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Investigation on Geo-Mechanical Properties of Rock Samples

Abhishek Kumar Tripathi[1], Ramesh kant[2]
** (Assistant Professor, Department of Mining Engineering, Godavari Institute of Engineering and Technology (A), Rajahmundry)*
*** (Assistant Professor, Department of Mining Engineering, Godavari Institute of Engineering and Technology (A), Rajahmundry)*
Corresponding author: Abhishek Kumar Tripathi

Abstract: *The mechanical behaviour of rock is a vital parameter for deigning a safe slope, and for the geological construction in open cast mines. In the present study the various mechanical parameters of the field collected rocks were tested and examined in the laboratory. The total ten number of different types of rock samples were collected from the field. The tested results demonstrate that the GTBH (Banded Hematite)-1 shown the good UCS and young's modulus than the other rock samples which were collected from the mines.The results of this study will help in the designing the optimum pit limit for a mine.*

Keywords: *Rock; Mechanical property; Geological construction; Optimum pit.*

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I. INTRODUCTION

Open pit mining refers to a method of extracting rock or minerals from the earth by making a series of benches opened to the sky. It is a mining that is suitable for surface or near surface deposits. The term is used to differentiate this form of mining from methods that require belowground workings. Open pit mines are used when deposits are found close to the surface; that is, where the overburden is relatively low or the material of interest is unsuitable for underground mining. Open pit mines that produce building materials and dimensional stone are commonly referred to as quarries. Open pit mines are not widened/ deepened when the increasing stripping ratio makes open pit mining uneconomic. After mining the abandoned open pit is sometimes reclaim with overburden or solid waste. However, it is advised not to allow water as reclaiming agent in the abandoned open pit. A simple layout of an iron ore mine-A is shown in Fig 1.

Fig. 1. Open pit mining method

The mechanicaland physical properties of rockare very important parameters forgeological engineering design and construction. In the case, of an iron ore mines many disasters happen due to the mis-concept of rock mechanical properties [1]. The failure of rock slope is most popular disaster canbe observed in any open cast mines [2]. The slope of an open cast mines is primarily depended on the mechanical properties of the rock. The physical properties of rock consist of density, porosity, andpermeability, etc. and the mechanical properties mainly include elasticmodulus, Poisson's ratio, and rock strength. These parameters can be obtained by lab experiments of core samples or by in-situ tests [3]. The othercharacteristics of rocks include time-dependent rheological and creep behaviors [4-5]. When the rock samples are not available, such as oiland gas drilling and mining at deep depth, the well log data and geophysical data can be used to analyze and interpret rock physical and mechanicalparameters [6-7]. In order to keep mechanical property in mind the prime objective of this paper is to study the mechanicalparameters of the field collected rock samples.

II. PERSUAL OF SELECTED SITE AND SAMPLE COLLECTION

The selected mine for the study is an open pit iron ore mine situated in the eastern part of India. The mine where the studies have been carried out is an already existing mine with multi bench workings. In this mine there were cases of mine slope failure, one of the causes of which have been attributed to movement of heavy machineries. It has been observed that slope failures are more pronounced in the rainy seasons. The rocks of this mine are comprised of laterite, banded hematite quartzite (BHQ), massive hematite, banded hematite, laterite with hematite intercalatious, laminated hematite, goethite/ limonite with iron ore, banded hematite jasper (BHJ) with laterite, limonite with hematite and laminated ore.Sample collection and testing is the first step of this study.Thr cores from various locations of the mine were collected using diamond drilling technique.Thereafter,the physico-mechanical properties of the rocks were tested. The 24 core samples from 12 boreholes of diameter 45 mm were tested for compressive strength, tensile strength, modulus of elasticity, Poisson's ratio, moisture content, and density.

III. DETERMINATION OF MECHANICAL PARAMETERS OF ROCK SAMPLES

The various rock samples from different locations of the iron ore mines were tested at the Rock Mechanics Laboratory for geotechnical investigation. The samples to be tested were prepared in the laboratory for determination of various rock properties as mentioned in the Introduction section. Firstly, rock samples were cut to the size specifications recommended by International Society of Rock Mechanics (ISRM). Then, the samples were polished at both the ends to make the both ends parallel and perpendicular to the longitudinal axis. A number of samples were prepared for the stipulated experiments as per the recommendation by International Society of Rock Mechanics (ISRM). The experiments are the uniaxial compression, tension, modulus of elasticity, Poisson's ratio, moisture content and density. Figure-2-5 show different types of work for sample preparation at laboratory. Table-1 shows the different rock cores collected from different mine locations and their rock type.

Fig.2. Cutting by diamond circular saw

Fig.3. Polishing with SiC

Fig. 4. Polishing by grinding machine

Fig.5. Polished samples

Table 1 Rock sample details

Sl. No.	Bore Hole No.	Sample No.	Rock Type
1	GTBH-1	GTBH-1/1	Banded Hematite
2	GTBH-5	GTBH-5/1	Laterite
3		GTBH-5/2	Laterite
4	GTBH-6	GTBH-6/1	Banded Hematite Quartzite (BHQ)
5		GTBH-6/2	Banded Hematite Quartzite (BHQ)
6	GTBH-7	GTBH-7/1	Massive Hematite
7		GTBH-7/2	Laterite with Hematite intercalatious
8	GTBH-8	GTBH-8/1	Laterite with Hematite and Goethite/Limonite
9		GTBH-8/2	Laterite (vesicular) with Iron ore
10	GTBH-9	GTBH-9/1	Laterite

Uni-axial Compressive Strength of Rocks

This method of test is intended to measure the uniaxial compressive strength of a rock sample in the form of specimens of regular geometry. The test is mainly intended for strength classification and characterization of intact rock. The test specimens are right circular cylinders having a length to diameter ratio of 2.5 to 3.0 and a diameter of 54mm. The uniaxial compressive strength of the specimen is determined by dividing the maximum load carried by during the test, by the original cross-sectional area of the sample. Figure-6 shows picture of samples under uniaxial compressive strength test.

Fig.6. A sample under UCS test

As we know, the compressive strength of the test specimen 'σ_c' is calculated by dividing the compressive load (P) at failure on the specimen by the initial cross-sectional area, A_o and therefore,

$$\text{Compressive strength, } \sigma_c = \frac{P}{A_o} \quad \text{-- (1)}$$

All the prepared samples were tested by INSTRON 3500 kN, a servo controlled compression testing machine in the rock mechanics laboratory**.** Table-2 shows the uniaxial compressive strength of the tested samples in the laboratory.

Table2. Uniaxial compressive strength of the rock

Sl. No.	Bore Hole No.	Sample No.	Rock Type	Length (mm)	Diameter (mm)	UCS (MPa)
1	GTBH-1	GTBH-1/1	Banded Hematite	88.18	45.52	58.89
2	GTBH-5	GTBH-5/1	Laterite	113.18	44.74	5.5
3		GTBH-5/2	Laterite	88.14	44.88	12.0

4	GTBH-6	GTBH-6/1	Banded Hematite Quartzite (BHQ)			
5		GTBH-6/2	Banded Hematite Quartzite (BHQ)	110.82	45.16	33.6
6	GTBH-7	GTBH-7/1	Massive Hematite	89.56	44.54	28.49
7		GTBH-7/2	Laterite with Hematite intercalatious	111.14	45.44	4.89
8	GTBH-8	GTBH-8/1	Laterite with Hematite and Goethite/Limonite	-	-	-
9		GTBH-8/2	Laterite (vesicular) with Iron ore	-	-	-
10	GTBH-9	GTBH-9/1	Laterite	113.22	45.02	8.3

Modulus of Elasticity and Poisson's Ratio of Rocks

Axial and lateral strains are calculated from the following equations

$$\text{Axial strains, } \varepsilon_a = \frac{\Delta l}{l_o} \text{ -- (2)}$$

$$\text{Lateral strains, } \varepsilon_d = \frac{\Delta d}{d_0} \text{ -- (3)}$$

Where,

l_o = original measured axial length,

Δl = change in measured axial length,

d_0 = original un-deformed diameter of the specimen, and

Δd = change in diameter of the specimen.

The axial Young's modulus, E, defined as the ratio of the axial stress change to axial strain produced by the stress change, can be calculated using any one of several methods employed in accepted engineering practice. The most common method of tangent modulus of elasticity at 50% of the ultimate uniaxial compressive strength is followed for this study.

$$\text{Young's modulus, } E_a = \frac{Axial\ stress}{Axial\ strain} \text{ -------------------------------- (4)}$$

Poisson's ratio is determined as the ratio of axial elastic modulus to the lateral elastic modulus using the following equation.

$$\text{Poisson's ratio, } \nu = -\frac{E_a}{E_l} \text{ --- (5)}$$

For Young's modulus and Poisson's ratio, axial strain is calculated by INSTRON 3500 KN, a servo-controlled compression testing machine itself and lateral stain is calculated by a strain gauge pasted laterally with the sample. The lead wires from strain gauge are then connected with readout box. The strain value in micro-strain is directly read out from the strain gauge indicator. Figure7 shows picture of a sample under uniaxial compressive strength test with lateral strain gauge and tested samples under uniaxial compressive strength test with lateral strain gauge.

Here, for Poisson's ratio three samples are tested by this testing machine. The post failure stress-strain behavior is also seen by this machine.

Fig.7. Samples under UCS test with lateral strain gauge

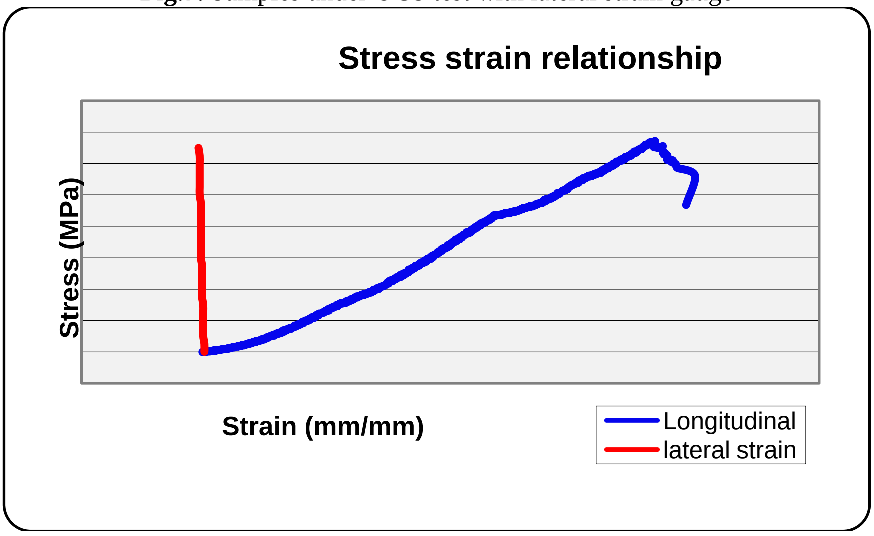

Fig.8 Strain-stress behavior of the sample GTBH-6_2

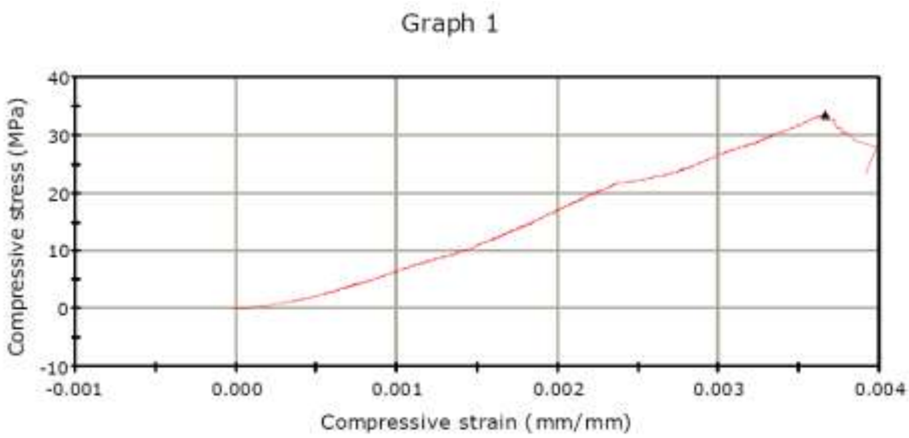

Fig. 9 Post failure stress-strain behavior of the sample GTBH-6_2

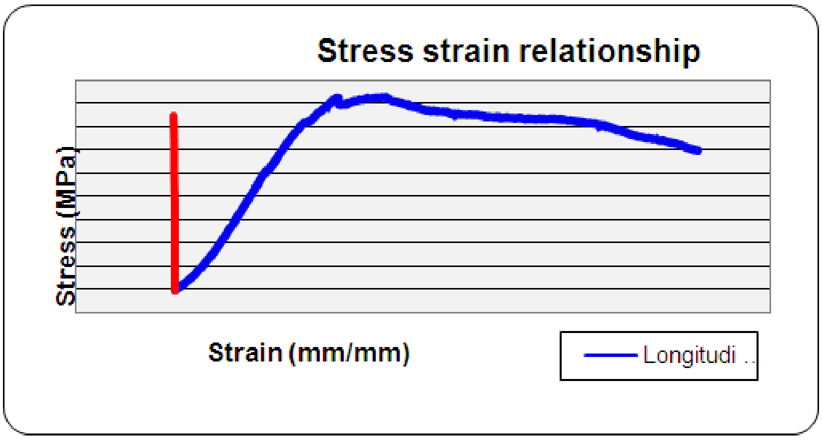

Fig. 10 Strain-stress behavior of the sample GTBH-9_1

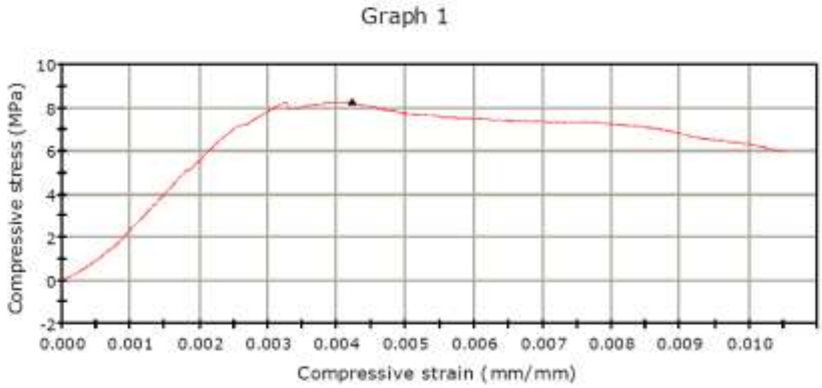

Fig.11 Post failure stress-strain behavior of the sample GTBH-9_1

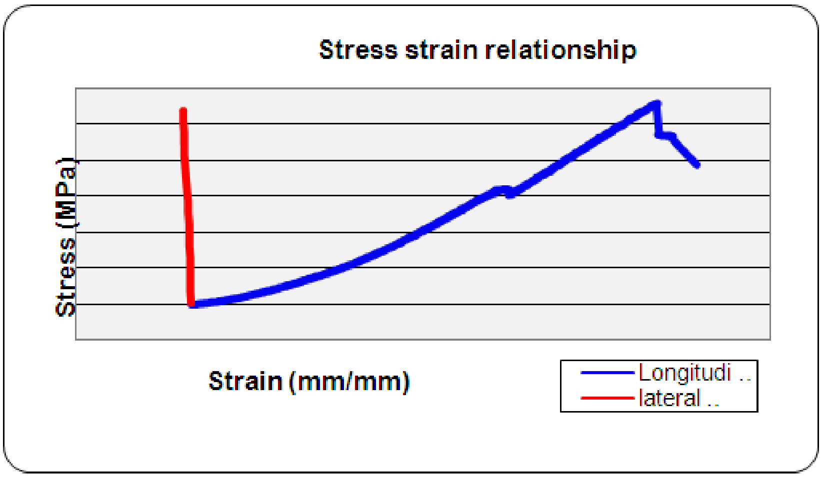

Fig. 12 Strain-stress behavior of the sample GTBH-15_2

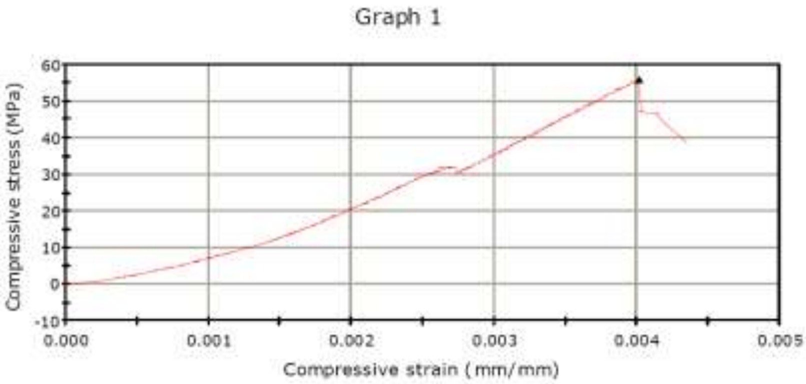

Fig. 13 Post failure stress-strain behaviour of the sample GTBH-15_2

Moduli of elasticity have been determined for all rocks and are listed in the Table-3.Poisson's ratio have been also calculated for three best suited rocks and listed in the same Table. Figures8-13 show the stress-strain behaviour of samples tested in the laboratory. Some of these figures depict both axial and lateral strains with load increments and some of these show post failure behaviour of the rocks. It may be noted that the axial strain is considered to be compressive (+ve) while lateral strains are tensile (─ve).

Table-3. Young's Modulus and Poisson's ratio of the rock

Sl. No.	Bore Hole No.	Sample No.	Rock Type	Length (mm)	Diameter (mm)	E (GPa)	Poisson's ratio (ν)
1	GTBH-1	GTBH-1/1	Banded Hematite	88.18	45.52	20.41	
2	GTBH-5	GTBH-5/1	Laterite	113.18	44.74	7.48	
3		GTBH-5/2	Laterite	88.14	44.88	4.10	
4	GTBH-6	GTBH-6/1	Banded Hematite Quartzite (BHQ)	-	-	-	
5		GTBH-6/2	Banded Hematite Quartzite (BHQ)	110.82	45.16	12.29	
6	GTBH-7	GTBH-7/1	Massive Hematite	89.56	44.54	11.53	
7		GTBH-7/2	Laterite with Hematite intercalatious	111.14	45.44	1.50	
8	GTBH-8	GTBH-8/1	Laterite with Hematite and Goethite/Limonite	-	-	-	
9		GTBH-8/2	Laterite (vesicular) with Iron ore	-	-	-	
10	GTBH-9	GTBH-9/1	Laterite	113.22	45.02	3.36	0.09

Tensile Strength of Rocks

Brazilian test is intended to measure the uniaxial tensile strength of a rock sample in the form of specimens of regular geometry. The test is mainly intended for strength classification and characterization of intact rock. The test specimens are right circular cylinders having a length to diameter ratio of 0.5 and a diameter of 54 mm. The uniaxial tensile strength of the specimen is calculated by dividing the maximum load carried by the specimen during the test, by the area of contact. This method of determining tensile strength is an indirect method, and is popularly known as Brazilian method.

In the indirect tensile strength test a cylindrical test specimen is placed horizontally between the bearing plates of a testing machine and loaded to failure in compression as shown in Figure-14. Results of tests are listed in Table-5. If the diameter of the specimen is D and the length is L, and a line load F is applied along the length of the specimen, a uniform, tensile stress is:

$$\sigma_T = \frac{2F_c}{\pi DL} \text{ -- (6)}$$

 

Fig. 14 Samples under Uniaxial Tensile Strength test (Brazilian test)

Table-5. Uniaxial tensile strength of the rock

Sl. No.	Bore Hole No.	Sample No.	Rock Type	Diameter (mm)	Thickness (mm)	Failure Load (kN)	Area (m^2)	UTS (MPa)
1	GTBH-1	GTBH-1/1	Banded Hematite	-	-	-	-	-
2	GTBH-5	GTBH-5/1	Laterite	44.64	24.14	4.1	0.0034	2.42
3		GTBH-5/2	Laterite	-	-	-	-	-
4	GTBH-6	GTBH-6/1	Banded Hematite Quartzite (BHQ)					
5		GTBH-6/2	Banded Hematite Quartzite (BHQ)	45.22	22.52	23.4	0.0032	14.63
6	GTBH-7	GTBH-7/1	Massive Hematite	-	-	-	-	-
7		GTBH-7/2	Laterite with Hematite intercalatious	44.54	22.06	4.4	0.0031	2.85
8	GTBH-8	GTBH-8/1	Laterite with Hematite and Goethite/Limonite	-	-	-	-	-
9		GTBH-8/2	Laterite (vesicular) with Iron ore	-	-	-	-	-
10	GTBH-9	GTBH-9/1	Laterite	-	-	-	-	-

Bulk Density of Samples

Bulk density is very important characteristic of rocks from the strength point of view. Due to the various conditions prevailing during the formation of rocks, pores are developed within the rock. The pores may or may not be interconnected. These pores are generally filled with air, water or any other fluid of geologic origin. Porosity reduces the effective density of rock and also affects the strength of rock. The bulk density of samples is obtained by the following formula.

Bulk density = mass of rock (dry) / Total (Bulk) volume (including the volume of pores)--(7)

Total (Bulk) volume = (π $D^2/4$) × L--(8)

Where,

D = Diameter of sample, and L = Length of sample.

Table6. Density of the rock materials

Sl. No.	Bore Hole No.	Sample No.	Rock Type	Weight (Kg)	Diameter (mm)	Length (mm)	Volume (cc)	Density (g/cc)
1	GTBH-1	GTBH-1/1	Banded Hematite	0.477	45.52	88.18	143.50	3.32
2	GTBH-5	GTBH-5/1	Laterite	0.432	44.74	113.18	177.93	2.43
3		GTBH-5/2	Laterite	0.318	44.88	88.14	139.43	2.28
4	GTBH-6	GTBH-6/1	Banded Hematite Quartzite (BHQ)	-	-	-	-	-
5		GTBH-6/2	Banded Hematite Quartzite (BHQ)	0.559	45.16	110.82	177.51	3.15

6	GTBH-7	GTBH-7/1	Massive Hematite	0.565	44.54	89.56	139.54	4.05
7		GTBH-7/2	Laterite with Hematite intercalatious	0.552	45.44	111.14	180.23	3.06
8	GTBH-8	GTBH-8/1	Laterite with Hematite and Goethite/Limonite	-	-	-	-	-
9		GTBH-8/2	Laterite (vesicular) with Iron ore	-	-	-	-	-
10	GTBH-9	GTBH-9/1	Laterite	0.527	45.02	113.22	180.23	2.92

IV. CONCLUDING REMARKS

The knowledge of mechanical properties of rock is very important phenomena of any surface mine project. In this paper an attempt has been made to investigate the mechanical properties field collected rock sample. The mechanical properties of field collected rock samples are experimentally examined in the rock mechanics laboratory. The complete procedure for the determination of mechanical properties of rock sample is explained briefly in this paper. It was found that among all collected samples the GTBH (Banded Hematite)-1 shown the good UCS and young's modulus than the other rock samples. Also, a decent failure profile was observed for GTBH-1 rock samples. The high UCS for GTBH-1 is due to its high bulk density which supports its mechanical property.

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