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A Review of the Blast Fragmentation Analysis Techniques used in Surface Mines

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Abstract

Fragmentation refers to the process of breaking solid in-situ rock masses into smaller pieces during excavation or material handling operations. The fragment size distribution and degree of fragmentation within the blasted rock mass stand as a critical aspect for optimizing the efficiency of loading, transportation, crushing, and milling operations. The analysis of blast fragmentation analysis is done by several existing modern techniques which include the visual analysis method, photogrammetric method, and image analysis method, etc. In this study, all the blast fragmentation techniques are reviewed, and the advantages and disadvantages of all the methods are discussed. Along with that, a blast fragmentation analysis is conducted for the rock pile images of a blasting site collected from Dongri Buzurg Mine (MOIL), India using the image processing technique in WipFrag software. The feasibility of the blasting patterns is judged based on the uniformity coefficient (Cu) and the coefficient of gradation (Cg) which are found to be 4.47 and 0.94 respectively. The fragmentation for the muck pile is found to be uniform and well-graded for the blast site and the methodology used is found to be simple yet effective for the analysis.

Keywords: *Coefficient of Gradation, Fragmentation, Fragment Size Distribution, Image Analysis Technique, Uniformity Coefficient*

1.0 Introduction

Blasting operations play a pivotal role in the economic dynamics of the mining industry. The characteristics of the blasted rock, including muck pile formation and fragment sizes, hold significant importance as they influence downstream processes, ranging from material transport to grinding[1-5]. The cost-effective production of a mine depends hugely on achieving optimal rock fragmentation through well-designed blasting patterns[6]. The Larger fragments can hinder equipment loading and hauling, leading to an increased frequency of sorting of oversized boulders and the need for secondary blasting, thereby increasing the mining costs. On the other hand, the excessive generation of fines is undesirable due to its impact on explosive consumption. Therefore, most of the mines desire a consistent fragment distribution that minimizes both fines and oversized fragments which will be key in optimizing the overall mining costs.

The ideal outcome of blasting operations is considered to be reached when a maximum percentage of fragments falls within the desired size range[7]. Achieving this requires a blast design with optimized controllable parameters so that the effects of the uncontrollable parameters can be minimized. The optimized fragment size distribution can be achieved after a series of trial blasts from which

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the controllable blasting parameters will be known. Quantifying fragmentation involves measuring the fragmentation to predict necessary adjustments in the blast design. These adjustments, when implemented, result in fragmentation that meets the required standards[8].

In this paper, a review of all the blast fragmentation techniques is discussed highlighting the advantages

Table 1. A review of all the fragmentation techniques used in surface mines

Techniques	Description	Advantage/ Disadvantage
Screening or Sieving[9]	The process involves passing rock fragments through various sieves with different mesh sizes to classify them according to size. The blast is characterized inferred by counting the number of fragments within each size category.	Direct and precise approach, but time-consuming and costly
Oversize boulder count method[10]	The oversized boulders that are beyond the capacity of shovels for handling are manually counted.	Useful for small-scale blasts, but manual method.
Shovel Loading Rate Method[11]	This method is particularly used for making precise comparisons of blast fragmentations for a series of blasts in a mine. It operates under the assumption that faster mucking indicates superior fragmentation.	Not effective for undersized fragment analysis
Visual Analysis Method[12]	This is a subjective evaluation approach in which the post-blast muck is visually inspected immediately after blasting.	Not reliable
Photogrammetry Method[13]	In this method, the calculation of fragmentation volume through three-dimensional measurements is done with the help of photographs.	Precise and reliable
Image Analysis Technique[14]	This analysis of blast fragmentation provides the size distribution without causing any disruptions or interference in production and significantly reducing the impact of sampling errors.	Enhanced Precision and cost-effective efficient method
Kuz-Ram Empirical model[15,16]	The most used empirical model to determine the mean fragmentation size of a blast. $X = A \times \left(\frac{V}{Q}\right)^{0.8} \times (Q)^{0.167} \times \left(\frac{E}{115}\right)^{-0.633}$ X = Mean fragment size, cm V = Volume of blasted rock, m^3 Q = Mass of explosive charge per hole, kg. E = Weight strength relative to ANFO A = Rock factor (varying between 0.8 and 22, depending on hardness and structure)	The validity of the formula can be questionable for different sites.

and disadvantages and the conditions at which each method will be suitable. The image processing technique is the most recent technique used in mines for blast fragmentation analysis. This study analyzes the blast fragmentation at three different sites for the same blasting pattern in a manganese ore mine in India and the results are judged based on the uniformity Coefficient (Cu) and the coefficient of Gradation (Cg).

2.0 Blast Fragmentation Measurement Techniques

Quantifying fragmentation on a large scale presents a complex challenge, leading to extensive research employing various methods and tools for measurement. Traditional techniques for assessing fragmentation measurement include methods like sieving or screening, the over-size boulder count approach, and the shovel loading rate method. In contrast, modern methodologies include visual analysis, photogrammetry, and image analysis techniques.

3.0 Evaluation of Blast Fragmentation Performance

The blast fragmentation analysis can be evaluated based on the uniformity of the muck pile generated after the blasting. This step is very crucial as the requirement of further secondary blasting or modifications in the blast design can be decided based on the analysis results. The blast fragmentation is analyzed again by a few coefficients known as the Uniformity Coefficient (Cu) and Coefficient of Gradation (Cg).

Based on a great number of tests with filter sands, a uniformity coefficient was formulated, which is a convenient mechanical analysis to express the grain-size characteristics of soil that indicate the dominant soil fraction[17].

$$C_u = D_{60}/D_{10} \quad (1)$$

where,

D_{60} is the grain size corresponding to 60% of the sample passing by weight

D_{10} is the grain size corresponding to 10% of the sample passing by weight

Similarly, the coefficient of Gradation is used to measure the shape of the particle size curve. Cg around 1-3 indicates the distribution of fragments[18].

$$Cg = (D_{30})^2/ (D_{60})*(D_{10}) \quad (2)$$

Table 2. C_u and Grain size characteristics

C_u	Grain size characteristics
$C_u < 5$	Very uniform
$C_u = 5\text{-}15$	Medium uniform
$C_u >15$	Non-uniform

4.0 Quarrying and Surface Mine Operations

The blast fragmentation analysis in surface mining and quarrying is different in terms of optimizing the blast design. The blasting operation in a large open-pit mine is very costly and that is the main reason why this requires frequent quantitative feedback regarding its performance. Fragmentation analysis methods offer a means to quantitatively measure blast performance, thus facilitating the effective optimization of the blasting process.

In quarry operations, blast optimization is also a concern, but maintaining rigorous quality control over the full-size fragment distribution of the rock piles mostly handles the uniform fragmentation. The method which is commonly used for this assessment is the image processing method. The alternative approaches to this are mostly subjective and time-consuming. The visual analysis and the photographic comparison method are mostly used in quarry operations during the loading of materials after the blasting operation is done. Even though the photographic comparison method[16] provides little advantages over the visual analysis technique but still the entire process is still time-consuming. As for fragment size distribution quality control, the conventional practice involves daily sampling and screening, which, unfortunately, fails to offer rapid feedback and may introduce substantial sampling errors.

5.0 Constraints

Frequently, the most significant challenge in an opencast mining operation involves capturing photographs without disrupting production activities. This often results in less-than-ideal photographic sampling schemes. The blasted materials can be sampled at various points, such as before excavation (at the muck pile surface), during excavation (at the working face), while in haul trucks, or on a conveyor (post-crushing). These methods may introduce errors due to subjective judgments about the materials to be photographed, as more material may be visible than can be sampled. To address this, the radial lines sampling method can be employed for rock pile surface sampling. The haul truck sampling can be utilized and it is advantageous as camera locations can be fixed to positions that do not disrupt production and can be automated, although the impact of material sorting during loading should be considered. The conveyor sampling also does not disrupt the production but is applicable primarily when sampling the crushed material, as is the case in quarrying operations.

Another significant challenge involves the surrounding environment while capturing the photographs which affects the quality of pictures. Similarly, inadequate lighting, shadows, and dust are also a few of the factors to control in surface mines while capturing the images of rock piles because of which the photographs may come with poor quality and low contrast and ultimately the fragmentation analysis will be affected.

6.0 Blast Fragmentation Analysis: A Case Study

6.1 About the Mine

The blast fragmentation analysis study is done at the Dongri Buzurg mine, MOIL, Maharashtra, India.

The strike length of the ore horizon is 2150 m trending E-W in the eastern and central part and ENE-WSW in the western part dipping moderately to steeply to the southern part. The thickness of the manganese deposit varies from 2 to 30 m.

Considering the mineralization and disposition of manganese ore, the extraction process is being done using the horizontal slicing method with the combination of the diesel-hydraulic shovel and rear dumper. The current mining method details are given below in Table 3.

6.2 Drilling and Blasting Operation Details

The rock mass conditions for the deposit are classified as poor to good as the RMR value ranges between 23 to 68. The current blasting practice involves the use of emulsion explosives and detonating fuse initiation with cord relay delay detonators. The blast pattern is usually 2.5 m x 2.0 m (spacing x burden) with a charge factor of 0.4 kg/m^3. This specific blast pattern with bottom-hole initiation is found

Figure 2. Working faces at Dongri Buzurg Mine, MOIL, India.

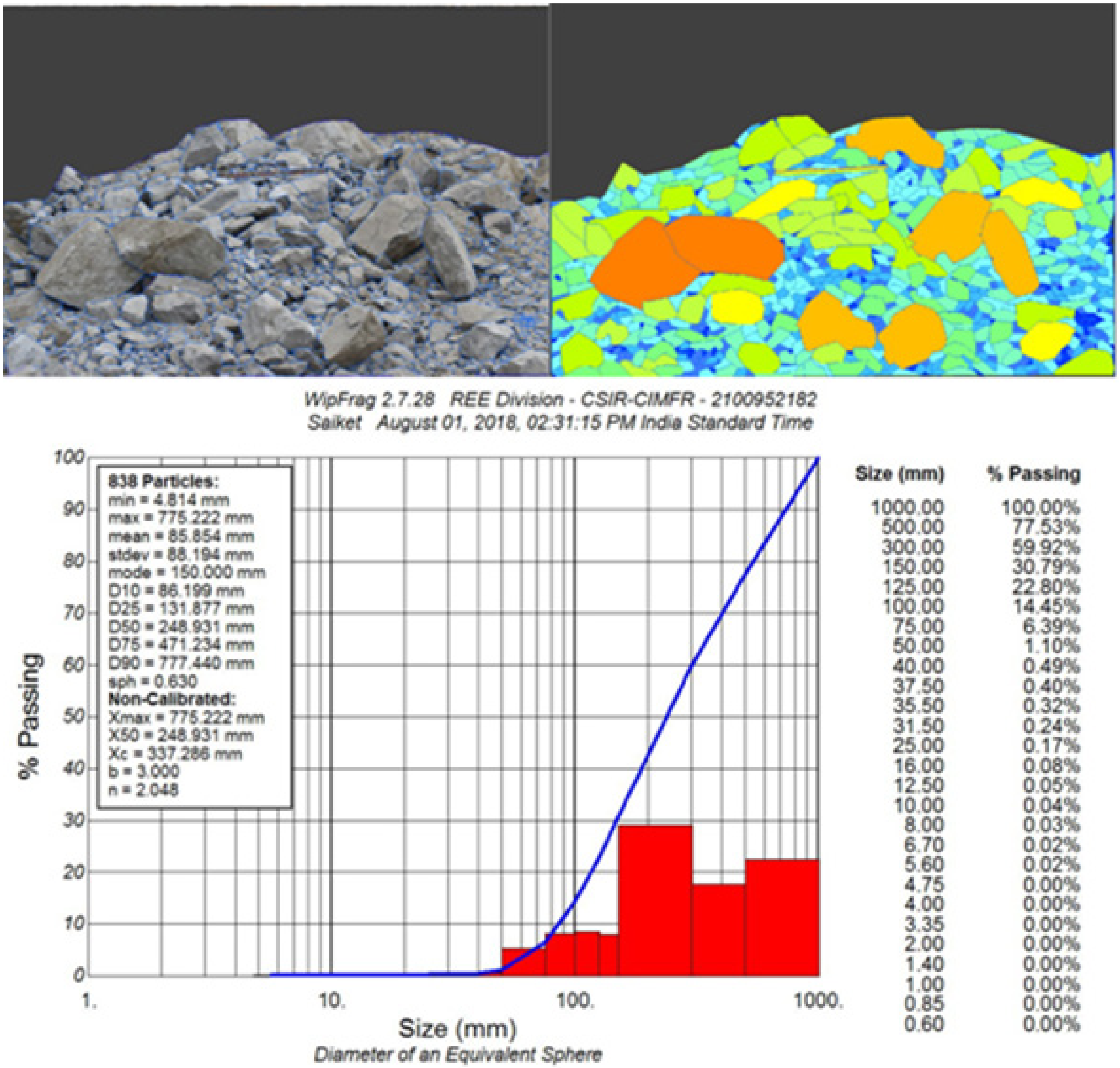

Figure 2. Netting, contouring and cumulative size distribution curve of the fragmented muck pile at Site-1.

to be optimum for this case and the blasts done in the working ore benches with this pattern produced uniform fragmentation. In some cases, if the lumps are required, then a blast pattern of 3.0 m spacing and 2.5 m burden is adopted and the charge factor of 0.41 kg/m^3 is kept.

6.3 Blast Fragmentation Analysis

The blast fragmentation analysis for the mine is done using the WipFrag image analysis software using the input photographs of the muck pile which are taken just

Table 3. Mining method details at Dongri Buzurg Mines, (MOIL)

Parameters	Size/Description
Current mining method	Opencast: Shovel dumper combination
Recovery factor	80%
Cut-off grade	25% Mn
Ultimate pit depth	205 mRL
Bench height	10 m
Bench width (working)	20 m
Bench width (non-working)	12 m
Bench slope angle	70^0
Overall pit slope angle	$32^0/33^0$
Stripping Ratio	1:9

Table 4. Blasting parameters

Blast Parameters	Size/Description
Blast Pattern	Staggered (Toe Blast)
Type of explosive	Emulsion
Bench Height	10 m
Burden	2.5 m
Spacing	3 m
Total charge	94.5 Kg
No. of rows	2
No. of columns	17
No. of Holes	34
Charge	Primer
Charge factor	0.4 Kg/m^3
Charge per hole	2.78 kg
Diameter of hole	100 mm
Stemming Length	2.5 m

after the blasting operation is performed. The analysis encompasses both single and multiple-image techniques.

The single-image analysis method provides the mean fragment size for a size distribution for a muck pile, while the rock fragmentation optimization can only be achieved from the multiple-image analysis technique.

The outcomes of individual single-image analyses are presented alongside their respective sample photographs.

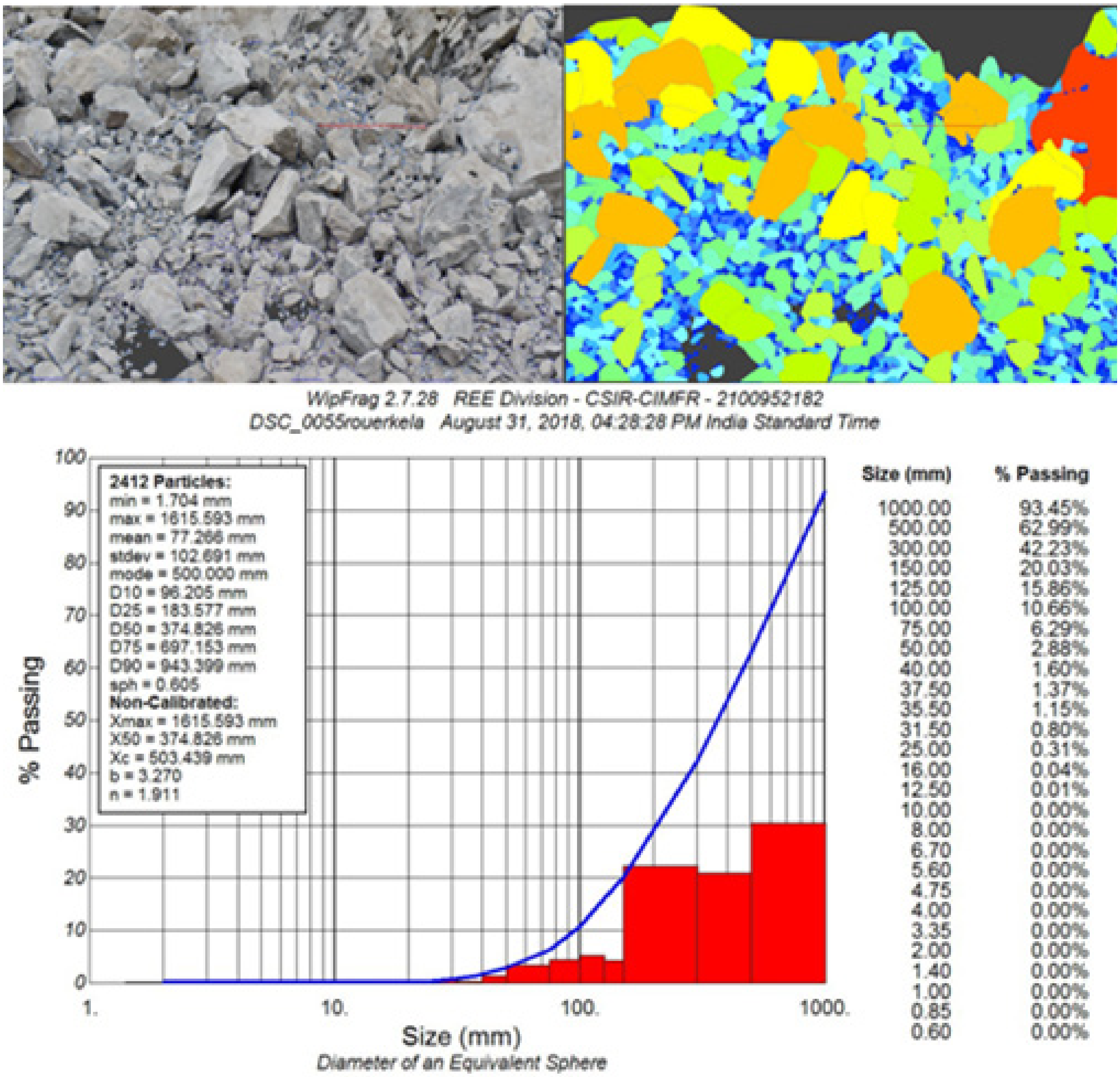

Figure 3. Netting, contouring and cumulative size distribution curve of the fragmented muck pile at Site-2.

It is important to note that the single-image analysis provides a cumulative representation of rock sizes through WipFrag. However, because the digital images used for analysis cannot fully reveal the fragmentation conditions beyond the muck pile surface, results from individual muck pile sample analyses are not considered definitive. Therefore, an averaged result is generated. This average result offers a higher level of precision, aiding in the prediction of optimal blast parameters.

To gain a deeper insight into blast fragment distribution, the uniformity coefficient and coefficient of gradation are computed.

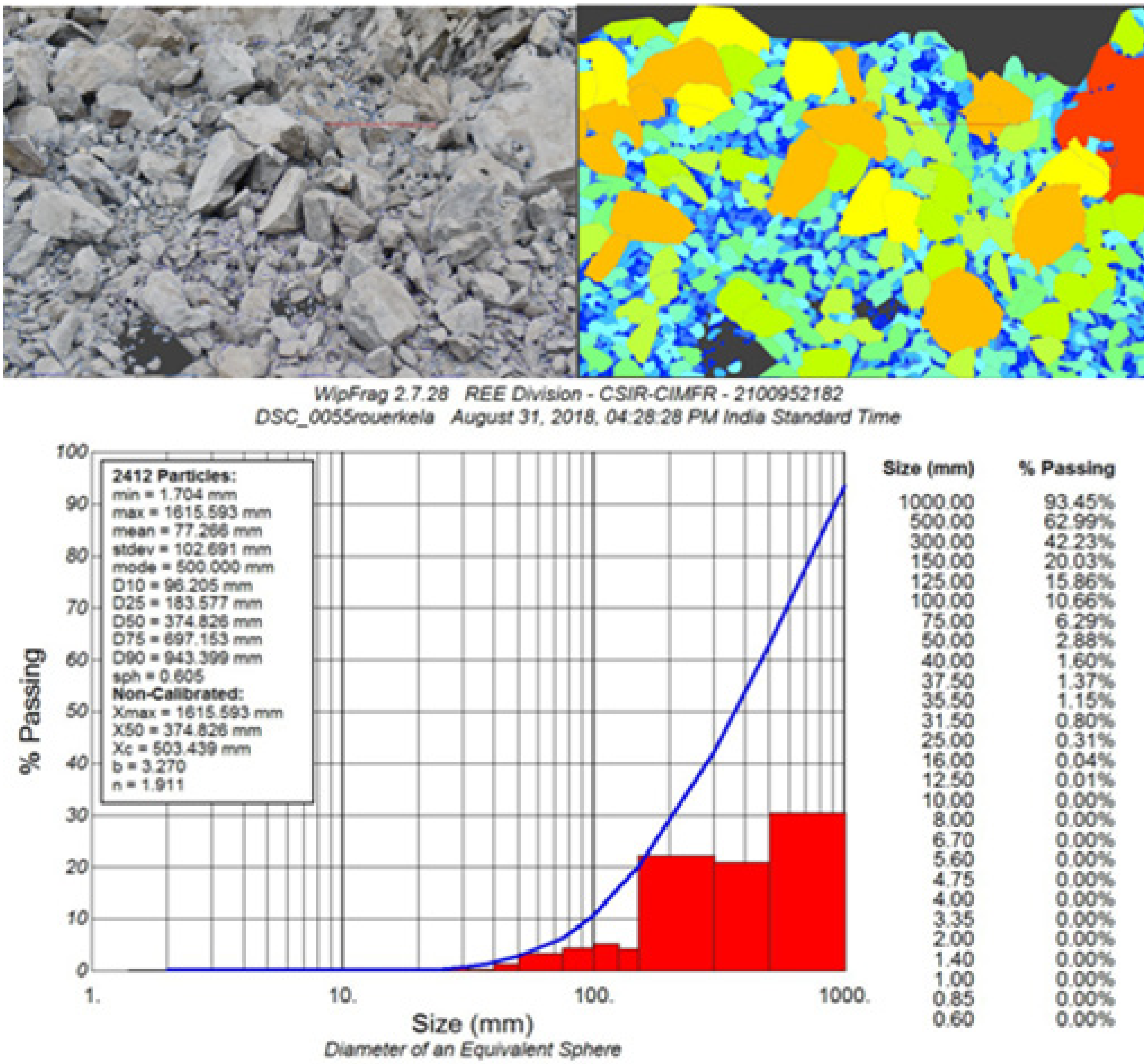

Figure 4. Netting, contouring and cumulative size distribution curve of the fragmented muck pile at Site-3.

6.4 Results

The fragmentation analysis and the size distribution curve for 3 sites are done and parameters like D_{10}, D_{30}, and D_{60} are derived and used for evaluation of the uniformity Coefficient (Cu) and the coefficient of Gradation (Cg).

The uniformity coefficient (Cu) and the coefficient of gradation (Cg) are evaluated based on the parameters obtained from the WipFrag analysis. The uniformity Coefficient (Cu) is 4.47 which indicates the fragment size distribution of the muck pile is very uniform and the

Table 5. Average values of D10, D30, and D60 obtained from the WipFrag analysis

PARAMETER	Site 1	Site 2	Site 3	Average
D_{10}	86.2mm	98.4 mm	96.2 mm	93.6 mm
D_{30}	152.9 mm	217.8 mm	206.7 mm	192.5 mm
D_{60}	300 mm	486.7 mm	468.8 mm	mm

coefficient of gradation (Cg) is found to be 0.94 indicating the distribution of fragments well graded. indicating the size grain characteristic of the muck pile is very uniform.

7.0 Conclusion

The measurement of fragment sizes resulting from blasting operations holds significant importance, particularly when dealing with ore body blasting. The analysis of fragment sizes serves as a basis for potentially optimizing blasting parameters to achieve the desired outcomes. Among the various methods for assessing blast fragmentation, the Digital Image Analysis technique has emerged as a highly effective tool, characterized by both its efficiency and cost-effectiveness.

In the context of this research, the blast fragmentation analysis is conducted using WipFrag software. However, it's crucial to acknowledge that results from individual rock pile sample analyses may not be considered flawless, as the digital images used in the analysis may not fully convey the conditions of fragmentation beyond the muck pile surface. To appraise the blast fragments effectively, the calculation of the Uniformity coefficient and Coefficient of gradation is done, and that showed a uniform and well-graded size distribution for the muck pile. Consequently, the results obtained through this approach offered a significantly more precise method for predicting optimal blast parameters.

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