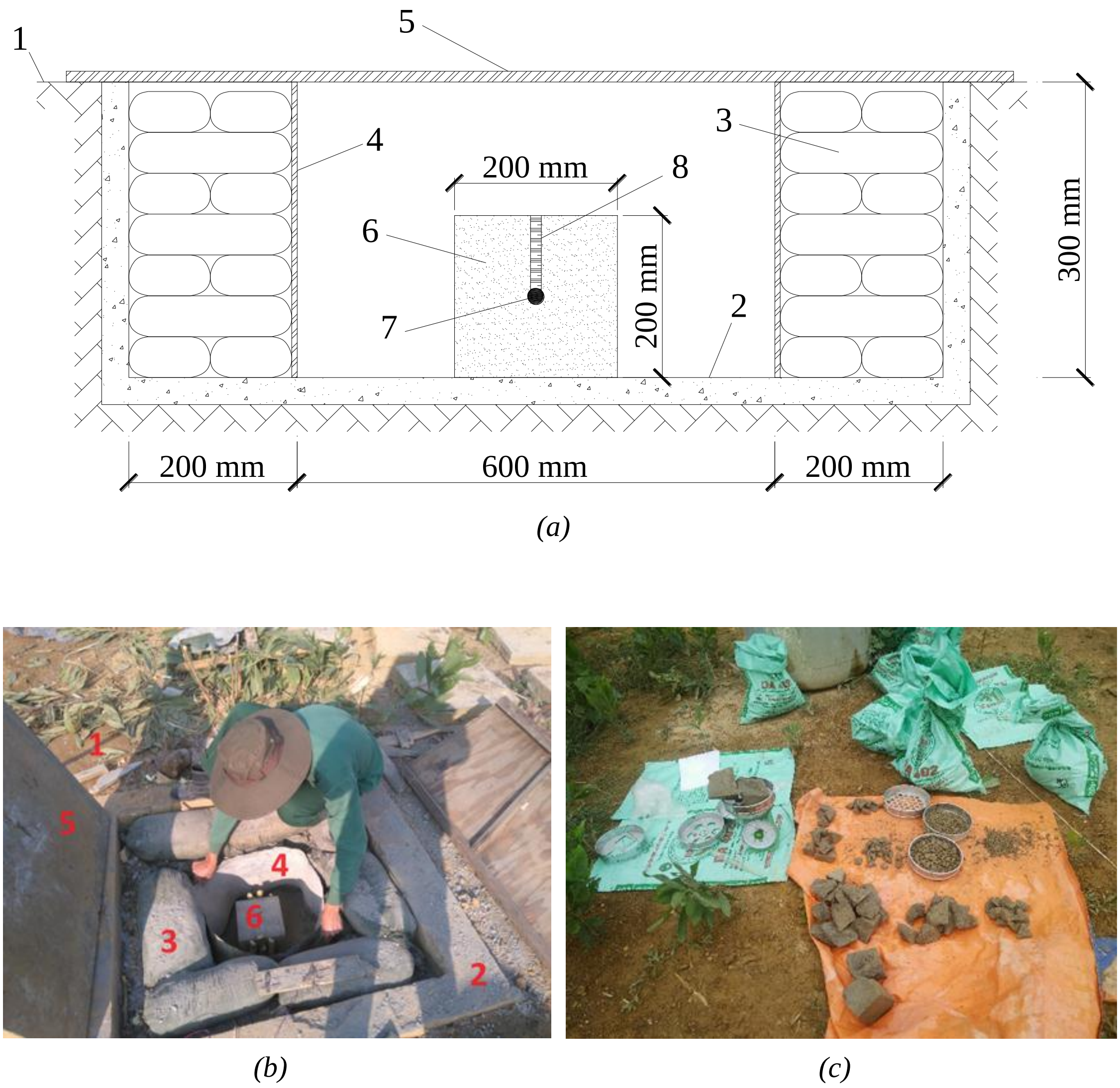


Fig. 1. Experimental model (a) and actual photos in the field (b, c)

1 - surface; 2 - concrete cover; 3 - sand bags; 4 - corrugated sheet; 5 - steel cover;

6 - experimental specimen; 7 - explosives charge and detonator; 8 - stemming materials.

2.2. Experimental data collection

Blasting products are analysed by sieves with sizes of 2.5, 5, 10, 20, 30, 40, 50, 60, and 70 (mm), respectively, obtaining 10 groups of average particle size following sieve size. Each group is then weighted as shown in Fig. 1(c), and information is summarized as a cumulative weight percentage. The data of 6 explosions is listed in Table 1 as follows:

Table 1. The table of cumulative weight percentage

No.	Sieve sizes *x*, mm										
	Interval	**< 2.5**	**2.5-5**	**5-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**> 70**
	Mean	**1.25**	**3.75**	**7.50**	**15**	**25**	**35**	**45**	**55**	**65**	**80**
1	$q = 0.6$	0.026	0.055	0.096	0.138	0.196	0.266	0.394	0.490	0.659	1.000
2	$q = 0.9$	0.045	0.088	0.164	0.246	0.337	0.431	0.555	0.691	0.833	1.000
3	$q = 1.2$	0.108	0.139	0.191	0.274	0.398	0.510	0.616	0.742	0.880	1.000
4	$q = 1.5$	0.176	0.271	0.385	0.493	0.586	0.682	0.787	0.863	0.949	1.000
5	$q = 1.8$	0.151	0.283	0.408	0.530	0.623	0.775	0.838	0.894	0.976	1.000
6	$q = 2.1$	0.166	0.324	0.438	0.606	0.771	0.859	0.912	0.947	0.979	1.000

In Table 1, experiments No. 1, No. 2, and No. 4 are novel-implementation explosions, the rest experiments are inherited from the previous study [26].

3. Methodology

3.1. Establishing Swebrec particle size distribution function

According to the results of J. A. Åström *et al.* [27, 28], the fragmentation phenomenon can be modelled using statistical principles and comply with universal mathematical laws such as exponential function and independent of the system scale. Swebrec function is proposed by F. Ouchterlony *et al.* [29] to describe the PSD of a muck pile after blasting.

$$\hat{P} = \hat{P}_{(x)} = \frac{1}{1 + \left[\dfrac{\ln\left(x_{\max}/x\right)}{\ln\left(x_{\max}/x_{50}\right)}\right]^b} \tag{1}$$

It can be seen that the particle size distribution is characterized by its exponential coefficient *b*, the article provides a direct method for determining this parameter.

Setting $\bar{x} = \dfrac{\ln\left(x_{\max}/x\right)}{\ln\left(x_{\max}/x_{50}\right)}$, and considering a lost function for variable *b*, including all average sieve sizes *x* (containing size 0) in Table 1 as follows:

$$L(b) = \frac{1}{2m}\sum_{i=1}^{m}\left(P_{(x_i)} - \hat{P}_{(x_i)}\right)^2 = \frac{1}{2m}\sum_{i=1}^{m}\left(P_i - \hat{P}_i\right)^2 = \frac{1}{2m}\sum_{i=1}^{m}\left(P_i - \frac{1}{1+\bar{x}_i^{\,b}}\right)^2 \tag{2}$$

In this step, finding the suitable PSD function is finding exponential coefficient *b* to minimize Eq. (2). Applying the chain rule law, carrying out partial derivative for *b*, obtaining:

$$\frac{\partial L}{\partial b} = \frac{1}{m}\left[\left(P_1 - \frac{1}{1+\bar{x}_1^{\,b}}\right)\left(\frac{\bar{x}_1^{\,b}\ln\left(\bar{x}_1\right)}{\left(1+\bar{x}_1^{\,b}\right)^2}\right) + \ldots + \left(P_m - \frac{1}{1+\bar{x}_m^{\,b}}\right)\left(\frac{\bar{x}_m^{\,b}\ln\left(\bar{x}_m\right)}{\left(1+\bar{x}_m^{\,b}\right)^2}\right)\right]$$

$$=\frac{1}{m}\left[\frac{P_1\overline{x}_1^{\,b}\ln(\overline{x}_1)}{\left(1+\overline{x}_1^{\,b}\right)^2}-\frac{\overline{x}_1^{\,b}\ln(\overline{x}_1)}{\left(1+\overline{x}_1^{\,b}\right)^3}+...+\frac{P_m\overline{x}_m^{\,b}\ln(\overline{x}_m)}{\left(1+\overline{x}_m^{\,b}\right)^2}-\frac{\overline{x}_m^{\,b}\ln(\overline{x}_m)}{\left(1+\overline{x}_m^{\,b}\right)^3}\right]$$

$$=\frac{1}{m}\left[\sum_{i=1}^{m}\frac{P_i\overline{x}_i^{\,b}\ln(\overline{x}_i)}{\left(1+\overline{x}_i^{\,b}\right)^2}-\sum_{i=1}^{m}\frac{\overline{x}_i^{\,b}\ln(\overline{x}_i)}{\left(1+\overline{x}_i^{\,b}\right)^3}\right] \tag{3}$$

Equation (3) must vanish, supplementing infinitesimal numbers into some specific positions, the parameter b is the solution of the following Eq. (4):

$$\sum_{i=1}^{m}\frac{P_i\overline{\overline{x}}_i^{\,b}\ln\left(\overline{\overline{x}}_i+\varepsilon\right)}{\left(1+\overline{\overline{x}}_i^{\,b}\right)^2}-\sum_{i=1}^{m}\frac{\overline{\overline{x}}_i^{\,b}\ln\left(\overline{\overline{x}}_i+\varepsilon\right)}{\left(1+\overline{\overline{x}}_i^{\,b}\right)^3}=0 \text{ with } \overline{\overline{x}}_i=\frac{\ln\left[(x_{\max}+\varepsilon)/(x_i+\varepsilon)\right]}{\ln\left(x_{\max}/x_{50}\right)} \tag{4}$$

where P_i or $P_{(x_i)}$ is cumulative distribution up to i^{th} fragment size from the sieve analysis, $\hat{P}_i$ or $\hat{P}_{(x_i)}$ is cumulative distribution up to i^{th} fragment size calculated from hypothesis (1), $x_{\max}$ is the largest fragment size (mm), x_{50} is median or size of 50% passing for which $P(x_{50}) = 0.5$, x is mesh size of sieve, b is the exponential coefficient of Swebrec function; m is the number of the mean of sieve sizes (including size 0), ε is an infinitesimal number.

3.2. Determining the mean particle size D_{tb}

The mean particle size D_{tb} is the mathematical expectation of the particle size x

$$D_{tb}=\int_0^1 xd\left[P_{(x)}\right]=\int_0^{x_{\max}} xp_{(x)}dx=D_{tb}=\int_0^{x_{\max}}\frac{b\ln^b\left(x_{\max}/x_{50}\right)\ln^{b-1}\left(x_{\max}/x\right)}{\left[\ln^b\left(x_{\max}/x_{50}\right)+\ln^b\left(x_{\max}/x\right)\right]^2}dx$$

$$=\sum_{i=1}^{iter}\frac{b\ln^b\left(x_{\max}/x_{50}\right)\ln^{b-1}\left(x_{\max}/(x_i+\varepsilon)\right)}{\left[\ln^b\left(x_{\max}/x_{50}\right)+\ln^b\left(x_{\max}/(x_i+\varepsilon)\right)\right]^2}\Delta x \text{ with } \Delta x=x_{\max}/iter \tag{5}$$

where D_{tb} is the mean particle size (mm), x is particle size (mm), $P(x)$ is PSD function obtained from Eq. (1), $p(x)$ is probability distribution of particle size x, obtained by partial derivative $P(x)$ for x, b is exponential coefficient of PSD, ε is an infinitesimal number, iter - iteration, chosen iter = 1000000.

3.3. Establishing the relationship between powder factor q and exponential coefficient b of PSD

It can be seen that the relationship between powder factor q and exponential coefficient b of PSD complies with a d-degree polynomial function. This is a simple regression function that can be established by various mathematical tools. However, because all calculation processes in this article are carried out in Python programming language, the multivariable regression method, which was proposed by D. T. Thang and V. T. Lam [7, 8], is applied for the circumstance that has only one independence variable as powder factor *q* and one dependence variable as exponential coefficient *b*. The relationship is as follows:

$$b=\sum_{i=0}^{d}\theta_i q^i \text{ , with } d = 3\text{, obtaining } b=\theta_0 q+\theta_1 q^1+\theta_2 q^2+\theta_3 q^3 \quad (6)$$

where *b* is exponential coefficient from Eq. (4); *q* is powder factor (kg/m^3); θ_i are variables of Eq. (6); *d* is degree of Eq. (6), chosen as 3.

3.4. Establishing the relationship between the mean particle size D_{tb} and powder factor *q*

Establishing the relationship between the mean particle size D_{tb} and powder factor as exponential function as follows:

$$q=\theta_4-\theta_5\ln\left(D_{tb}\right) \quad (7)$$

where *q* is powder factor (kg/m^3); D_{tb} is mean particle size (mm); θ_4 and θ_5 are variables for Eq. (7).

Vanishing the partial derivative of Eq. (7) for variables θ_4 and θ_5, obtaining parameters θ_4 and θ_5 are solutions of the following equations, respectively:

$$\sum_{i=1}^{n}q_i\ln\left(D_{tb_i}\right)-\sum_{i=1}^{n}\theta_4\ln\left(D_{tb_i}\right)+\sum_{i=1}^{n}\theta_5\ln^2\left(D_{tb_i}\right)=0 \quad (8)$$

$$\text{with } \theta_4=\left[\sum_{i=1}^{n}q_i+\sum_{i=1}^{n}\theta_5\ln\left(D_{tb_i}\right)\right]\Big/n \quad (9)$$

where *n* is total number of experiments, *n* = 6; other parameters are chosen as Eq. (7).

3.5. Establishing the relationship between the mean particle size D_{tb} and exponential coefficient b of PSD

Substituting Eq. (7) into Eq. (6), obtaining the relationship between the mean particle size D_{tb} and exponential coefficient *b* of PSD as follows:

$$b=\sum_{i=0}^{d}\theta_i\left[\theta_4-\theta_5\ln\left(D_{tb}\right)\right]^i \quad (10)$$

where *b* is exponential coefficient *b* of PSD; D_{tb} is mean particle size, (mm); θ_0, θ_1, θ_2, θ_3, θ_4, θ_5 are calculated parameters from Eqs. (7), (8), and (9), respectively.

4. Results and analysis

Equation (5) can be solved by Riemann sum, obtaining variable D_{tb}. Eqs. (4), (8), and (9) are transcendental that can be resolved by variable approximation techniques such as bisection or Newton-Raphson methods, though, obtaining variables b, θ_4, θ_5. On the other hand, variables θ_0, θ_1, θ_2, θ_3 of Eq. (6) can be resolved by gradient descent technique. Consequently, all variables b, D_{tb}, θ_0, θ_1, θ_2, θ_3, θ_4, θ_5 can be found.

All obtained PSDs are shown in Fig. 2. Specifically, PSDs are determined under Eq. (4), while D_{tb} is determined under Eq. (5). Detailed analysis results of PSDs in Fig. 2 are listed in the following Table 2.

Table 2. Summary table of PSD parameters

No.	**Powder factor, *q* (kg/m³)**	**Exponential coefficient, *b***	**Coefficient of determination, R^2**	**D_{tb} from PSD (mm)**	**D_{tb} from sieve analysis (mm)**	**Differences of D_{tb} %**
1	0.6	1.219	0.9982	49.081	52.579	6.653
2	0.9	1.375	0.9978	38.505	42.398	9.182
3	1.2	1.375	0.9993	34.212	38.581	11.325
4	1.5	1.355	0.9950	22.666	27.085	16.314
5	1.8	1.582	0.9934	19.677	24.166	18.576
6	2.1	2.015	0.9982	15.655	19.359	19.130

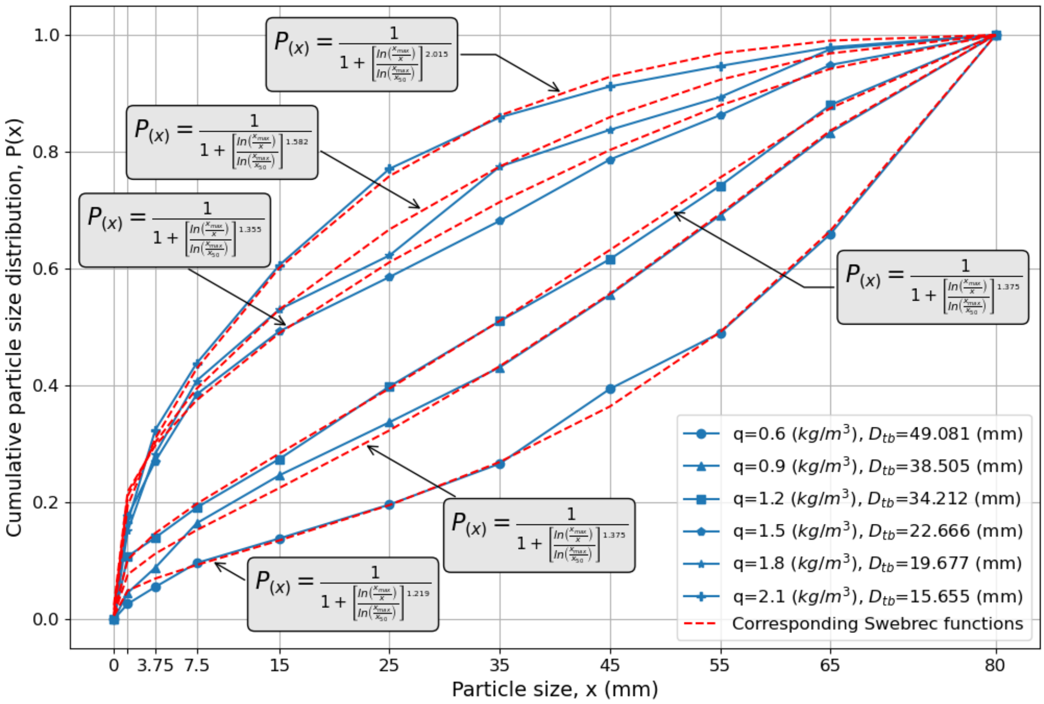
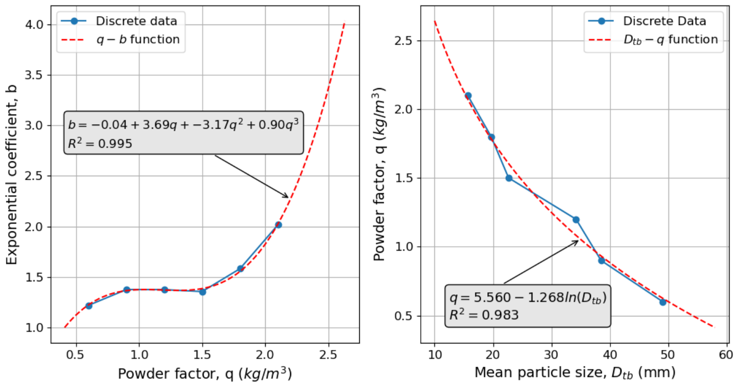


Fig. 2. Analysis results of PSDs corresponding to 6 blasting experiments.

According to F. Ouchterlony [30], a plethora of cylinders of rocks and mortar were blasted and sieved in the LESS FINES project of the European Union. This is a basis to indicate that the exponential coefficient b lies in the closed interval between 1 and 4. With this b limit, the article establishes and predicts pair relationships among blasting parameters, including q - b under Eq. (6), q - D_{tb} under Eqs. (7), (8), (9), D_{tb} - b under Eq. (10) as shown in the following figures.



(a) *(b)*

Fig. 3. Relationship of q - b (a) and D_{tb} - q (b) with the value range of $1 \le b \le 4$.

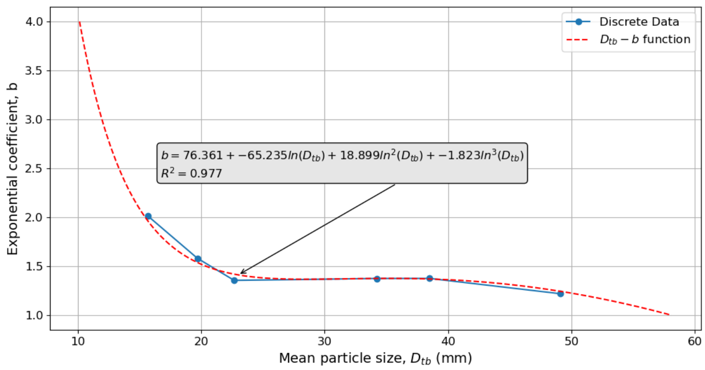


Fig. 4. Relationship between D_{tb} - b, corresponding to the value range of $1 \le b \le 4$.

All established equations from (4) to (10), combined with Fig. 2, 3, 4, allow a summary table of the value range for 3 blasting parameters b - q - D_{tb} in a certain value range is established, corresponding to the case study of the article as shown in Table 3. Accordingly, one-dimensional interpolation can be applied to find intermediate values.

For quantitative analysis, from Fig. 2 and Table 2, it can be seen that Swebrec PSDs almost completely fit the obtained data from sieve analysis, with accuracies above 0.99 for all 6 blasting experiments. However, the mathematical mean particle sizes calculated from PSDs are fairly different from that of sieve analysis, the more powder factors, the higher the differences, from 6.653% for q = 0.6 (kg/m^3) to 19.130% for q = 2.1 (kg/m^3). Basically, this is consistent with the actual law when a large powder factor increases comminution, causing more fine grain, which is hard to accurately analyse with low-resolution sieves.

From Fig. 3(a), it can be seen that the relationship q - b is a monotonic non-decreasing function, meaning that the higher the coefficient b, corresponding to the PSD in Fig. 2 is more skewed to the left, the larger the powder factor q, this is opposite of GGS distribution which was previously indicated [26]. Fig. 3(b) shows that the relationship q - D_{tb} is a monotonic non-increasing function, meaning that the higher the powder factor q, the lower the mean particle size D_{tb}, and vice versa. In addition, Table 3 and Fig. 3 also provide predicted information when the value range of b lies into the closed interval from 1 to 4, the value of q fluctuates between 0.41 to 2.60 (kg/m^3). Similarly, Table 3 and Fig. 4 provide information about the relationship D_{tb} - b, indicating that b increases when D_{tb} decreases, with the value range of D_{tb} lying in the interval between 10 and 58 (mm).

Table 3. Summary table of value range for 3 blasting parameters b - q - D_{tb}

The range of *b* values	**The range of *q* values (kg/m^3)**	**The range of D_{tb} values (mm)**
1.00	0.411	58.098
1.25	0.632	48.784
1.50	1.739	20.383
2.00	2.090	15.454
2.50	2.278	13.325
3.00	2.416	11.946
3.50	2.529	10.929
4.00	2.625	10.130

5. Conclusion and recommendation

The mean particle size of a muck pile after blasting is a crucial criterion for evaluating the quality of an explosion. The article established a method determining PSD under the Swebrec function form of a muck pile after blasting and also predicted the value range of blasting parameters b - q - D_{tb} based on the original range of $1 \leq b \leq 4$ [30]. The obtained mean particle sizes D_{tb} between PSDs and sieve analysis have differences from 6.653% to 19.13%, showing that grain size plays an important role in the total particle distribution. The obtained PSDs with the input data taken from sieve analysis fit completely, with all R^2 values above 0.99. All obtained relationships, in addition to having R^2 values greater than 0.98, also have predictive significance. Moreover, all output results can be explicitly calculated from equations (4) to (10) interpreted in the article without any prior knowledge of machine learning techniques for usage by all mining engineers. Besides, the methodology presented in this article can be reused to establish regression curves that best fit with data in terms of mathematical optimization under a prescribed function, this can be considered as an interesting direction in experimental blasting research.

All calculations in this article are modulized as a package with Python programming language, it is considered as a solver with the input data taken from sieve analysis, including the average sieve size x, percentage passing through at particle size x, $P(x)$, and powder factor q. The output includes parameters such as Swebrec PSD and its exponential coefficient b, mean particle size D_{tb}, and pair relationships among 3 parameters b - q - D_{tb}. The results of this article can help mining engineers quickly evaluate the quality of an explosion, reasonably calibrating parameters to improve the quality of rock breaking as desired in the case study of blasting 6-surface specimens.

Recommendation: This solver can be applied not only to the input data taken from sieve analysis, which takes much time and effort to obtain but also to a digital image of a muck pile after blasting that fragments can be automatically segmented.

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MỘT CÁCH TIẾP CẬN ĐỂ XÁC ĐỊNH VÀ DỰ ĐOÁN CỠ HẠT TRUNG BÌNH CỦA ĐỐNG ĐÁ SAU NỔ THEO QUY LUẬT PHÂN BỐ CỠ HẠT SWEBREC DỰA TRÊN DẠNG LƯỢNG NỔ ĐƠN HÌNH CẦU VỚI QUY MÔ PHÒNG THÍ NGHIỆM

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Tóm tắt: Trong quy trình sản xuất tại các mỏ lộ thiên, thi công đường hầm hay đào luồng, làm tơi đất đá tới một cỡ hạt phù hợp là một trong những khâu công nghệ đầu tiên, ảnh hưởng trực tiếp đến hiệu quả của các khâu tiếp theo trong quy trình tổng thể khoan - nổ - bốc xúc - vận tải. Hiện tại, phương pháp khoan - nổ mìn vẫn là một giải pháp hiệu quả trong ngành. Tuy nhiên, việc điều khiển các tham số nổ mìn để thu được cỡ hạt trung bình phù hợp là một công việc khó khăn không chỉ với các kỹ sư mỏ mà còn với những nhà khoa học trong ngành. Do đó, với quy mô phòng thí nghiệm, nghiên cứu này thực hiện 6 thí nghiệm nổ dựa trên dạng lượng nổ đơn hình cầu với chỉ tiêu thuốc nổ khác nhau trên cùng một điều kiện mẫu, sau đó xây dựng các phương trình xác định trực tiếp quy luật phân bố cỡ hạt Swebrec thông qua dữ liệu đầu vào từ phân tích sàng, từ đó xây dựng từng cặp quan hệ giữa các tham số như hệ số mũ của hàm Swebrec b, cỡ hạt trung bình D_{tb} và chỉ tiêu thuốc nổ q. Kết quả cho thấy hàm phân phối gần như khớp hoàn toàn với số liệu thí nghiệm, tất cả 6 bộ dữ liệu đều có hệ số xác định R^2 lớn hơn 0,99. Các cặp quan hệ giữa b, D_{tb}, q ngoài việc đều có hệ số xác định R^2 lớn hơn 0,98, còn mang ý nghĩa dự đoán. Các tính toán được mô đun hóa bằng ngôn ngữ lập trình Python để sử dụng như một gói. So với các phương pháp khác hiện có, kết quả của bài báo có thể giúp đánh giá nhanh chất lượng một vụ nổ, hiệu chỉnh các tham số nổ phù hợp để thu được mức độ đập vỡ đất đá theo ý muốn mà không yêu cầu kiến thức về học máy, thống kê.

Từ khóa: *Mức độ đập vỡ đất đá; phân phối cỡ hạt (PSD); hàm Swebrec; đập vụn; cỡ hạt trung bình.*

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