

Topic: Geomechanical

Evaluation of load modules for the construction of a dam in volcanic rocks

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Abstract. This paper presents the results of in situ load modules 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, with field and laboratory information, in an area of volcanic rocks is described. These data will be of great importance to face common challenges such as evaluating the load capacity of the structure, stability and determining the treatments of the works later.

Keywords: characterization, discontinuities, intact, mass, rock.

1 Objective

The objective of this article is to present the geomechanical characterization along the dam foundation, focusing on the volcanic rock zone, as well as to analyze the results obtained from fieldwork and laboratory testing (Figure 1).

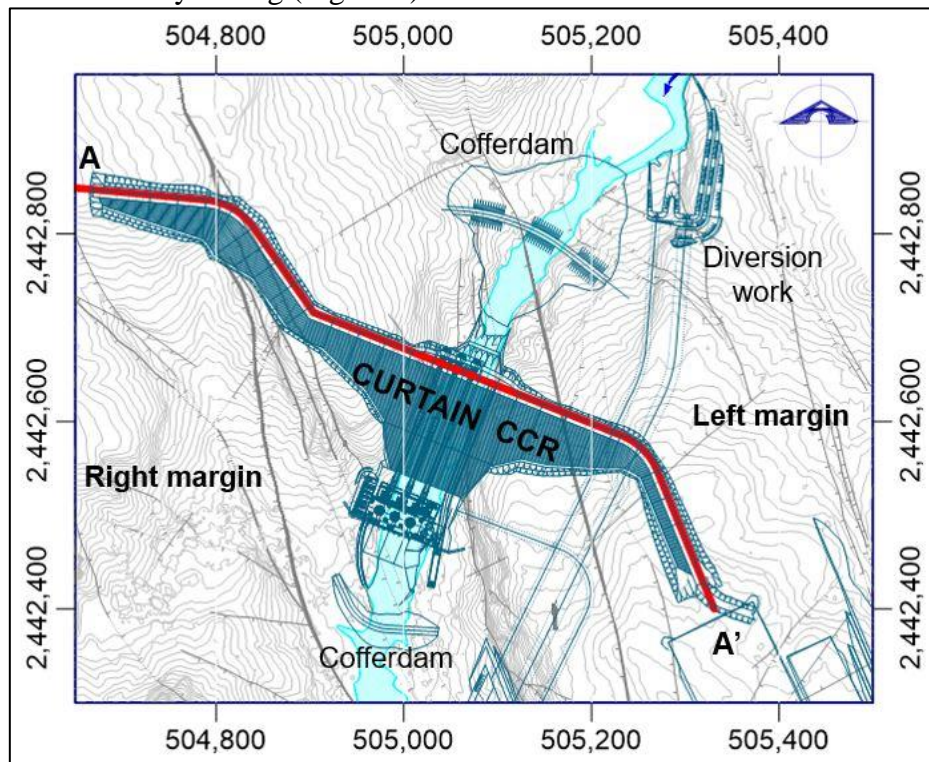


Figure 1 Location of the containment work of the Dam.

2 Methodology

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).

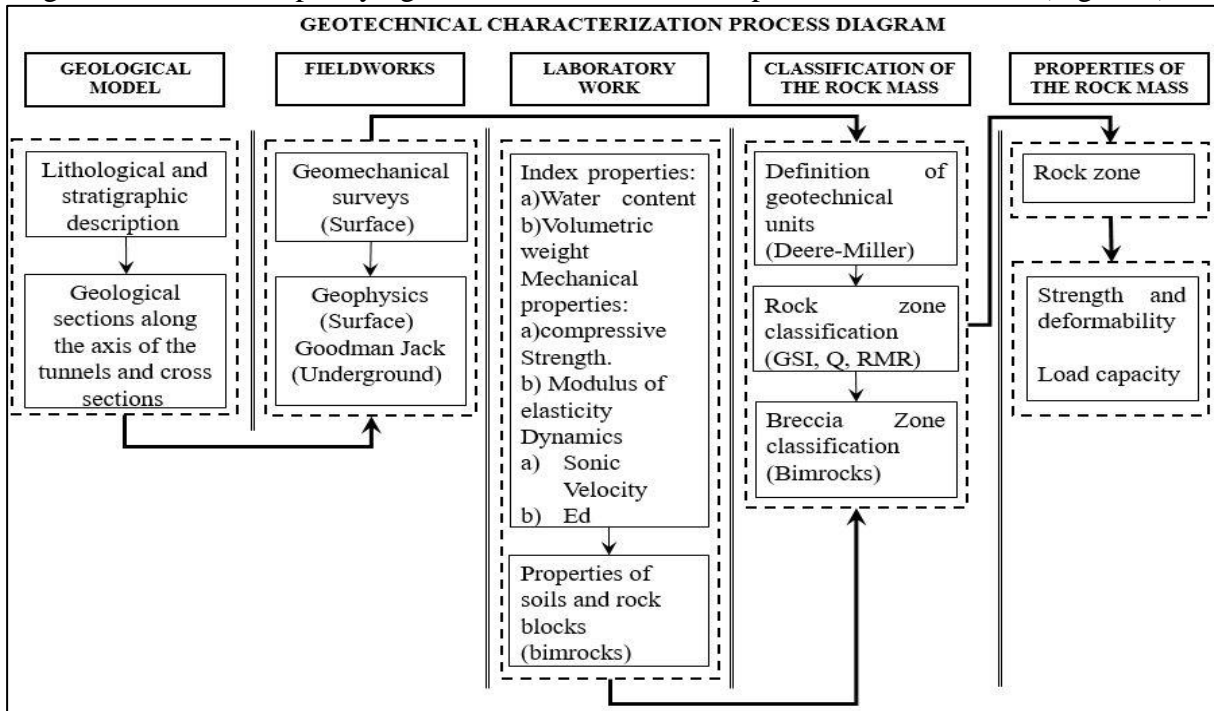


Figure 2 Geotechnical characterization process diagram.

3 Geological model

3.1 Lithology

The study site is geologically located in the Ignimbrite sequence of the Nayar, composed of the Corapan and Las Cruces formations, formed by rocks of volcanic origin with an intercalation of tuffs and ignimbrites. Regarding lithology, the Corapan unit is formed by Ignimbrites (Tm-ci1) of light gray color, pyroclastic texture, composed of potassium feldspars, plagioclases, quartz and ferromagnesians, followed by the Reddish Tuff (Tm-ct1) of reddish color, pyroclastic texture, compact structure with angular fragments of rhyolitic ignimbrite of various sizes, until reaching the Las Cruces unit, in its upper part (Tm-ic2) is made up of light gray rhyolitic lithic ignimbrites of fine-grained pyroclastic texture and is underlain by the vesicular Ignimbrite with cavities and vesicles mostly filled, see figure 3.

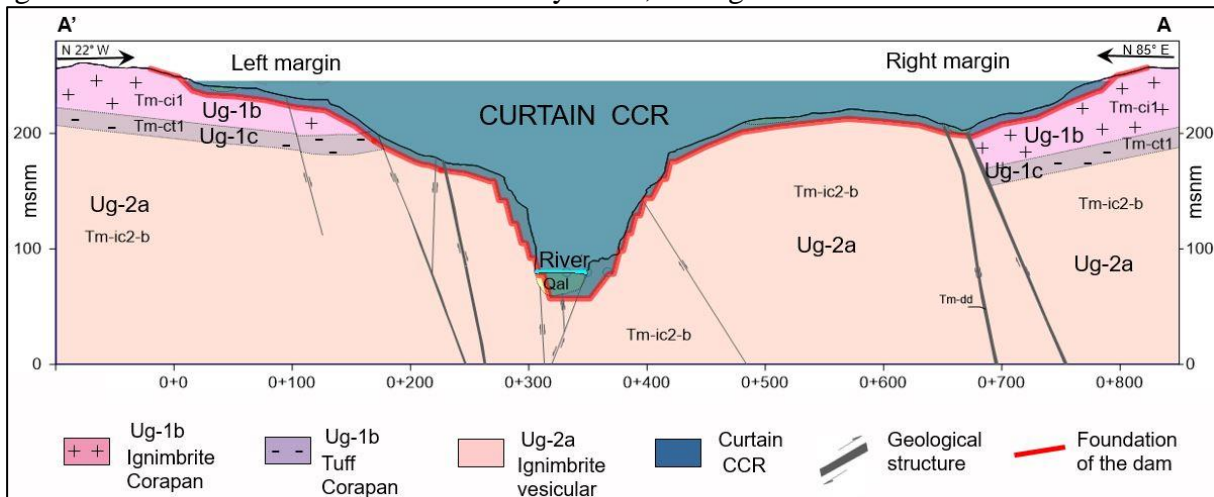


Figure 3 Geological section of the study area.

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.

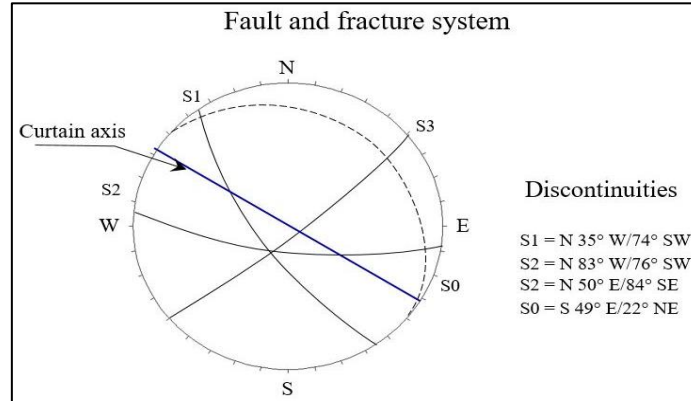


Figure 4 Stereonet with the orientations of the main fault and fracture systems.

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.

In the study zone, geomechanical surveys were carried out using the methodologies proposed by Bieniawski RMR [1], Barton Q. (Barton N. 2002) [2], Hoek, E. et al. (2002) [3] and Morelli (2017) [4].

Similarly, tests were carried out with the Schmidt hammer (sclerometer), on the surface of the healthy rock (R) and on the joints (r), by the correlations Miller (1965) [5], and Chable J. et al. (2022) [6], for the different rock-rock contacts (figure 5). Additionally, small-scale roughness (figure 5), and large scale roughness, figure 12 were evaluated.

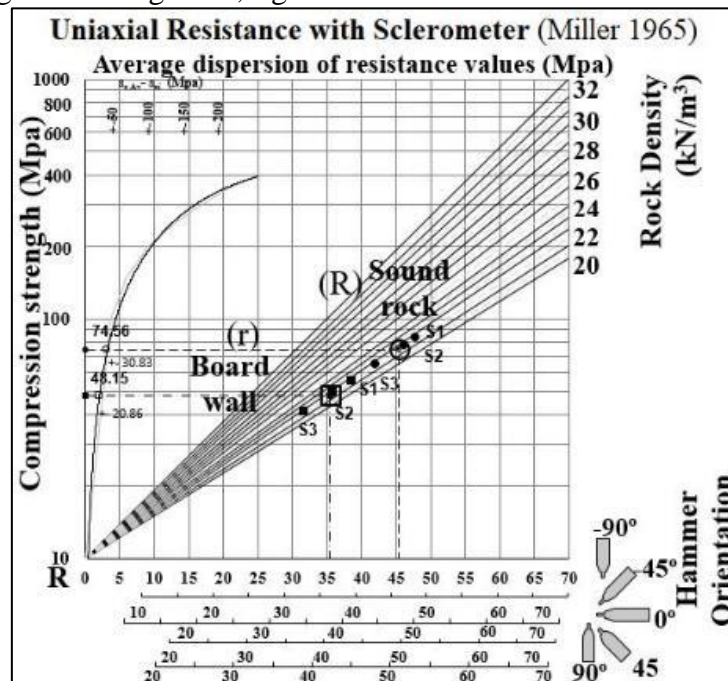


Figure 5 Abacus for calculating the JCS with the sclerometer in the field, from Miller 1965.



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 (V_p and V_s).

5.1 Index properties

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

Table 1 Average values of index properties of the intact rock.

Lithology	Description	Volumetric weight (kN/m ³)		Water content (%)
		γ ambient	γ saturated	
Ug-1b	Corapan Ignimbrite	21.20	21.93	5.33
Ug-1c	Corapan Rhyolitic Tuff	22.06	23.41	4.21
Ug-2a	Ignimbrite	21.50	22.78	5.77

5.2 Mechanical 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 (σ_1 , σ_3), moduli of elasticity (E_{t50}), The average results by rock type are shown in Table 2.

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

Lithology	Description	σ_t (MPa)	σ_c (MPa)	E_{t50} (MPa)	σ_1 (MPa)	σ_3 (MPa)
Ug-1b	Corapan Ignimbrite	5.97	67.20	19031	90.25	13.92
Ug-1c	Corapan Rhyolitic Tuff	6.60	66.56	18931	86.58	14.05
Ug-2a	Ignimbrite	6.14	76.12	21270	94.27	9.86

5.3 Dynamic properties

Similarly, in order to assess the degree of alteration of the rock, tests were carried out on the speed of propagation of elastic compression waves (V_p) and transverse (V_p), to determine the moduli dynamic (E_d) and Poisson parameter (μ).

Table 3 Average values of index 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-1b	Corapan Ignimbrite	3140	2888	15804	0.21
Ug-1c	Corapan Rhyolitic Tuff	3541	1911	19014	0.27
Ug-2a	Ignimbrite	3809	2395	22304	0.35

6 Classification of the rock mass

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) [7] was used, which takes into account the simple compressive strength and the Et50 modulus of the intact rock (figure 6)

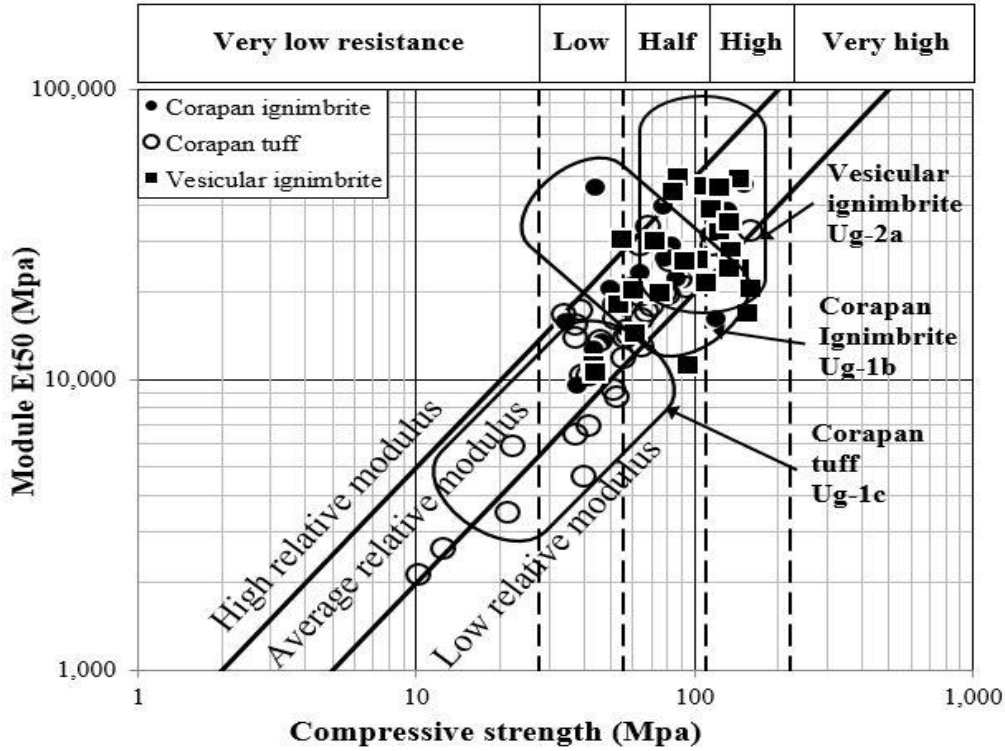


Figure 6 Classification of geotechnical units, Deere-Miller 1966.

6.2 Geological Strength index, GSI

The value of the Geological Strength Index (GSI) was determined using the criteria of Hoek et al. (2013) [8], the parameter JCond89, comes from the joint condition of the Bieniawski's RMR89 [9] classification, from field surveys, using the equation 1.

$$GSI = 1.5J_{Cond89} + \left(\frac{RQD}{2}\right) \quad (1)$$

Additionally, the criterion of Morelli (2017) [4] 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 J_v is the joint volumetric index. R_r , R_w and R_f are parameters of the Bieniawski's RMR89 classification, roughness, filling and alteration of the joints respectively, which are described in equation 2 and 3.

$$SR = 1.75 \ln(J_v) + 79.8 \quad (2)$$

$$SCR = R_r + R_w + R_f \quad (3)$$

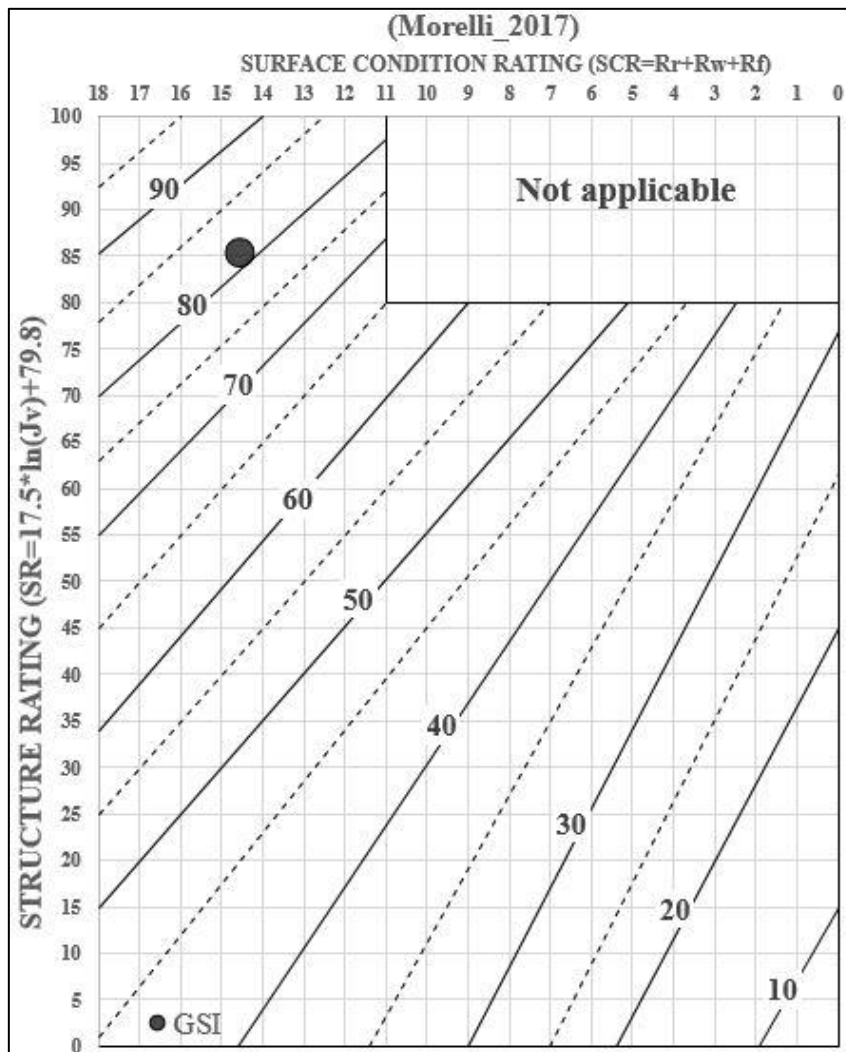


Figure 7 Calculation of GSI (Morelli, 2017).

7 Evaluation of modules in-situ in the curtain deployment area

In order to evaluate the parameters of rock quality, strength, deformability and alteration in the area of the dam curtain, in situ tests were carried out to analyze the load (E_m) and dynamic (E_d) modules to evaluate the stability of the structure of the dam curtain, as indicated below.

- Load module (E_m).
- Comparison of load modules (E_m).

7.1 In-situ testing

In the study zone, seismic refraction lines with (Geophysics) were carried out, obtaining the primary sonic velocity (V_p), deformability tests (Goodman Jack) 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 (E_m) vs RQD was created (figure 7).



Table 4 . Results of in situ tests the study zone.

Lithology	Description	RQD	Sclerometer		E G. Jack (MPa)	Velocity, V_p (m/s)
			R	r		
Ug-1b	Corapan Ignimbrite	80	62	45	6,558	4,413
Ug-1c	Corapan Rhyolitic Tuff	85	60	42	7,522	3,541
Ug-2a	Ignimbrite	91	56	42	8,950	3,809

7.2 In-situ charging module (E_m)

In order to analyze the behavior of variation in resistance and deformability of the rock mass, the following correlations were made:

- In-situ load modulus vs. rock quality (RQD).
- In-situ load modulus and intact rock (E_m/E_i) vs. rock quality (RQD).

7.2.1 In-situ load modulus vs. rock quality (RQD)

In the study area, two boreholes were executed (BR-85 and 91), with core recovery to describe the rock quality (RQD). Subsequently, tests were carried out with the rock pressuremeter (Goodman Jack), to record the load module (E_m), which are indicated below.

- Calidad de Roca (RQD).
- Modulo de carga in-situ (Presiómetro de roca, Goodman Jack).

Subsequently, with the results obtained, a correlation of the load module as a function of rock quality (RQD) was carried out, in order to prospect the value of the module at any point in the study area, as indicated in Figure 8.

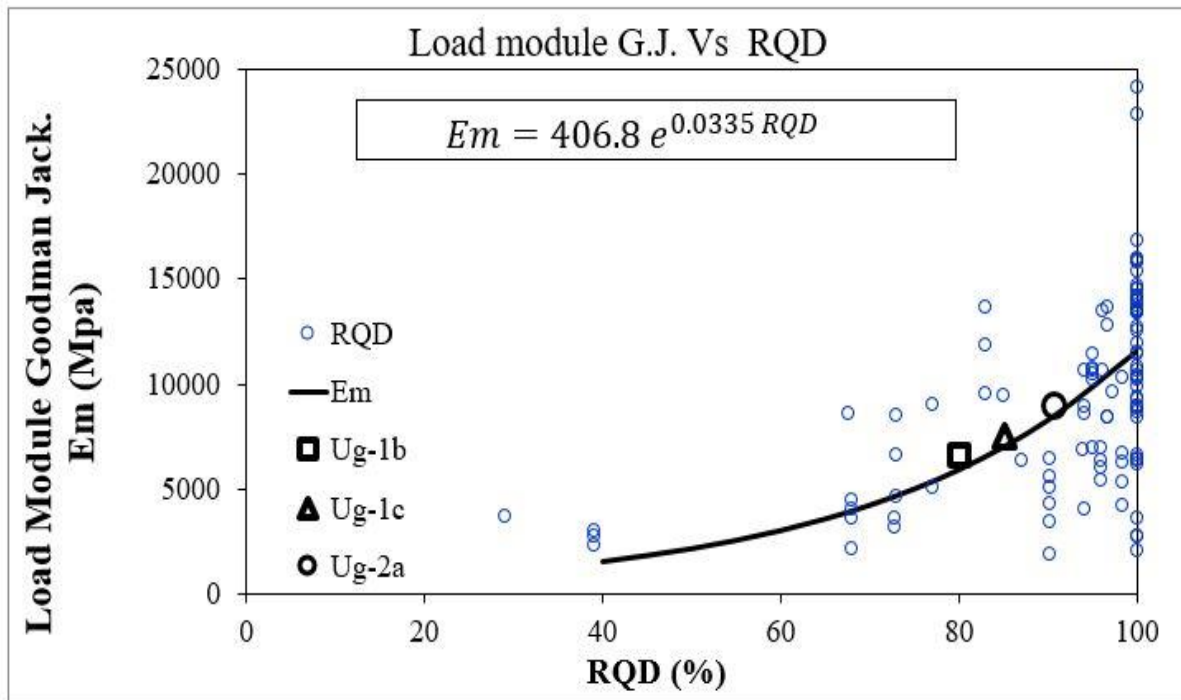


Figure 8 Goodman Jack load Module vs RQD.



7.2.2 In-situ and intact rock load modules (E_m/E_i) vs. rock quality (RQD)

Similarly, to evaluate the relationship between the in-situ (E_m) and intact rock (E_i) loading modules, as a function of rock quality, the following field tests were performed

- Primary velocity test on intact rock (V_p).

Derived from the previous test, the in-situ dynamic module was calculated, based on the primary field velocity (V_p), as indicated in the following figure.

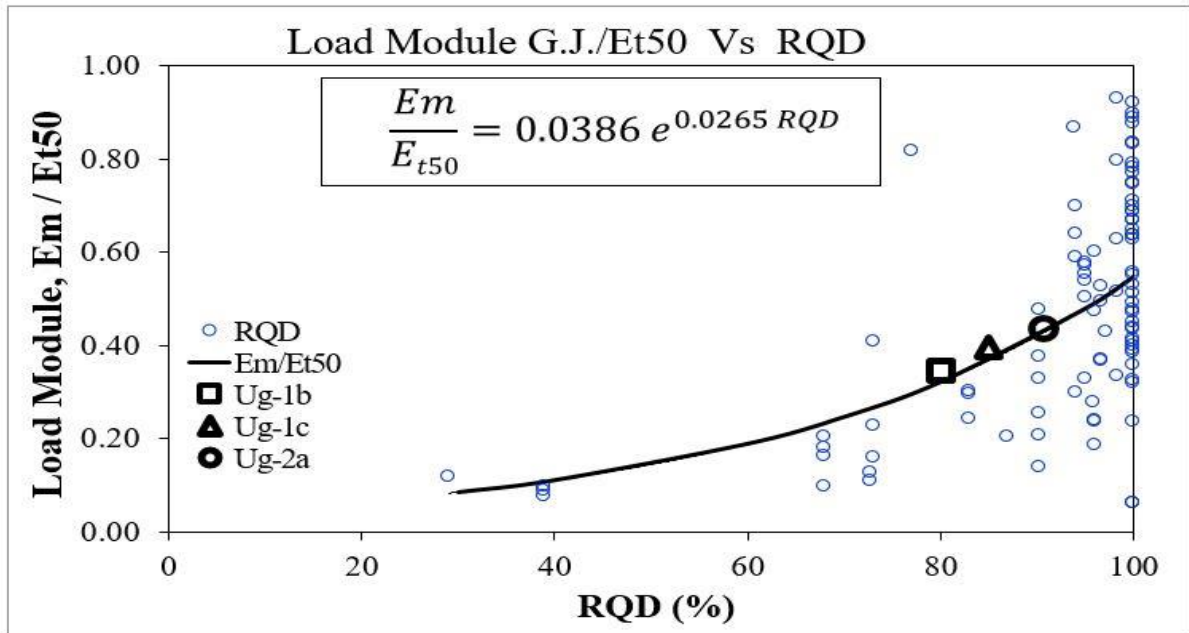


Figure 9 Goodman Jack load Module/Et50 vs RQD.

7.3 Comparison of Load Modulus (E_m)

In order to analyze the degree of weathering and alteration of the rock mass, the following correlations were made.

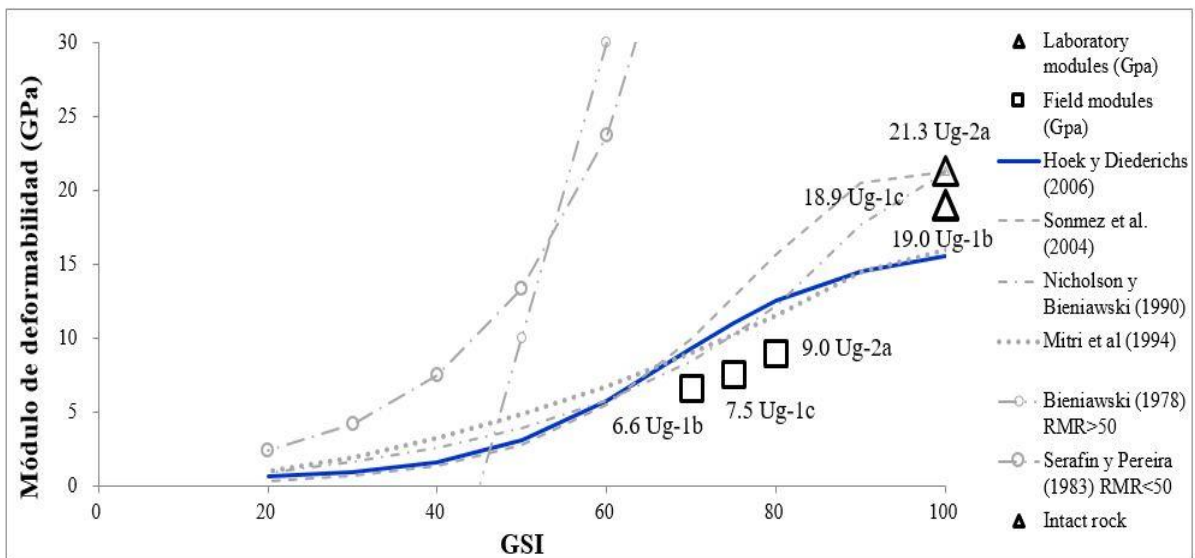


Figure 10 Goodman Jack load Module/Et50 vs RQD.



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 oressure gauge tests, Goodman Jack), to obtain in different areas in a more practically, the parameters that will be used in the treatments of the rock mass.

In the study zone, 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..

The execution of pressure gauge tests (Goodman Jack) is of great importance since they are smaller than those of intact rock, for this case study they vary by 50%.

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