INTERNATIONAL SOCIETY FOR
SOIL MECHANICS AND
GEOTECHNICAL ENGINEERING

This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

https://www.issmge.org/publications/online-library

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Invited contribution: Slope failures on the volcano 'el Reventador' in eastern Ecuador (Discussions on volcanic debris)

Contribution d'un conférencier invité: Rupture de talus sur le volcan 'el Reventador' en Equateur de l'est (Discussions sur les sols volcaniques)

L.C. BELLONI, Terracon S. R. L., Milano, Italy

The presentation will discuss the slope failures which occurred on the slopes of the volcano el Reventador following a strong earthquake after a prolonged rainy period.

The area interested had an extention of some 25 km^2. Failure removed the cover down to rockhead on a thickness of approximately 3 m.

El Reventador is located in Eastern Ecuador, in a sub-tropical environment, and is still active. Epicenters of the earthquakes, two main shocks of 6.1 and 6.5 M_b within the space of 2 hours, are located in the neighbour of the volcano itself. The first (6.1) caused large scale landslides on the steep slopes of the region which blocked many of the rivers with debris dams. The second (6.5) caused further slides and the destruction of many debris dams, releasing the impounded water and resulting in extensive damage downstream.

The soil nature is presented on the basis of identification tests carried out on representative samples. They may well be described as volcanic debris, being the partially weathered product of the various eruptions that covered the area, and comprising of clays, pyroclastics, quartz sands, lahars, agglometares, with cinders and lapillites.

The implication of the particular nature of the soil with reference to their geotechnical characteristics are discussed, emphasizing the importance of their structure which presents inter particle bonding and therefore a structure which is likely to collapse under the effect of the imposed loading.

The mechanism of the landslides is then discussed, the slopes were saturated and ground water level was most probably coincident with the natural soil profile.

The slopes angle was between 35° and 60°, and even under the severe conditions factor of safety against sliding was more than unity. The material thus proves to possess some cohesion in addition to friction.

The earthquake provided the trigger mechanism and under the action of the horizontal and vertical accelerations deformations were produced so that cohesive resistance was destroyed, leaving the material only with the frictional resistance. Presumably the material slid down the slope with a high velocity since all of it fell at the bottom of the valley and was transported by the river that, in two hours only, was able to build the debris dams and impound enough water, before the second main shock.

It is therefore postulated that, in addition the structure collapsed, a phenomenon similar to liquefaction, raising the pore water pressure, this mechanism being favoured by the prolonged pulsating stresses applied by the earthquake. These generated high pore pressure which further reduced the frictional strength along the slip plane causing the mass of debris to flow down the slope with a consistant velocity.

Volcanic ash soils: Problem soils of miracle soils

Sols de cendres volcaniques: sols à problèmes ou sols à miracles

L. D. WESLEY, Civil Engineering Department, University of Auckland, New Zealand

1 GENERAL

Volcanic ash soils have a somewhat mixed reputation among geotechnical engineers. In some quarters they are labelled "problem soils" or "troublesome soils", and are regarded as undesirable engineering materials.

The principal purpose of this contribution is to suggest that volcanic ash soils are generally good engineering materials (in both their undisturbed and compacted state) and major engineering works can be satisfactorily carried out in these soils. In some respects they could well deserve the title "miracle" soils rather than "problem" soils.

2 OCCURRENCE

Volcanic ash soils discussed here are those derived from weathering of volcanic ash and whose behaviour is predominantly influenced by the amorphous clay mineral allophane. Widespread occurrence - Hawaii, New Zealand, Indonesia, New Guinea, Japan and West Indies (see Wesley and Matuschka 1988).

3 OBSERVED PERFORMANCE

- Performance in natural and cut slopes is outstanding. Lum (1982) describes cuts up to 25 m high at 63° (2:1) remaining stable. Moore (1988) mentions cuts 10 m high standing almost vertical. Steep terraced ricefields of Southeast Asia are a graphic demonstration of remarkable stability.

- Literature covering their performance as foundation materials is not widespread. Wesley and Matuschka (1988) describe satisfactory performance on some major projects in Indonesia and New Zealand.
- Performance in embankment dams outstanding. Four dams built in Indonesia in 1925 to 1930 (heights from 17.5 m to 30 m) still in operation today.
- Compaction of volcanic ash soils has been the main source of difficulties and source of adverse reputation.

4 COMPACTION

Difficulties can arise because:

- unusual shape of compaction curves and influence of drying;
- sensitivity and "over compaction" effect;
- wide variation in properties;
- adverse climatic conditions may make drying impractical.

Despite the above difficulties successful compaction has been undertaken on numerous occasions. Compaction control should be in terms of air voids and shear strength (see Pickens, 1980 or Wesley and Matuschka, 1988).

5 DISTINCTIVE PROPERTIES

Their most distinctive properties are:

- Very high water contents and Atterberg Limits
- Irreversible property changes when dried
- Flat compaction curves without peaks
- Conventional empirical relationships often not applicable
- Generally good engineering properties

6 EVALUATION AND DESIGN ASSESSMENT

There are basically two ways in which geotechnical engineers evaluate soils as engineering materials:

(a) By directly observing their performance in the field.
(b) By carrying out a range of standard soil mechanics tests.

Volcanic ash soils provide something of an object lesson in the use of these methods. Too many accounts of properties of volcanic ash soils focus only on the results of soil mechanics test (especially empirical tests) without reference to observed behaviour in the field. On the basis of conventional soil mechanics trends (or empirical relationships) conclusions are drawn from the test results that the soils are unsatisfactory materials or "problem soils".

The lessons to be learned from volcanic ash soils as far as the evaluation or assessment of soils as engineering materials are concerned appear to be the following:

(a) We must not give paramount importance to test results in themselves.
(b) We should not assume that empirical trends valid for "conventional" soils are universally applicable.
(c) More attention should be paid to the direct observations of field behaviour.

Test results may well suggest the description "problem" soils; field behaviour, at least in terms of slope stability, might justify the term "miracle" soils.

REFERENCES OF RELEVANCE

GIDIGASU, M.D. and BANI, S.K., 1973, "Geotechnical characteristics of troublesome lateritic materials", Proc. 8th Int. Conf. on Soil Mechanics and Foundation Engineering, Moscow, Vol. 4, 89-96.

MORIN, W.J. and TODOR, P.C., 1975, "Laterite and lateritic soils and other problem soils of the tropics", USAID 3682, Lyon Assoicates, Baltimore, U.S.A.

PICKENS, G.A., 1980, "Alternative compaction specifications for non-uniform fill materials", 3rd Aus-N.Z. Conf. on Geomechanics, Wellington, Vol. 1, 231-235.

WESLEY, L.D., 1973, "Some basic engineering properties of halloysite and allophane clays in Java, Indonesia", Geotechnique, Vol. 23, No. 4, 471-494.

WESLEY, L.D., 1974, "Tjipanundjang dam in West Java, Indonesia", ASCE Journal of Geotechnical Engineering, Vol. 100, No. 4, 503-522.

WESLEY, L.D., 1977, "Shear Strength properties of halloysite and allophane clays in Java, Indonesia", Geotechnique, Vol. 27, No. 2, 125-136.

WESLEY, L.D. and MATUSCHKA, T., 1988, "Geotechnical Engineering in Volcanic Ash Soils", Proc. Second Int. Conf. on Geomechanics in Tropical Soils, Singapore, Dec. 1988, Vol. 1, 333-340.

Invited contribution: Design assessment of lateritic and saprolitic soils (Discussion on laterites and saprolites)

Contribution d'un conférencier invité: Etablissement des projets sur les latérites et les éluvions (Discussion sur les latérites et les éluvions)

J.B.QUEIROZ DE CARVALHO, Department of Civil Engineering, Federal University of Paraiba, Campina Grande, Brazil

In relation to the design assessment of tropical lateritic and saprolitic soils, not much has been divulged to date and consequently papers are scarce. This fact was noted at the 1st International Conference on Geomechanics in Tropical Lateritic and Saprolitic Soils (Brasilia, 1985) and little improvement can be seen today. Are the lateritic and saprolitic soils showing similar behaviour to other soils when the classical soil mechanics concepts are used? Not exactly.

It is known that lateritic and saprolitic soils display certain characteristics similar to those of sedimentary deposits, but these soils (lateritic and saprolitic) have quite a peculiar mode of formation, normally indicated by the act of weathering. It has been shown that due to the mode of formation, certain lateritic and saprolitic soils are susceptible to handling and thereby alter some of their basic properties, e.g., grain size distribution and plasticity. On the other hand, other lateritic and saprolitic soils do not change these properties upon handling, however, all of these soils are classified as lateritic and saprolitic soils.

If, in a broad sense, lateritic and saprolitic soils are considered residual soils, then their in-situ properties are adequately established for most engineering purposes. However, this situation is due to the fact that the soils were classified using a general classification regarding the place of formation and was done without considering the peculiarity of lateritic and saprolitic soils.

Lateritic and saprolitic soils are more complex in genesis which gives origin to widely different chemical and mineralogical properties, which in turn can affect significantly (or not) their geotechnical properties.

Currently, the traditional concepts of soil mechanics are based mostly on results from investigations of sedimentary deposits of unweathered soils which have common basic properties. Therefore extrapolation should not be done to all lateritic and saprolitic soils.

In the opinion of the author, a proper understanding of lateritic and saprolitic soils involves their mode of formation (with the resulting basic and peculiar properties being taken into consideration for a classification) which adequately reflects these type of soils in the same way as happens with unweathered soils. With this in hand, the design assessment of lateritic and saprolitic soils will not only depend on traditional concepts and judgement but also on their intrinsic and peculiar characteristics.

As mentioned before, the amount of published papers regarding the performance of lateritic and saprolitic soils (in relation to design assessment) is relatively small, and as results conclusions when made, have to account for this limitation or at least extrapolation when done must refer to the conditions of the soil deposits and design criteria used.

Case histories on the subject are extremely important, but unfortunately not much has been published. Although at the 2nd International Conference on Geomechanics in Tropical Soils (Singapore, December 88), papers relating case histories were presented, and while being very interesting and well documented, the papers were of limited amount and to some extent concentrated on a particular type of residual soils, which included lateritic and saprolitic soils.

A point has been reached where there is a need for a comprehensive report or a state-of-the-art on the design assessment of lateritic and saprolitic soils. In such a report or state-of-the-art, the experience of researchers and the amount of available experimental data should be considered and conclusive answers must be reached.

Engineering properties of residual soils

Propriétés relatives à l'ingéniérie des sols résiduels

A.SRIDHARAN, Civil Engineering Department, Indian Institute of Science, Bangalore, India

Engineering Properties

Residual soils are derived in-situ by chemical weathering and alteration of the underlying rock. The combined influence of differing parent rock and differing weather conditions give rise to widely different minerology and granulometry with widely varying proportions of fully altered material.

Shear strength, compressibility and permeability form important components of engineering properties. The shear strength is strongly influenced by the effective stress.

Effective Stress

While the conventional effective stress for saturated soil system is easy to estimate, it is difficult for partly saturated, anisotropic bonded system like tropical soils. Obviously the effective stress equation should also take into consideration the bonds that are present. One may write the equation as

$$\sigma' = \sigma - \bar{U} + A \qquad ..... (1)$$

where $\bar{U}$ is the effective pore water pressure which can be written as

$$\bar{U} = a_w u_w + a_a u_a$$

a_w - fraction of the area thro' which the pore water pressure acts.
a_a - fraction of the area thro' which pore air pressure acts.
u_w, u_a - pore water and pore air pressure respectively.

Since in a partly saturated system, the pore water pressure will be in tension, this will further increase the effective stress. Measurement of pore size distribution using porosimeter and using the same for estimation of negative pore water pressures, assuming that finer pores are first filled, could be attempted. One has to devise a proper method of estimation of "A" by appropriate testing procedures.

Shear Strength

Unlike in a saturated normally consolidated soil, tropical soils will show significant "cohesion" in the shear strength plot. While this can be attributed to the partly saturated condition and "bond strength", in many instances, the cohesion due to negative pore water pressure will be relatively less because most of the externally applied load could be taken by the "soil skeleton" because of bond strength.

Effect of wetting and drying under tropical conditions assumes great importance. It is possible that repeated wetting and drying can either increase or decrease the strength of soils. More concentrated investigations are required. Bonds are formed/broken; aggregation and formation of weaker planes is possible during wetting and drying.

Degree of saturation plays an important role in affecting the shear strength. Appropriate test procedure for saturating the sample before testing the sample is necessary. Sample size may play a dominant role.

Compressibility

The prediction of settlements of structures in residual tropical soils is usually made using the conventional procedures. Since most of the tropical soils are partly saturated, the deformations that may occur due to saturation could be critical in some cases. Prediction of deformation/settlement (or collapse) due to saturation and the consolidation of bonded material like tropical soils require development of new procedures. Collapse behaviour of decomposed gneiss and other saprolitic soils has been reported. Sample size in testing plays a significant role.

Permeability

Because of the hetrogeneity in their macrofabric, the permeability data on residual soils are not consistent. Field measurements are necessary for these soils and laboratory results may mislead. The presence of macropores and channels associated with laterisation process are of importance in controlling the flow thro' these materials.

Two points related to gneissic saprolitic soils
Deux points concernant les sols gneissiques saprolitiques

SANDRO S. SANDRONI, Geoprojetos Eng. Ltd, Rio de Janeiro, Brazil

1 INTRODUCTION

The Discusser would like to raise two points related to saprolitic soils from gneissic rocks:

1. In a particular felspar-poor saprolitic soil there seems to have occurred a significant volume reduction associated with weathering from fresh rock to saprolitic soil.
2. In felspar rich saprolitic soils fracturing of weathered felspar grains seems to occur at low stress levels.

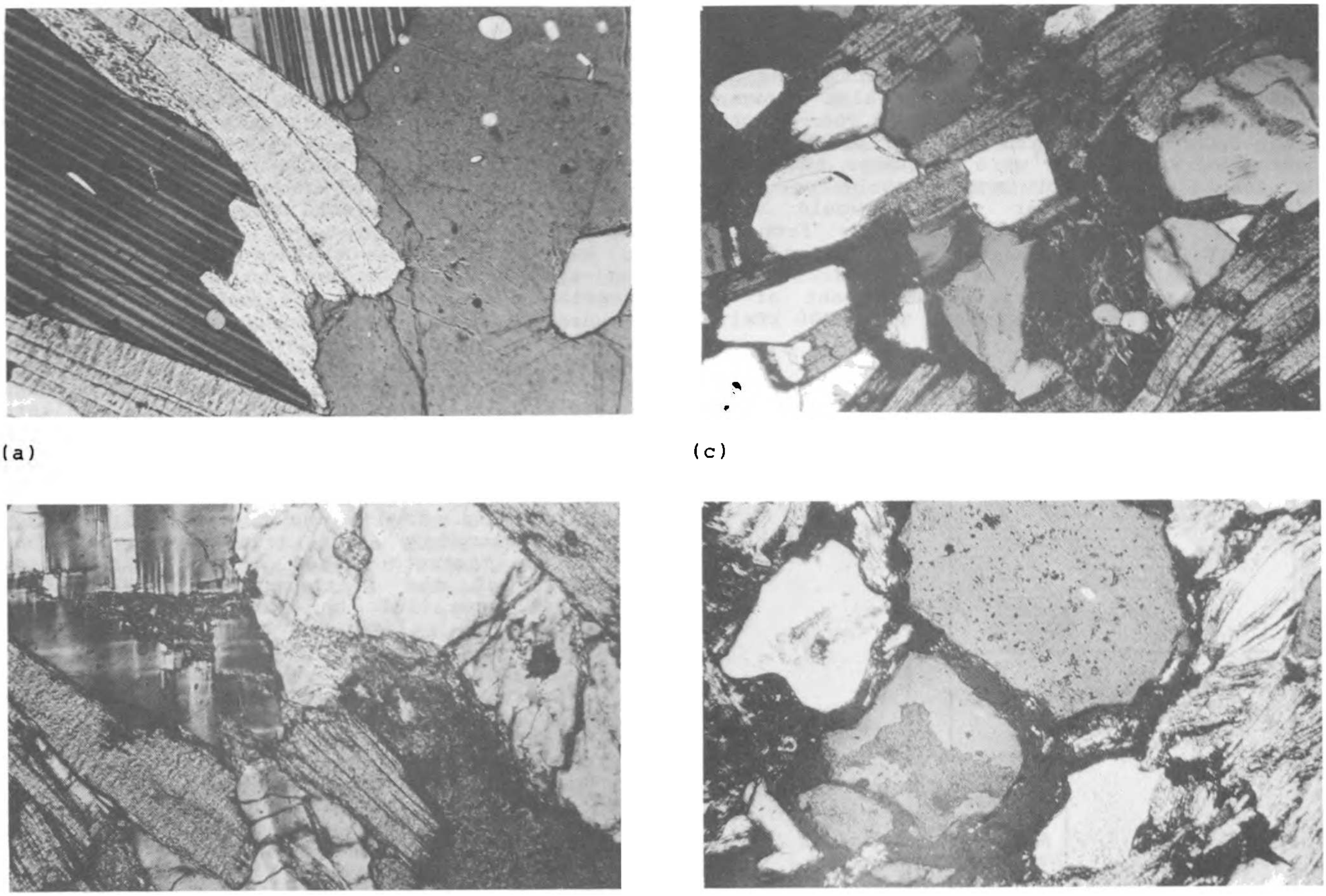
2 VOLUME REDUCTION UPON WEATHERING

The first point will be illustrated with the aid of the optical microphotos shown in Figure 1. These are typical of a number of optical microscope studies carried for a landslide site in the "Serra do Mar" mountain range. The four photos shown in Figure 1 correspond to the weathering stages of the gneissic rock from the site given in Table 1.

Table 1.

Photo	Description	Water Absorption %
(a)	Slightly Weathered	1.4
(b)	Weathered Rock	4.0
(c)	Strongly Weathered Rock	10.0
(d)	Saprolitic Soil	Crumbles

The decrease in distance between the quartz grains, the increase in distortion of the mica booklets and the increasing absence of felspar crystals as weathering progresses can be readily observed in the microphotos. Several indications that the structure of the saprolitic soil is of a collapsed nature have been observed during the microscopic study such as sheared and distorted mica booklets. A study of the



(a)

(c)

(b)

(d)

Figure 1. Optical microphotos of different stages of weathering.

average distance of the quartz grains also indicated a global diminution of volume between fresh and the totally weathered conditions. The volume reduction has been grossly estimated at about 10% to 20%.

It is a well known fact that felspars expand upon weathering and therefore, it must be accepted that in the initial stages of the weathering process there is a local increase in volume which may even help breaking the structure of the rock. This can be seen in Figure 1 (a) and (b). As the weathering process continues to evolve the expanded felspar may begin to loose substance both by dissolution (something which also happens with quartz and mica) and by direct transportation. A number of electron microphotos of weathered felspar grains showed that from a physical point of view the weathering of felspar is a micro-exfoliation process in which minute flakes and particles as small as a few tenths of a micron break out from the grains.

The Discusser does not think that volume reduction is a general process valid for all gneissic saprolitic soils. He had the opportunity to observe other saprolitic soils in which he could not find evidence of this process. It seems that there are certain proportions of felspar, mica and quartz in the present rock which favour the phenomenon. In the particular case under study the average percentage of the main minerals in the fresh rock are: quartz 30 to 40%, biotite 20 to 30% and felspar 25 to 35%. It is to be expected that local circumstances such as type of felspar mineral, tectonic history of the site, rock fracture system, hydrogeological setting of the site, etc play a role.

3 FELSPAR GRAIN FRACTURING

Felspars in the fresh state are quite hard minerals. They are not, however, very resistant to weathering. From the three main minerals that constitute gneissic rocks felspars are the more sentitive. Upon weathering felspars get progressively softer. The Discusser had the opportunity of carrying out fracture tests in weathered felspar grains from a saprolitic soil site in the south east coast of Brazil. A miniature testing apparatus, developed by Dr A. Skinner at Imperial College, connected to an automatic recorder has been used to test grains selected from the soil with diameters between 0.5 and 2.5 mm. The average test results are shown in Figure 2 together with bands obtained by Billam (1971) for other minerals and rocks. A series of tests has been carried out in quartz to confirm the consistency of the tests and, as also shown in Figure 2, gave good results. The fracture tests have been carried out in the "stronger" felspar grains which were the ones that could be singled. If all grains could be tested the weathered felspar results would surely fall in a wider range spanning from the anthracite to the chalk bands. As shown by Billam (op.cit.) soils with such grain strengths are stress level dependent at low and medium stress levels (say, 50 to 200 kPa).

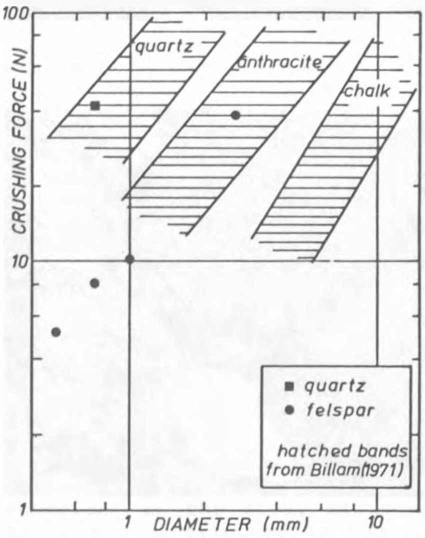


Figure 2. Grain-fracturing tests.

Implications of the occurrence of progressive grain fracturing at varying low to medium stress levels are quite broad. One could justify several commonly observed behavioural patterns such as the persistent cohesion intercept at high stress levels, the change in stress-strain behaviour from brittle to plastic and the existence of yield surfaces.

Again here, as for the first point, the Discusser does not think this as a general fact valid for all gneissic saprolitic soils. It seems that a high percentage of felspar in the mother rock and a smaller freedom of transport by internal drainage favour the occurrence of saprolitic soils which retain weathered, fracture-prone felspar grains.

Discontinuities and anisotropy in residual soil mass behaviour

Discontinuités et anisotropie dans le comportement de la masse des sols résiduels

L. DOBEREINER, Enge-Rio S.A., Rio de Janeiro, Brazil

Most references related to geotechnics of weathered rock and/or saprolitic and residual soils, do not include an adequate geological description of the materials concerned, which makes difficult the precise interpretation of their engineering behaviour. In order to understand the engineering behaviour of those materials one has to relate to their structure and mineralogy. In several cases, the characteristics of residual soils are broadly generalized and not evaluated in terms of the geotechnical aspects which are related to the parent rock.

As an example, outlined by Prof. Blight in the invited lecture to this discussion session, the strength of saprolites may be governed almost entirely by their inherited fabric or structural features. A comparison of various small scale strength measurements with strength-in-mass calculated from back analysis of a waste rock dump foundation failure on a weathered shale is shown (Blight, 1989). It can be observed that the strength values obtained on in-situ measurements with the field vane apparatus and unconsolidated undrained triaxial and direct shear tests, performed in the laboratory, are invariably higher than the shear strength values obtained on the back analysis of the weathered shale foundation failures, parallel to parent rock bedding planes.

This interesting example clearly shows that in some cases the mass strength is governed by the strength along discontinuities. Deere (1975) also outlines the relevance of bedding plane or foliation shear zones in the sedimentary and metamorphic rocks.

However, there are also examples in which the importance of discontinuities on the behaviour of a residual soil mass is overestimated, as in cases where the discontinuity or anisotropy pattern is less persistent, randomly or in favorably oriented directions.

There are several cases in residual soils originated from gneiss, granite, etc, in which the strength measurements obtained in laboratory or small scale field tests, underestimate the real mass strength; such an example is now presented:

On the open pit graphite mine in the Pedra Azul area in the Minas Gerais state, Brazil, the graphite occurs disseminated in Precambrian gneiss, which is weathered to a saprolitic soil and above water level for a depth of around 100 m. In order to obtain a safe design for the pit slopes (Cella et al, 1989), triaxial and direct shear tests were performed on undeformed samples in the laboratory and the strength envelopes obtained for saturated and natural moisture content states.

To evaluate the meaning of those results, careful geotechnical mapping and back analysis on the pre-existing stable slopes were performed. Considering that the foliation of the gneiss saprolite was folded and the existing faults had a favorable orientation in relation to the slope face, and also the back analysis performed, shear strength parameters of c=60 kPa and ϕ=34° where choosen for final design, and a chart for slope height versus inclination was produced. For this chart it was assumed planar failure with the most critical orientation of the foliation at 50°, inwards to the excavation.

However, due to extreme production needs, steeper slopes than those recommended had to be used in one of the pits, with heights reaching almost 80 m with slope inclinations of more than 62°. Even then, no stability problems were encountered, indicating that the saprolitic mass had a higher strength than the one predicted in the direct shear tests. In this case it was considered that the folded foliation has improved strength and therefore stability conditions.

This example shows the importance of the characterization and description of discontinuities and/or anisotropy, in terms of orientation, persistence, etc, in order to better assess their relevance to the engineering behaviour of the mass.

Sandroni & Macarini (1981), Cheung et al (1988), Costa Filho et al (1989) have also performed direct shear and/or triaxial tests in gneissic or granite saprolitic soil in different directions, as parallel and perpendicular to anisotropy, with results showing essentially no influence of structural anisotropy on the geomechanical characteristics of these soils. It seems that in more weathered materials, the anisotropy could be more relevant in soils originated from low grade metamorphic or sedimentary rocks as for example reported by Campos (1974), Durci & Vargas (1983) or Sandroni (1985).

There is an urgent need for further research, to better understand the behaviour of discontinuities and anisotropy in residual soil masses. More testing in different types of residual soils, as well as the tests on discontinuities with different characteristics are needed before the behaviour of a residual soil mass could be accurately predicted.

REFERENCES

Blight, G.E. (1989) Design assessment of saprolites and Laterites-Invited Lecture-Discussion Session 6. XII International Congress of Soil Mechanics and Foundation Engineering. V5, Rio de Janeiro.

Campos, T.M.P. (1974) Shear strength of micaceous residual soils. MSc Thesis-PUC-RJ (in portuguese)

Cello, P.R.C., Dobereiner, L., Nunes,N. (1989) The study of the slope stability of Pedra Azul mines, Nacional de Grafite LTDA. II EPUSP Symposium of Rock Mechanics applied to mining. Soo Paulo. (in portuguese)

Cheung, C.K., Greenway, D.R. & Massey, J.B. (1988) Direct shear testing of a completely decomposed granite. 2nd International Conference on Geomechanics in Tropical Soils. V1, Singapore

Costa Filho, L.M., Dobereiner, L., Campos, T.M.D., Vargas, E. (1989) Fabric and Engineering Properties of Saprolites and Laterites-Invited Lecture-Discussion session 6. XII International Congress of Soil Mechanics and Foundation Engineering, V5, Rio de Janeiro

Deere, D.V. (1975) Applied Rock Mechanics of Weak Materials-Technical Report. 5th Panamerican Congress of Soil Mechanicsand Foundation Engineering, p479-502, Buenos Aires

Durci, C.L. & Vargas, M. (1983) Strength and compressibility of residual soils derived from Phylites-Internal Research Report, Soil Mechanics Laboratory, University of Soo Paulo

Sandroni, S., (1985) Sampling and testing of residual soils in Brazil, Sampling and Testing of Residual Soils-ISSMFE Scorpion Press, Hong Kong

Sandroni, S. & Macarini, M. (1981) Triaxial and direct shear tests in an occurrence of young gneissic residual soil rich in feldspar. Brazilian Seminar on Tropical Soils in Engineering. V1, COPPE-UFRJ (in portuguese)