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Rockmass Classifications and Probability Distribution Functions of Intact Rock Properties of an Open Pit Mine, Ebonyi State, Nigeria

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ABSTRACT
This paper present the results of rock mass classification of Eyigbashales hosted lead zinc open pit mine and probability distribution functions of intact rock properties from laboratory experiment. The studylocation is within Ikwo and Abakaliki Local Government Areas of Ebonyi State between latitude 6°09’ and 6° 14N and longitude 8°05’E and 8° 10’E longitude The objectives are to map (scanline method) the discontinuities (joints, faults, folds) cut across the eastern part of the mine, classify the rock mass and performed montecarlos simulation on the intact rock properties from laboratory experiment to produce probability distribution functions of these properties. Rock mass rating (RMR), Rock quality designation (RQD), and Q system are the rock classifications system used in the assessment of the rock mass quality. RMR, Q and RQD confirmed that the rock quality is Fair. There are variations in the properties of the intact rocks, where only a single (deterministic) value cannot sufficient represent these properties. Consequently, the used of probabilistic distribution method is suggested and applied to quantify the uncertainty and variability of these properties. The results can served as input parameters for the determination of the rock mass properties and in numerical modeling operations.

Keywords: rock mass classification systems, intact rock properties, probability distribution function, Monte Carlo simulation, and discontinuities.

I. INTRODUCTION

Experimental methods or normal empirical methods are used to determine the rock mass properties such as the strength and deformability. Experimental methods such as in-situ tests are expensive and they require a test drift which may not be available at the preliminary design stage (Idris 2013). Therefore rock mass classification and characterization systems are frequently used together with deterministic methods to determine these strength and deformability properties. Rock mass rating (RMR) Bieniawski, (1989), Q system Barton et. al., (1974), and Geological Strength Index Hoeket. al., (1995) are the most common systemsfor rock mass classification system.

The study presented in this paper includes the classification of the rock mass of Eyigba open pit mine and development of probability distribution functions for the laboratory intact rock properties.

Due to difficulties in handling the variations and uncertainties of rock properties, traditionally deterministic methods which result in single or mean values for the rock mass properties are often adopted. However, uncertainty and variability are prevalent in intact rock and rock mass properties. Therefore to be able to make a more reliable approach the uncertainty and variability should be dealt with. As a result of this effort probabilistic approaches have been increasingly used by many researchers (Kim et. al., 1995; Sari, 2009; Sari et. al., 2010; Cai, 2011).

The aim of this research is to classify the rock mass and use probabilistic method (montecarlos simulation) to incorporate the uncertainties of intact rock properties. By means of the approach it is possible to obtain not only the expected value but also the possible deviation, therefore a much more complete description of the rock mass behaviour when rockmass is considered.

II. GEOLOGY OF EYIGBA, EBONYI STATE

Enyigba is located within Ikwo and Abakaliki Local Government Areas of Ebonyi State within Latitudes 6°10'40" N to 6°11'30" N and Longitudes 8°08' 08” E to 8°09' 10”E (figure 1) and falls within the lower Benue sedimentary formation of southeastern Nigeria. The region is noted for Lead-Zinc mineral (Pb/Zn) mining activities by the locals. Pb/Zn deposits have been found in the lower Abakaliki Basin where metallic ores occur as epigenetic fracture-controlled vein deposits, and are restricted to gently dipping carbonaceous black shale spatially distributed (Fatoyeet. al., 2014). Cratheley and Jones (1965) had earlier attempted to map possible trends of these deposits within the entire Benue Trough. The cretaceous sequence of the lower Benue Trough consists of shale, limestone, minor intrusions and pyroclastics and belongs to the Asu River geologic group of Albian age. These are the earliest sediments that were deposited uncomfortably on subsiding basement topographical depression in the Benue basin (Burke et al., 1970). Pb-Zn occurrences in Nigeria are associated with saline water intrusion in the sedimentary basins or fractured/shear zones in crystalline rocks. Figures1 and 2 showed the study location. The terrain is generally flat-lying with occasional small hills on which the mines are commonly located. The first recorded production of Pb-Zn ore was in 1925. Mining was abandoned in some of the mines during the civil war of 1966 to 1970 (Umeji, 2000). The Lead-zinc open pit mine is operated by First Patriot International Mining Company with a large processing plant located along Abakaliki –Ikwo Road, Eyigba, Ebonyi State.

Eyigba Open pit mine is divided into four divisions for this study, namely North, South, East and western part. The Eastern part of the mines lies the working face, while the lead –zinc ore bodies occurred in veins that runs from North-South direction of the mine. Mapping, measurement, and data collection were done across the length of the Eastern part.

Figure 1. Map of Ebonyi State showing the LGAs.

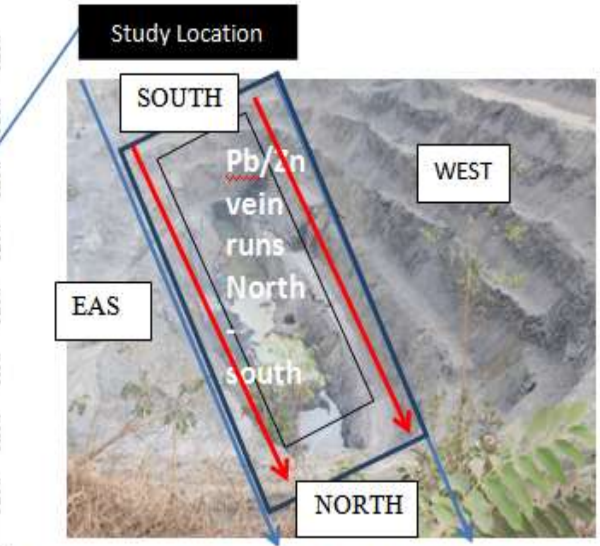

Figure 2: Arial view of Eyigba Shale hosted Lead-Zinc Open pit

2.1 Site Characterization and Rock Mass Classification

Site characterization is the process of developing an understanding of the geologic, hydrologic and engineering properties at the site including the soil, rock, along with groundwater and in many cases, man-modified conditions in the subsurface (e.g. utilities, structures,mines and tunnels) that can impact site conditions. It also includes the spatial and temporalassessment of contaminants when they are present. Various terms such as site investigation, site assessment and site characterization have been used to describe this process and areoften used interchangeably (Richard et al.2016).

Each site characterization is a unique combination of setting, objectives, logistics, technical issues and non-technicalissues (budget, politics, etc.). Davies (1977) and Fookes (1997) believe that every site characterization in karst mustbe treated as unique and the unexpected should be anticipated until proven otherwise. There are generally, two different times when a site characterization is required for a project:

(a). before a problem has occurred, prior to construction of abuilding, bridge, dam or nuclear power plant, etc. toassess the potential for settlement, collapse, or leakage.This is the easiest and most cost effective time to complete a site characterization since there is usually bettersite access and problems can be corrected or avoidedbefore construction.

(b) After a problem has occurred investigating the cause of settlement, collapse or leakage at an existing facility inorder to address problems that have already occurred and plan remediation action (Richard et al. 2016). This is usually a more difficulttime to complete a site characterization due to the presence of existing structures both above and below groundlimiting access, interfering with measurements as well asincreasing cost.In either case, a site characterization is required. If donebefore construction or development you will save money andtime and have the opportunity to incorporate findings into a quality design (Davies 1977).

Rock mass classification is to establish the quality of a particular rock mass (or part of a rock mass) by assigning rating values to aset of rock parameters (John et al. 2000)**.** Rock mass is a matrix consisting of rock material and rock discontinuities. Its characterization and classification aim to determine the rock mass characteristics by assigning values to a set of rock parameters. The behavior of intact rock material can be determined by continuum mechanics but rock masses are usually highly fractured. The fact that fractures control the mechanical response of rock masses makes the determination of their mechanical behavior difficult. Consequently, simplified classification systems capable of dealing with the geological and geotechnical uncertainties evolved for various engineering design purposes. Those systems were based on empirical correlations between rock mass parameters and practical engineering projects including foundations, tunnels, slope stability, and mining. According to Bieniawski (1993), the rock mass classification systems were designed to act as an engineering design aid and were not intended to substitute field observations, analytical considerations, measurements, and engineering judgment.

The natural variabilities of rock propertiesis a major source of uncertainty in civil and geotechnical engineering (Quanet al. 2016). When the materials are natural rock, the only thing known with certainty is that this material will never be known with certainty (Goodman 1995). Obviously, there are several common sources of uncertainty in rock engineering analysis such as the intrinsic uncertainty of rock composition, the incompleteness of statistical data, the use of simplified models, and experimental errors made during the manual operation of test equipment (Quanet al. 2016). However, only the natural variability of the rock material itself is irreducible (Cai 2011).

The presence of numerous defects in rock, such as pores, flaws, and micro-cracks, has a considerable effect on its mechanical properties including the Young’s modulus, the uniaxial compressive strength, the internal friction angle, and the strain of peak stress. There is no way to predict accurately what the value of any one of these parameters of the rock will be at any given field investigation without account for these uncertainties, a stochastic rather than a deterministic description for the mechanical parameters of rock is more realistic and acceptable (Quanet al. 2016). In the deterministic estimation of the properties of a rock mass, only a unique value is used, and usually the average of the investigated property taken from a number of core samples. In stochastic estimation, the full range of data concerning a specific characteristic is considered.

In practice, the probabilistic approach, which views each variable not as a single value but as probability distribution, is more useful. This approach has been used as a powerful tool for representing uncertainty in the physical parameters of different materials and corresponding mechanical models during rock engineering analysis (Hoek 1998; Nilsen 2000; Duzgunet al. 2003; Goh and Zhang

2012). Large data sets are needed to accurately carry out such probabilistic analyses (Park et al. 2005; Low 2007) because the appropriate probability distribution functions for the key mechanical parameters are vital for a reasonable estimation. In practice, it is desirable to use an adequate number of reliable laboratory tests or in situ observations to estimate uncertainty (Sari et al. 2010; Nomiko and Sofianos 2011; Park et al. 2013).

Both the ISRM and the ASTM suggested that the number of specimens should be sufficient to adequately represent the body of rock being studied, recommending a minimum of five specimens per set of testing conditions (ASTM 1995; ISRM 2007).

2.2 Types of Classification Systems

On the basis of mode of characterization, these systems can be grouped as qualitative and quantitative. Qualitative implies descriptive systems that includes Geological Strength Index (GSI), and Rock Load; while Rock Mass Quality (Q), Rock Mass Rating (RMR), Rock Quality Designation (RQD) systems are quantitative.

Rock mass classification schemes took its origin to 1879 when Ritter (1879) devised an empirical approach to tunnel design for finding out support requirements (Hoek, 2007). Since then, these systems have been developing with several modifications and guidelines in their project applications. Most of the multi-parameter classification schemes (Barton et al. 1974; Bieniawski, 1968; 1973, 1989; Wickham, 1972) were developed from civil engineering case histories (Hoek, 2007). The rock mass classification schemes that are often used in rock engineering for assisting in designing underground structures and slope stability analyses are rock mass rating (RMR), rock quality designation (Q), and geological Strength Index (GSI) systems.

a. Rock Quality Designation (RQD)

In order to quantify the quality of the rock from drill cores, Deere et al. (1967) developed the concept of the RQD. RQD is defined as the percentage of intact core pieces longer than 100 mm (4 inches) in the total length of core having core diameter of 54.7 mm or 2.15 inches (Hoek, 2007).

$$RQD = \frac{\sum length\ of\ core\ pieces\ > 10cm}{total\ length\ of\ the\ core}\ x\ 100\% \qquad (1)$$

RQD is a measure of degree of fracturing of the rock mass and is aimed to represent the in situ rock mass quality. The greater the RQD value the better the rock mass quality. RQD is used as an input parameter in RMR and Q systems, Cording and Deere (1972), Merritt (1972) and Deere and Deere (1988) related RQD to Terzaghi's rock load factors and to rock bolt requirements in tunnels.

b. Rock Mass Rating (RMR) System

The RMR system (geo-mechanics)of classification was developed by Bieniawski during 1972-1973 in South Africa to assess the stability and support requirements of tunnels (Bieniawski, 1973b). Since then it has been successively refined and improved as more case histories have been examined. Five parameters, that is, strength of rock, rock quality designation (RQD), spacing of joints, condition of joints and groundwater conditions, were used to estimate RMR as indicated in Equation 2.

$$RMR = \sum(i + ii + iii + iv + v) \qquad (2)$$

where i, ii, iii, iv and v represents the rating of values of strength of rock, rock quality designation (RQD), spacing of joints, condition of joints and groundwater conditions respectively

c. Rock Tunneling Quality Index Q-System

The Q-system was developed in 1974 by Barton, Lien and Lunde at the Norwegian Geotechnical Institute, Norway for the determination of rock mass characteristics and tunnel support requirements (Barton et al. 1974). RMR and Q-Systems uses essentially the same approach but different log-scale ratings, as Q-value is product of ratio of parameters while RMR is the sum of parameters (Hoek, 2007). The Q-rating is developed by assigning values to six parameters that are grouped into three quotients (Singh and Geol, 1999). The numerical value of the index Q ranges from 0.001 to a maximum of 1,000 on a logarithmic scale (Bieniawski, 1989).

Value of Q is defined and is calculated as:

$$Q = \left(\frac{RQD}{J_n}\right)\left(\frac{J_r}{J_a}\right)\left(\frac{J_W}{SRF}\right) \qquad (3)$$

Where RQD is Rock quality designation;J_n is Joint set number;J_r is Joint roughness number; J_a is Joint alteration number; J_W is Joint water reduction factor; and SRF Stress reduction factor.

The first quotient$\left(\frac{RQD}{J_n}\right)$ represents the rock mass geometry and is a measure of block/wedge size. Since RQD generally increases with decreasing number of discontinuity sets, the numerator and denominator of the quotient mutually reinforce one another (Hoek, 2007).

The third quotient $\left(\frac{J_W}{SRF}\right)$is an empirical factor representing active stress incorporating water pressures and flows, the presence of shear zones and clay bearing rocks, squeezing and swelling rocks and in situ stress state (Hoek, 2007). According to Singh and Geol (1999), SRF is a measure of: (i) loosening load in the case of an excavation through shear zones and clay bearing rock, (ii) rock stress in competent rock, and (iii) squeezing loads in plastic incompetent rocks. The quotient increases with decreasing water pressure and favorable in situ stress ratios.

III. INTACT ROCK PROPERTIES

Intact rocks may be classified from a geological or an engineering point of view. Therefore, engineering classifications of intact rocks are more related to the engineering properties of rocks (Zong-XianZhang, 2016; Hoek, 1994; Hudson and Harrison, 1997). Intact rock refers to the unfractured blocks between discontinuities in a typical rock mass. These blocks may range from a few millimeters to several meters in size (Hoek, 1994; Hudson and Harrison, 1997). Intact rocks are classified into three main groups according to the process by which they are formed: igneous, metamorphic and sedimentary. The properties of intact rock are governed by the physical properties of the materials of which it is composed and the manner in which they are bonded to each other (Afuet.al., 2024). The parameters which may be used in a description of intact rock include petrological name, color, texture, grain size, minor lithological characteristics, density, porosity, strength, hardness, and deformability (Lianyang Zhang, 2017).

3.1 Probability Distribution Function of Intact Rock Properties of EyigbaEbonyi State

In this research work, Uniaxial tensile strength (UTS), Uniaxial Compressive Strength (UCS), Deformation Modulus (Em), Poisson Ratio (υ), Young modulus (E), and Cohesion (ϕ), density (ρ), absorption capacity (β), porosity (ψ), and specific gravity (ρg) have been considered as random variables instead of assigning a single value. To define the range of each variable, probability density functions (PDF) are used. In PDF, the mean value (MV) represents the best estimate of the random variable and the uncertainty is assumed and described by the standard deviation (STDV). The mean and standard deviation values for the PDF are assigned based on the available data from field observations, literature and laboratory.

Table 1:Mechanical properties of intact rock

Rock type	UTS (MPa)	ϕ (MPa)	E_m (GPa)	υ	E (GPa)	UCS (MPa)
Shales	4.18±0.37	14.60±4.93	339.48±4.97	0.28±0.09	37.60±7.70	209.91±36.33

Table 2: Physical Properties of Intact rock

Rock type	ρ (kg/m^3)	β (%)	ψ (%)	ρg
Shales	290.73±2.63	0.47±0.03	15.67±3.87	2.59±0.02

Monte Carlo Simulation is applied to the intact rock properties to generate the probability distribution function for each of the properties using the mean and the standard deviation. Probabilistic approach to the input parameters can be deterministic and probabilistic. Deterministic parameters are considered as fixed parameters with single values. For example the density, specific gravity can be considered as a deterministic parameters. Unlike density and specific gravity factors, Uniaxial tensile strength (UTS), Uniaxial Compressive Strength (UCS), Deformation Modulus (Em), Poisson Ratio (υ), Young modulus (E), and Cohesion (ϕ), absorption capacity (β), and porosity (ψ) are considered as probabilistic parameters. For each probabilistic parameter a probability density function (PDF) characterized by two statistical parameters namely mean and standard deviation has to be assigned. Normally PDF and its statistical parameters should be assigned by analyzing the laboratory or field test results and the measured data. Nevertheless, for the parameters whose data are insufficient to fit a PDF known distributions for such parameters may be assumed. Moreover for the ease of computation the normal distribution is suggested (Sari, 2009; Cai, 2011; Hoek 1998).Having assigned the mean and standard deviations for the intact rock parameters, the normal distribution is assigned for all the intact rock properties investigated (Sari et. al., 2006).

3.2 Methodology

Monte Carlo simulation were performed using @risk version 5.5 to generate the probability distribution functions for each of the intact properties determined from the laboratory experiment. 100,000 iterations were performed on these intact rock parameters in a range representing 90% confidence limit. The intact rock properties are assumed to followed normal distribution.

Scan line mapping method was used in mapping the discontinuities features across the eastern part of the pit and featured (joints, faults, folds) encountered were measured and recorded.

IV. RESULTS AND DISCUSSIONS

The results of probability distribution functions generated are hereby presented below, and followed by the rock mass classification assessment of the Eyigba shale hosted lead-zinc open pit mine for slope stability analysis.

i. Probability Distribution Functions of Intact rock properties

Table 1 and 2 shows the means and standard deviation of the intact rock properties to incorporate the variability in the parameters determined in the laboratory.

Figures 3 – 13 show the probability distribution functions for the various properties of the intact rock.

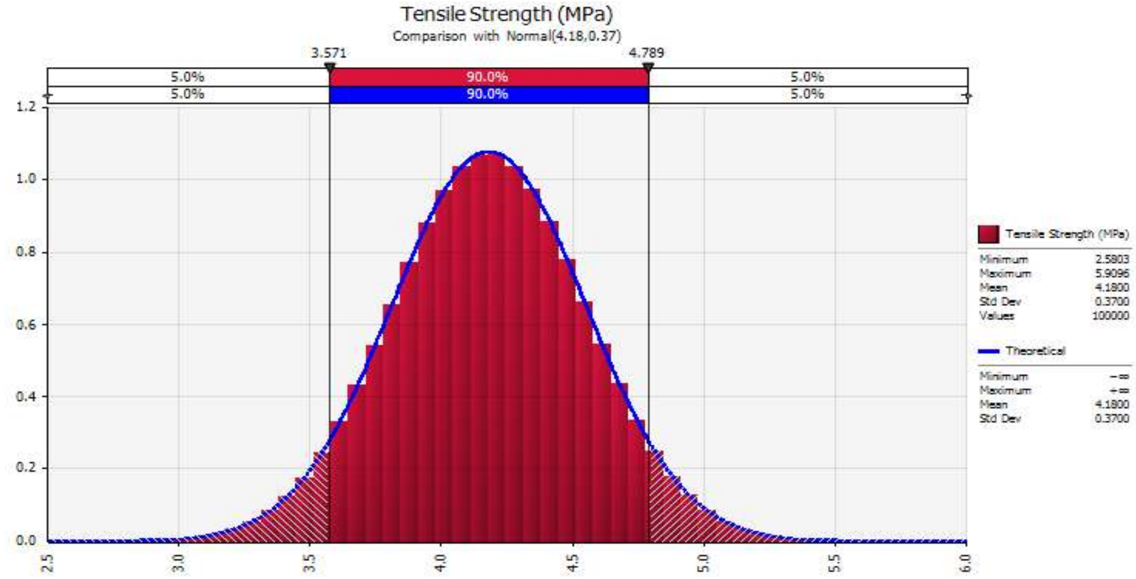

Figure 3: Probability distribution function of Intact rock Tensile Strength (MPa)

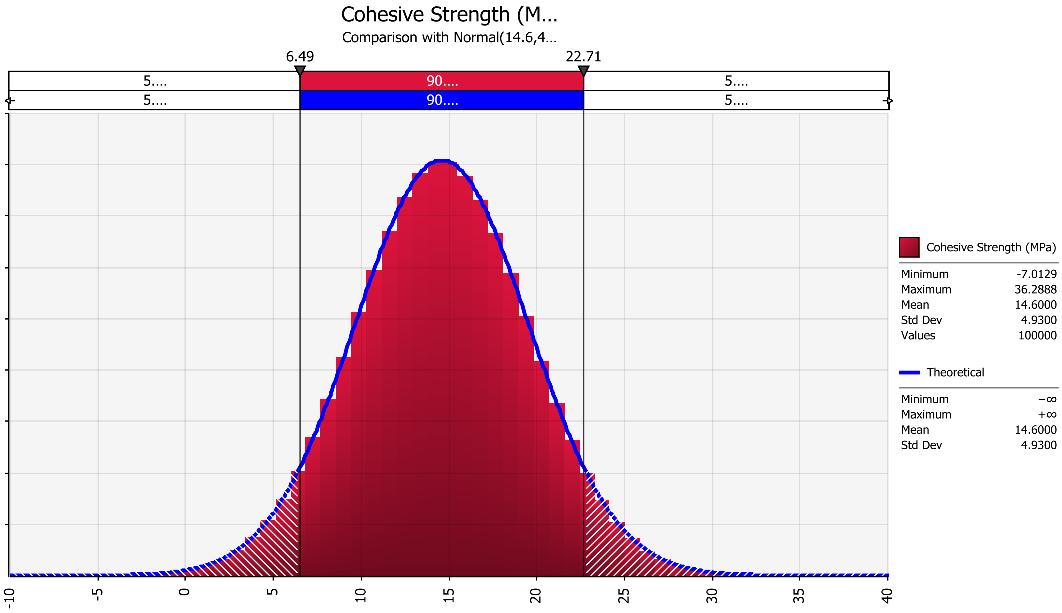

Figure 4: Probability distribution function of Cohesive Strength (MPa)

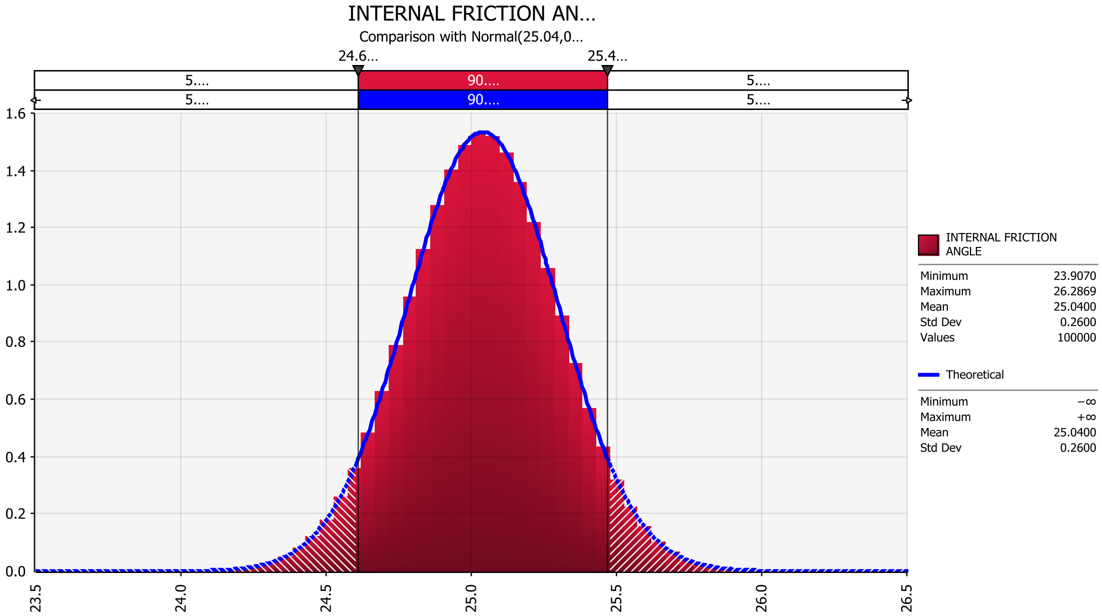

Figure 5: Probability distribution function of Internal Friction angle (°)

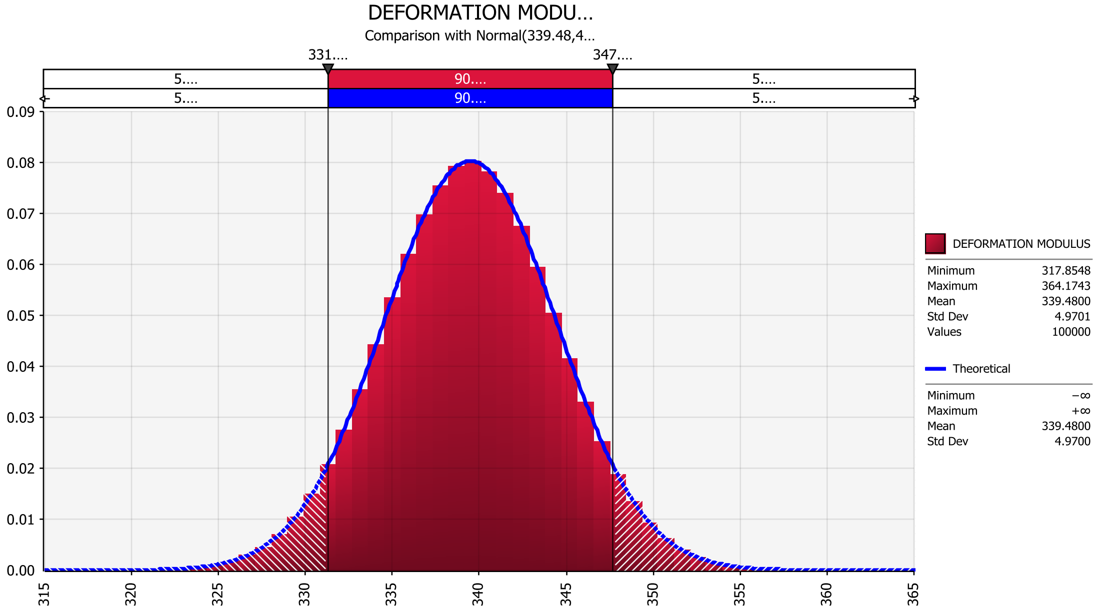

Figure 6: Probability distribution function of deformation modulus

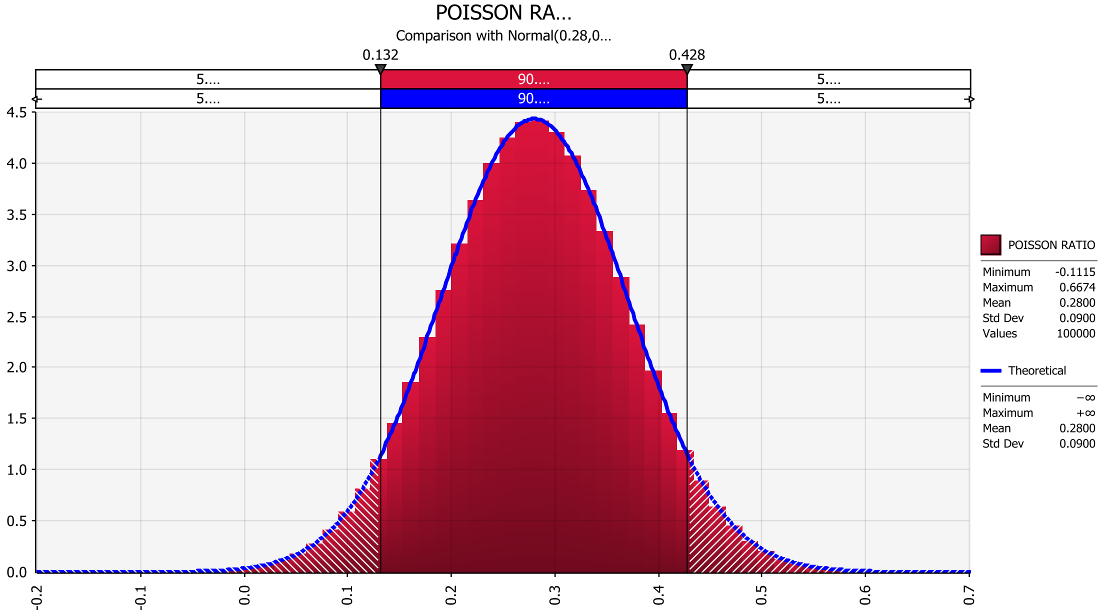

Figure 7: Probability distribution function of Poisson ratio

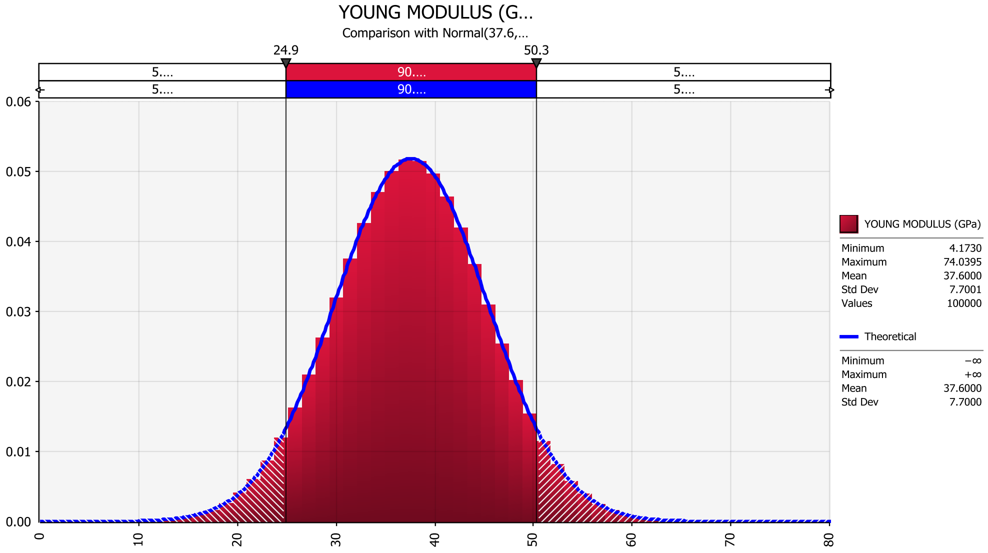

Figure 8: Probability distribution function of Young Modulus

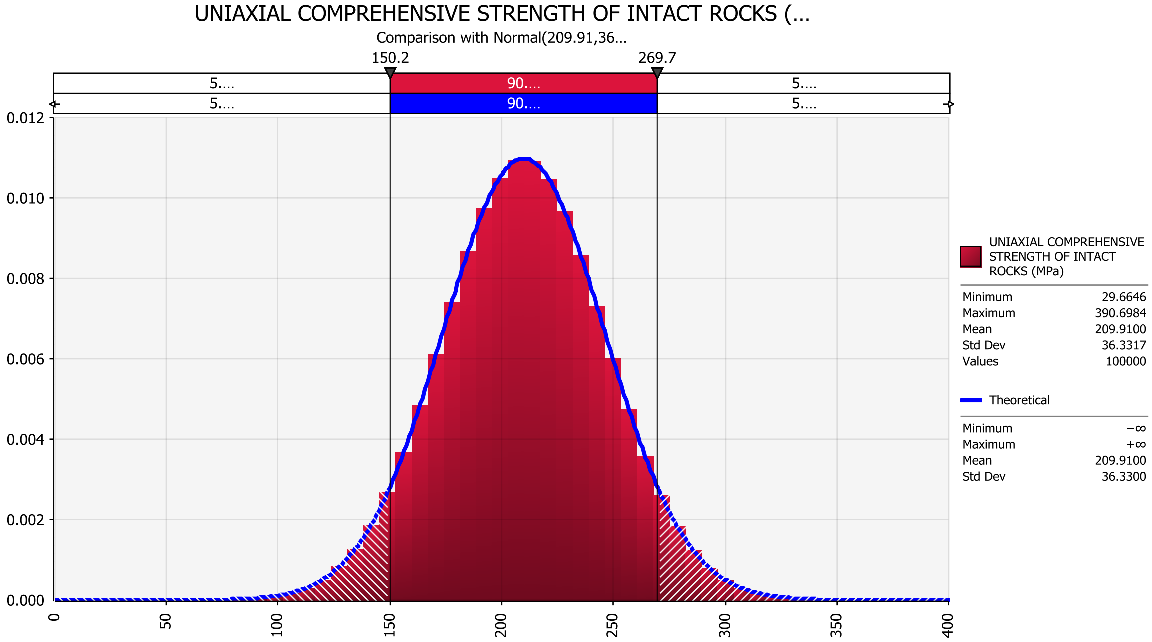

Figure 9: Probability distribution function of UCS (MPa)

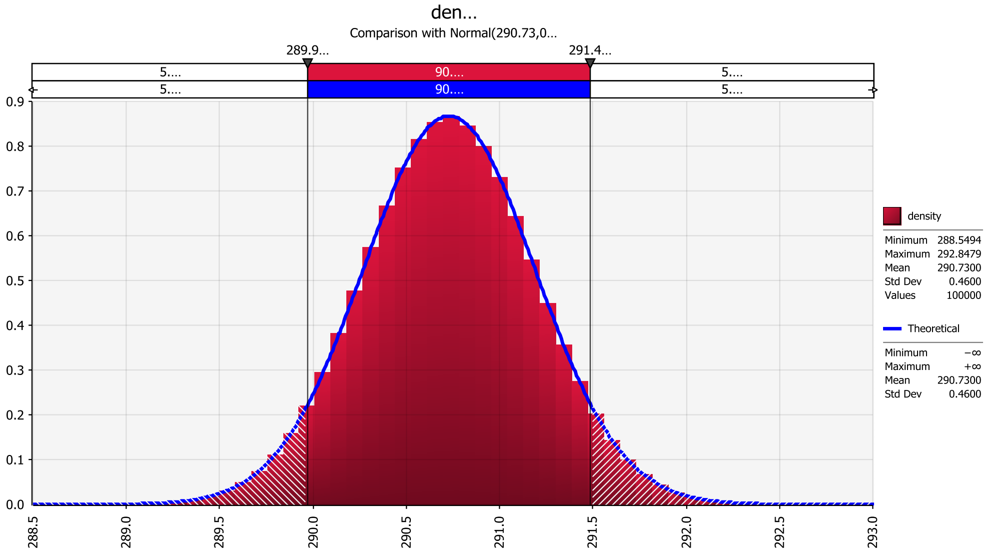

Figure 10: Probability distribution function of density

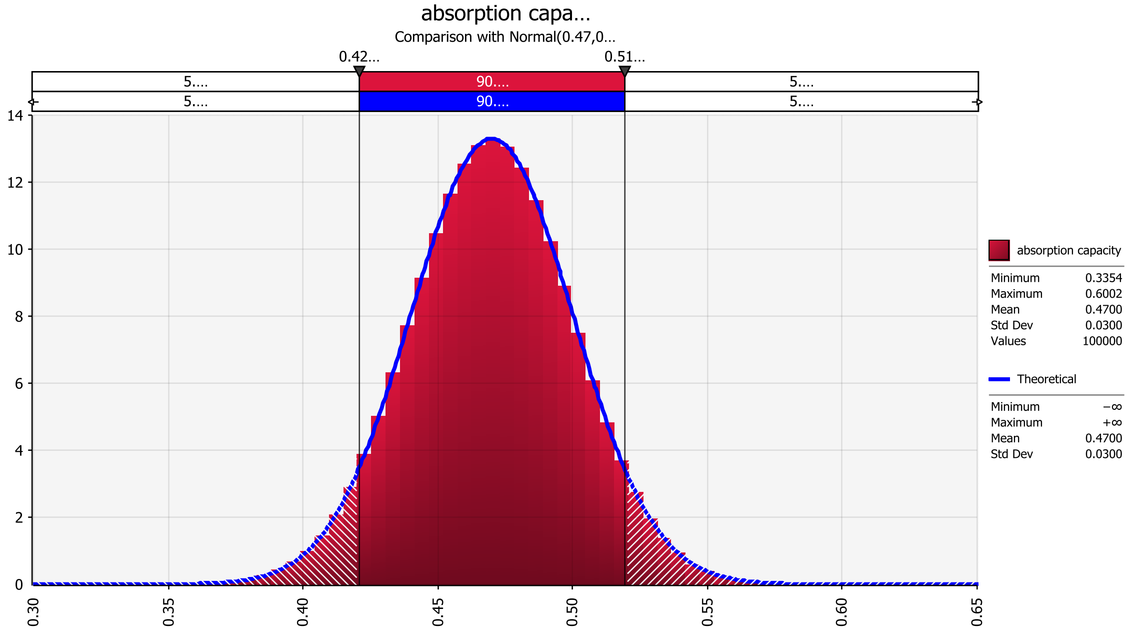

Figure 11: Probability distribution function of Absorption Capacity (%)

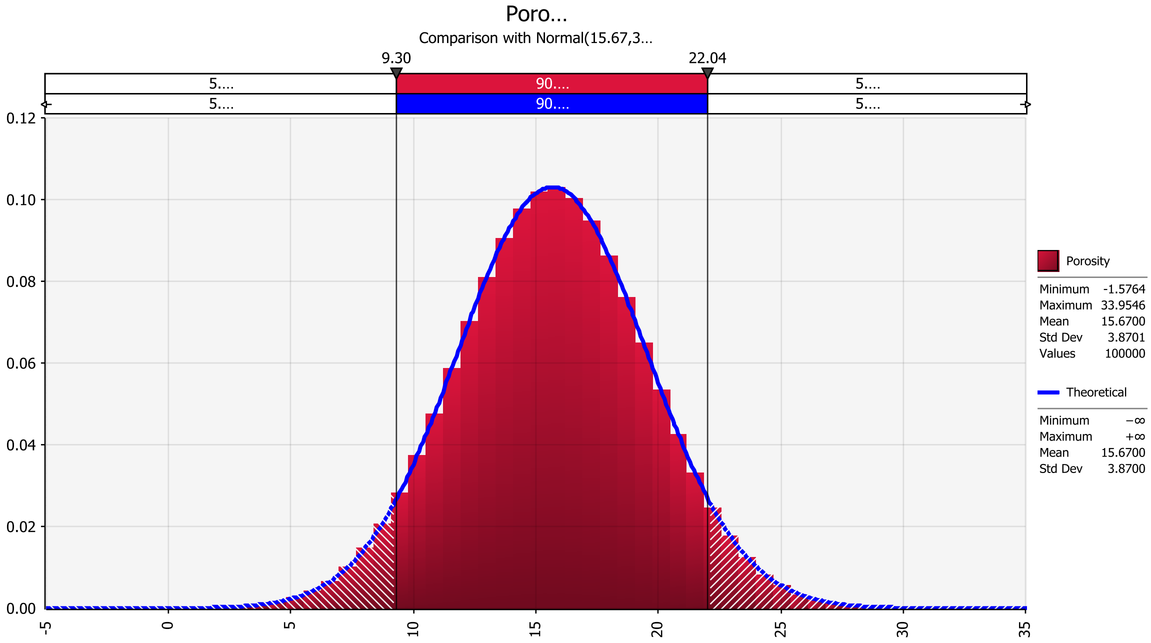

Figure 12: Probability distribution function of Porosity (%)

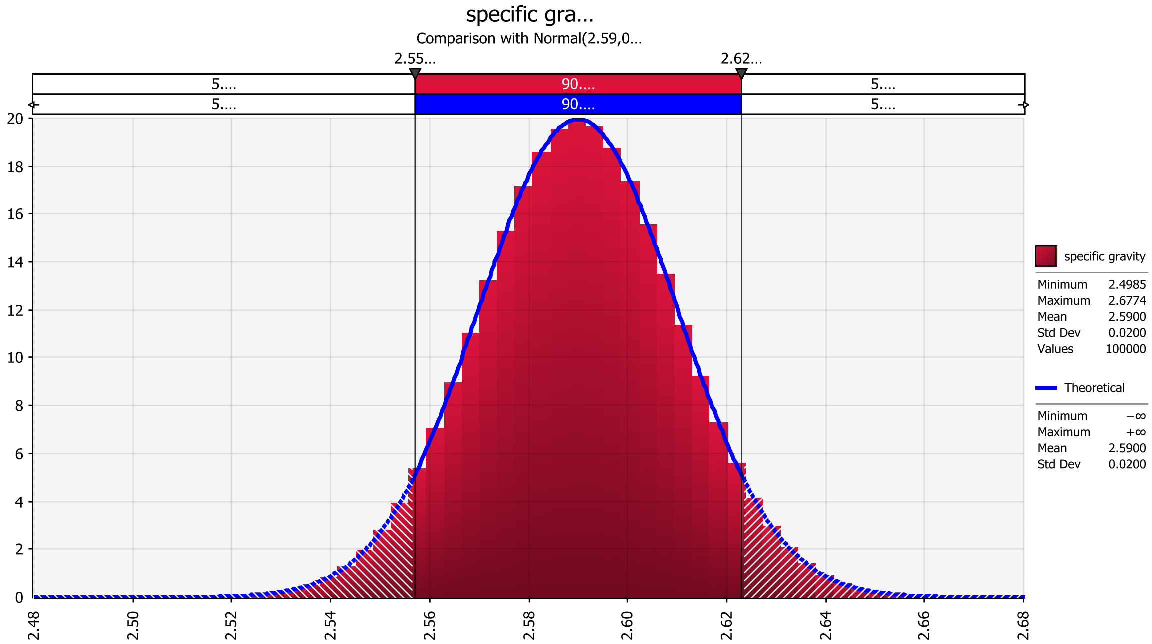

Figure 13: Probability distribution function (PDF) of Specific gravity

Note that the minimum and maximum values obtained from laboratory tests with the standard deviation determined whether the output PDF would be wider or not.

Table 3: RQD Measurement (Across the Eastern Part of the mine)

ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	15	20	23	21	32	20	15	15	18	20	10	16	12	10	17	12	23	20	31	10	13	16	16	12	23
	15	19	21	13	15	15	15	16	14	12	15	13	15	12	15	10	15	21	15	15	15	10	12	13	12
	17	17	11	16	16	15	12	10	20	20	16	12	12	15	16	13	16	21	18	23	10	12	14	16	10
	20	16	15	12	10	18	20	12	15	20	15	20	14	23	14	14	20	12	21	13	12	14	12	17	12
	-	-	-	-	-	-	12	16	10	0	20	15	15	13	15	16	10	10		21	14	15	10	20	10
Sum of length≥ 10cm	67	72	70	62	73	68	74	69	67	72	66	71	68	73	74	65	74	84	73	82	64	67	64	78	67

Table 4: Rock Mass Quality Classification According to RQD (Deere et al. 1967)

RQD	**Rock Mass Quality**
<25	Very poor
25 – 50	Poor
50 – 75	Fair
75 – 90	Good
90 – 100	Excellent

Note: (i). where RQD is reported as ≤ 10 (including 0), a nominal value of 10 is used to evaluate Q. (ii). RQD interval of 5, (i.e. 100, 95.90. etc, are sufficiently accurate)

Table 5: a. Rock Mass Rating (RMR) Measurement

Rating parameters	NE1	NE2	E1	E1	E3	E4	E5	E6
Uniaxial Compressive Strength value	207.85-214.25 (MPa)	207.85-214.25 (MPa)	207.85-214.25 (MPa)	207.85-214.25 (MPa)	207.85-214.25 (MPa)	207.85-214.25 (MPa)	207.85-214.25 (MPa)	207.85-214.25 (MPa)
Rating	12	12	12	12	12	12	12	12
RQD	75 -90	75-90	75-90	75-90	75-90	75-90	75-90	75-90
Rating	17	17	17	17	17	17	17	17
Spacing of Discontinuities	0.6-2	0.6-2	0.6-2	0.6-2	0.6-2	0.6-2	0.6-2	0.6-2
Rating	8	8	10	10	10	10	8	8
Condition of Discontinuities (Rating)	10	10	10	10	10	10	10	10
Ground water (Dry season)/(Wet season) Rating	7	4	4	7	4	0	0	7
TOTAL	54	51	53	56	52	49	49	54
class number	III	III	III	III	III	III	III	III
Description	**Fair rock**	**Fair rock**	**Fair rock**	**Fair rock**	**Fair rock**	**Fair rock**	**Fair rock**	**Fair rock**

Table 5b: Rock Mass Rating Measurement (continuation)

Rating parameters	E7	E8	E9	E10	E11	E12	SE
Uniaxial Compressive Strength value	207.85-214.25 (MPa)	207.85-214.25 (MPa)	207.85-214.25 (MPa)	207.85-214.25 (MPa)	207.85-214.25 (MPa)	207.85-214.25 (MPa)	207.85-214.25(MPa)
Rating	12	12	12	12	12	12	12
RQD	75-90	75-90	75-90	75-90	75-90	75-90	75-90
Rating	17	17	17	17	17	17	17
Spacing of Discontinuities	0.6-2	0.6-2	0.6-2	0.6-2	0.6-2	0.6-2	0.6-2
Rating	8	8	8	8	8	8	8
Condition of Discontinuities (Rating)	10	10	10	25	25	25	25
Ground water (Dry season)/(Wet season) Rating	7	7	0	7	7	7	7
TOTAL	54	54	47	69	69	69	69
class number	III	III	III	II	II	II	II
Description	**Fair rock**	**Fair rock**	**Fair rock**	**Good rock**	**good rock**	**Good rock**	**Good rock**

Table 6 : Q System Classification for the shales hosted lead-zinc deposit

ID	NE1	NE2	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	SE
RQD	88.23	88.23	88.23	88.23	88.23	88.23	88.23	88.23	88.23	88.23	88.23	88.23	88.23	88.23	88.23
J_n	3	6	4	3	3	4	3	4	4	4	3	3	3	3	3
J_r	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
J_a	2	1	1	2	2	1	2	2	1	1	2	2	2	2	2
J_W (dry season)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
J_W (wet season)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
SRF	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Q (Dry season)	8.82	8.82	13.2	8.82	8.82	13.2	8.82	6.62	13.2	13.2	8.82	8.82	8.82	8.82	8.82
Q (Wet season)	4.41	4.41	6.61	4.41	4.41	6.61	4.41	3.308	6.62	6.62	4.41	4.41	4.41	4.41	4.41
Rating	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Poor	Fair	Fair	Fair	Fair	Fair	Fair	Fair

Where RQD is Rock quality designation;J_n is Joint set number;J_r is Joint roughness number; J_a is Joint alteration number; J_W is Joint water reduction factor; and SRF Stress reduction factor.NE - North East), E - East, SE – South East part of the mine.

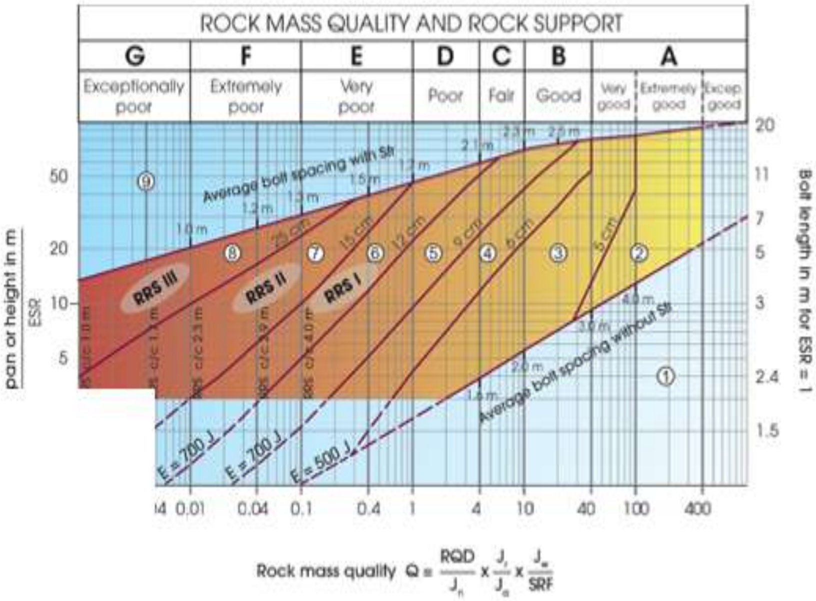

Figure 12: Q Chart (Barton et al. 1974)

ii. Rock Mass Classification System forEyigba, Ebonyi State

Rock mass classification systems used in this study are Rock quality designation (RQD), Rock mass rating, Q system and Geological Strength Index (which will be presented in another paper). The results are hereby presented below.

a. Rock Quality Designation (RQD)

RQD values for the measured rock mass is tabulated in table 3, RQD measurement for the rock mass ranges from 62 to 84, and when compared to the rock mass quality classification table 4. It shows that the rock mass quality is generally Fair quality rock (62-74). The rock mass quality is of fair rock type.

b. Rock Mass Rating (RMR)

Table 5a and 5b show the rating for the RMR measured across the eastern part of the mine (working face). RMR ratings generally ranges between 47 and 56 (Fair rock quality), and few locations recorded 69 (Good rock quality). The rock mass quality is of Fair quality rock.

c. Rock Tunneling Quality Index Q-System

Measurement and recording of various Q parameters from equation (3) when applied at different locations in the East (E) and South East (SE) of the open pit in other to determine the rock mass quality were tabulated were tabulated in Table 6. According to equation (3) yielded the Q (rating). At Worst scenario (Q wet season), rating for Q system value for 13 location points on the rock mass rating were between 4.41 and 6.62 which fall in Class C (fair rock mass) from Q Chart (Figure 19) except at E8 location where we have class of rock mass to be poor rock mass (D) at value of 3.31. In dry season, Q values ranges between Fair rock mass (C Class) when 4 < Q <10, and good (B class) when 10 <Q <40. Hence, the worst situation (wet season) was selected that fell in the class of C, Fair rock mass quality (Figure 3). The quality of the rock mass is fair. This is in conformity with that of RMR.

V. CONCLUSION AND RECOMMENDATIONS

In this article a probabilistic technique is used to determine the properties of intact rock properties of Eyigbashales lead –zinc hosted massive deposit based by considering the variabilities and uncertainties in these properties. Hence, a single deterministic value will not be suitable to quantify some of these properties due to higher variations within the properties under consideration. The rock mass quality of Eyigba is fair, which indicated that adequate care and hand on experience of the mining operator need to come to play in design and assessing the slope stability of the mine. The result presented can be considered as preliminary input parameters for rock mass properties using Hoek-Brown as well as to obtain equivalent Mohr-Coulomb parameters.

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