Determination of intact rock properties of Eyigba lead – Zinc Shale hosted Sedimentary rock Ebonyi State

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Abstract-This paper aim at presenting the intact rock properties of Eyigba, Ebonyi State. The study location 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 of this paper include; collection of rock samples (for coring of core samples), determine the mechanical, physical and shear strength properties of the intact rock samples. The following standards were used: ISRM 1989 (uniaxial compressive strength, UCS), ASTM D 7012-14 (Young Moduli and Poisson ratio), ASTM D 2216 (Bulk Density), ASTM D6473-15 (Specific gravity and water Absorption Capacity), and ASTM C97-83 (Porosity); ASTM D2936-71 (tensile strength) while, ASTM D5608-08 (cohesion and friction angle). The mean and standard deviations for these properties are; UCS (209.90 ± 36.33) MPa, Young Modulus (37.60 ± 7.7) MPa, Poisson ratio (0.28 ± 0.09), Deformation modulus (339.48 ± 4.9), Cohesion (14.60 ± 4.93) MPa, Tensile strength (4.18 ± 0.37) MPa, density, ρ (290.70 ± 2.63) kg/m^3, water absorption (0.47 ± 0.03) %, porosity (15.67 ± 3.87) %, and the friction angle (25.04 ± 0.26)° respectively. There is variation in the rock properties (due to high standard deviation) except for Poisson ratio, water absorption, tensile strength and friction angles which is less than 0.5. In conclusion single value should not be used to represent rock properties due to variability (uncertainty) presence in the measured values. Hence, probability distribution function should be employed to predict the representative values (function) of intact rock properties of this nature. Stochastic methods of quantifying intact rock properties is hereby recommended.

Key words: density, intact, rock properties, Shale, tensile strength, uniaxial compressive strength

1. INTRODUCTION

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 [12], [13]. 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. 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[15].

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 [27], [12], [13].

Due to the presence of lead and Zinc in the black shale deposit of Eyigba, Ebonyi State which occurred as Pb/Zinc veins running North South in commercial quantity after exploration work has been completed. It is expedient to investigate the intact rock properties as mining progresses in order to characterize both the intact and the rockmass properties respectively. Black shale is an example of sedimentary rocks. Sedimentary rocks are formed from the consolidation of sediments. Sedimentary rocks cover three-quarters of the continental areas and most of the sea floor. As a result of this process, sedimentary rocks almost invariably possess a distinct stratified, or bedded, structure[18].

Laboratory tests carried out on the intact rock properties includes; bulk density, porosity, water absorption capacity, deformation modulus, interface friction angle, cohesion, tensile strength, uniaxial compressive strength, young modulus and Poisson ratio.

2. DESCRIPTION OF THE STUDY AREA

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[10],[9]. 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[12]. Pb-Zn occurrences in Nigeria are associated with saline water intrusion in the sedimentary basins or fractured/shear zones in crystalline rocks. 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[24].

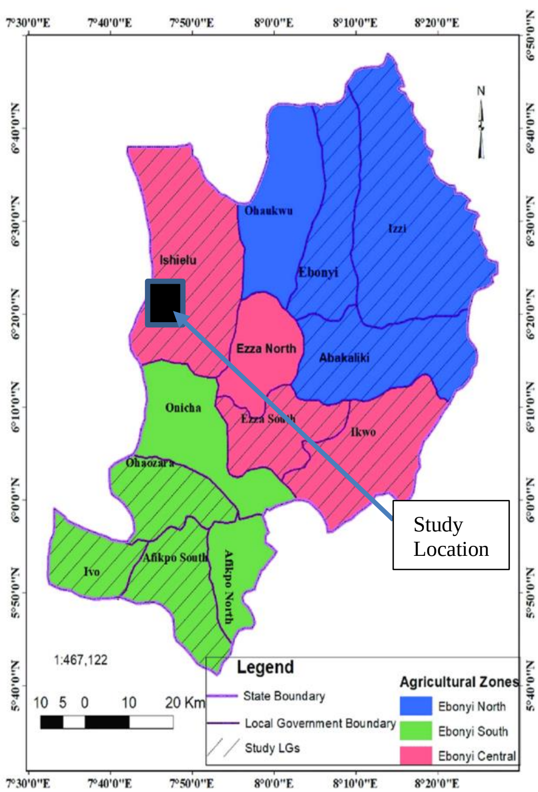

Figure 1. Map of Ebonyi State showing the LGAs.

Source: [23]Map of Ebonyi state showing the local government areas.

2.3 Intact Rock Properties of Shales

Intact rock properties can be divided into mechanical properties, Physical properties and shear properties.

Intact shale properties include the following listed below.

1. The (total) porosity, n, is defined as the ratio of void or pore volume, Vv , to the total volume, V, of the rock.

$$n = \frac{V_V}{V} = \frac{V - V_S}{V} \quad (1)$$

Where *Vs* is the volume of the grains or solid matrix substance, measured in (%). Porosity is usually given as a percentage. The porosity of rocks can be determined by using the method suggested by[12].

2. The density is defined the mass per unit volume of a material. Since a rock contains both grains (solid matrix material) and voids, it is necessary to distinguish between different densities which are related to different parts or components of the rock, measured in (kg/m^3). The density of rocks can be determined using the method suggested by[12].
3. Permeability, mathematically, it is the open space in a rock divided by the total rock volume (solid and space). Permeability is a measure of the ease of flow of a fluid through a porous solid. A rock may be extremely porous, but if the pores are not connected, it will have no permeability. Measured in milli darcy.
4. Uniaxial compressive strength also known as the unconfined compressive strength, of a rock may be regarded as the highest stress that a rock specimen can carry when a unidirectional stress is applied, normally in an axial direction to the ends of a cylindrical specimen. It is measured in MPa.
5. Young's modulus (E) is one of the basic geomechanical parameters used in rock engineering in practice. It is determined based on uniaxial compressive test (UCS). However, according to International Society of Rock Mechanics it can be calculated by three different ways: as the tangent, secant and average modulus.
6. The modulus of deformation (Mpa) that is, the stiffness of the rock is significant in

problems involving movement under stress and in sharing of load between rocks.

7. The Poisson's ratio highly depends on the ratio of uniaxial compressive strength and tensile strength (i.e., brittleness) of the intact rock, increasing the brittleness of the rock, the Poisson's ratio decreasing.
8. Cohesion (c), (MPa). The cohesion of an intact, fracture-free rock is very high[26].
9. Friction angle (ϕ), degree
10. Tensile strength (**(σ_t),** MPa
11. P wave velocity (m/s), refers to the speed at which primary waves (P-waves) travel through a medium, such as the Earth's crust. P-waves are a type of seismic wave that compress and expand the material they move through, similar to sound waves in air. They are the fastest seismic waves and are typically the first to be detected by seismographs during an earthquake.

The internal friction angle is one of the two main shear strength parameters of rock materials, determines the rate of increase in shear strength depending on normal stress and is used in many rock engineering applications. Shear strength of rock materials is often determined by Mohr-Coulomb (MC) failure criterion. The shear strength proper-ties of rock materials, cohesion and internal friction angle, are determined by carrying out tri-axial strength test on cylindrical core specimens in laboratory and the test results are represented by Mohr Circles[11].

2.4 Significance of Intact Rock Properties of Shales

The uniaxial compressive strength (UCS) of rocks is a vital geo-mechanical parameter widely used for rock mass classification, stability analysis, and engineering design in rock engineering. Various UCS testing methods and apparatuses have been proposed over the past few decades[28]. Although its application is limited, the uniaxial compressive strength allows comparisons to be made between rocks and affords some indication of rock behaviour under more complex stress systems (International Association of Engineering Geology).

Extensive rock tri-axial tests were carried out to determine intact strength properties. Consequently equivalent rock mass properties were calculated based on GSI (Geology Strength Index) and D (Excavation Damage Factor) those were recorded from rock face mapping. In situ horizontal stresses of rock mass were measured before and during rock cavern excavation. The stability analysis was carried out based on those parameters by using 2D FEM program such as Phase 2 and UDEC[26].

Young's modulus of intact rock is used by all numerical models for stress and deformation analyses such as FLAC, PHASE or UDEC for rock engineering problems[22].

The most obvious application of the correlations is borehole-stability evaluation. With the sources available for P-wave velocity estimates, this can be done in all stages of drilling, (i.e., planning, follow-up during drilling, and post-analysis). Correlations can be implemented directly in log analysis software, for example, thus providing a shale mechanical-properties log. The time-dependent response of the shale during the openhole period may be monitored also by comparing one or more sources (MWD, wireline log, etc.) from different times after drilling.

Mechanical properties are used also as a basis for other drilling parameters, selection of drill bits, e.t.c. [20, 21.] . This is another potential application of the correlations. The correlations provide a possibility of mapping the mechanical properties of the shale in the overburden of a field. These are important input parameters in a subsidence analysis for a potentially compacting reservoir. Because the P-wave velocity in the shale is the primary input to the correlations, it is recommended to include P-wave velocity logging routinely in overburden sections, at least in the early stages of field development

3. MATERIALS AND METHOD

3.1 Materials

Eight (8) shale rock boulders were collected from the mine site (resulted from fresh blasting), for laboratory test which include coring of samples shale rocks (intact core samples). Physical, mechanical and shear properties were determined from 25 core samples of shale. The coring was done at Mining Laboratory, Federal University of Technology Akure, Ondo State. The laboratory tests were conducted at Rolab Research and Diagnostic Laboratory, Ibadan, Oyo State, Nigeria.

3.2 Methods

The American Society for Testing and Materials (ASTM)[1],[2] and the International Society for Rock Mechanics (ISRM)[17] are the standards used for intact rock testing for this study. Mechanical Property of the Intact Core Samples include uniaxial compressive strength, were conducted using the following standards; [19], [6]Was used for Young Moduli and Poisson ratio determination.

Physical Properties of the Intact Core Samples include bulk density (BD), specific gravity (SG), absorption capacity (AC), and Porosity. The tests were conducted according to the following standards; [4](Bulk Density, Specific gravity and water Absorption Capacity), and [5](Porosity).

Shear Properties of the Intact Core Samples include tensile strength, cohesion and friction angle. The tests were conducted according to [3]standards (tensile strength), [6][16][17] (Shear Strength - cohesion and friction angle).

4. RESULTS AND DISCUSSION

The result of test conducted on the mechanical properties of intact rock samples is presented in table 1.

Table 1: Mechanical properties

ID	Uniaxial Compressive Strength, UCS (σ) (MPa)	Young Modulus *Y*, (GPa)	Poisson Ratio (*P*)	Deformation Modulus, γ
1	224.20	40.50	0.20	336.25
2	220.40	36.70	0.28	340.20
3	238.70	27.90	0.20	338.33
4	140.50	49.50	0.40	348.40
5	220.20	41.50	0.20	333.35
6	239.50	27.20	0.40	338.00
7	138.90	48.50	0.20	342.20
8	223.40	39.50	0.40	334.00
9	225.40	35.70	0.20	338.50
10	232.70	28.60	0.40	345.32
11	220.20	37.60	0.20	338.24
12	219.40	35.70	0.40	341.52
13	236.70	25.90	0.20	337.13
14	143.50	47.50	0.28	348.40
15	225.20	41.70	0.40	332.30
Mean	209.90	37.60	0.28	339.48
SD	36.33	7.70	0.09	4.97

(Where σ is the uniaxial compressive strength, *Y* is the young modulus, γ is the deformation modulus.)

Discussion:

The uniaxial compressive strength (σ) of the intact rock samples ranges between 138.90 and 239.50 MPa, with the mean value of 209.90 MPa and a standard deviation (SD) of 36.33 MPa. Higher standard deviation shows that the UCS varies significantly within the core samples, hence there is need to account for its variability.Young modulus (*Y*) of the intact rock samples ranges between 25.90 to 49.50 GPa, with the mean value of 37.60 and SD of 7.70. There exist large variation in the Young Modulus of the intact rock properties (SD = 7.70 GPa). Poisson ratio (*P*), has a mean value of 0.28 and SD of 0.09. It has little variation. Mean value of deformation modulus, γ is 339.48 with S.D of 4.90.

Table 2: Physical Properties

ID	Density, ρ (kg/m^3)	Absorption capacity, β (%)	Porosity, φ (%)
1	293.00	0.46	19.90
2	291.00	0.44	17.90
3	287.00	0.52	11.50
4	293.00	0.44	11.80
5	292.50	0.46	19.90
6	286.60	0.46	11.90
7	292.80	0.46	11.70
8	292.50	0.46	19.90
9	290.80	0.46	17.90
10	286.60	0.54	11.90
11	292.50	0.46	19.90
12	290.80	0.46	17.5
13	286.60	0.54	11.90
14	292.80	0.46	11.60
15	292.50	0.46	19.90
Mean	290.70	0.47	15.67
SD	2.63	0.03	3.87

The mean density (ρ) is 290.70 with a SD of 2.63. Water absorption capacity (β) has a mean value of 0.47 with SD of 0.033. The porosity (φ) has a mean value of 15.67% and SD of 3.87

Hence, variability within these properties need to be quantified.

Table 3:

ID	Cohesion, *C* (MPa)	Friction angle, ϕ (°)	Tensile strength (MPa)
1	8.70	24.95	4.50
2	12.60	24.90	3.85
3	16.30	25.44	3.80
4	22.46	24.90	4.60
5	8.30	24.65	4.48
6	16.00	25.44	3.82

7	14.40	24.90	3.80
8	18.70	24.95	4.60
9	15.60	24.90	3.74
10	20.20	25.44	4.52
11	8.20	24.95	4.40
12	11.80	24.90	3.82
13	15.87	25.44	3.80
14	21.86	24.90	4.58
15	8.03	24.95	4.38
Mean	14.60	25.04	4.18
SD	4.93	0.26	0.37

Cohesive strength (*C)* MPa, has a mean value of 14.60 and SD of 4.93; while the mean friction angle, ϕ (°) is 25.04 and SD of 0.26. The mean value of the tensile strength of the intact rock properties is 4.18MPa with the standard deviation of 0.37.

Intact rock properties of the core samples varies considerably except for Poisson ratio and absorption capacity respectively. This variability need to be quantify in order to select a representative value that adequately represent the intact rock properties of this location.

Hence, we need to further the study to quantify the uncertainty in these properties list above using @ risk software.

In conclusion, rock is a heterogeneous in nature that varies across the whole deposit. Adequate quantification of variability and uncertainty of intact and rock mass properties played a significant role in prediction of slope stability analysis of an open pit mine. The intact rock properties of the location varies with significant standard variation. Thereby ranges of these properties need to be specified, otherwise stochastic approach need to be employed to adequately quantify the variability that exists amongst the intact rock properties of the core samples from the study location. As a result, intact rock strength serves as input parameters in numerical modelling in mining project. Hence the reason why the uncertainty should be quantified adequately.

The followings are hereby recommended:

1. More intact rock properties laboratory tests should be conducted to established empirical formula for this kind of location
2. Fund should be made available to carry out research of this nature

Further research

Correlation of these intact rock properties should be done. Quantification of uncertainty in the properties investigated should the done for accurate prediction of properties.

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