A NOTE ON SOME OBSERVATIONS ON A MIGMATITIC RESIDUAL SOIL FROM RIO DE JANEIRO

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ABSTRACT

The Note presents results of an investigation on two principal types of a residual soil (saprolite) derived from migmatite, encountered on a 30m high cut in Rio de Janeiro. The main difference in mineralogy between the two soil types lies in the proportion of biotite and alkaline feldspar. A large number of drained shear tests were carried out to compare the shear strength of compacted and undisturbed samples in both partially saturated (unsoaked tests) and saturated conditions. Unlike the type A soil consisting essentially of quartz and feldspar, the type B micaceous soil shows a distinct difference in shear strength in the compacted and undisturbed states. A number of characterization tests performed to evaluate the variation of physical properties along the weathering profile show a decrease in particle size and specific unit weight of soil grains with weathering.

Key words: direct shear test, residual soil, shear strength, weathering

IGC: B1/D1/D6

INTRODUCTION

In spite of the extensive and impressive use made of residual soils in Civil Engineering works throughout the tropical and sub-tropical regions of the world, there is as yet relatively little information regarding their geotechnical properties in natural and compacted states. These soils can be extremely variable in nature, depending on the type of parent rock, rock minerals, and climatic factors, and, indeed, often display different characteristics even in the same location. More specifically in the Brazilian context where experience from numerous projects involving the use of residual soils derived from gneiss is available, it is noted that the shear strength parameters do not, in general, vary considerably despite large variations in factors such as mineralogy, soil structure (undisturbed field samples or compacted in the laboratory) and the degree of compaction. It was therefore considered to be of interest to analyse residual soil profiles and study the variation of shear strength parameters with soil structure by testing undisturbed field samples and laboratory compacted samples of the different soil types encountered on the weathering profile.

The investigations described in this Note were carried out on two principal types of residual soils encountered on a 30m high, near vertical, cut in Estrada de Furnas, in Rio de Janeiro. Over 80 drained direct shear were carried out to compare the shear strength of undisturbed and laboratory compacted samples in both saturated and partially saturated (unsoaked) conditions. Further a number of characterization tests were performed to

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evaluate the variation of physical properties along the weathering profile.

THE SITE AND ITS ENGINEERING GEOLOGY

Photo. 1 shows a general view of the section of cut studied, while Fig. 1 shows a schematic representation of the same section.

Photo. 1. General view of soil profile

Fig. 1. Schematic representation of the section of the cut studied

The cut shows three well-defined horizons A, B, and C, with the horizon A consisting of structureless top soil with organic matter, while horizon B contains essentially colluvial deposits. The C horizon, which is of interest in this study, comprises residual soil resulting from weathering and decomposition of migmatite, the parent rock. The C horizon, often called saprolite or young residual soil (Vargas, 1953, Deere and Patton, 1972), maintains the original structure of the parent rock and shows the presence of two distinct types of residual soils easily distinguished visually by their tonality; type A, being dark while type B being light in colour.

It would be noted that the sequence of horizons departs from the typical residual soil profile where a horizon of "mature" residual soil, resulting from the decomposition of parent rock but not preserving the original structure, is normally encountered above the C hori-

zon. In the present case this horizon of mature residual soil is inexistent and substituted by deposits of colluvial soil.

Visual and X-ray diffraction analysis (Table 1) show the soil type *A* to consist essentially of quartz, partially decomposed feldspar and biotite with presence of some kaolinite as a result of decomposition of feldspar, while the darker type *B* soil consists of biotite, quartz and decomposed feldspar and presents schistosity. Hence the basic difference between the two soils lies in the presence of a large proportion of biotite and completely decomposed feldspar in soil type *B*.

Table. 1 Mineral and chemical analysis

Analysis	Soil Type			Analysis	Soil Type	
<i>Mineral Analysis :</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>Chemical Analysis :</i>	<i>A</i>	<i>B</i>
Quartz %	50	53	70	C _a mE/100g	0.4	0.4
Alkaline Feldspar %	41	14	10	M _g mE/100g	1.7	1.7
Biotite %	9	33	16	Al mE/100g	0.5	0.4
Magnetite %	—	—	3	SiO ₂ %	13.5	18.6
Ferruginous-clay %				Al ₂ O ₃ %	10.8	13.8
Concretions %	—	—	0.5	Fe ₂ O ₃ %	1.7	4.9
Muscovite	—	trace	trace	TiO ₂ %	0.2	0.7

The height of the residual soil exposed in the cut is about 26 metres. It is easily noticeable in this layer (horizon *C*) that feldspar and mica show uneven degrees of weathering in the various locations, probably as a result of variation of the degree of saturation along the cut. In regions of higher moisture content, feldspar can decompose easily by hydration while at low water contents mica tends to oxidise before total hydration of feldspar can occur. In the case of residual soil derived from decomposition of acidic igneous rocks, Lumb (1965) observed that under high moisture contents feldspar decomposed before biotite, while quartz remained unaltered. It was also observed that in soil type *B* feldspar was completely decomposed in the light coloured soil *A*. This may be explained by the presence of alkaline feldspar in soil *A*, and that of some alkaline feldspar with predominance of calcic-alkaline-sodic feldspar in soil type *B*; the latter being less resistant to weathering. However it must be mentioned that the chemical analysis carried out on the two types of residual soils, Table 1, does not show any apparent large differences in decomposition.

The section under study showed a vertical fault clearly visible in Photo. 1 and Fig. 1 together with the presence of various sills consisting of completely oxidised biotite, feldspar and quartz.

SAMPLING AND TEST PROCEDURE

Fig. 1 shows the location of all samples that were obtained for characterization of residual soils along the cut. In view of the convenience of obtaining large quantities of undisturbed samples for direct shear tests, the typical samples of type *A* and *B* soils were obtained from locations marked 1 and 2 in Fig. 1 at the base of the cut. The classification tests were carried out primarily to evaluate the variation in physical characteristics with the location of the sample with respect to the zones most readily susceptible to weathering, i.e., the top of the cut and the vertical fault easily visible in Photo. 1.

In literature some difficulty has been reported on conducting standard classification tests on micaceous residual soils. Ruddock (1967), for example experienced difficulty in liquid

limit test because the residual soil slid instead of flowing in the Casagrande apparatus. A similar observation was also made with the residual soils under consideration when the test was conducted starting from water content below the liquid limit. However no sliding was observed when the procedure was modified so that the test was commenced with soil at water content above the liquid limit and the moisture content was lowered successively.

The direct shear tests were carried out on compacted and undisturbed samples at both initial water content (unsoaked samples) and saturated conditions. The compacted samples were first prepared in the Proctor mould with Proctor normal energy and then trimmed to fit the shear box (dimensions : 3.75 cm dia and 5 cm high). It was noted that the removal of the compacted sample from the Proctor mould caused a maximum decrease of dry density of about 7% and 4% for soils A and B respectively. A similar observation on compacted clays has also been made by Casagrande and Hirschfield (1960).

Normal stresses of 0.25, 1.5, 2.0 and 5.0 kg/cm² were used in each series of tests to evaluate the Mohr Coulomb strength envelope. The shearing rate for a drained test at consolidation pressure of 5 kg/cm² was found to be 3×10^{-2} cm/sec., a speed too fast for manual recording of test data. Hence a shearing rate of 2.5×10^{-4} cm/sec. was selected for convenience. Lambe (1951) found that for non-cohesive samples, shearing rates of 2.5×10^{-4} cm/sec. and 42.3 cm/sec. caused a variation of only 2% in the angle of friction, ϕ' .

Shearing was commenced only at the end of the consolidation phase which took about 30 minutes for the unsoaked samples and 9-11 hours for the saturated samples at the maximum consolidation pressure of 5 kg/cm².

Three series of tests were run to approximately evaluate residual shear strength by using the polished cut plane technique. At the end of the first travel of the shear box, a thin wire saw was run across the shear surface and the two halves were polished on plate glass. The sample was then re-assembled, re-consolidated and sheared.

At the end of all tests, samples were taken from the shear zone and away from it for water content and grain size analysis. An area correction was applied to all measurements of direct shear tests.

TEST RESULTS AND COMMENTS

Fig. 2 shows grain size curves for soil A (sample no. 2), and soil B (sample no. 1) used for direct shear tests and also for the colluvial soil (sample no. 11). Both soils, A

Fig. 2. Grain size analysis

and *B*, may be classified as slightly silty sand with the micaceous soil *B* being somewhat finer. It is evident from Fig. 2 and Table 2 that the colluvial soil at the mantle of the cut does not depict any similarity to the residual soils derived from migmatite. The residual soils on this cut do not show a plastic limit. Fig. 3 shows standard Proctor compaction characteristics of the residual soils.

Grain size analysis carried out on samples of the two soil types collected along the height of the cut show a small but distinct increase in fineness as the sample is situated closer to the top of the cut, or to the central fault.

Fig. 3. Standard Proctor compaction curves

Table 2. Some physical characteristics of soil types

Soil Type	Sample	LL %	PL %	% Clay 2	G_s
A	2	28	NP	4	2.62
B	1	32	NP	6	2.72
Colluvial	11	59	42	40	—

Table 3. Liquid limits

Soil Type A		Soil Type B	
Sample no.	LL %	Sample no.	LL %
2	28.5	1	32.0
4	29.0	3	29.5
6	28.5	5	32.0
8	27.0	7	31.5
10	27.5	9	43.0
15	26.0	12	33.5
16	26.0	14	28.5

Refer to Fig. 1 for sample location.

Table 4. Specific gravity of soil grains, G_s

Soil Type A		Soil Type B	
Sample no.	G_s	Sample no.	G_s
10	2.57	9	2.64
8	2.61	7	2.66
15-6-16	2.61-2.62-2.59	12-5-14	2.69-2.69-2.65
4	2.62	3	2.70
2	2.62	1	2.72

Refer to Fig. 1 for sample location

Table 3 shows that the liquid limit for these residual soils do not vary systematically according to the location of the sample*. Similar observations on a study of Keuper Marl in laboratory have been reported by Dumbleton and West (1967), when extreme exposure to wetting and drying and freezing and thawing did not produce any significant change in the liquid and plastic limits. Determinations of specific gravity of grains (passing U.S. Sieve 40), Table 4, show that G_s decreases with weathering. The action of weathering resulting in mineral fracture and transformations, for example that of feldspar to kaolin, is probably responsible for this decrease in G_s for both types of residual soils.

Figs. 4 and 5 show typical stress displacement curves for the two soil types, while strength envelopes from all tests are presented in Fig. 8 and 9.

Tests on compacted soils at their moulding water content show that the type A suffers a significant drop in drained apparent cohesion and an increase in ϕ' with increase in moulding water content while the soil type B remains virtually unaffected. The decrease of apparent cohesion with moulding water content for soil A is shown in Fig. 6 and is mainly due to the reduction of capillary tension with increasing degree of saturation.

Other secondary factors such as the effect of water in weakening cohesive bonds and the

Fig. 4. Typical stress-displacement curves for type A residual soil

* The discrepantly high value of $LL=43\%$ for sample no. 9 may be explained by the presence of montmorillonite detected in the X-ray diffraction analysis. It was the only sample which showed the occurrence of this clay mineral.

Fig. 5. Typical stress-displacement curves for type B residual soil

dispersed structure of the soil particles near the optimum water content (Lambe, 1960) may also be prevalent. The effective cohesion of compacted and saturated type A soil samples increases with increase in moulding water contents up to the optimum, probably as a result of lower void ratios. Values of cohesion for the micaceous type B soil remain in the range of 0.35–0.40 kg/cm² and 0.23–0.35 kg/cm² for the unsoaked and saturated samples respectively with water content ranging from –9% to 4% of the optimum.

The angle of friction ϕ' for compacted samples increases with moulding water content for both saturated and unsoaked type A samples, while it does not show any significant increase for the type B samples. This may be explained by the observations made by Horn and Deere (1962) that in granular materials with three dimensional crystalline structure (e.g. quartz and feldspar), water destroys the lubricating film around the crystals and increases the angle of friction by acting as an anti-lubricant. However in the case of layer lattice minerals such as biotite, water weakens the bonds in cleavage planes by hydrating the ions thus reducing the angle of friction. The above hypothesis would appear to be plausible for type A material which consists essentially of quartz and unweathered feldspar, while the effect may be masked for the type B soil containing both biotite and quartz in large proportions.

It is of interest to note that the minimum displacement required to achieve failure for type B soil was without exception found to occur at the optimum water content (Fig. 7). The results for type A samples, however showed a scatter, although a tendency for the above behaviour could be noted. Result also show that for each series of tests, the deformations required to achieve failure increased with the magnitude of normal stress applied, in a behaviour similar to that observed by Krsmanovic (1967) for direct shear tests on rocks. An explanation for this observation may lie in particle breakdown on shearing reported later, when an increased normal stress would result in more particle breakdown

Fig. 6. Variation of apparent cohesion with compaction water content

Fig. 7. Variation of displacement to failure with compaction water content

and hence more particle contacts, which would successively require larger deformations to achieve complete failure.

All tests on compacted and undisturbed samples show a larger decrease in volume with increasing normal stress (see, for example, Figs. 4 and 5). This decrease in volume at normal stresses of 2–4 kg/cm² is probably due to particle (or particle aggregate) breakdown. Although these values of normal stress are relatively low, they are, nevertheless, capable of suppression of dilatancy in soils containing feldspar and mica because of planes of weakness in these minerals (Barden and Proctor, 1971). This behaviour is similar to that of a dense sand sheared under very high stress when its stress-deformation curve is similar to that of a loose sand with decrease in volume due to particle breakdown (Bishop, 1971). The results at low normal stress level of 0.25 kg/cm² for these residual soils however show a curious aspect of an increase in volume without the stress-deformation curve showing a marked peak usually associated with the dilatant behaviour of a particulate material. The undisturbed shear strength parameters were found to be $C'_{app} = 0.30$ kg/cm², $\phi' = 43.2^\circ$ and $C' = 0.20$ kg/cm², $\phi' = 44^\circ$ for the soil A unsoaked and saturated samples respectively, while the corresponding values for soil type B are given by $C'_{app} = 0.40$ kg/cm², $\phi' = 29.5^\circ$ and $C' = 0.18$ kg/cm², $\phi' = 29.5^\circ$. The respective position of the undisturbed shear strength envelopes with respect to the compacted samples is shown in Figs. 8 and 9. It may be noted that despite large differences in void ratios the strength envelopes for undisturbed soil type A lie within the range of values for the compacted samples (the apparent cohesion for the undisturbed samples being lower than for compacted samples), and shows that at least for this soil type the shear strength is not significantly dependant on soil structure, but probably on the grain size and the type of grain minerals. A similar observation has been made by Lumb (1962) on residual soils derived from decomposition of granite. It may also be argued that in case of soils with predominantly three-dimensional crystalline mineral grains the difference in structure and particle arrangement produced by compaction is probably not widely different from in-situ conditions, in contrast with soils containing layer lattice minerals where a significantly different soil structure may be expected. The maximum shear stress for the undisturbed micaceous soil type B is about 15% smaller than for compacted samples (Fig. 9), probably due to a more intensely laminated macro-structure, observed in the natural samples than was produced in compacted samples, and also because of a significantly higher field void-ratio. The results also show that the saturation of a

Fig. 8. Strength envelopes for type A residual soil

Fig. 9. Strength envelopes for type B residual soil

normally unsaturated natural slope, for example by a heavy rainstorm, shall cause a larger drop in cohesion for the micaceous type B soil than for the type A material. In general the difference in shear strength for two types of residual soil from all shear tests is found to be about 30%.

The comparison of 79 results of grain size analysis of material collected from the slip surface (aprox. 15g) and away from shear zone showed that in 85% of cases particle breakdown occurred, in the coarse and medium sand fraction, ranging from 1 to 10% with a mean value of 4.5%. Noticeably higher breakdown was observed with the type A soil. A similar study had earlier been carried out to determine particle breakdown during consolidation phase when no such strong tendency could be detected.

The results of cut plane tests to determine the residual strength of undisturbed samples showed that the drop in ϕ' from peak to residual is smaller for type A soil (from 37.5° to 32°) than for the micaceous type B soil (from 35° to 26°) while the cohesion drops virtually to zero, (Table 5). The slope of the volumetric strain curves for these tests show that the complete residual state had not been achieved; however in view of the granular nature of the two soils the difference is likely to be negligible.

Table 5. Residual shear tests-innundated

Soil Type	γ_t g/cm ³	w_t %	e_t	S_t %	Peak Parameters		Residual Parameters	
					C' kg/cm ²	ϕ'	C'	ϕ'_r
A Compacted	1.92	9.5	0.52	50	0.35	37.5	0	32.0
B Compacted	1.91	16.1	0.65	67	0.35	35.0	0	26.0

CONCLUSIONS

This brief study has revealed some important differences in the shear strength behaviour of the two residual soil types from the same location. Unlike the type A soil consisting essentially of quartz and feldspar, the type B micaceous soils shows a distinct difference in shear strength in the compacted and undisturbed states. However, the variation in shear strength with moulding water content for the compacted samples is smaller for the micaceous type B soil. The minimum displacement required for failure for both types of compacted soils was found to occur at the optimum water content. Some evidence of particle breakdown was also found.

Physical characteristics tests showed a decrease in particle size and specific unit weight of soil grains with weathering.

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NOTATION

e_t =initial void ratio
 w_t =initial water content
 C'_{app} =apparent drained cohesion
 C' =drained cohesion
 G_s =specific gravity of soil grains
 LL =liquid limit
 PL =plastic limit
 NP =non-plastic
 S_t =initial degree of saturation
 ϕ' , ϕ'_r =drained peak and residual angle of friction respectively

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