Inherent anisotropy in allophane clay in Colombia

Anisotropie inhérente des argiles allophane Colombiennes

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ABSTRACT

Allophane clays are derived primarily from the in situ weathering of volcanic ash, although they may be derived from other volcanic material. This parent material may be either basic or acidic in nature. It appears that the primary condition for Allophane formation is that the parent material be of non-crystalline (or poorly ordered structure) composition. Volcanic ash meets this criteria; it is formed by the rapid cooling of relatively fine-grained pyroclastic material, the cooling process being too rapid for the formation of well ordered crystalline structures.

In addition to the above requirement regarding non-crystalline parent material, it appears that the weathering environment must be well drained, with water seeping vertically downward through the ash deposit. High temperatures also appear to favor or accelerate the formation of Allophane clays. Generally the Allophane content of such clays in Indonesia is substantially higher than in similar clays in the cooler, temperate climate of New Zealand (Wesley, 1990).

The weathering process is essentially one of the chemical conversion and leaching out of silica by seeping pore water. A requirement for the weathering process to progress from Allophane to halloysite and on to kaolinite (and the sesquioxides) appears to be a warm wet climate of the kind found in the wet tropics.

From a geotechnical point of view a very good approach to the understanding to how this material behaves is done until now. Rao (1995) gave us an approach to the shear strength of this Allophane clay, the same as Meyer (2005); some others made contributions on the evaluation of volcanic soil properties (Nanzyo). In addition, Charles W. Ng (2002) worked on the behavior of compaction on Allophane clays, while So (1998) worked on the correlation between the Allophane content and the index properties, just to mention a few.

Recently Meyer (2005) made the first approach to the understanding of the dynamic properties of this material, but until now no more additional material has been written in this topic.

Based on what we know about this material until now, this paper will show the results from a study on inherent anisotropy on undrained condition, since information in this topic is very limited; Moreover, this paper is a contribution towards filling this gap.

RÉSUMÉ

Les argiles allophane sont issues principalement des procédées de transformation in situ des cendres volcaniques, bien que ils peuvent être dérivés d'autres matériaux volcanique. Ce matériel parental peut être acide ou base et la condition première pour la formation des argiles allophane est le fait que le matériel soit d'une composition non - cristalline (o avec une structure non - ordonnée). Les cendres volcaniques répondent à ce critère.

Une exigence additionnelle concernant la composition non cristalline des argiles est le fait que l'environnement doit assurer des bonnes conditionnes de drainage vertical de l'eau dans le réservoir des cendres. Les températures élevées accélèrent aussi la formation de ces argiles, par exemple, la quantité de allophane dans les argiles en Indonésie est plus élevée que dans les argiles trouvées dans les régions froides de la Nouvelle-Zélande (Wesley 1990).

Du point de vue géotechnique, de bonnes approches pour comprendre le comportement de ce type de matériel a été fait jusqu'à présent. Rao (1995) et Meyer (2005) ont effectué une approche à la résistance au cisaillement. Charles W. Ng (2002) a réalisé une recherche sur les propriétés de compactage des argiles allophane et So (1998) a développé une corrélation entre le contenu des allophane dans les argiles et ces propriétés indicielles. Récemment, Meyer (2005) fait une première approche pour comprendre les propriétés dynamiques.

Sur la base de ce que nous savons à ce jour sur ce type de matériel, cet article montre le résultat d'une étude sur l'anisotropie inhérente à des conditions non drainées, étant donné que l'information sur ce sujet est très limité ; cet article est une contribution pour réduire ce gap.

Keywords: Volcanic ash, inherent anisotropy, direct shear test.

1 INTRODUCTION

The volcanic activity around the world produces different materials each time they make eruptions. This activity is mainly produced around the well-known circum pacific belt, which crosses almost all countries that border the Pacific Ocean. Yet, it is not the only one.

Among the materials that emerge on volcanic eruptions there is a particular one found in every eruption, and which calls our attention: the volcanic ash and the way it behaves as a geotechnical engineering material.

Once this particular material is resting on the ground, it transforms into a very singular material due to a weathering process, singular in terms of combination of shape and chemical composition, which gives this material a very unique

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mechanical behavior. The weathering process makes this initial material change from volcanic ash to allophane and imogolite, then to halloysite, then to kaolinite, then to sesquioxides, and finally into laterite (Wesley 1973). This rapid change in the material produces two particular materials involved in the previous description as allophane and imogolite. The first one is an irregular spherical particle, hollow and with different diameter range changing from 3 to 5 nm. On the other hand, the imogolite is a paracrystalline material, which means that it crystallizes only in one direction in a particular shape called "nanotube" (Verdugo, 2008) .

With this unique and unusual particle morphology, this paper will focus on the behavior of this allophane clay with the inherent anisotropy involved on it is geological and weathering formation.

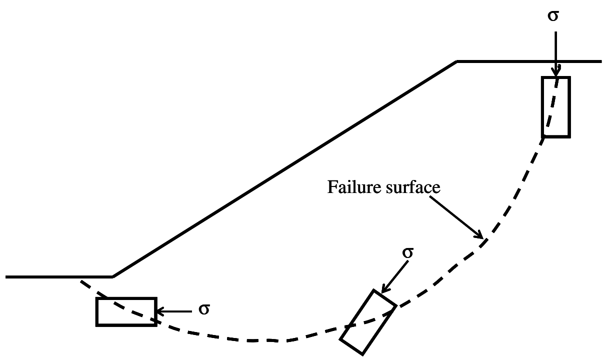

Figure 1. Stress variation with failure plane.

2 ALLOPHANE CLAY

Allophane clays are derived primarily from the in situ weathering of volcanic ash, although they may be derived from other volcanic material as well. This parent material may be either basic or acidic in nature, and it appears that the primary condition for Allophane formation is that the parent material be of non-crystalline (or poorly ordered structure) composition. Volcanic ash meets this criterion, since it is formed by the rapid cooling of relatively fine-grained pyroclastic material, the cooling process being too rapid for the formation of well ordered crystalline structures.

In addition to the above requirement regarding non-crystalline parent material, it appears that the weathering environment must be well drained, with water seeping vertically downward through the ash deposit. High temperatures also appear to favor or accelerate the formation of Allophane clays. Generally the Allophane content of such clays in Indonesia is substantially higher than in similar clays in the cooler, temperate climate of New Zealand (Wesley, 1990).

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3 SOIL ANISOTROPY

The influence of particle orientation on the constitutive behavior of soils has long been recognized. The stress-strain relationship and shear strength have been found to depend on the direction of loading with respect to the direction of particle orientation (Duncan & Seed, 1966; Arthur & Menzies, 1972; Mitchell, 1972;).

Soil properties are highly influenced by geological forces during the formation process, which is very important when soils are subjected to different kind of stress levels. For example: the slope stability analysis where regularly all soil samples are taken from the ground in vertical direction, and the soil shear strength tends to change as the inclination of the failure surface does, as t is seen on figure N° 1.

Two kinds of anisotropy could be found on soil nature. The first one is given by soil formation which is *inherent* to each soil and depends mainly on geological factors. On the other hand, the second one is given due to the human soil interaction where soil changes the natural structure due to human action and the stress is *induced* to the soil.

In a traditional slope stability analysis, is a regular procedure to evaluate the shear stress only in vertical direction, since regularly all the soil samples are retrieved in this direction. Yet, with normal procedure the stress variation is not followed and some overestimation of soils properties takes place. In addition, the evaluation of safety factors does not give the most accurate perspective of the slope analysis.

4 LABORATORY PROGRAM

Soil samples from different depths were taken in a central part of Colombia were different volcanoes are located. Many of them contribute to changes in the local topography due to enormous amount of volcanic ash launched into the atmosphere. In this part of Colombia depths up to 20m can be found on volcanic ash.

The samples were taken in a central part of Colombia, near the city of Pereira, using the regular procedures to ensure that they were still on natural conditions. The samples were covered with wax and plastic wrap and transported carefully to the laboratory ensuring in this way the high quality of the samples.

The laboratory test was focused first on index properties, atterberg limits and finally on direct shear box test, using for all the experiments the natural soil samples retrieved from the ground. For the first ones remolded samples were used, the points lied below the A-line, as could be seen on Figure N° 2.

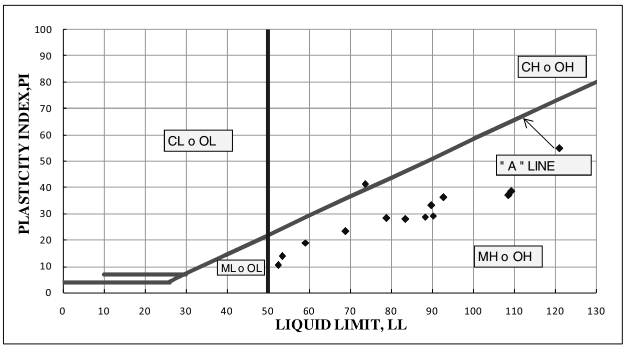

Figure 2. Plasticity chart

The laboratory routine consisted on the preparation of a soil sample to be tested on a direct shear box with an inside diameter of 6cm, and the angle of sample retrieved changed from completely vertical to completely horizontal. From hereafter completely vertical soil samples were called 0° degrees and completely horizontal were called 90°.

Forty experimental tests on this soil were carried out on 0°, 30°, 60° and 90°. The equipment used was a direct shear box test with a digital load cell up to 5 kN, the horizontal displacements were measured with a digital local displacement transducers, all the test were performed with a 1mm/min shearing rate , the type of tests were unconsolidated- undrained

UU and consolidated- undrained CU, the data collection was fixed to a frequency of a two data per second, the load cell data and horizontal displacement data was storage using a data logger to obtained the information from the direct shear box equipment, for later evaluation and interpretation.

The normal stress was set up from the beginning as 4,96; 9,07 and 13,2kPa.

Typical values of moisture content, wet and dry unit weight could be summarized on the next table for some of the soil samples tested.

ω	γ_s	γ_d
%	T/m³	T/m³
64,32	1,58	1,04
67,19	1,41	0,84
70,28	1,50	0,87
64,00	1,45	0,88
98,98	1,37	1,03
60,56	1,48	0,90
76,28	1,37	0,78
71,22	1,40	0,82
53,68	1,84	1,17
65,80	1,47	0,87
125,50	1,26	0,51
117,90	1,37	0,63

5 EXPERIMENTAL LABORATORY RESULTS

A typical strain-stress curve is presented in the next figure, in which it could be seen how the strain rate increases as normal and shear stresses increases.

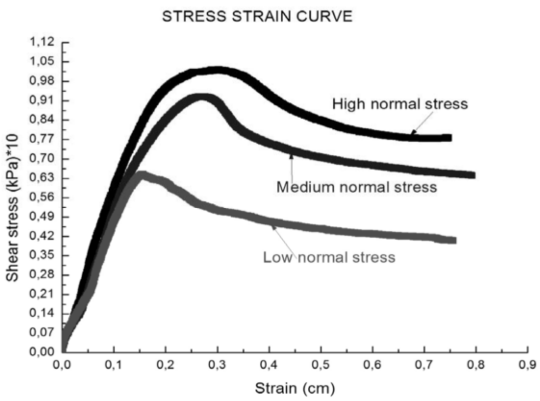

Figure 3. Typical strain-stress curve for allophane clay

As it is shown in Figure 3, when a very low normal stress has been applied, there is a linear behavior until a maximum soil capacity is reached and then it falls drastically; for medium normal stresses, a linear behavior also appears but the linearity disappears when the shearing stress is getting near the 6kPa, after this point some relaxation takes place, because under smaller shearing stress increments, the strain gets higher until the soil reaches the maximum capacity and falls. Finally, when the soil is loaded with high normal stresses, the behavior is linear until the strain-stress curve changes suddenly and starts showing some kind of creep, the strain increases under the same shearing stress and then the curve falls in a very smooth way.

At very small strains, in the linear range, the soil shows independency of the stress level since there is not significant variation as the normal stress is increased in each trial, varying from 4,96kPa to 13,2kPa showing the same tendency for all three trials, as it is shown in the figure 4.

In figure 5, the continuous line shows the curve for soils under the consolidated-undrained test (CU), and the broken line shows the curve for unconsolidated-undrained test (UU).

As it is shown in figure 5, both test methodologies are showing the same tendency. The cohesion value changes each time the soil angle varies with respect to the vertical direction. The soil cohesion decreases as the inclination angle (δ) increases from zero degrees until a value close to 60° degrees. Such variation could be seen as linear. After this point the

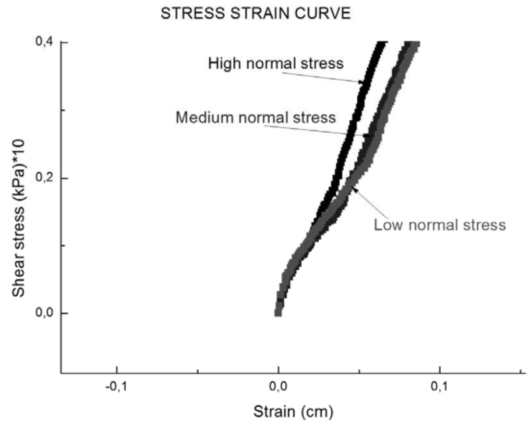

Figure 4. Linear behavior at small strains.

cohesion increases until it reaches the highest possible value following a linear trend as well.

The reduction in cohesion as it reaches 60° degrees is approximately 40% of its original value, and after this angle, it increases linearly until it arrives to a value near 40% over the original value.

The gap between these two curves depends on how the soil was tested. In a CU test, due to the consolidation process, the void ratio decreases, the unit weight and the shearing strength increase, giving a higher cohesion value compared with the soil in a UU test. In this type of test pore pressures and void ratios are held constant.

It is probable that the cohesion reduction shown on figure 5 when the vertical inclination angle (δ) is near 60° degrees, may have a particular relation with the nanotubes orientation.

As it was previously mentioned, the imogolite material is a paracrystalline material, which means that it crystallizes only in one direction. This particular shape called "nanotube" might be responsible for this cohesion variation. At this point the applied stress could be higher than the resistant stress of the nanotubes cluster, and the soil becomes weaker in this plane giving a small value of cohesion under this inclination angle.

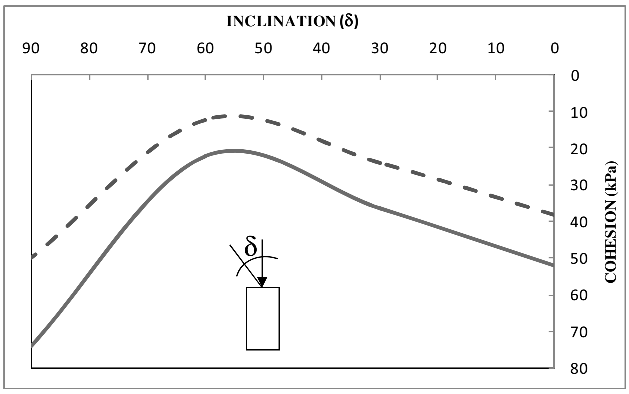

Figure 5. Inherent Anisotropy curve for allophane clay.

Cohesion normalization is made to evaluate the changes with respect to the vertical cohesion as is shown in the following figure.

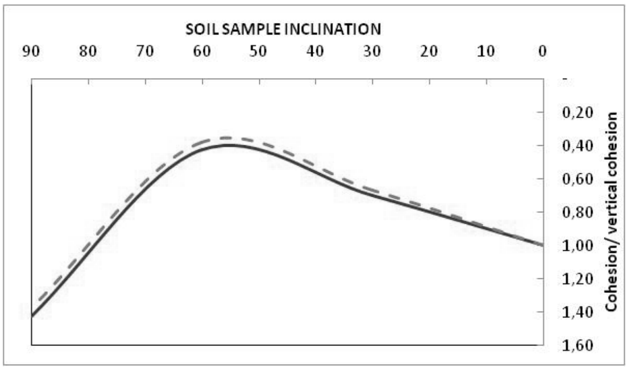

Figure 6. Normalization of cohesion

As it is shown in figure 6, no significant variation is shown when the cohesion under inherent anisotropy is normalized with the vertical cohesion value.

The broken line is the normalization with vertical cohesion under the UU test, and the continuous line shows the tendency under the CU test.

From figure 6, both types of test are showing the same pattern under different test considerations. This particular behavior indicates that the variation in cohesion relative to the one obtained for 0 degrees is the same. The process of consolidation does not change the rate of variation in cohesion due to the orientation of the particles. In other words, the cohesion ratio is independent of the source used in the direct shear box test.

6 CONCLUSION

A series of direct shear box test were performed in allophone clay, a very particular material generated by the weathering of volcanic ash under high temperature and humidity.

To evaluate the anisotropy of allophone clays a series of experiments were carried out to evaluate the cohesion in terms of the inclination angle (δ) of the samples, the behavior under small strains and normalization against the results of regular procedures.

From the test results, the cohesion parameter presented a higher value when CU test was performed compared with the UU test. This behavior is owing to the consolidation load. It was found that the cohesion under a UU test presented a linear variation decreasing its original value until it reached the approximate angle of 60° (δ=60°). At this point the cohesion reached a value near the 40% of its original value. From this point (δ=60°) the cohesion increased linearly until it obtained an inclination of 90° (δ=90°). At this position the cohesion reached a value near 40% above its original value. When CU tests were, performed the same pattern was found.

The cohesion variation from its original value to a smaller value at a 60° inclination could be interpreted as strength reduction of the entire nanotubes cluster, which could be found on the soil due to the geological formation of this particular soil. Since geological formation and weathering process play a very important role on the mechanical behavior of this type of soil , a very deep and rigorous study should be addressed to understand the general frame of this volcanic soil.

No significant variation was found when the normalization procedure was used for both types of tests, since cohesion values showed the same variation under different soil sample inclination. The normalized cohesion showed a similar trend as many others soil types reported on available literature..

In this paper the evaluation of cohesion value under different inclination angles was studied, applying two of the most well-known direct shear test methodologies. This investigation will have many practical uses since slope stability analysis, foundations engineering, retaining walls and many other geotechnical structures are involved in this type of phenomena.

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