Geotechnical characterization of rocky materials from Arteara rock avalanche (Gran Canaria)

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ABSTRACT: This work discusses the laboratory geotechnical characterization made with rocky materials coming from the Arteara rock avalanche, situated in Gran Canaria island. The study is based on laboratory test obtained for seven different lithotypes. The aim of them is to define strength and deformational parameters enabling subsequent modelling of the avalanche. The laboratory tests carried out included: the determination of porosity and absorption of the rock, the measurement of wave propagation speed, the evaluation of the strength in triaxial compression tests made in a Hoek cell and the shear strength in direct shear tests.

1 INTRODUCTION

The aim of this work is the description of the geotechnical properties of the volcanic materials existing in Arteara rock avalanche, located in Fataga ravine, in the south of Gran Canaria island (Canary Islands, Spain) (Figure 1).

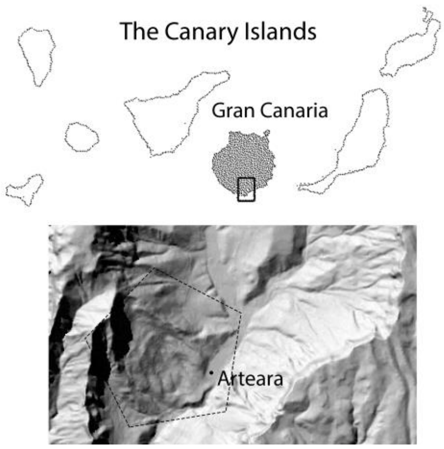

Figure 1. Location of Arteara rock avalanche, Canary Island, Gran Canaria Island, Fataga ravine

The geomorphology of this rock avalanche was studied previously (Yepes et al., 2009) and the material involved in this deposit was described in a previous work (Rodríguez-Peces et al. 2013), where the mechanical behavior of rocks were estimated by alternative indirect methods. The rock strength was determined by means of several in situ test using a L-type Schimdt Hammer, and PLT in laboratory conditions. The results of both geotechnical tests were correlated with uniaxial compressive strength, indirect tensile strength and Young´s modulus following empirical correlations. The basic friction angle was obtained by means of the tilt test (Rodríguez-Peces et al., 2013).

At the present study, the geotechnical characterization is based on laboratory tests such as triaxial or direct shear tests. Moreover, the characterization of lithotypes was completed with other tests as the determination of real density, porosity, absorption or P wave velocities.

As result of the study there is a complete geotechnical characterization of the lithotypes involved in Arteara rock avalanche. Those values will support the future modelling of this rock avalanche.

2 GEOLOGICAL CHARACTERISTICS OF THE LYTHOTYPES

The avalanche is mainly formed by phonolitic ignimbrites and lavas. In the previous study five lithotypes were described in Arteara rock avalanche: Massive phonolitic lava, Phonolitic agglomerate breccia, Reddish non welded ignimbrite, Welded fiamme bearing ignimbrite and Pumice tuff with lithics. In the present work two more lithotypes have been included: non welded ignimbrite and very welded ignimbrite. Those lithotypes were divided into two groups: Soft Rocks and Hard Rocks. This classification is mainly based on the aspect of each lithotype, so the Soft Rocks are formed by the more porous materials and they are slightly more crumbled.

Table 1 shows the classification and the aspect of each lithotype defined in this work.

Table 1. Classification of lithotypes

Group	Lithotype	Image	Colour	Texture	Others	(n)
Soft Rocks	Non welded ignimbrite		5Y 6/4	Aphanitic, with rectangular pyroxene crystals that are orientated	Significant number of vacuoles with millimeter dimensions and with a subhorizontal orientation	3
	Reddish non welded ignimbrite		2.5YR 5/4	Aphanitic with rectangular fragments of rocks into the matrix	High erodible	5
	Pumice tuff with lithics		5Y 8/6	Aphanitic with polygenic fragments of rocks into the matrix	Important number of centimetric spherical vacuoles without any orientation. Low density	3
Rocks	Massive phonolitic lava		Gley 1 7/5G	Aphanitic with rectangular plagioclases without orientation	Massive without significant porosities	4
	Welded fiamme bearing ignimbrite		5Y 6/4	Aphanitic with fragments into the matrix	Presence of orientated porosity, fiammes	3
	Very welded ignimbrite		Gley 1 7/5G	Aphanitic with significant number of plagioclases	The porosity is a little bit higher than in massive phonolitic lava	3
	Phonolitic agglomerate breccia		Gley 1 8/N	Aphanitic with an important number of vacuoles and lithic fragments of light color	The main porosity is around the lithic fragments	3

n: Number of specimens

3 IDENTIFICATION AND CLASSIFICATION PROPERTIES

The identification and classification of the volcanic rocks have been made based on the following laboratory test results: chemical analysis, porosity, absorption, real density.

The first classification was based on SiO_2 content (Streckeisen al., 2002) measured by the X-ray fluorescence (XRF) test results.

The measurements of porosity, absorption and real density were made according to UNE-EN 1097-6.

On the other hand, the number of specimen tested is not very high due to some difficulties during the extraction of the samples from the blocks. Table 2 shows the mean values obtained in laboratory.

Table 2. Mean values of identification and classification properties. Legend: (n) Number of specimens

Group	Lithotype	SiO_2 (%)	(n)	Classification	Real density (g/cm^3)	(n)	Porosity (%)	(n)	Absorption (%)	(n)
Soft Rocks	Non welded ignimbrite	70	3	Acid Rock	2,42	3	27	3	15	3
	Reddish non welded ignimbrite	60	3	Intermediate Rock	2,44	3	30	2	18	2
	Pumice tuff with lithics	55	2	Intermediate Rock	1,95	2	35	2	28	2
Hard Rocks	Massive phonolitic lava	60	3	Intermediate Rock	2,53	4	2	4	1	4
	Welded fiamme bearing ignimbrite	65	3	Acid Rock	2,41	3	17	3	9	3
	Very welded ignimbrite	70	3	Acid Rock	2,58	3	4	3	2	3
	Phonolitic agglomerate breccia	65	2	Intermediate Rock	2,51	3	8	3	3	3

As shown, all the lithotypes have a content of SiO_2 between 55 and 70% so they can be classified as intermediate and acid rocks. The real density is quite similar in the two groups, although the lowest values correspond to the soft rocks. Values of porosity and absorption are significantly higher in soft rock group.

Furthermore, the permeability coefficient was obtained only for the reddish non welded ignimbrite at different hydraulic gradients following BS 1377 Part 6. The permeability tests were run in a triaxial cell with specimens of 53 mm diameter and 106 mm high. The mean values obtained were between 1,5 and 6,0 $x \cdot 10^{-7}$ m/s. According to González de Vallejo et al. (2011), these values are in lowest range of volcanic rocks (between 10^{-7} to 10^{-12} m/s).

4 MECHANICAL PROPERTIES

The characterization of mechanical properties of the two groups of rocks was made based on the following laboratory tests: Determination of P and S wave velocities (V_p, V_s), Uniaxial compressive strength (UCS), Triaxial test in Hoek cell and Consolidated drained direct shear test.

The determination of P and S wave velocities was made according to ASTM D2845 in dry conditions. Based on those velocities, dynamic Young´s modulus (E_d) were calculated.

Determination of UCS involves the use of cylindrical specimens with a 54 mm of diameter and a length to diameter ratio of 2,5. This test was completed by the use of strain gauges to obtain the Young´s (E) and Poisson´s coefficient (ν). The calculation of Young´s modulus was determined at a stress level equal to 50% of ultimate compressive strength (E_{50}). Those data are not available in some of the lithotypes due to its high porosity that made impossible to paste the gauges. Table 3 shows the results obtained in these tests. Moreover, a PLT test was carried out over the phonolitic agglomerate breccia lithotype. The ratio between point load index (I_{s50}) and UCS was 8.5, which is inside the interval (6-10) given by Romana (1996).

Table 3. Mean values of V_P, V_S, dynamic Young´s modulus, UCS, Young´s and Poisson´s modulus Legend: (n) Number of specimens

Group	Lithotype	V_p (m/s)	V_s (m/s)	E_d (MPa)	ν	(n)	UCS (MPa)	E_{50} (MPa)	E lineal (MPa)	ν	(n)
Soft Rocks	Non welded ignimbrite	1890	875	3420	0,36	3	8,0	4025	3690	0,28	2
	Reddish non welded ignimbrite	2085	900	3500	0,33	2	6,0	-	-	-	2
	Pumice tuff with lithics	1995	800	2100	0,40	2	4,9	-	-	-	3
Hard Rocks	Massive phonolitic lava	5280	1860	23,650	0,42	4	53,5	27.920	29,200	0,21	4
	Welded fiamme bearing ignimbrite	3040	1345	9600	0,37	3	29,0	6730	9000	0,20	3
	Very welded ignimbrite	4685	1585	17,230	0,42	3	96,4	24,750	27,900	0,25	3
	Phonolitic agglomerate breccia	3745	1510	14,545	0,39	3	44,7	39,100	37,300	0,18	1

The following aspects can be highlighted:

- Values of velocities of P waves are quite high in the hard rock group and significantly greater than soft rock values, due to its lower porosity. Those values are in the range measured for similar volcanic materials (Yüksek & Demirci, 2010).
- There are significant differences between the Young´s modulus calculated in static or dynamic tests. Typically E_d is larger than E and the ratio E_d/E varies from 1 to 3, but there are several other correlations (Read, 2009). In our case, E_d/E varies from 0,4 to 1,45, with an average value of 0,85, being the found relationship: E=0,9Ed+5300.
- There are significant differences in UCS values between the two groups. According to ISRM (1981), the soft rock group are assessed as "very soft rocks" (1-5 MPa), while the hard rocks are classified as "moderately hard (25-50 MPa) and hard (50-100 MPa)".
- It seems that soft rocks have greater Poisson´s coefficients than hard rocks.
- There is a linear correlation between Vp and E_{50} (E_{50} = 7,5 Vp-11000) with R^2 =0,9.
- Figure 2 shows the good correlation (R^2 = 0.91) between V_p and UCS, using a potential law, quite often for rocks (Perucho et al., 2012). The dispersion in UCS values for reddish lithotype can also be seen, that is in line with the heterogeneous aspect of the samples, possibly caused by the different weathering degree among them.

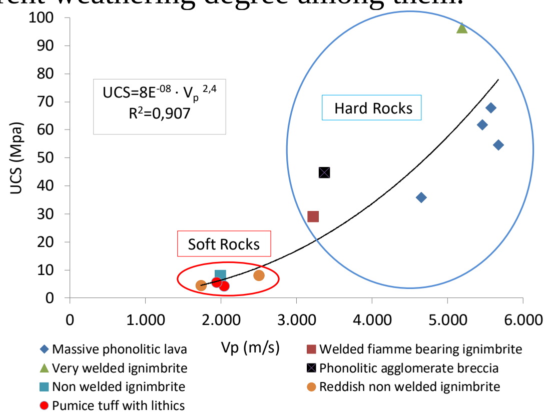

Figure 2. Relationship between UCS and V_p

- The welded fiamme bearing ignimbrite has characteristic between hard and soft rocks due to its high porosity (17%) and its anisotropic fabric induced by the fiammes.

The strength characteristics of four of the lithotypes were also evaluated by triaxial tests performed in Hoek cell (UNE 22950-4, 1992). The confinement pressure ranged between 5 to 50 MPa. Young´s and Poisson´s modulus were calculated by means of strain gauges. Table 4 collects the test results.

Table 4 Values obtained in triaxial tests using a Hoek cell

Group	Lithotype	σ_3 (MPa)	$\sigma_1 - \sigma_3$ (MPa)	$E_{50(\%)}$ (MPa)	ν
Soft Rocks	Non welded ignimbrite	10	33	4340	-
		5	1	2885	0.40
Hard Rocks	Welded fiamme bearing ignim.	30	60	3725	-
		4	47	5945	-
	Very welded ignim.	30.6	383	24,640	0.22
		50.4	474	22,890	0.26
	Phonolitic agglomerate breccia	50.6	220	-	-

Those results are considered together with the UCS values to obtain the strength parameters of Mohr-Coulomb failure criteria: cohesion (c) and friction angle (φ). Figure 3 shows the s-t diagram for each group and Table 5 collects the numerical results.

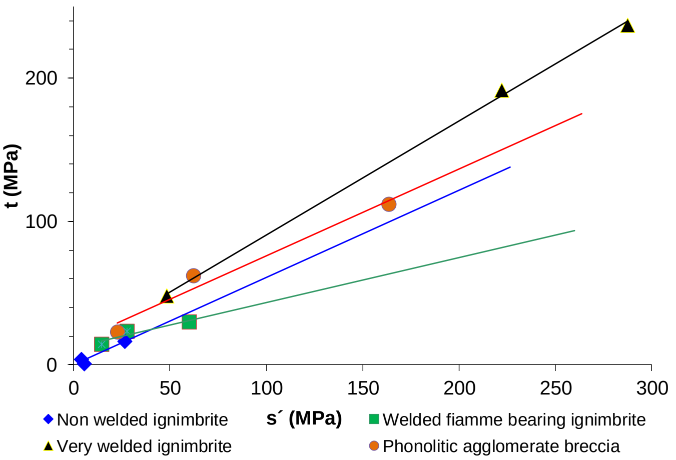

Figure 3. S-t diagram obtained with UCS and triaxial tests. Legend: (s) = $(\sigma_1+\sigma_3)/2$; (t) = $(\sigma_1-\sigma_3)/2$

Table 5. Mohr-Coulomb parameters obtained from tests

Group	Lithotype	c (MPa)	φ (º)	R^2
Soft Rocks	Non welded ignimbrite	0	37.5	0.92
Hard Rocks	Welded fiamme bearing ignimbrite	13	18.0	0.88
	Very welded ignimbrite	18	52.0	0.99
	Phonolitic agglomerate breccia	19.5	37.5	0.96

It must be noted that the strength values of welded fiamme bearing ignimbrites are quite low due to its significant anisotropic fabric of fiammes.

Moreover, eight consolidated drained direct shear tests were carried out with the soft rocks and according to UNE 103401. The strain rate was 0,020 mm/min. The rocks were crushed, passed through a 0,4 mm sieve and placed in a 60 mm large box with 10% of water content and a dry density of 1,76 t/m^3. Figure 4 shows the results obtained and Table 6 collects the numerical results.

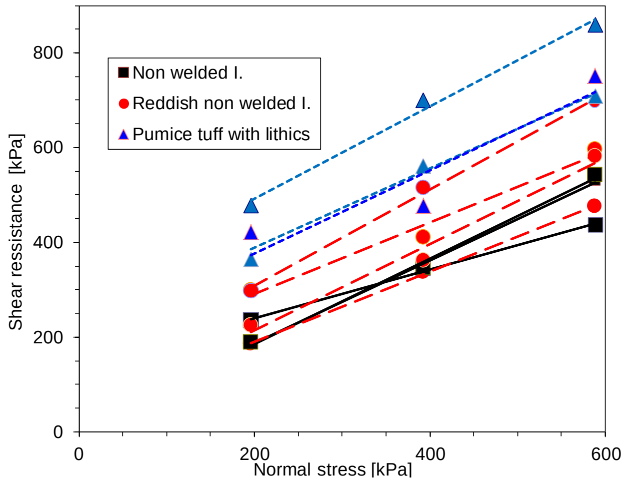

Figure 4. Results of direct shear tests (Soft Rocks)

Table 6. Strength parameters obtained with direct shear test for soft rocks.

Lithotype	c (kPa)	φ (º)	R^2
Non welded ignimbrite	10	41	0.99
	5	42	0.99
	135	27*	0.99
Reddish non welded ignimbrite	35	42	0.98
	105	45.5	0.99
	40	36.5	0.99
	140	37	0.98
Pumice tuff with lithics	220	40	0.87
	200	41	0.99
	300	44	0.99

*Considered not valid for this purpose as an asymptotic line in shear stress/deformation curve of the test was not reached.

All the tests show a high correlation coefficient (R^2>0.9). The Mohr-Coulomb lines are quite parallel, as friction angles are between 37 and 45º, while cohesion ranges between 5 and 300 kPa.

To complete the characterization of the reddish non welded ignimbrite, which is very erodible when submerged in water, one residual shear test was made following ASTM D 6467. The sample was submerged in water during one week, passed through a 0,04 mm sieve and prepared with 10 % of water content and with a dry density of 1.76 t/m^3. Two normal stresses were applied: 50 and 100 kPa. The residual friction angle obtained for reddish non welded ignimbrite was 34.3º, while the cohesion was zero.

Figure 5 and 6 show the strength parameters (cohesion and friction angle) obtained using all the test results (UCS, triaxial and direct shear tests). Each group has been plotted in different graphics because the high variation in the values of cohesion.

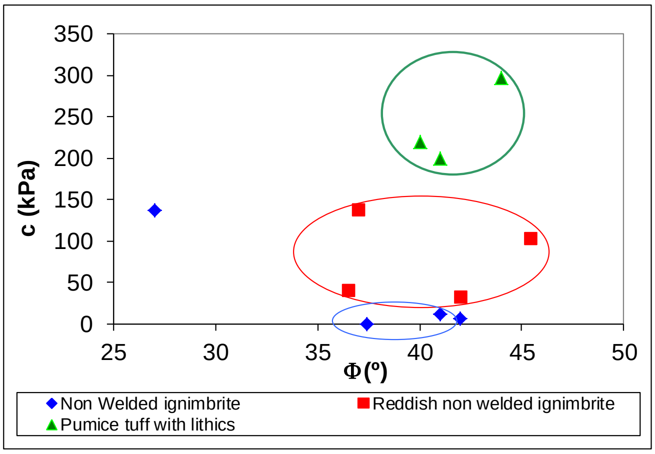

Figure 5. Strength parameters of soft rock group

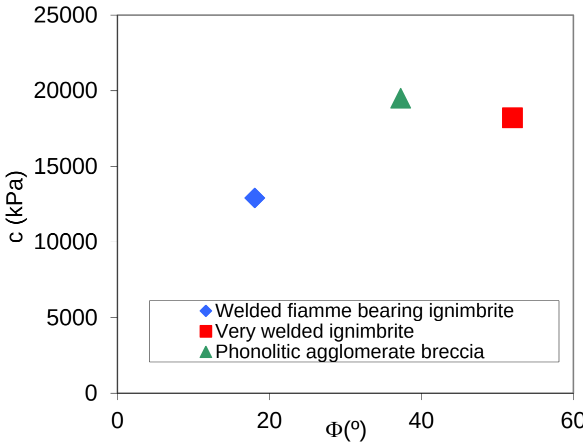

Figure 6. Strength parameters of hard rock group

It must be noted that reddish non welded ignimbrites exhibit the highest friction angle interval, which it is due to the different weathering degree in the samples tested, as noted in Vp values.

As a summary of all the tests, Table 7 shows the characteristic value adopted for each lithotype.

Table 7. Characteristic values of strength parameters

Group	Lithotype	c (kPa)	φ (º)
Soft Rocks	Non welded ignimbrite	10	41
	Reddish non welded ignim.	60	40
	Pumice Tuff with lithics	250	42
Hard Rocks	Massive phonolitic lava	15,000	40
	Welded fiamme bearing ignim.	13,000	18
	Very welded ignimbrite	18,000	52
	Phonolitic agglomerate breccia	19,500	37

The strength parameters of massive phonolitic lava have extrapolated from UCS results, taking into account the values obtained for phonolitic agglomerate breccia.

5 DISCUSSION

The samples investigated in this work were collected from the Arteara Rock Avalanche. The mechanical properties of the rocks and deposits involved in this area were previously characterized and described (Rodríguez-Peces et al. 2013). The present work has completed the characterization using laboratory test results that it is thought to provide a better determination of the strength parameters.

The laboratory tests showed that the hard rock group has higher UCS, V_p and E_{50} values and lower porosity. The welded fiamme bearing ignimbrites are an exception in this group as they show high porosity and the lowest UCS values in the group. These values are due to the important anisotropic fabric associated with the fiammes.

On the other hand, the values of friction angle for soft rocks are quiet similar. The highest variability is in the reddish non welded ignimbrites, probably due to the different weathering degree of the sample material. This fact is in accordance with its erodible behaviour, the dispersion also shown in UCS and VP values and already suggested in field descriptions.

The next tables show the results of laboratory test for each lithotype and the values compiled by other authors in similar materials (Rodríguez-Peces et al., 2013).

The main conclusion of this comparison is that the strength values obtained in this work are quite similar to the values previously deduced.

Table 8. Comparative chart for the soft rock group

PROPERTIES	(1)	(2)	(3)	(4)
Reddish non welded ignimbrite				
SiO_2 (%)	60	-	-	-
Real density (kN/m^3)	24.4	14.76-15.25	9-23	9 - 23
Porosity (%)	30	-	-	-
Absorption (%)	18	-	-	-
Vp (m/s)	2085	-	-	-
UCS (MPa)	6	5 - 12	4 - 34	2 - 5
E_{50} (GPa)	-	1.7 – 3.1	4 - 12	-
ν	-	-	-	0,28
φ (º)	40	25 - 38	25 - 38	25 - 38
Pumice tuff with lithics				
SiO_2 (%)	55	-	-	-
Real density (kN/m^3)	19.5	10.62 - 14.57	-	8 - 18
Porosity (%)	35	-	-	-
Absorption (%)	28	-	-	-
Vp (m/s)	1995	-	-	-
UCS (MPa)	4.9	8 - 24	-	1 - 50
E_{50} (GPa)	-	1.5 – 2.9	-	0.1 - 22
ν	-	-	-	-
φ (º)	42	37 - 42	-	25 - 42
.c (kPa)	250	-	-	-

(1) The present study; (2) Rodríguez-Peces et al. 2011; (3) Rodríguez-Losada et al. 2009; (4) González de Vallejo et al. 2008

Table 9. Comparative chart for the hard rock group

PROPERTIES	(1)	(2)	(3)	(4)
Massive phonolitic lava				
SiO_2 (%)	60	-	-	-
Real density (kN/m^3)	25.3	19.5-21.3	19 - 29	-
Porosity (%)	2	-	-	-
Absorption (%)	1	-	-	-
Vp (m/s)	5280	-	-	-
UCS (MPa)	53.5	62 - 108	30 - 114	-
E_{50} (GPa)	27,9	12 - 24	-	15 - 30
ν	0.21	0.29	-	-
φ (º)	39	38 - 41	36 - 54	-
.c (MPa)	15	-	-	-
Welded fiamme bearing ignimbrite				
SiO_2 (%)	65	-	-	-
Real density (kN/m^3)	24,1	17.9-18.5	13 - 29	13 - 29
Porosity (%)	17	-	-	-
Absorption (%)	9	-	-	-
Vp (m/s)	3040	-	-	-
UCS (MPa)	29	22 - 47	22 - 92	15 - 70
E_{50} (GPa)	6.7	4 - 10	30 - 50	30 - 50
ν	0.20	0.20	0.20	-
φ (º)	18	36-39	30-40	-
.c (MPa)	13			
Phonolitic agglommerate breccia				
SiO_2 (%)	65	-	-	-
Real density (kN/m^3)	25.1	18.6-21.0	-	12-28
Porosity (%)	8	-	-	-
Absorption (%)	3	-	-	-
Vp (m/s)	3745	-	-	-
UCS (MPa)	96.4	24 - 73	0.5-30	0.5-30
E_{50} (GPa)	24.7	0.7 – 4.6	-	0.1 – 4.7
ν	0.25	-	-	-
φ (º)	37	-	-	25 - 42
.c (MPa)	19.5	-	-	-

(1) The present study; (2) Rodríguez-Peces et al. 2011; (3) Rodríguez-Losada et al. 2009; (4) González de Vallejo et al. 2008

With this study, the characterization of the main lithotypes involved in Arteara rock avalanche has been improved. These values will be used for the stability model of the slope as a tool to determine the cause of the rock avalanche. At this respect, the high and orientated porosity of the welded fiamme bearing ignimbrites and the great dispersion in the angle of friction of the reddish non welded ignimbrites let suppose that these two materials had a significant role in the slides observed in the area of study.

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