Contribution To Geotechnical Characterization Of Basaltic Pyroclasts

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ABSTRACT: Both the Azores and Madeira islands, located in North Atlantic Ocean, are of volcanic nature.

The present work focuses on the geotechnical characterisation of basaltic pyroclasts from the Azores and Madeira, in order to get some comparison among them. In order to characterize, evaluate the geomechanical properties and get some more geotechnical data about basaltic pyroclasts, some samples were collected in both archipelagos, to do some laboratory tests. *In situ* tests were also made with these materials.

Results include data on SPT tests, plate load tests, Los Angeles tests, *in situ* dry density and specific weight tests, determination of particle size distribution, compaction and CBR tests and consolidated drained (CD) direct shear tests.

Some correlations between several properties are presented, namely between the strength and the deformability of volcanic materials.

Finally, some considerations are made about the potentially utilizations and problems related to engineering applications.

1 INTRODUCTION

Being the Madeira and the Azores archipelagos of volcanic origin, volcanic materials have always been, not only the main construction material for the local buildings, but also the only foundation terrain of all the constructions in these islands.

The increasing development in civil engineering works has shown the need to know better the geotechnical characteristics of volcanic materials, as they have some particularities and differences relatively to the non volcanic materials and besides, studies on that subject are very scarce. One of the existing volcanic materials that assume particular importance due to its applicability in the scope of Civil Engineering is basaltic pyroclasts. These materials are often used in the Azores, but its exploration is conditioned in Madeira archipelago, due to its reduced expression.

However, as it is of great interest to get a deeper knowledge of its geotechnical characteristics, it was considered important to make a survey of some tests executed with this type of material in both archipelagos, in order to be able to make some eventual comparisons.

In this context, this paper aims to contribute for a better knowledge of some geotechnical aspects of basaltic pyroclasts, given its specificities, aiming an eventual wider application, as well as to improve the current uses.

2 SOME GEOLOGICAL CARACTERISTICS

Fragments of rock thrown out by volcanic explosions are called *ejecta*, and accumulations of such fragments are known as *pyroclastic rocks* (MacDonald 1972).This type of material has also other designations, such *tephra, volcanic scoria,* "*bagacina*", the common name given at the Azores islands or even "*areão*" as it is known at Madeira.

Pyroclastic deposits form directly from the fragmentation of magma and rock by explosive volcanic activity. There are several ways to classify pyroclastic rocks. The most important classification of tephra is the one based on the size of the fragments (MacDonald 1972). MacDonald (1972) defined Bombs (round to subangular) and Blocks (angular) as ejecta lager than 64 mm, Lapilli if the average diameter is between 2-64 mm and Ashes if the diameter is < 2 mm.

They also can be grouped into three genetic types according to their mode of transportation and deposition: Falls, Flows and Surges.

Volcanic scoria are integrated in the first group.

Explosive activity builds scoria, cinder or spatter cones, or both, at the vent, with scoria-fall deposits of limited aerial extent and volume being deposited around and downwind of the vent. Those cones well defined, are usually symmetric, with a height that rarely exceeds a few hundreds meters. The inclination of the slopes of these cones is normally close to 33º (natural slope angle of loose scoria), value that changes with the time, due to erosion (Fraga 1988).

Scoria-fall deposits are composed largely of vesiculated basalt to near-basaltic magma. These are the deposits characteristic of strombolian explosive activity. Such eruptions eject scoria and relatively fluid lava spatter, and are often accompanied by the simultaneous effusion of lava.

Deposits of scoria cones often consist of rather poorly bedded, very coarse-grained with metre-sized ballistic bombs and blocks.

Scoria is typically dark gray to black in color, mostly due to its high iron content. Sometimes, oxidation (of iron) by hot gases streaming preferentially through the central part of the volcanic edifice, leads to a deep reddish-brown color (Scmincke 2006).

On what concerns mineralogical composition, some comparisons were made between X ray diffractometry analyses made with both Madeira (LREC Madeira) and Azorean samples (Fraga 1988). In both cases, mineralogy was similar: the most abundant mineral was a plagioclase (anorthite), in second place, pyroxens (augite) and then olivines (Forsterite). In the samples of the red basaltic pyroclasts, there was still the presence of hematite (resultant from the iron oxidation).

3 GEOTECNICAL CARACTERISTICS OF PYROCLASTS MATERIALS

Due to its volcanic nature, basaltic pyroclasts are a frequently heterogeneous material, non plastic, porous and with low density, with high levels of water absorption, being more or less consolidated.

The loose pyroclastic deposits are, therefore, a group of specific materials (on what regards its geotechnical characteristics) as they don't have the typical behaviour of a rock or of a soil; so they should be analysed as an independent geotechnical group. Being a rock, from a geological point of view, its geotechnical behaviour approaches, however, to that of a soil, with the particularity of being almost indifferent to the water content. Especially due to this characteristic and because they are formed by grains, volcanic scoria should be treated as an aggregate (non crushed natural aggregate) (Fraga 2009).

Its properties depends on the size of the grain, the shape, the porosity and petrological composition as well as the degree of packing among the particles, compaction state of the deposit and resistance of the referred particles (Vallejo et al. 2006).

Some geotechnical characteristics of the tested materials are presented below. Several Madeira samples of basaltic pyroclasts were tested as well as some samples from the Azores.

The following laboratory tests were performed with the Madeira samples: tests for grain size distribution, specific weight, compaction and CBR tests (Californian Bearing Ratio) and consolidated drained (CD) direct shear tests.

Consolidated drained direct shear tests were made on 7 samples, being tested separately the fractions with sizes inferior to 2.00 mm (sieve ASTM nº 10) and with the fractions of sizes inferior to 4.75 mm (sieve ASTM nº 4), in a shear box with the following dimensions: 100x100x25 mm^3.

For two of the samples, consolidated drained direct shear tests were performed on the entire samples, in shear box with the dimensions 300x600x200 m^3, existing in the Laboratory of Construction Materials of the Faculty of Engineering of the University of Porto.

Some in situ tests were performed to determine the dry density, and plate load tests to determine the characteristics of natural deposits of basaltic scoria.

In Azorean samples the following laboratory tests were performed: tests for grain size distribution, Los Angeles, CBR and specific weight tests.

The following in situ tests were also performed: SPT, plate load tests and *in situ* dry density.

One should remark that the in situ tests in Madeira were performed on natural deposits, while the ones performed in the Azores were executed on landfill material, with exception of the SPT tests which were performed on natural terrain.

3.1 – *Results of the tests performed.*

3.1.1. *Madeira samples*

On what concerns the pyroclastic materials of Madeira Island, the values obtained for the main geotechnical properties are: specific weight = 24.7 - 29.1 kN/m^3, dry density = 12 - 14 kN/m^3, cohesion = 0 - 0.1 MPa, friction angle= 29 - 50º.

One should emphasize that though these materials are loose, in consolidated drained direct shear tests a "cohesion" value was obtained which is associated to the form and imbrication of the grains and to the need of an increase of the volume of the specimens to provide the shear failure.

The values of friction angle obtained in the consolidated drained direct shear tests, with the fractions passed through the 2.00 mm sieve and through the 4.75 mm sieve are similar, while the obtained values for the cohesion show a wide variety (Figure 1).

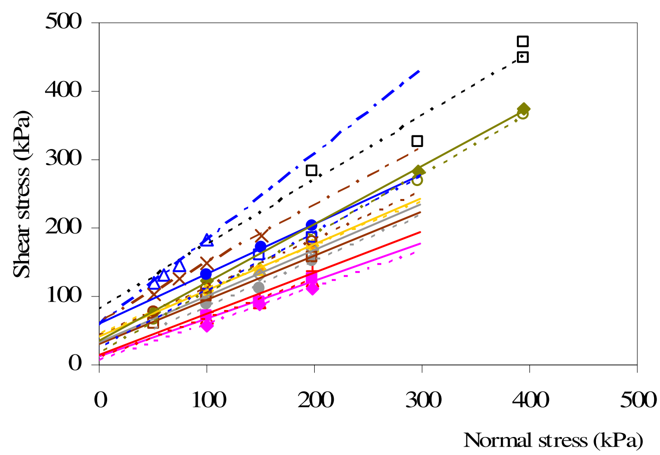

Figure 1. Results obtained with the consolidated drained direct shear tests on Madeira samples.

The consolidated drained direct shear tests results on the two entire samples led to higher values, both in friction angles and cohesion, when compared to previous results, which are obviously related to the bigger dimensions of the particles and the correspondent increase volume during the shear failure phase.

Figure 2 shows an example of a test made with the entire grading on the big shear box.

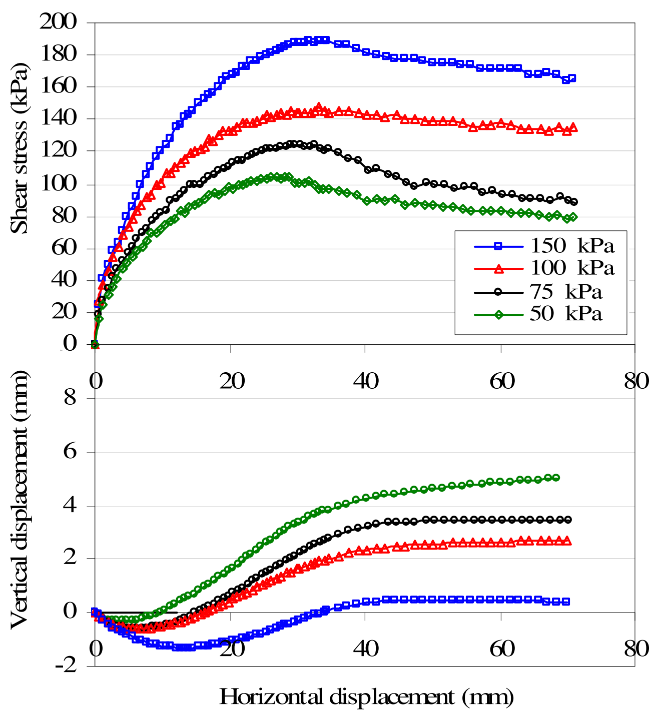

Figure 2. Example of a test made with the entire grading in the big shear box.

Compaction and CBR tests were also performed, and values for the maximum dry density were obtained between 13.5 and 17.1 kN/m^3, for the optimum water content values between 4.5 and 17.7 %. For the CBR the values varied between 40 and 96 %.

Seven in situ plate load tests were performed with a 0.6 m diameter plate. In these tests a wide dispersion in the values of the deformability secant modulus was obtained, which varied between 10 and 250 MPa, for a tension of 300 kPa.

The values of the deformability modulus obtained in situ are closer to the values obtained in the laboratory tests, presented by Serrano et al. (2007), and are more different from the values presented by Uriel & Serrano (1976, *in* Serrano et al. 2007), which were obtained with in situ plate load tests, using a 1x1 m^2 plate.

3.1.2 *Azores samples*

Tests for grain size distribution, specific weight determination, CBR and Los Angeles were performed in laboratory on these materials.

Particle size distribution results are presented in Figure 5, being possible to see that they are mainly well graduated gravel. On what concerns the particle specific weight, the values are between 19.6 and 21.6 kN/m^3, and the water absorption range between 3.3 and 14.8 %

Results from Los Angeles on the 18 samples tested are presented in Figure 3, showing a high variation of values, between 25 % to 70 %.

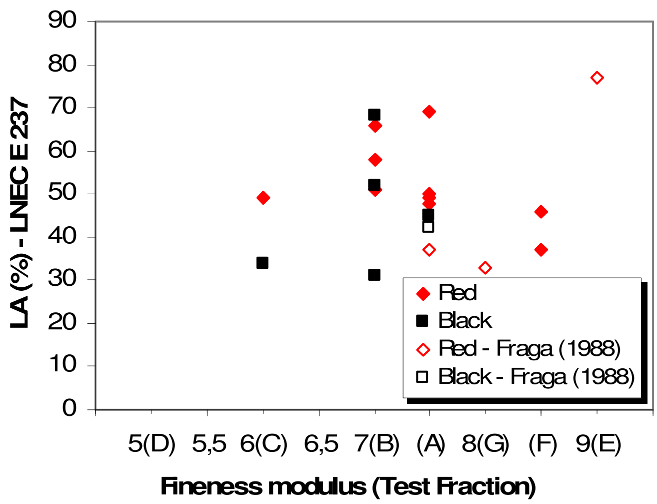

Figure 3. Los Angeles tests done in Azorean samples.

According to Fraga (1988) the coefficient of Los Angeles in these materials varies with the fraction of material that is tested. That researcher found that the same material had a value of Los Angeles coefficient that was lower when tested in the finer fractions and higher in the coarser fractions. He also found that this variation was linearly with the fineness modulus. The behaviour of this material thus differs from that observed in basalts, in which the results are much the same regardless to particle size fraction of material that is tested.

The compaction tests made with the Azorean samples exhibit values for the maximum dry density between 12.1 and 14.1 kN/m^3, for the optimum water content values between 15 and 35 %.

In the laboratory the mechanic resistance of the basaltic pyroclasts was evaluated through CBR tests, having obtained values that varied between 42-73 %. It was possible to verify that this mechanic resistance is much better if the tested granulometric fraction is finer.

On what regards the in situ tests, as it was already mentioned, the presented results were obtained in different tests executed in different landfills, such as in situ dry density, determinated in experimental landfills, and plate load tests (PLT).

The values obtained for the in situ dry density in landfills varied between 12.2 and 18.7 kN/m^3, and it was possible to verify that their value increases with the decrease of the particle dimensions, showing the opposite on what regards of water absorption (Fraga 2009)

Nineteen plate load tests were performed with 0.3 and 0.6 m diameter plates, obtaining values that varied between 70 MPa and 140 MPa, for the deformability secant modulus for a tension of 300 kPa, and between 120 and 480 MPa in the recharge (Figure 4).

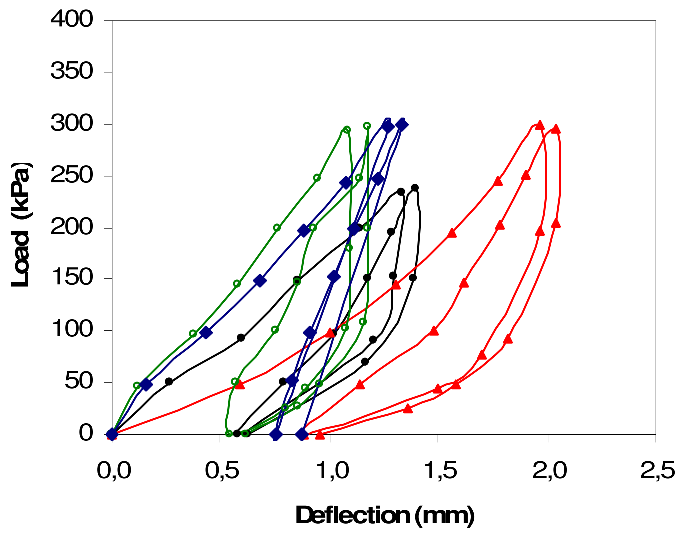

Figure 4. Typical plate load test curves obtained on landfills made with basaltic pyroclastic rocks.

Besides the tests performed in landfills, some SPT tests were executed in natural deposits, and N_{SPT} values between 4 and 20 were obtained, with a medium value of 12. These low values in a rocky material show the loose and uncompact state of these formations in nature due to their genesis.

3.2 – *Comparison of test results.*

Figure 5 shows the results of the tests for particle size distribution of samples. The grading of Madeira basaltic pyroclasts are presented with a continuous line while the ones of the Azorean samples are presented with a hatched line.

According to the ASTM D2487 standard, the majority of Madeira samples are classified as sand and those of the Azores as gravel.

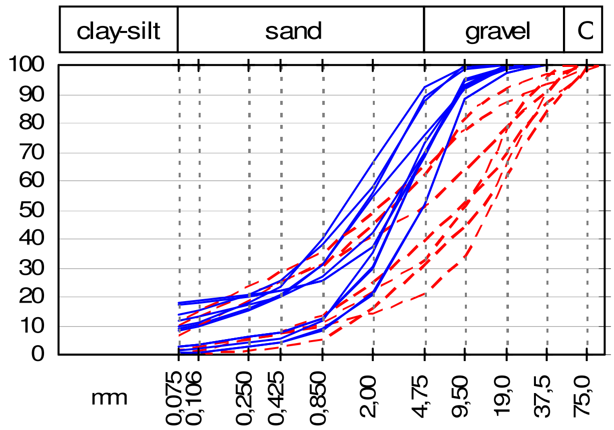

Figure 5. Comparison of the particle size distribution curves obtained on Madeira and Azores pyroclastic rocks.

For a better comparison of the results obtained in the tests for the determination of specific weight, dry density, CBR, friction angle, and cohesion, a table was elaborated (Table 1) where these values are presented for the Madeira, Azores and Canarias archipelagos.

Table 1. Results from tests made on Madeira, Azores and Canary Islands samples

Tests	Units	Madeira	Azores	Canarias*
Specific Weight	kN/m^3	25-29	20-22	23-25
In situ Dry Density	kN/m^3	12-14	-	8-15
Maximum Dry Density	kN/m^3	14-17	12-14	-
CBR	%	40-96	42-73	-
Friction Angle	º	29-50	-	30-45
Cohesion	MPa	0-0.1	--	0-0.1

*(Gonzalez Vallejo et al. 2007)

On what regards the specific weights values, it is possible to verify that the Azorean samples are the ones that presents lower values followed by those of Canarias, being the ones from Madeira, those with higher specific weights.

On what concerns the results obtained for the in situ dry density, it is possible to verify that there is a range of values common to Madeira and Canarias archipelagos, though Canarias presents a wider range. The values of maximum dry density found in the Azorean pyroclasts are lower than to those obtained in the laboratory for the Madeira pyroclasts as observed for the specific weight.

Data related to CBR tests, friction angle and cohesion are similar in the existing samples. However, it's possible to verify the existence of higher CBR values for Madeira samples.

Regarding the results obtained in the plate load tests, it is possible to see that with the Azorean pyroclasts the dispersion of value is smaller than the Madeira ones, which is expectable, once the values refer to compacted landfills and in Madeira samples, the values refer to natural deposits with different degrees of compaction.

4 SOME APPLICATIONS OF BASALTIC PYROCLASTIC ROCKS ON CIVIL ENGINEERING WORKS

As volcanic scoria are plentiful in the Azores, specially in S. Miguel Island, and due to its geotechnical characteristics, they assume particular importance because of its use in different kinds of civil engineering works.

One of the uses of this material is in the execution of landfill (improvement of the soil foundations, landfills on roads, etc), and they can be used in any part of these.

Because scoria is very hard and porous, it makes a good base for roads.

They have been used traditionally as a material for pavement layers of roads, as well as used in pavement beds, and for the improvement of excavation areas. In most cases it is used only as sub-base layer, but sometimes as base and wear coarse layer in roads with little traffic (Fraga 1988)

In both these applications, once its grain size distribution suffers changes by particles breakage and crush, particularly when compacted, the control of this material in civil engineering works should only be executed considering the grain size distribution that the materials shows after compaction.

The industry of making masonry bricks also uses volcanic scoria as row material.

Crushed and screened to specific sizes, the open structure and excellent drainage properties of volcanic scoria creates a truly versatile product for both landscaping purposes and as a bedding material for under soil drainage applications, and behind retaining walls.

5 CONCLUSIVE REMARKS

As it was possible to see by the results presented in this paper, there are several similarities between the Madeira and the Azores basaltic pyroclasts. In the first case, they are finer, with slightly bigger specific weights as well as maximum dry density. CBR values presents a wider range than the Azorean ones.

Though it's possible to take some conclusions with the existing data, it's necessary to proceed the investigation with the execution of more tests to understand better the geotechnical behavior of these materials in order to improve their applications in civil engineering works.

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