Estimation of Serpentinite Rock Mass Strength of Placetas - Cuba Underground Gold Mine Deposit

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Abstract— This study estimated the strength of the serpentinite rock mass of the underground gold mine "Oro Descanso" Placetas, Cuba. The rock mass was classified into its lithological group of massive, sheared serpentinite rocks and gabbros. The geo-technical information from the well log data obtained during drilling process (geological logs). The structural analysis was carried out through field observation and quantified by Geological Strength Index (GSI) of average values for massive serpentinite 60, sheared serpentinite 38 and gabbros 78. The generalized Hoek-Brown criterion with software programme, Rocklab 1.0, 2004 version was employed for the analysis and the determination of the rock mass local compressive strength (massive serpentinite = 1.733Mpa; sheared serpentinite = 0.464Mpa; gabbros = 10.354Mpa) and the global strength (massive serpentinite = 6.561Mpa, sheared serpentinite = 5.657Mpa and gabbros = 22.547Mpa). These estimated values characterize brittle type of failure mode and thus supports are recommended.

Keywords: Rock mass, Strength, Underground mine

1 Introduction

The Cuba gold mineralisation is wide spread, occuring as alluvia and endogenous deposit. Available report shows that they are classified as Au-Ag deposit with Sb veins; quartz-Au sulphides with chalcopyrite. There are several distinct mining districts where gold has been mined with over 400 mining companies operating in Cuba (Figure 1). Many gold mines are located near Santa Clara in central Cuba. The Placetas underground mine is not as famous as some other dated back to the prehistiric era in Cuba or early Spanish conquest [Gold in Cuba – Mining and Prospecting Areas (Rare Gold Nuggets June 28, 2015)] Much geotechnical information on ore deposit is required in designing prior to mining and extraction.

Reports (Qui *et al*.., 2017) show that the mechanical properties of transversely isotropic rocks have attracted much research interest in the past years (Cho *et al*., 2012; Dan *et al*., 2013) for the anisotropic behavior exhibited by this type of rock (Vervoort *et al*., 2014) and also for huge number projects built on these rocks. Thus it is necessary to understand the anisotropic behavior of these rocks, such as the exploitation of shale gas, (Harris *et al*., 2011), roof support design of transversely isotropic rock, (Lee *et al*., 2008) and excavation of anisotropic rocks in underground tunnels (Zhang and Sun, 2011).

The estimation of the strength and strength parameters of the rock mass of any underground mine demands a high level of reliability. The strength of any rock mass depends on many factors like: strength of the intact rock, the condition of discontinuity, water inflow, anisotropy, homogeneity, etc. In order to include all these parameters for a reliable estimate of the rock mass is a complex task and many a times need the complex and costly state of art measuring instruments (Zhao *et al*, 2010) and which are not affordable by most third world countries, but many researcher had proposed empirical and theoretical methods which have receive worldwide acceptance due to their practical approval. Barton (1973) and Barton and Choubey (1977) proposed empirical method for the estimation of shear strength of rock mass, Maksimovlc, (1996) proposed hyperbolic relation which does not need any empirical assumption in order to determine shear strength of rock mass as compared to Barton's. Hoek and Brown (1980), Hoek (2007) proposed semi-empirical method for the determination of rock mass strength, which is the method that is applied, in this study, to estimate strength of the rock mass of Oro Descanso Mine.

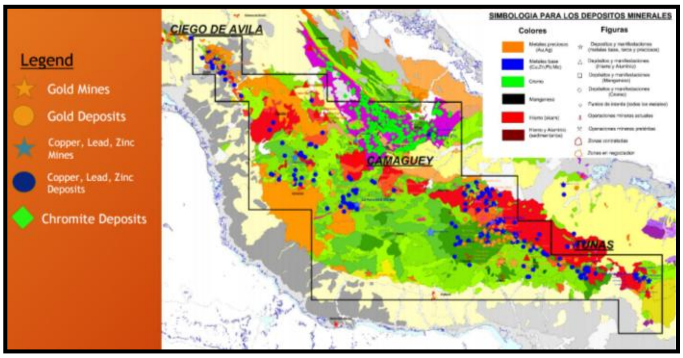

Fig 1: Gold-Projects-Cuba-HSBC-Nov-18-2016. (Source: Sierra Geological Consultants Inc)

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1.1 Geological Characteristics of the Deposit

The study area is located in the municipal of Placetas, Villa Clara, Cuba, with coordinates points according to Lambert system: A(274300,628000), B (274300, 628450), C (273850, 628450) and D (273850, 628000). Geologically, it is located in a principal substratum folds in the central region of Cuba where a complex rock mass is found of the continental nature, oceanic nature type ophiolitic and with different mixture of earth types. The deposit is found within complex ophiolitic rocks located in wild form over the sedimentary sequence of the continental bank and at the same time over run by volcanic cretaceous arc. (Orestes *et al*. 2010). The principal rock mass type is massive serpentine with veins of gabbros. The mineral occurrence is associated with the tectonic zone conserved within massive serpentine wedge. Serpentinite is formed from olivine via several reactions between the magnesium-endmember forsterite and the iron-endmember fayalite. In the reaction there is exchange of silica between forsterite and fayalite thus forming serpentine group minerals and magnetite as represented in equations (1-3).

$$3Fe_2SiO_4 + 2H_2O \rightarrow 2Fe_3O_4 + 3SiO_2 + 2H_2 \quad (1)$$
Fayalite Magnetite aqueous silica

$$3Mg_2SiO_4 + SiO_2 + 4H_2O \rightarrow 2Mg_3Si_2O_5(OH)_4 \quad (2)$$
Forsterite aqueous silica serpentine

$$2Mg_2SiO_4 + 3H_2O \rightarrow Mg_3Si_2O_5(OH)_4 + Mg(OH)_2 \quad (3)$$
Forsterite serpentine brucite

The zone is affected by systems of faults of orientation between 250º-285º and dip within 65º-90º, also there exist transverse fractures with little development along its length, all these provoke displacement generally not more than 0.2m.

1.2 Generalised Method of Hoek and Brown

This criterion was obtained through the curve of best fit of the experimental data of rock failure drawn on a principal stress plan σ_1-σ_3 and as one of the few techniques available for the estimation of the strength of rock mass with the aid of geological data, it is based on the assumption that the rock mass consists of a sufficient number of joint sets (at least three), such that the rock mass behaves as an isotropic material, such rock masses are interlocked, but the interlocking level is relatively low, as joints are persistent and therefore sliding on block boundaries dominates failure, with some rotation of intact rock pieces (blocks)., this criterion is often used for analysis in rock mechanics (Cartaya and Blanco, 2000; Bahrania and Kaiser, 2013). Hoek and Brown (2002) proposed the following expression (4) for the determination rock mass:

$$\sigma_1 = \sigma_3 + \sigma_{ci}\left[m_b \frac{\sigma_3}{\sigma_{ci}} + s\right]^a \quad (4)$$

where:

σ_1, and σ_3 are principal effective stresses.

σ_{ci} is the compressive strength of the intact rock.

s and a are constants which depend on the rock mass characteristics.

m_b is a reduced value of material constant

m_i is the constant of the intact rock which is determined by statistical analysis of triaxial values of principal stresses or through chart (Hoek, 2007).

The values of m_i and σ_{ci} are obtained by statistical fit to peak strength data within a confinement range of 0 to 0.5sci. The empirical constants m_b and s are related in a general sense to the angle of internal friction of the rock mass and the rock mass cohesive strength respectively, a, controls the curvature of the failure envelope. The parameter a, is typically near 0.5 for high GSI-values (>55) and reaches 0.6 for extremely poor ground (Han *et al*, 2012; Bahrania and Kaiser, 2013)

Initially, this criterion was developed for the analysis of fractured but unaltered rock mass with resistant and hard intact rock, supposing that the blocks of rock are interlocked and that the strength of the rock mass depends on the strength of the discontinuities (Hoek and Brown, 1980).Therefore, this failure criterion is valid for isotropic rock mass and do consider the factors that determine the large scale failure of rocky medium, factors like: no linearity of a certain level of stresses, the influence of the types rock, the relation between the compressive and traction strength, the reduction of frictional angle with the increase in confining stress, etc. The strength of a jointed rock mass depends on the properties of the intact rock pieces and also upon the freedom of these pieces to slide and rotate under different stress conditions. This freedom is controlled by the geometrical shape of the intact rock pieces as well as the condition of the surfaces separating the pieces. Angular rock pieces with clean, rough discontinuity surfaces will result in a much stronger rock mass than one which contains rounded particles surrounded by weathered and altered material (Bahrania and Kaiser, 2013). The quantitative value of Geological Strength Index (GSI) was introduced by Hoek (1994, 2007), through which the quality of the rock mass is estimated in

function of the level and characteristic fracturing of the rock mass, its geological structure, block sizes and condition of discontinuities, but Sonmez and Ulusay (1999, 2002) amended this by introducing chart which included the structure rating, SR, based on volumetric discontinuity frequency, introduced to describe the rock mass structure and the surface condition rating, SCR, estimated from roughness, weathering and infilling conditions, to describe the discontinuity surface conditions (Zhang, 2005; Shen *et al* 2013). The values of m_b, s and a are determined by the following equations (5-7):

$$m_b = m_i exp\left(\frac{GSI-100}{28-14D}\right) \quad (5)$$

$$s = exp\left(\frac{GSI-100}{9-3D}\right) \quad (6)$$

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right) \quad (7)$$

D is a factor which depends on level of disturbance by blasting and stress relaxation.

The constants 28 and 9 in Eqs.(2) and (3) are called the degradation constants, as they control the reduction rate of m_b and s as a function of GSI. The uniaxial compressive strength, σ_c, and tensional stress, σ_t are estimated by equations (8) and (9) respectively

$$\sigma_c = \sigma_{ci} s^a \quad (8)$$

$$\sigma_t = -\frac{s\sigma_{ci}}{m_b} \quad (9)$$

2 Methodology

The geo-technical information from the well logging data obtained during process drilling process based on visual inspection of samples brought to the surface (geological logs) and validated by the physical measurements made by instruments lowered into the hole (geophysical logs). The Well logging record of rock mass with the description of the lithology is presented in Table 1.

Plate 1 shows pictorial view of the Oro Descanso - Placetas, Cuba underground mine deposit. The mine was lithological zoned into three major rock type namely massive serpentinite, sheared serpentinite and gabbros. The density, humidity and compressive strength tests of the intact rocks were carried out using 20 to 30 numbers of 54 mm diameter core samples. The tests were performed at three laboratories (Geominera Mining Company, Hidráulicos' Company and Recursos Company) in Santa Clara, Cuba. The average result of these properties was estimated by t-student statistical method at the probability of 0.95.

Table 1: Summary of Well Log Record of Rock Mass.

Samples	From (m)	Down to (m)	Lithological Description
E1001	0,00	3,20	Fillings composed of oxidized serpentinites
E1002	3,20	3,80	Shale serpentinite, limonitized in shear planes
E1003	3,80	4,60	Shaly serpentinite budinada limonitized by the weathering effect.
E1004	4,60	14,40	Serpentinite slate budinada, sizes between 20 and 50 cm.
E1005	14,40	16,90	Serpentinite massive fractured from dark green to black.
	16,90	17,85	Black massive serpentine with intercalations of leucocratic gabbro
	17,85	24.20	Interval of leucocratic gabbro in crushed and carbonated parts
	24.20	28,40	Serpentinite massive plagioclase (plg 10-20%)
	28,40	36,30	Serpentinite massive fractured from dark green to black
E1006	36,30	38,70	Serpentinite massive dark green to black
	38,70	54,80	Black massive serpentine fractured with abundant veins
	54,80	62,00	Normal gray gabbro (light to dark) with intercalations of massive serpentinite and leucocratic gabbro
	62,00	68,00	Massive serpentinite with white plagioclase
	68,00	68,30	Serpentinite schistous

Plate 1: Oro Descanso - Placetas, Cuba underground mine deposit (photograph date 2015-02-12)

The quantitative value of GSI was estimated using the Sonmez and Ulusay's chart (Sonmez and Ulusay, 1999, 2002). Likewise the values of m_b, a and s. are determined using equations 2-4. The values of D based on the disturbance level (during blasting at Oro Descanso Mine) and the values of m_i for massive serpentinite, sheared serpentinite and gabbros were estimated using the Hoek's chart (Hoek, 2007). The data was processed with the aid of Rocklab 1.0, 2004 computer program from which the estimated values of rock mass strength and its strength parameters are obtained.

3 Results

Table 2 shows the values of compressive strength of saturated intact rocks of the rock mass, the values of the density and humidity. The values of m_i, D, surface structures, roughness, weathering and the filling materials were determined based on the data obtained from the field. Using the charts of Sonmez and Ulusay (1999, 2002); Zhang (2005) and Hoek, (2007). The GSI values were determined for each rock type (Table 3). Also, the values of

m_b, s and a were determined using equations (2, 3 and 4) while the local strength equations for each rock mass type are presented in Table 4. Plate 2 shows the section through the deposit showing different rock aggregates.

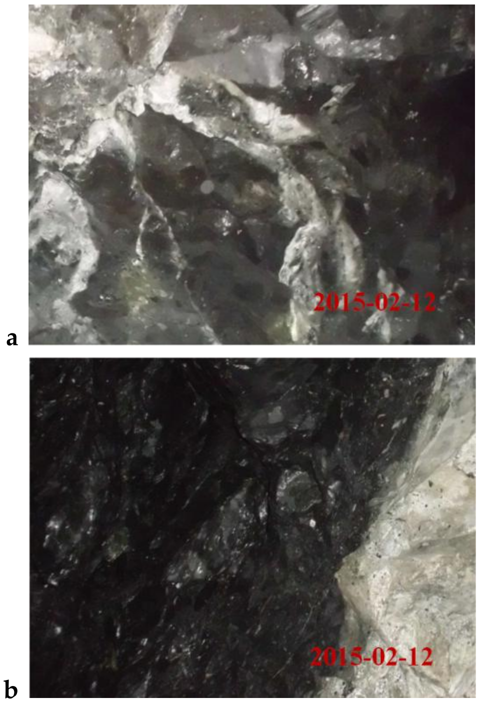


Plate 2: Sections (a,b) through the deposit showing different rock aggregates of Oro Descanso - Placetas, Cuba underground mine deposit

Figures 2 to 4 were obtained through computer program, Rocklab 1.0, 2004 using data values of unconfined compressive strength of intact rock, m_i, GSI, and D. The graphical plots of principal stresses (σ_1-σ_3); m_b, s and a, from the Hoek-Brown criterion; as well as the cohesion and friction angle were obtained from Mohr-Coulomb criterion.

Table 2: Physical Mechanical Properties of Massive Serpentinite

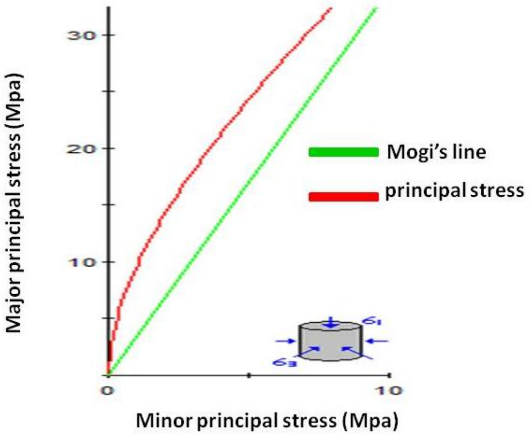
Properties	Massive Serpentinite		Sheared Serpentinite		Gabbros	
	Average Values	Coefficient of Variation	Average Values	Coefficient of Variation	Average Values	Coefficient of Variation
Compressive Strength (MPa)	31.97	0.41	46.63	0.41	54.96	0.63
Density (g/cm³)	2.78	0.04	2.88	0.36	2.98	0.03
Humidity (%)	0.42	0.86	0.44	0.41	0.33	0.45

Table 3: Estimation of GSI by the Method of Sonmez and Ulusay (1999, 2002)

Mine Workings	Parameter	m_i	D	Surface Structure	Roughness	Weathering	Filling	Total Value	GSI Values
	Types of rock				Values from Sonmez and Ulusay's Chart				
Gallery	Massive Serpentinite	21	0.7	50-60	5	5	2	12	55-64
	Sheared Serpentinite	28	0.7	30-40	5	5	2	12	32-44
	Gabbros	30	0.7	70-80	3	5	2	10	74-81

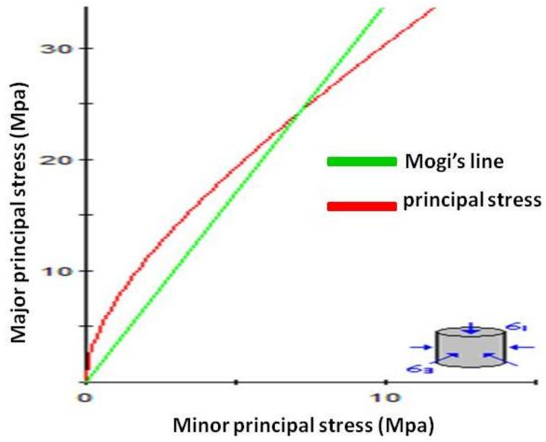
Table 4: Oro Descanso Rock Mass Strength Estimation Equation

Mine Workings	Rock Types	m_b	s	a	GSI	Hoek Criterion for Rock Mass Strength
Gallery	Massive Serpentinite	2.34	$3.5.10^{-3}$	0.503	60	$\sigma_1 = \sigma_3 + 29.64(0.0790\sigma_3 + 0.0035)^{0.503}$
	Sheared Serpentinite	0.98	$1.8.10^{-4}$	0.514	38	$\sigma_1 = \sigma_3 + 54.92(0.0178\sigma_3 + 0.0002)^{0,514}$
	Gabbros	8.88	$4.34\,10^{-2}$	0.501	78	$\sigma_1 = \sigma_3 + 69.91(0.127\sigma_3 + 0.0434)^{0,501}$



Hoek-Brown classification
Intact uniaxial compressive strength 31.97 MPa
GSI = 60 mi = 21 Disturbance factor = 0.7
Hoek-Brown criterion
mb = 2.332 s = 0.0030 a = 0.0503
Mohr–Coulomb Fit
Cohesion = 1.769MPa Friction angle = 33.33 deg
Rock mass parameters
Tensile strength -0.042MPa
Uniaxial compressive strength 1.733MPa
Global strength 6.561MPa
Modulus of deformation 6535.59MPa

Fig 2: Analysis of Oro Descanso massive serpentinite rock strength using Rocklab 1.0, 2004)



Hoek-Brown classification	
Intact uniaxial compressive strength	46.63 MPa
GSI = 38 mi = 28	Disturbance factor = 0.7
Hoek-Brown criterion	
mb = 2.928 s = 0.0001 a = 0.513	
Mohr – Coulomb Fit	
Cohesion = 1.778MPa	Friction angle = 25.69 deg
Rock mass parameters	
Tensile strength	-0.006MPa
Uniaxial compressive strength	0.464MPa
Global strength	5.657MPa
Modulus of deformation	2224.57MPa

Fig 3: Analysis of Oro Descanso sheared serpentinite rock strength using Rocklab 1.0, 2004)

4 Discussions

The strength of rock mass depend on various factors like the mineral components of the intact rock, the strength of the rock grains internal bonding force, cohesive force, the level discontinuity and its binding force, water content, etc, that is why the values of compressive strength (σ_{ci}) of massive serpentinite, sheared serpentinite and gabbros (Table 2) were reduced from 31.97Mpa, 46.63Mpa, 54.96Mpa to 1.733Mpa, 0.464Mpa, 10.354Mpa respectively in the rock mass (Figures 2-4), also, the deposit zone has been affected by fault, past tectonic activities and constant minor seismic disturbances which do occur in central province of Cuba. The humidity of the mine is between 0.33-0.44, this is partly due the fact that the water inflow is low. The knowledge of the state of the GSI (Table 3) local strength of the rock around the excavations, the global strength and modulus of deformation of the rock mass (Figure 2-4) will aid in the design of the excavation, selection of proper support method and mining system so as to avoid the danger of the falling of small pieces of rock during mining activity. Generally, the values m_b, ranges from 0.98 to 8.88, s from 1.8. 10^{-4} to 4.34. 10^{-2} and a, from 0.501 to 0.514 the significance these variations of the material constant of the rock mass due to different lithology in the rock mass, and this values are of great importance in the numeric analysis of the rock mass which is beyond the scope of this paper. The Mogi's line (green) in Figures 2-4, which is defined by the ratio of the principal stress as σ_1/σ_3 = 3.4 is generally found below the principal stress failure envelop (red), this means that the failure mode that will occur in Oro Descanso rock mass will be brittle type.

5 Conclusions

Applying the generalized empirical criterion of Hoek-Brown, the local strength, global strength and modulus of deformation of Oro Descanso underground rock mass were determined which could be effective data for the design of the mine support, excavation design and for the selection mining system. Also, the material constants of the mine rock mass were determined and the equations that relate the principal stresses were established. The type of failure mode will be brittle. Hence the needed support are designed and recommended.

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