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Geomechanical characterization of the rock mass tunnels in rock zone and breccia zone

Caracterización geomecánica de túneles de macizo rocoso en zona de roca y zona de brecha

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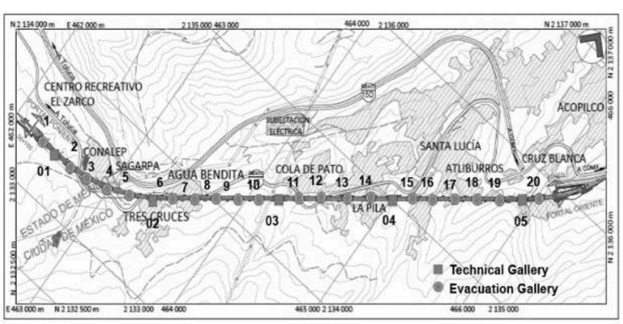
ABSTRACT: This article shows the results of the geomechanical characterization of the rock mass, to demonstrate the importance of generating field information on its geotechnical characteristics, according to the results of the geological and geotechnical conditions of the study site, since the intact rock does not represent the entire rock mass. Subsequently, the procedure to define the properties of the rock mass is described, with field and laboratory information, in a rock zone and breccia zone or conglomerate. These data will be of great importance to evaluate the stability and determine the treatments of the works. later.

KEYWORDS: tunnel, geomechanical, survey, characterization, discontinuities, intact, RQD, deformability, rock, mass.

1 OBJECTIVE

In the study of the twins tunnel project, geology and geophysics studies were conducted, including 32 surveys and approximately 150 samples for each laboratory test. The project comprises two tunnels separated by only 16 meters, each one with a circular section of 7.5 meters in diameter and a length of 4.7 kilometers. Five technical galleries and 20 evacuation galleries will be located along the bitunnel. The construction of the bitunnel was carried out using two tunnel boring machines with a diameter of 8.5 meter. The interior of the tunnel was lined with a series of 1.5-meter-long rings, each one made up of six concrete voussoirs. The objective of this article is to present the geomechanical characterization along the twins tunnel, focusing on the rock zone (Andesite, oxidized andesite) and breccia or conglomerate (Andesitice and Tabaceous breccia), as well as to analyze the results obtained from fieldwork and laboratory testing (Figure 1).



To synthesize the geomechanical characterization methodology of the rock mass, a process diagram was created, specifying the activities to be developed in each work area (Figure 2).

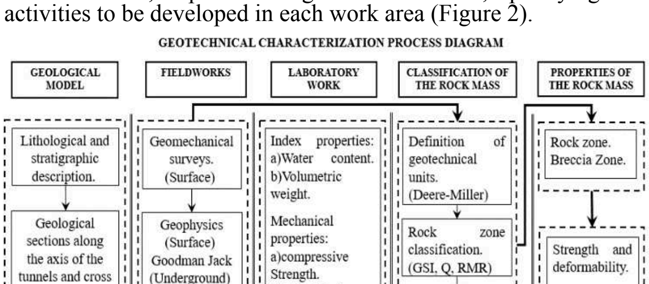


Figure 2. Geotechnical characterization process diagram.

3 GEOLOGICAL MODEL

3.1 *Lithology*

Firstly, it is necessary to obtain information from the geological studies conducted in the study area. It is important to understand each of the geological strata and regional orientations to know the soil conditions at depth where the works will be carried out. Regarding lithology, the superficial layer consist of residual soil (Qrs). At greater depth lies the light gray Tabaceous breccia, composed of angular to subrounded fragments of andesitice composition, with sizes from 0.02 to 0.06 m, embedded in a fine to coarse sand matrix (0.8 to 4.8 mm). Below this layer is the oxidized Andesite altered rock of reddish color, of low resistance. Finally, there is the Andesite, a gray rock of medium to low resistance, see figure 3.

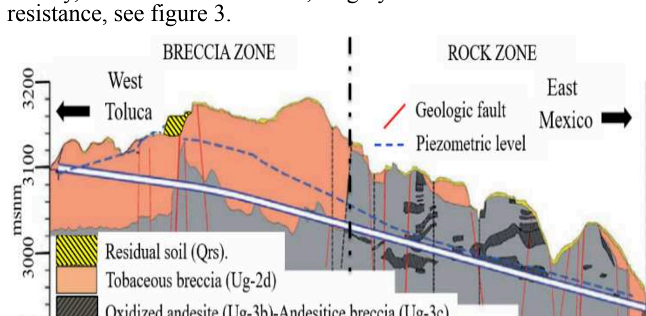
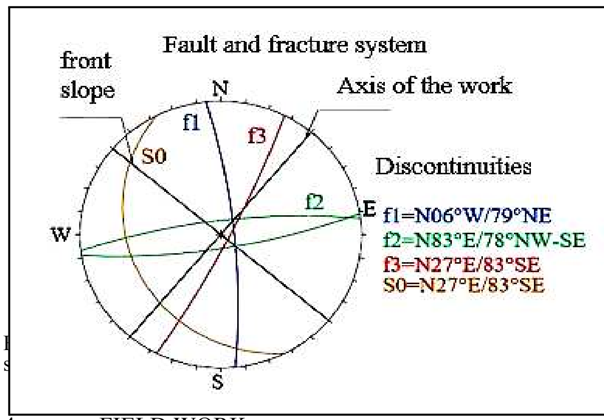


Figure 3. Geological section of the study area.

3.2 *Structural Geology*

With the data obtained from the geological surveys in the area, the stereonet shown in figure 4 was elaborated. The fault and fracture systems at the site coincide with the orientations of the dominant systems at the regional level.



4 FIELD WORK

4.1 *Geomechanical surveys*

During the fieldwork for geotechnical characterization, geomechanical surveys were carried out in the study area, identifying a rock zone and another of breccia.

In the rock zone, geomechanical surveys were carried out using the methodologies proposed by Bieniawski RMR, Barton Q. (Barton N. 2002), Hoek, E. et al. (2002) and Morelli (2017).

Similary, tests were carried out with the Schmidt hammer (sclerometer), on the surface of the healthy rock (R) and on the joints (r), for the different rock-rock contacts (figure 5). Additionally, small-scale roughness (figure 11), and large scale roughness, figure 12 were evaluated.

Figure 5. Abacus for calculating the JCS with the sclerometer in the field, from Miller 1965.

In the breccia zone, the surveys were carried out using the methodology proposed by Kalender et al. (2014) for bimrocks.

Within these surveys, the degree of weathering of the rock is described, according to the method suggested by (ISRM, 1978), figure 6.

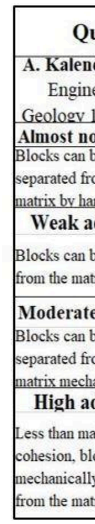


Figure 6. Qualitative classification of Bimrock in breccia zone, A. Kalender et al., 2014.

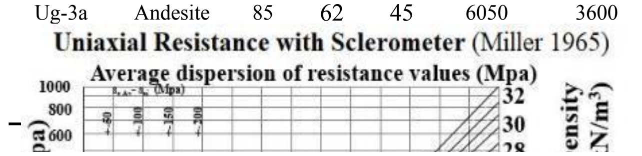
4.2 *In-situ Testing*

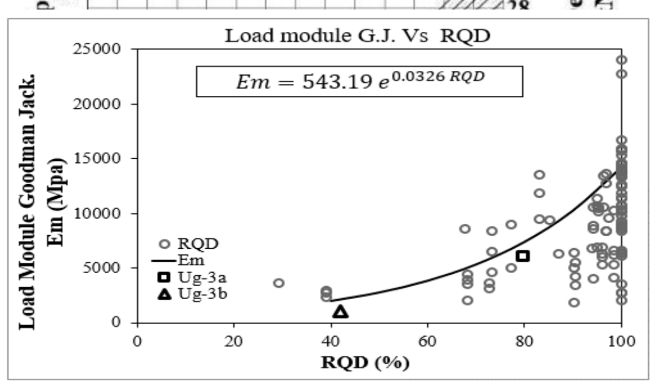
In both areas (breccia-rock) seismic refraction lines with (Geophysics) were carried out, obtaining the primary sonic velocity (Vp).

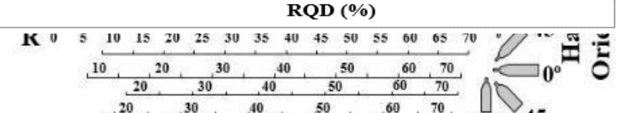
In the rock area, deformability tests (Goodman Jack) were carried out in drillings. For the calculation, the load deformability module was considered (Table 1). To quickly determine the load modulus as a function of the Rock Quality Designation (RQD), a graph of the load modulus (Em) vs RQD was created (figure 7).

Table 1. Results of in situ tests in rock zone.

Litholog y	Descriptio n	RQ D	Sclerometer R	Sclerometer r	E G. Jack (MPa)	Velocity, V_p (m/s)
Ug-3a	Andesite	85	62	45	6050	3600







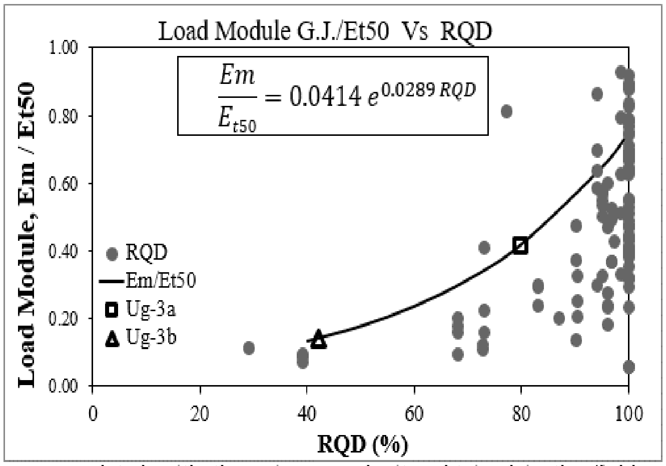


Figure 7. Goodman Jack load Module vs RQD.

5 LABORATORY WORK

In the laboratory work, healthy samples without alteration or fractures were selected to carry out compressive strength tests. this allowed to obtain the moduli of elasticity, as well as its dynamic properties with the primary and secondary velocity (Vp and Vs).

5.1 *Index properties*

Table 2 presents the average values corresponding to the water content and the volumetric weight from laboratory results.

Table 2. Average values of index properties of the intact rock.

Description	Properties	UG-3a (Andesite)	UG-3b (Oxidized andesite)	UG-3c (Andesitic Breccia)
Index Properties	Water content (%)	2.51	4.91	6.41
	Volumetric ambient weight (kN/m3)	24.53	21.98	20.59

5.2 *Mechanical – dynamic properties*

To evaluate the stress-strain behavior of the intact rock, compressive strength (σ_{ci}) tests were performed to obtain the indirect (σ_t), as well as triaxial stress tests, moduli of elasticity (E_{t50}), and dynamic (E_d). The average results by rock type are shown in Table 2.

To obtain the relationship between the field modules (Goodman Jack) and laboratory Et50, the RQD was used (tables 3 and 4, and figure 8).

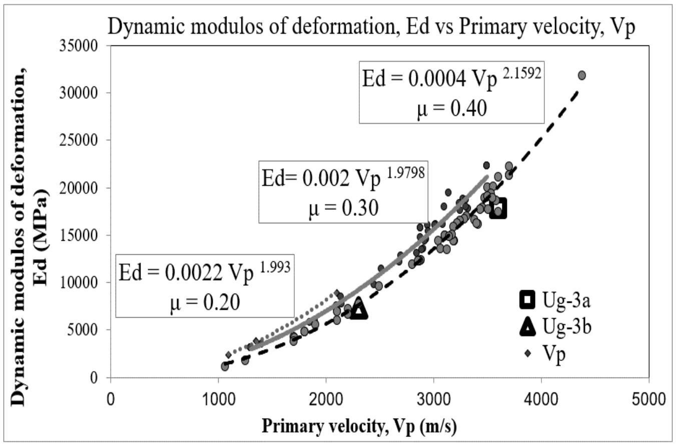
Table 3. Average values of mechanical properties of the intact rock.

Lithology	Description	σ_{ci} (MPa)	σ_t (MPa)	E_{t50} (MPa)
Ug-3a	Andesite	74	6.41	14675
Ug-3b	Oxidized andesite	23	4.15	7350
Ug-3c	Andesitice Breccia	9.4	3.49	5566

Table 4. Average values of dynamic properties of the intact rock.

Lithology	Description	Velocity, V_p (m/s)	Velocity, V_s (m/s)	E dynamic (MPa)	Relation of Poisson (μ)
Ug-3a	Andesite	4500	2700	17849	0.29
Ug-3b	Oxidized andesite	3500	2100	11954	0.36
Ug-3c	Andesitice Breccia	2200	600	4641	0.45

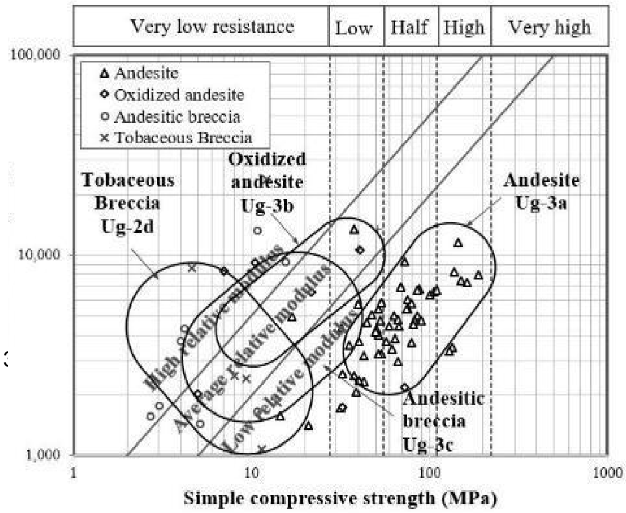
was correlated with the primary velocity obtained in the field (Vp), taking different Poisson parameters (μ) as reference, figure 9.



6.1 *Definition of geotechnical units*

In the rock mass classification, the geological information was taken as a reference. Together with the results of the laboratory tests, the geotechnical units were defined.

Based on the above, the classification from (Deere and Miller, 1966) was used, which takes into account the simple compressive strength and the Et50 modulus of the intact rock (figure 10).



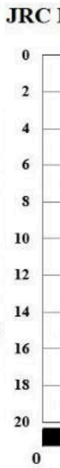


Figure 10. Classification of geotechnical units, Deere-Miller 1966.

6.2 *Rock Zone*

For the geomechanical survey of the discontinuities in the rock zone, the following criteria were considered.

6.2.1 *Compressive strength of discontinuities, JCS*

To calculate the JCS value, the average rebound values are obtained with the Schmidt hammer for the different rock-rock contacts to later calculate the resistance with the abacus from (Miller, R.P. 1965), (figure 4) or by equation (1).

$$log_{10}JCS = 0.00088_{\gamma} r + 1.01 \quad (1)$$

6.2.2 *Roughness, JRC*

The roughness coefficient of the discontinuity (Joint Roughness Coefficient) was determined in the field on a small scale using the criterion from (Barton, N., & Choubey, V. 1977), and on a large scale using the criterion from (Barton, N. 1982), figures 11-12.

6.2.3 *Scaling the parameters JCS y JRC*

The JRC (small scale) and JCS values were normalized for the large scale rock mass, according to the length of the discontinuities, by means of the equations 2 and 3.

$$JRC_n = JRC_0\left(\frac{L_n}{L_0}\right)^{-0.02JRC_0} \quad (2)$$

$$JCS_n = JRC_0\left(\frac{L_n}{L_0}\right)^{-0.03JRC_0} \quad (3)$$

Figure 11. JRC roughness small scale, Barton-Choubey, 1977.

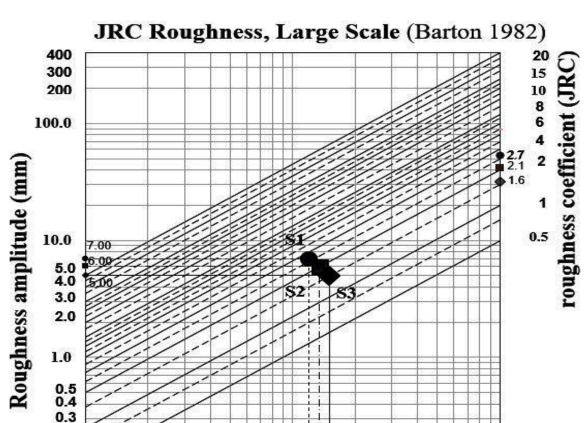


Figure 12. JRC roughness large scale, Barton, 1982.

6.2.4 *Shear strength of discontinuities*

To determine the shear strength of discontinuities in rock-rock contact, the (Barton, N., & Choubey, V. 1977) criterion was used (equation 4).

$$\tau = \sigma_n tan\left[\emptyset_r + JRC_n\, log_{10}\left(\frac{JCS_n}{\sigma_n}\right)\right] \quad (4)$$

The maximum friction angle is a function of the roughness (JRCn) and resistance (JCSn) components of the discontinuities, as well as the residual (φr) and basic (φb) angles. The basic angle depends on the rebound values (R - r), of the sclerometer in healthy rock and the rock-rock contact joint, as given by equations 5-7, and table 5.

$$\emptyset_r = (\emptyset_b - 20) + 20\left(\frac{r}{R}\right) \quad (5)$$

$$\emptyset_{max} = JRC_n\left[\emptyset_r + log_{10}\left(\frac{JCS_n}{\sigma_n}\right)\right] \quad (6)$$

$$\text{If}\left(\frac{JCS}{\sigma_n}\right) > 50, \emptyset_{max} = \emptyset_r + 1.7(JRC) \quad (7)$$

Table 5. Basic, residual and maximum friction angle of discontinuities, Barton-Choubey criterion.

System	Friction angle type (°)	(Ug-3a)	(Ug-3a)
S1	ø (basic)	39	35
	ør (residual)	32	29
	ø (maximum)	41	40
S2	ø (basic)	35	35
	ør (residual)	31	30
	ø (maximum)	41	40
S3	ø (basic)	35	35
	ør (residual)	31	29
	ø (maximum)	41	40

6.2.5 *Geological Strength index, GSI*

The value of the Geological Strength Index (GSI) was determined using the criteria of Hoek et al. (2013), the parameter J_{Cond89}, comes from the joint condition of the Bieniawski's RMR_{89} classification, from field surveys, using the equation 8.

$$GSI = 1.5J_{Cond89} + \left(\frac{RQD}{2}\right) \quad (8)$$

Additionally, the criterion of Morelli (2017) was used to estimate the GSI value (figure 13), which results from plotting the Structure Rating (SR) as a function of the Surface Condition Rating (SCR), where Jv is the joint volumetric index. Rr, Rw and Rf are parameters of the Bieniawski's RMR_{89} classification, roughness, filling and alteration of the joints respectively, which are described in equation 9 and 10.

$$SR = 1.75\, ln(J_v) + 79.8 \quad (9)$$

$$SCR = R_r + R_w + R_f \quad (10)$$

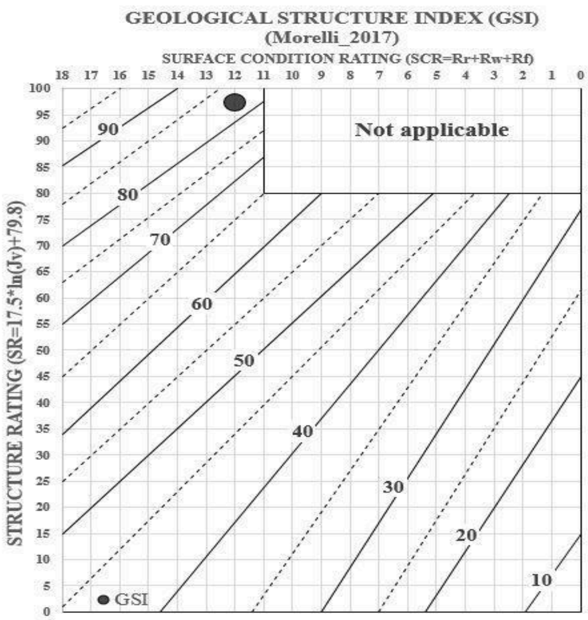


Figure 13. Calculation of GSI (Morelli, 2017).

6.3 *Breccia Zone*

The characterization of the breccia or mixed materials was carried out based on the methodology proposed by (Kalender et al. (2013). Similarity, the mechanical properties of materials formed by geotechnically significant blocks within a finer textured matrix (bimrocks) were evaluated. The mechanical parameters of these materials are estimated from the equations 11-13.

$$\emptyset_{br} = \emptyset_m \left[1 + \frac{1000\left[\left(\frac{\propto}{\emptyset_m}\right)-1\right]}{1000+5^{\left[\frac{(100-VBP)}{15}\right]}}\right]\left(\frac{VBP}{VBP+1}\right) \quad (11)$$

$$RCS_{br} = \frac{\left(A-A^{\left(\frac{VBP}{100}\right)}\right)}{(A-1)}\left(RCS_m\right) \quad (12)$$

$$c_{br} = \frac{\left(RCS_{br}\right)\left(1-seno\left(\emptyset_{br}\right)\right)}{2cos\left(\emptyset_{br}\right)} \quad (13)$$

The RCSm parameter (compressive strength of the matrix) was determined using several methodologies: with a Schmidt hammer (figure 5), to define the upper limit of resistance in areas where the cemented matrix was found, through laboratory tests on recovered cores and from empirical considerations according to the appearance of the matrix (ISRM, 1978). On the other hand, RCSbr parameter is the compressive strength of the breccia.

The parameter φm (internal friction angle of the matrix), was determined from the results of the field tests (classification of the material and phicometer); as well as from laboratory triaxial tests, the parameter φbr is the internal friction angle of the breccia.

The parameters VBP (volumetric proportion of blocks) and α (Angle of repose of the blocks) were determined from the number and shape of the blocks present in the characterized units. This information was primarily defined on representative excavation outcrops, table 6.

According to (Sonmez et al. 2009), the parameter A (figure 14) quantifies the contribution of the matrix and the blocks in the shear strength of the bimrock, and can present values from 0 to 500. The value of A increases when the adhesion between the blocks and the matrix increases, as well as when the angularity of the blocks increases, table 6.

Based on the criteria described above, the table 7 presents the parameters identified in each geotechnical unit.

The deformability of the breaches was obtained in the field through pressure meter tests.

Table 6. Variation of parameter A (Sonmez et al., 2009).

Test	Parameter A
No adhesion (cohesion) between blocks and matrix with rounded blocks.	0
Weak adhesion (cohesion) between blocks and matrix with half rounded blocks.	10
Moderate adhesion (cohesion) between blocks and matrix with half angular blocks.	50
Strong adhesion (but less than matrix cohesion) between blocks and matrix with angular blocks.	500

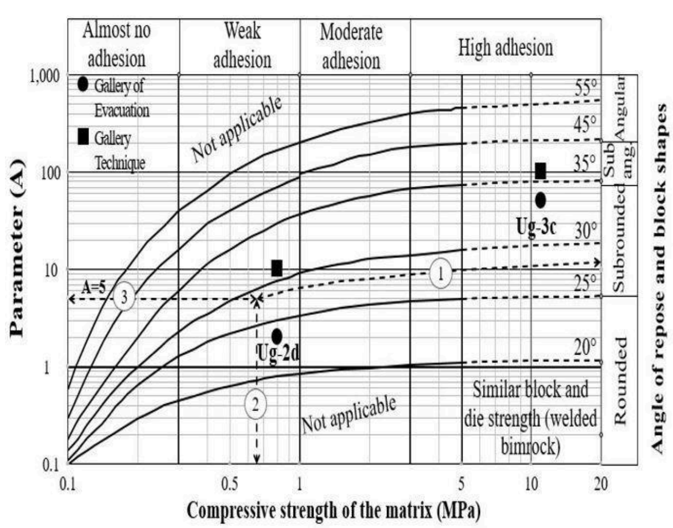


Table 7. Characterization parameters of the breccia.

Geotechnical Unit	Block Size (m)	V.B.P (%)	Angle of repose	Parameter A
Ug-2d	0.15-0.25	25-50	22-32	2-10
Ug-3c	0.20-0.30	50-75	30-40	50-100

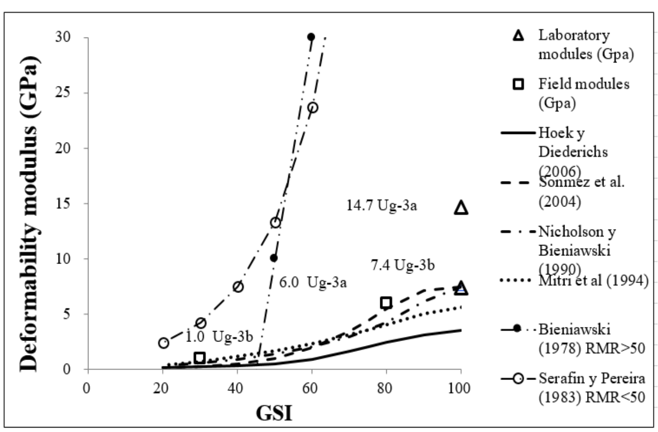
7 PROPIERTIES OF THE ROCK MASS

7.1 *Strength and deformability*

According to the criteria indicated in the previous section, table 8 presents the parameters determined for each geotechnical unit. The equation from (Hoek, E., Diederichs, MS. 2006) most closely approximates the parameters of the rock mass (figure 15).

Table 8. Characterization parameters of the rock zone and the breccia zone.

Geotechnical Unit	RMR	Q	GSI	mi	Cohesion	Friction angle	Em
Ug-3a (Andesite)	87	32	84	12	1	47	6
Ug-3b (Andesite Oxidized)	22	11	22	12	0.28	40	1
Ug-2d (Tobaceous Breccia)	NA	NA	NA	9	0.15	30	0.1
Ug-3c (Andesitic breccia)	NA	NA	NA	9	0.2	37	0.7



8 CONCLUSIONS

The purpose of this study is to show the methodology used to determine the resistance and deformability parameters of the rock mass, which will be the basis of the treatments to be applied.

Using the field and laboratory results, correlations were made based on the field results (RQD and the primary velocity Vp), to obtain in different areas in a more practically, the parameters that will be used in the treatments of the rock mass.

In the rock area, a fair to good rock was identified, with the most competent being the one found at the greatest depth. Concerning the andesitic lithological unit, two conditions were presented in the rock mass, one with average RMR values of 80 and the other with 22, as well as simple compressive strength of the intact rock of 74 and 23 MPa, respectively.

In the area of andesitic and tuffaceous breccias, a V.B.P. 25-50% and a low resistance matrix.

Treatments can range from selective anchors for the most favorable conditions in the rock zone, to metal structures and shotcrete for the most critical conditions in the rupture zones.

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