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CSD CORRECTION AS A TOOL FOR ESTIMATING 3D BLOCK SIZE DISTRIBUTION

Rusi M.[1] and Hoxha P.[2]

[1] *Jacobs Consulting Geologists, baugeologie.at, Leobendorf, Austria, megirusi@yahoo.com.*

[2] *Polytechnic University of Tirana, Albania, Faculty of Geology and Mining, Department of Applied Geology, Environment and Geoinformatics, p_hoxha@yahoo.com.*

Abstract

For the headrace Moglicë-Grabovë, part of Devoll Hydropower Project in Albania, two different techniques of tunnelling are planned: DS TBM for the Flysch series starting in Moglicë and Drill & Blast for the Ophiolite section, starting in Grabovë. A major question concerning the tunnelling seems to find the point where DS-TBM excavation from the Moglicë side should stop to "wait" for the Drill&Blast excavation from the Shemsit access tunnel side. Assumed that the so called "block in matrix" rock mass is very unfavourable, respectively disqualifying for TBM excavation. These mixtures of hard blocks embedded in weaker and finer matrix that are very difficult to characterize, frequently challenge the engineering geologists with the characterization, design and construction problems associated with them. Evaluating Block Size Distribution in the BiM rock zone of this project area has been only the first step in characterizing all the geological and geotechnical parameters of the rock mass which will influence a decision that has major economic consequences. CSDCorrections 1.39 is the program used to convert the two dimensional data gathered from thin sections, outcrops, photographs etc. to true three dimensional crystal size distributions (CSD).
Key words: *Block& Matrix, tunnelling, geotechnical parameters.*

Περίληψη

Η σήραγγα του αγωγού μεταφοράς νερού Moglicë-Grabovë, που αποτελεί τμήμα του Υδροηλεκτρικού έργου Devoll στην Albania, θα διανοιχθεί με δυο διαφορετικές τεχνικές, με χρήση TBM διπλής ασπίδας στην περιοχή του φλύσχη στην περιοχή Moglicë και με χρήση εκρηκτικών στην περιοχή οφιολίθων στην περιοχή Grabovë. Βασικό ερώτημα για τον σχεδιασμό κατασκευής των σηράγγων αποτελεί ο προσδιορισμός του σημείου που θα σταματήσει η διάνοιξη με χρήση TBM για να συναντηθεί με την εκασκαφή με εκρηκτικά από τη σήραγγα πρόσβασης Shemsit. Η παρουσία των πετρωμάτων "block in matrix"είναι δυσμενής για τη διάνοιξη με χρήση TBM. Τα συγκεκριμένα μίγματα σκληρών τεμαχών εντός ασθενούς συνδετικού υλικού είναι δύσκολο να χαρακτηριστούν και σχετίζονται με προβλήματα σχεδιασμού και κατασκευής των σηράγγων. Η εκτίμηση της κατανομής του μεγέθους τεμαχών στα ετερογενή πετρώματα bimrock της περιοχής του έργου αποτελούν το πρώτο στάδιο χαρακτηρισμού των γεωλογικών και γεωτεχνικών παραμέτρων της βραχομάζας και επηρεάζουν την απόφαση σχεδιασμού. Για την μετατροπή των δυσδιάστατων δεδομένων από λεπτές τομές, εμ-

φανίσεις πετρωμάτων σε τρισδιάστατες κατανομές μεγέθους των τεμαχών (CSD) έγι-ναν με χρήση του προγράμματος CSDCorrections 1.39.
Λέξεις κλειδιά: *Ετερογενείς βραχόμαζες, σήραγγες, γεωτεχνικές παράμετροι.*

1. Introduction

Block-in-matrix rocks (BiM rocks) are mixtures of hard blocks embedded in weaker and finer matrix that are very difficult to characterize. Engineering geologists and the geotechnical engineers are frequently challenged by the characterization, design and construction problems associated with these heterogeneous geological mixtures. The Moglicë - Grabovë headrace tunnel in the Devoll Hydropower Project will go throw this type of Rock. Evaluating Block Size Distribution in the BiM rock zone of this project area is only the first step in characterizing all the geological and geotechnical parameters of the rock mass which will influence a decision that has major economic consequences.

1D Borings and 2D outcrop and maps of melanges and BiM rocks produce distributions that differ considerably from the 3D block size distributions, but there is promise that rules may yet be devised to estimate reliable block size distributions of melanges from chord length and surface distributions. Estimation of 3D particle size distributions from measurements in 1D and 2D are considered by stereology, a discipline blended from geometrical statistics, mathematics, microscopy, image analysis and empirical research. The paper at hand is an attempt to show why there is currently little reliable procedures for evaluating spatial distribution of block size, which are these methods and how can they be applied in the engineering practice.

2. Material and Method

2.1. Description of the Project

Devoll Hydropower Project consists of developing, planning, constructing and operating three hydropower plants along the Devoll River with an installed capacity of approx. 280 MW. DHP has the right to harness the hydrological potential of the Devoll River between 95 and 810 m above sea level, between Banjë Village in Elbasan District and Maliq Municipality in Korçë District. Through the three hydropower plants, Banjë HPP, Kokël HPP and Moglicë HPP the project will yearly generate approx. 800 GWh of renewable, environmental-friendly energy, increasing the current electricity production in Albania by approx. 20%. Based on average electricity consumption for Albanian household of 200 kWh/month, the energy generated by the Devoll Hydropower Project can supply more than 300.000 Albanian households. Devoll Hydropower Project is one of the largest hydropower investments in the Balkans and the first large scale Public-Private-Partnership investment in Albania. The Moglicë Hydroelectric Project will utilise a head of 300 m along an about 22 km long stretch of Devoll River between 650 m a.s.l. and 350 m a.s.l.. The intake is situated upstream the 140 m high rock fill dam planned at Moglicë. The powerhouse is located in an underground cavern on the east bank of Devoll River and has two Francis units with total capacity of 165 MW. Transmission voltage is 220 kV and estimated average annual energy production is 452 GWh. The tailrace outlet is at the upper end of the reservoir created by a 50 m high dam planned at Kokël. Approximately 11.7 km of tunnels with a diameter of 5.4m will be excavated in different rock masses and 700m of which will go throw BiM rocks and mélanges.

2.1.1. Geological and Tectonic Features

Moglicë hydropower project is part of two major tectonic zones. The eastern most part lies within the Mirdita zone which consists of alloctone Jurasic Ophiolithic massifs of Vallamara, Voskopoja and Devoll. The last one is placed isolated in the west and it is separated from the other ophiolithic massifs throw a corridor which belongs to the Krasta tectonic zone. The Grabove-Moglice tunnel system will be excavated throw the Devoll ophiolithic massif of Mirdita zone as well as throw the flysch series of sandstones, clays, siltstones, conglomerates and limestone rocks of ages Crete-Eocene which belong to the Krasta zone. The lithological unit that will be studied in this paper represents the transitional area between the flysch series and ophiolitic body which consists of reprocessed material originating from the ophioliths as well as the flysch. The part of the Mélange which covers the ophiolithic complex is also part of Mirdita tectonic zone. We can distinguish four rock types within the area of the Mirdita heterogeneous melange. According to the principle used in this paper regarding their mechanical behaviour during excavation, all these rocks nevertheless the type, strength, the cementation degree etc. belong to the Block in Matrix rock type. But according to a genetic and lithological characterization, the encountered rock types in this area are more than one. After the competition of the detailed mapping campaign in 2011 it was concluded that the rock types are lhercolites / serpentinites, ophiolitic tectonic breccias, vulcanites, radiolarites and limestones. One of the results of this geological mapping phase was the preparation of the detailed longitudinal profiles and cross sections over the tunnel axis. The main rock lithologies that are found along the tunnel axes in the melange zone include sheared serpentinites, ophiolithic breccias, flysch formations of folded limestone, radiolarites, vulcanites.

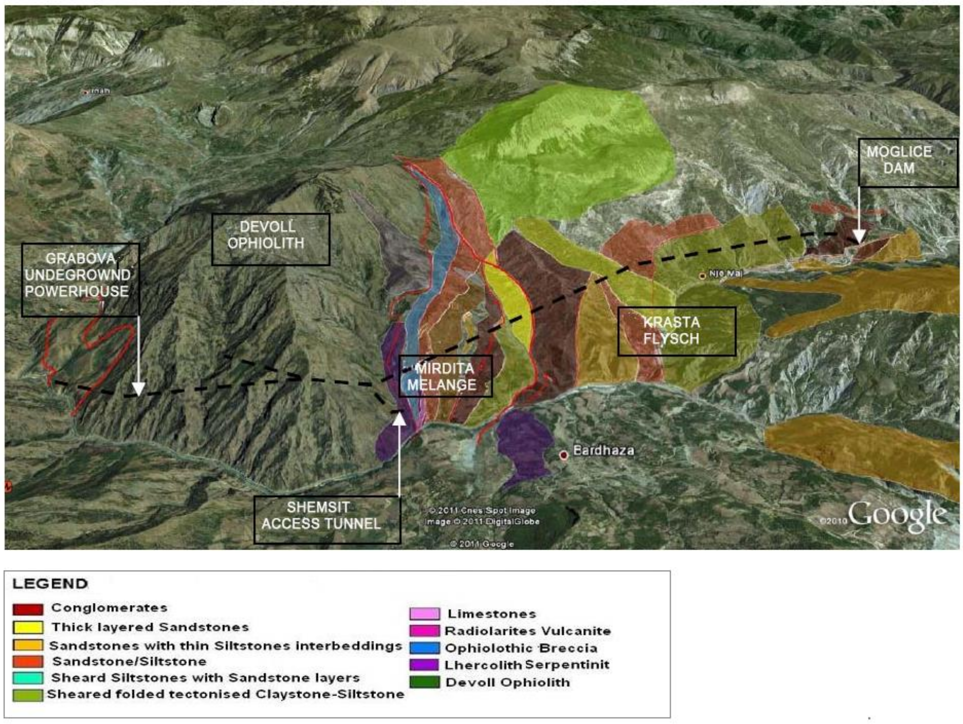


Figure 1 – The main lithologies mapped in the Mirdita melange zone.

2.1.2. Tunnel Sections

The alignment of the headrace tunnel was divided in sections referring to the present lithology and rock conditions. In total 28 tunnel-sections were defined along the overall length of 11.775 meters. Five of these sections which consist of approximately 700m of tunnel alignment run throw the mélange zone.

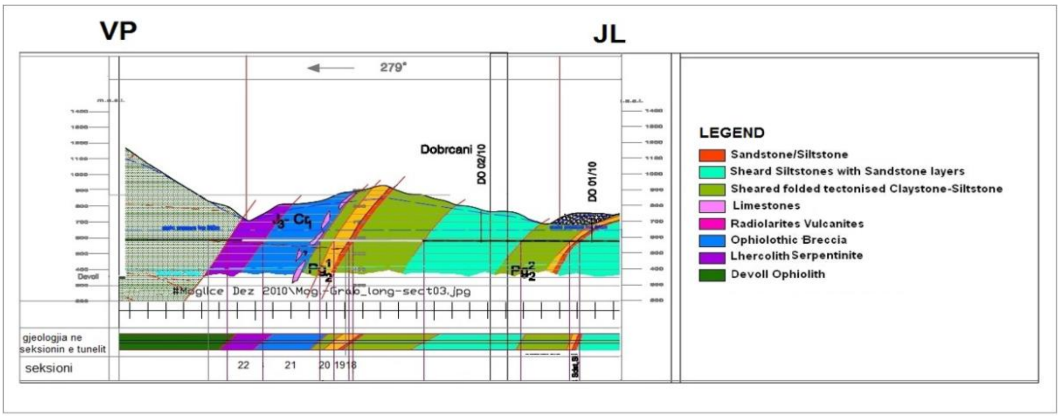


Figure 2 - Geological longitudinal section along tunnel axis in the Melange zone.

- From station 7450 m to approx. station 7550 m the tunnel alignment crosses section 18 and 19 and is expected to run through medium to thick bedded inter beddings of sandstone and siltstone layers with intercalations of silty shale layers over a length of approx. 100 m. The strata dip moderately steep between 45 and 65° to the NW to NNW. The borders of this section are not known very well.
- From station 7.550 m to approx. station 7.630 m, section 20, the tunnel alignment is expected to run through thin to medium bedded inter beddings of clayey shale and siltstone layers with intercalations of sandstone layers and randomly occurring lenticular lenses of conglomerates over a length of approx. 80 m. The strata dips moderately steep between 45 and 65° to NW to NNW.
- In section 21 from station 7.630 m to approx. station 7.950 m the tunnel alignment is expected to run through the rim related ophiolitic fault conglobreccia of the Devoll ophiolith over a length of approx. 320 m. This rock can be named a real tectonic mélange. The strata dips 35 and 50° NNW.
- From station 7.950 m until station 8.150 m the tunnel alignment passes section 22 and it is expected to run through intensely tectonized and highly alterated lherzolites that are already part of the Devoll ophiolith massif along a distance of approx. 200 m.

2.2. The Method

The transition zone affected by the ophiolithic thrusting is the project area to which a special attention has been given during all the stages. Ophiolithic breccias and different melange zones, BIM rocks, together with intensively folded flysch formations and complex tectonic history were the object of the detailed mapping for this study. More than 100 outcrops have been documented in this area which is 700 m along the tunnel axes. The outcrops have been randomly selected throw scanlines. These outcrops have been photographed with high resolution cameras, and the pictures have been reworked afterwards.

2.2.1. Guide to Digitalisation

Before using the photograph for CSD it needs to be properly digitalised with image treatment programs and graphic programs (Adobe Photoshop, Adobe Illustrator, ImageJ etc.). Every block has to be outlined and layered separately. After outlining all the blocks, and turning off the picture layer it is needed to export the black and white image as an uncompressed tif. file to the ImageJ .This program makes possible the scale, measurement, particle analyses.

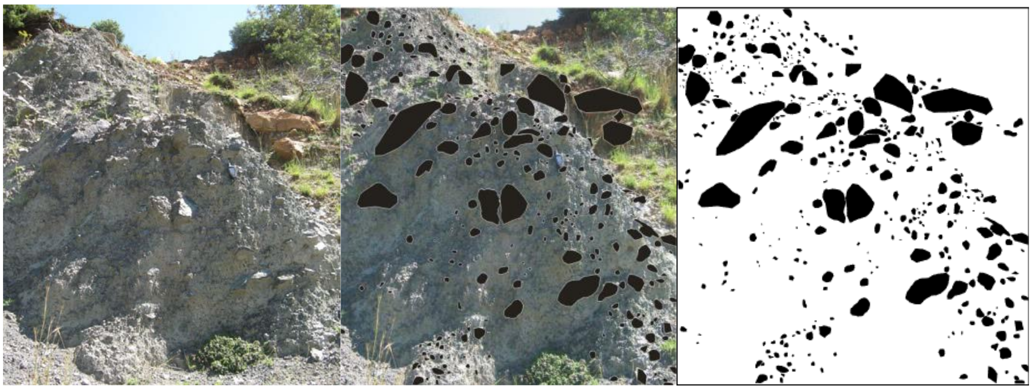


Figure 3- BiM rock outcrop and Digitalising Method.

2.2.2. CSD Correction Utilisation

CSD Corrections 1.39 is a program for converting two dimensional intersection data gathered from thin sections, outcrops, photographs etc. to true three dimensional crystal size distributions (CSD).The program constructs a solid of the dimensions indicated by the Short, Intermediate and Long dimensions. The orientation of the solid is constrained by the nature of the fabric (massive or foliated or lineated), the quality of the foliation (weak to strong) and the orientation of the desired section (parallel or normal to the fabric). This is sectioned by a plane placed a random distance from the centre of the solid. The outline of the intersection of the solid with the plane is determined and the length and width calculated. The distribution of these lengths and widths is used to correct the two dimensional for the cut section effect. The most likely intersection length (or width) is used to correct for tailing to smaller intersections. There is no tailing correction for intersections larger than the most likely intersection. This is rarely a problem if wide bins are used for the frequency distribution. After these tailing corrections have been made then corrections for the intersection probability effect are applied.

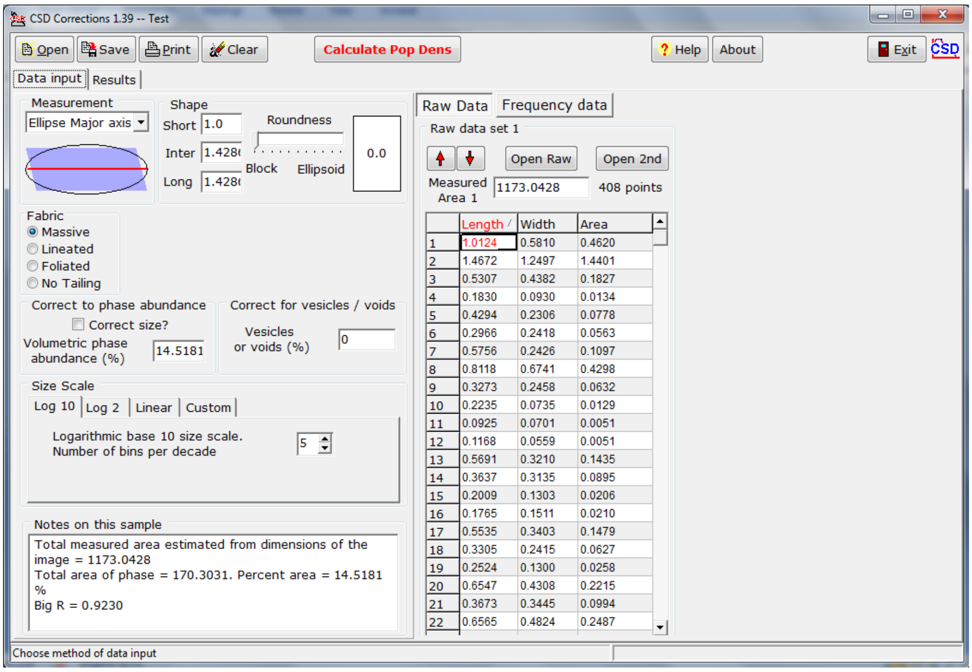


Figure 4 - CSD Correction Program Preview.

2.2.3. Data Entry

Data can be entered as a list of Lengths, Widths and/or Areas. They can be typed directly into the grid or loaded from a simple file of data, with one measurement on each line. They can also be pasted from the clipboard if the cell has a dotted line around it (push the up and down arrows to get this). A maximum of ten thousand points can be measured. Rows can be deleted (with Del) or inserted (with Ins) if the cell has a dotted line around it. Data can be transferred directly from the ImageJ image processing program. It is possible to load two separate data sets. These will be summed. This may arise if data is measured at two different scales on the same rock. Data can also be loaded as a series of bins (size intervals) and number of measurements in each bin. The upper limit of the bin is put in the left column, with the number opposite in the right column. The last line must be the lower limit of smallest bin size and the number zero in the adjacent column. Bin sizes must decrease downwards. Rows, and hence bins, can be deleted (with Del) or inserted (with Ins) if the cell has a dotted line around it.

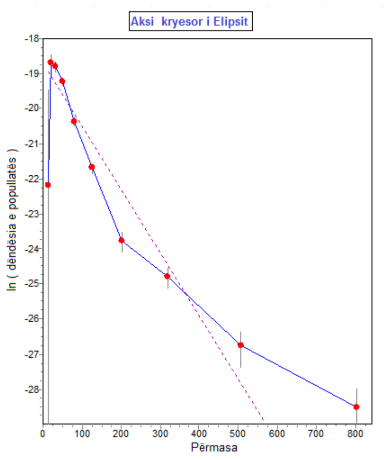
3. Results and Discussion

Results are shown in tables and diagrams. The table columns show the following data. Column 1: Corrected Size of the middle of the interval. The size is long dimension of parallelepipeds, the major axis of ellipsoids, or the diameter of spheres. Errors are calculated using only the counting statistics. No error has been accorded to the tailing corrections, because it is not clear how to do this. Hence the error bars should be regarded as minimum values. Column 2: The natural logarithm of the population density. Column 3, 4: The error limits of the population density. They are calculated from the square root of the number of intersections in each bin. This is propagated to the other bins. The error calculations do not take into account any error in the correction factors, and hence should be viewed as minimum errors. Column 5: Numbers of crystals per unit volume in the interval. This can be used to make other kinds of CSD diagram. Column 6: Per cent volume of crystals in each interval. The error in the larger size intervals can be significant.

The diagrams in show the crystal size distributions through the a) CSD in semi logarithmic diagram, b) Cumulative Distribution Function diagram, c) Fractal Dimension diagram and d) Population Density diagram.

Te dhenat tre dimensionale					
Interv. Mes	ln(den pop)	ln(min DP)	ln(max DP)	Num Kris	Vol %
801	-28.51	-29.74	-27.98	1.53E-10	4.714
506	-26.74	-27.39	-26.35	5.66E-10	4.393
319	-24.79	-25.13	-24.54	2.51E-09	4.888
201	-23.77	-24.11	-23.52	4.39E-09	2.145
127	-21.69	-21.85	-21.54	2.23E-08	2.743
80.1	-20.37	-20.51	-20.25	5.24E-08	1.618
50.6	-19.24	-19.36	-19.12	1.03E-07	0.798
31.9	-18.79	-18.97	-18.64	1.02E-07	0.197
20.1	-18.69	-19.03	-18.44	7.07E-08	0.034
12.7	-22.18	infinit	-19.46	1.37E-09	0
8.01	Over				
5.06	Over				

Vol nga siperf. inter(%)	14.52	
Numri Total nga CSD	3.59E-07	
Vol total (%) nga CSD	21.5	8.2
Regresion-nderprerje	-18.72	0.09
Regresion-shpat	-0.0181	0.0006
Regresion-volum (%)	25.13	6.678
Param. Goodness of fit	3.264E-18	
Min, Max CL	-2.13167	166.95548



ln (Limimiti i permas. siperm)	% Kumulative	CDF
6.45	100	3.33
5.99	99.8	2.88
5.53	99.1	2.37
5.07	97.9	2.03
4.61	91.7	1.38
4.14	77.1	0.741
3.68	48.4	-0.041
3.22	20.1	-0.839
2.76	0.381	-2.67
2.3		
1.84		
1.38		

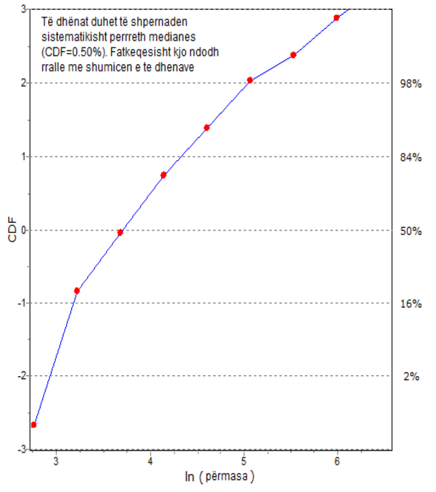
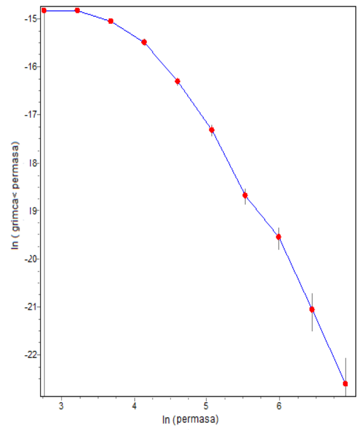


Figure 5 - CSD in semi logarithmic diagram and Cumulative Distribution Function diagram.

ln (Limimiti i permas. siperm)	ln (n < permas)	Min	Max
6.91	-22.6	-22.1	-23.8
6.45	-21.1	-20.7	-21.5
5.99	-19.6	-19.4	-19.8
5.53	-18.7	-18.5	-18.9
5.07	-17.3	-17.2	-17.4
4.61	-16.3	-16.2	-16.4
4.14	-15.5	-15.4	-15.6
3.68	-15.1	-15	-15.1
3.22	-14.8	-14.8	-14.9
2.76	-14.8	-14.8	
2.3			
1.84			
1.38			



Limiti permases se siperme	Dendesia popullates	Min PD	Max PD
1.00E+03	4.14E-13	1.21E-13	7.06E-13
631	2.43E-12	1.27E-12	3.59E-12
398	1.71E-11	1.22E-11	2.20E-11
251	4.73E-11	3.38E-11	6.08E-11
158	3.82E-10	3.23E-10	4.40E-10
100	1.42E-09	1.24E-09	1.60E-09
63.1	4.42E-09	3.90E-09	4.94E-09
39.8	6.91E-09	5.78E-09	8.04E-09
25.1	7.63E-09	5.45E-09	9.80E-09
15.8	2.34E-10	0.00E+00	3.53E-09
10	0.00E+00		
6.31	0.00E+00		
3.98	0		

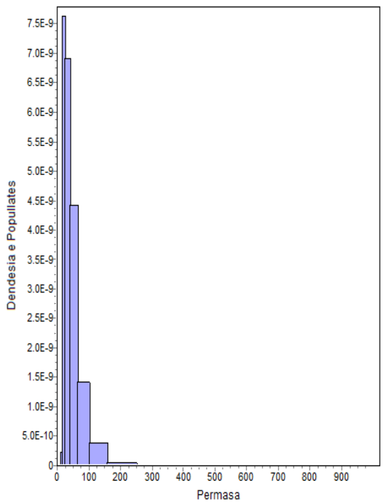


Figure 6- Fractal Dimension diagram and Population Density diagram.

3.1. Result Interpretation

The semi-log graph or semi-log plot shows the visualizing data that are changing with an exponential relationship. If CSD is linear in this diagram it matches with the regression line and slope angle can be defined. It is obvious that the size distribution in this case at some point does not align very well with the law and the log shape makes the match impossible. Possible errors correspond to the statistical counting. The refraction of CSD-curve comes from mixed population (blocks of various proportions), but the proportions of the blocks are reasonable. It is noted that the overall low is that by increasing the size of the blocks their density decreases. But there is also a decrease in population density for blocks of smaller size, which is actually normal for natural samples. Such a reversal in small sizes in natural rocks may come as a result of many reasons, one of which may be inadequate spatial resolution. Log-normal distribution is a continuous probability distribution of a random variable whose logarithm is normally distributed. Cumulative data are transferred by using the normal standard cumulative distribution function inverse. In this diagram the log normal distribution appears as a straight line. Mixtures of log normal distributions are identified as two or more straight segments of the graphic. In our case, we can see four such distributions. In the third plot, the steepness of the line can be used to determine the Fractal dimension distribution. In the cases where the line has more than one visible slope, the distribution can be described as multi Fractal. In our chart although the curve does not match 100% the straight line, it can be determined only one Fractal dimension with a value of approximately 1.45.The histogram is a graphical representation showing a visual impression of the distribution of data. It is an estimate of the probability distribution of a continuous variable. It proves the first statement that the overall low is that by increasing the size of the blocks their density decreases.

3.2. Discussion

Mélanges and BiM rocks are very common in nature and a lot of engineering projects are obligated to be constructed in these chaotic rocks. Excavating tunnels in BiM rocks can result highly problematic for a number of different reasons, one of which is the fact that in these types of rocks the blocks vary in size. Knowledge of the size distribution of blocks is a key parameter that should be evaluated in these studies. Between the maximum and minimum block size, in the scale range, it is important that the blocks are characterized by their respective volumes. The methods presentet in this paper intend to help geologists and engineers in the characterization of melange blocks. CSD Correction is a useful tool in the field of mineralogy and petrology, but there are still doubts about its use in big ‘sample’ size. With a more detailed research and study it can be helpful for the engineering geologist and for further developing the BiM rock study. The CSD produced by the program for small size sections have reasonable errors from 10%, but for complex shapes the application of CSD Correction seems to make just a first aproxximation, so care should be taken for the interpretations.

4. Acknowledgments

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