Geogr. Fis. Dinam. Quat.
23 (2000), 33-41, 15 figg., 2 tabb.

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SHEAR STRENGHT OF THE MATERIALS APPLIED TO THE SLOPE STABILITY ANALYSIS IN A HUMID TROPICAL ENVIRONMENT (SÃO PAULO, BRASIL)

ABSTRACT: CRUZ O. & COLANGELO A.C., *Shear strenght of the materials applied to the slope stability analysis in a humid tropical environment (São Paulo, Brasil).* (IT ISSN 0391-9838, 2000).

In the humid tropics, where converge intense rainy events with high temperatures, the dinamics of geomorphic systems is very intense. The superficial and subsuperficial waterflows are very active and landslides are a frequent and intense kind of processes, either in the scarps of «Serra de Caraguatatuba» and in the subsequent Paraibuna plateau. In the morphoclimatic point of view, the area of study is in the core of the «domínio dos mares de morros» of the brazilien southeast, with long, convex steep slope and deep weathering materials have been submeted to a intense throughflow in the rainy season and a surcharge represented by the forest canopy with a very superficial root system. The subject of this paper is to evaluate the thresholds of declivity for the hillslopes stability, combining a usual «limit equilibrium method» with the «infinite slope analysis». For to reach this purpose was necessary to make measures of shearing stresses: in this case with the «Cohron Sheargraph» apparatus. Another important strategy applied here was to compare the results of the shearing assays in these two contiguous, but distinct relief systems: scarps and plateau systems.

KEY WORDS: Coastal geomorphology, Slope stability, Infinite slope analysis, Tropical environment, S.P. (Brasil).

SUMÁRIO: CRUZ O. & COLANGELO A.C., *Resistência ao cisalhamento dos materiais aplicada à análise de estabilidade de encostas num ambiente tropical úmido (São Paulo, Brasil).* (IT ISSN 0391-9838, 2000).

Nos trópicos úmidos, onde convergem intensos eventos pluviométricos e elevadas temperaturas, a dinâmica dos sistemas geomórficos é muito intensa. Os fluxos hídricos superficiais e subsuperficiais são muito ativos, de modo que os movimentos coletivos de solo correspondem a eventos com intensidade e freqüência elevadas, tanto nas escarpas da «Serra do Mar», como no «Planalto de Paraibuna». Do ponto de vista geomórfico a área de estudo encontra-se no «core» do «domínio dos mares de morro do Brasil de sudeste». Neste tipo de sistema de relevo as encostas são íngremes e extensamente convexizadas, cujos profundos regolitos estão sazonalmente submetidos a uma queda de resistência ao císalhamento que freqüentemente leva à ocorrência de processos de movimentos de massa: planares nas escarpas retilinizadas e rotacionais nos morros convexizados. Isto graças ao intenso escoamento subsuperficial presente na estação chuvosa de verão e à mata pluvial tropical, Mata Atlântica, que favorece a infiltração da água no solo e representa também uma sobrecarga a ser sustentada pelos materiais superficiais. O objeto deste artigo é avaliar os limiares de declividade para a estabilidade das vertentes, combinando o «método do limite de equilíbrio» com a «análise de vertente infinita». Para tanto, foram feitas medidas de resistência ao cisalhamento com o aparelho «Cohron Sheargraph». Foram comparados os resultados dos ensaios de resistência ao cisalhamento, da granulometria e dos limites de «Attreberg» realizados nos regolitos e solos do «Planalto de Paraibuna» e das escarpas da «Serra do Mar» em Caraguatatuba.

PALAVRAS CHAVE: Estabilidade se encostas, Resistência ao cisalhamento, Análise de limite de equilíbrio, Movimentos de massa, Limiares de declividade, São Paulo (Brasil).

THE «SERRA DO MAR» IN STUDY AREA

The steep slopes of the «Serra do Mar» in Caraguatatuba-SP, present peculiar features, such as strong declivities, rectilinear profiles, great topographical amplitude (until 800 m), rocky substratum in general formed for oftalmic migmatites and intense pluvio-fluvial drainage (fig. 1). The area suffered catastrophic debris avalanche and planar landslides, provoked for rains of great magnitude and intensity, that had reached than 420 mm in March 18 - 1967, preceded for a very humid summer.

It had more than 110 fatal victims, having been the valley of the river Santo Antonio, next to the foot of scarps, totally buried for debris materials with more than 10 meters of thickness.

In the reverse of these scarps, the Paraibuna and Paraitinga plateaus present ridges with rectilinear scarps and convex hills, «morros mamelonados», with rocky substratum formed mainly for granite-gnaisse, migmatits and mica-schists. In this case, the topographical amplitude is lesser (until 400 m), with predominance of the ones in the

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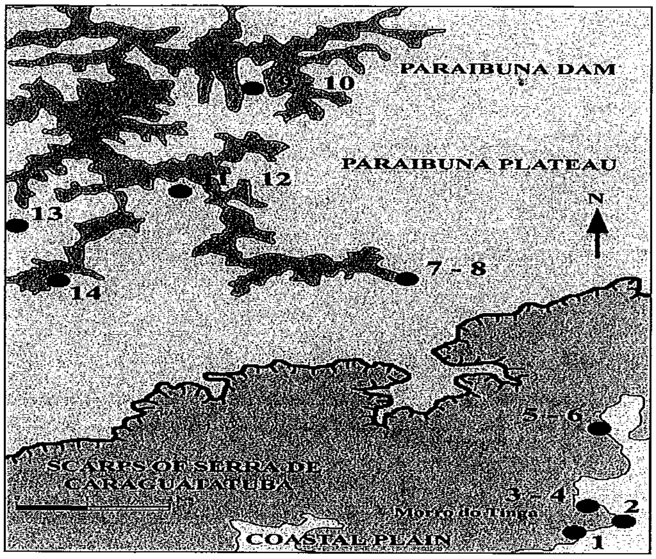

FIG. 1 - Local study area in the «Serra do Mar», São Paulo State. The figures refer to the points of shearing tests and sampling.

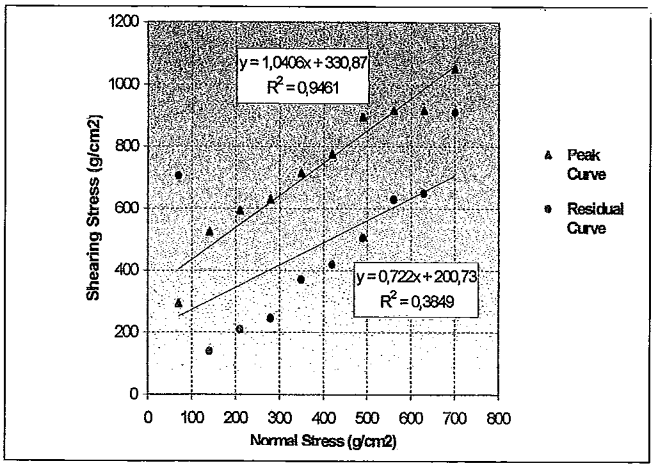

FIG. 2 - Shear strength of colluvium in East face of «Morro do Tinga», point 1.

range 80-200 meters and annual average rain amounts in general reach ciphers between 1200 and 1600 mm. A rainy event with magnitude of about 280 mm in 24 hours, registered in the area of the «Núcleo Santa Virginia do Parque Estadual da Serra do Mar» in «São Luis do Paraitinga», occurred in March of 1996, induce a great number of planar landslides in this plateau. It had register of only 2 fatal victims, becose the low demographic density existing in the area. However, the «Rio do Chapéu», small tributary of the Paraitinga river, for some hours, presented competence for an upper outflow to the one of the Paraitinga and a carrier of matacões with more than 2 meters of diameter, thus producing one hydraulic jump of more than 6 meters.

The top of the «Alto Grande» mounts, in the plateau of the Paraitinga, raised at 1600 meters, has suffered the impact of the core of this enormous pluviometric concentration, whose effect was the great number of landslides (Colangelo, 1997).

THE SHEAR STRESS AND SHEAR STRENGTH

The hillslopes of the mounts and hills in those plateaus, scarps and plains compose forms of the relief, considering its topographical declivities, extension, amplitude and high. In the local scale, the relief forms can be convex, rectilinear and concave, in the two plans of plan and profile, resulting, according to Ruhe (1975), nine basic types of forms. Colangelo (1995) attributes to each one of these types a distinct geoecological status, affirming that this is clear when we confront the convex and concave forms, because they are antagonistic not only with respect to the geometric point of view, but also of the hydrodynamics of surface, the dominant pedogeochimical processes, the superficial formations and soils, the composition of the vegetal covering and also with relation to the microclimatic factors. Gregory (1978) supplied an equation, also adopted, amongst others, for Derbyshire & *alii* (1979), where the form of the relief (F) appears as a dependent variable of the processes (P) and the materials (M) in the time, as the expression: F = (P, M) dt.

The dynamics of the hillslopes is commanded by a budget of tensions that it interacts directly with the geomorfic processes. It has a permanent confrontation between the passive tensions, that support the superficial materials and the active tensions of shear.

All and any process always is unchained from the overcoming of passive tensions for active tensions, when the resistance, tied with the passive tensions, reaches its threshold value. In the case of the superficial materials, by being unconsistent material they are supported by cohesion, proceeding mainly from clays, and for the friction, mainly associate to the sandy fraction. Obviously, a series of factors intervines on these variables, well favoring the tension of shear strenght, well favoring the shear stress. In a geomorphic system, a series of factors, between which the rainfall and the pluvial draining must be salient, periodically promotes the fall of the resistance, which can reach critical values, next or upper to its thresholds, what it can lead to the mobilization of the materials in the hillslopes.

The mass movements, amongst which if they detach the landslides, correspond to a reply of these systems to the convergence of innumerable factors. Without a doubt, in humid tropical environment, we must also emphasize the participation of the subsurface (hipodermic) draining as a factor of increase the dynamic of hillslopes.

As well as the superficial draining (pluvial and fluvial), the subsurface runoff flow is, in great part, controled for the magnitude, intensity and frequency of the pluviometric event. Its quality and, secondly, its amount are controled

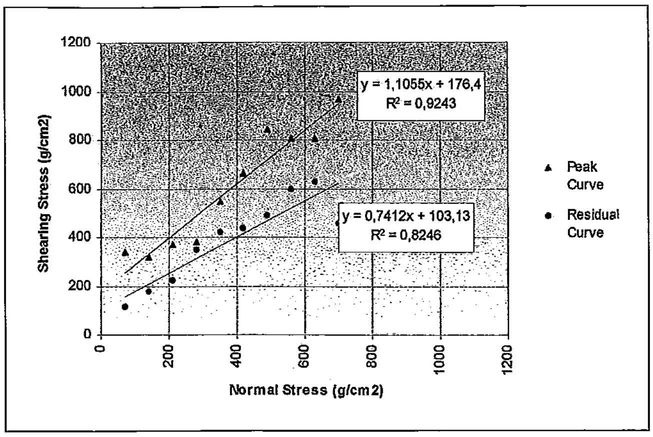

FIG. 3 - Shear strength of weathearing material (C horizon) in East face of «Morro do Tinga», base of Caraguatatuba scarps, sample point n. 2.

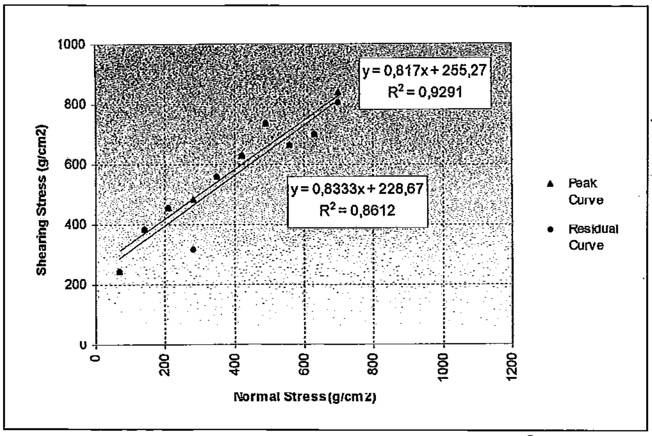

FIG. 4 - Shear strength of coluvium material (B horizon) in North face of «Morro do Tinga», base of Caraguatatuba scarps, sample point n. 3.

for the morphology of the land, litotectonic structure, superficial weathered material and soil (depth, texture, structure and composition), amount and quality of the organic matter, biological activity, root system, vegetation structure and intervention of the human action.

The algorithm of the function that correlates the two components of the shear strenght was considered by Coulomb in 1776 (apud Carson & Kirkby, 1972), express for the equation:

$$S = C + \sigma \cdot \tan \phi$$

being S the shear strenght, C the cohesion, σ the normal tension to the plan of shear and ϕ the angle of soil internal friction. Terzaghi (1950) modified the original equation of Coulomb, which started to also contemplate the intervention of the neutral tension of the water (μ) on the cohesion and the normal tension, being the modified equation express in the following way:

$$S = (C - \mu) + (\sigma - \mu) \cdot \tan \phi$$

The model of Terzaghi indicates minus that the pressures of the water in the pores lead to the reduction of the shear strenght, intervening on the two terms of the equation, consequently reducing the angle of internal friction and the cohesion of the soil materials. Temple & Rapp (1972) had affirmed that intense rains can cause fast movements, which in normal conditions, would lead of 25 the 50 years to occur. De Ploey & Gabriel (1980) mentioned the mudflow, as consequence of fast decrease of the apparent internal friction coefficient (tan('), for strong rain event, that it leads to the total liquefaction of the material. For Carson & Kirkby (1972), the landslides are «... a dramatical expression of the stress tension on the strength of the materials in the hillslopes...». The role played for the normal tension to the plan of shear is to favor the shear strenght, because it mobilizes, or becomes effective, the friction, that is intrinsic property of the materials. The friction manifest itself in terms of a increase of the shear strenght proportional to the increase of the normal tension, in a ratio that is defined by the tangent of the apparent angle of soil internal friction. It's clear, that even so internal friction an intrinsic ptoperty of the material, its manifestation depends on the application of external shear stress.

In the case of the occurrence of landslides in steep rectilinear hillslopes profiles, where the rupture surface is parallel to the land surface, with very lesser depth (1 m - 3 m) that the size of the hillslope (of 100 m as far as 600 m), the infinite slope model is frequently used. Chowdhury (1978), when applying the «limit equilibrium analysis» in the evaluation of the stability of hillslopes, separates the relatively static body of the ground of the dynamic body that constitute the percolating water. The author also assumes in his analysis, four well defined hydrodynamic situations: submerged ground, fully drained soil, partially saturated soil with the water flow parallel to the surface and soil fully saturated with water flow parallel and reaching the surface. Moreover, it fulfills to point out the importance that represents for this analysis the referring additional overload to the vegetal covering, treated in details for Sidle & *alii* (1985). Although these authors consider the increase of cohesion (ΔC) represented by the root system of vegetation cover, they do not take in consideration the aiding of the percolating of the water for increment of soil hydraulic condutivity (k) promoted by microroots, dead roots and organic matter in decomposition (De Ploey & Cruz, 1979). It would be thus the forest covering promoting an increase of the instability of the land, in function of a bigger percolating of the water promoted for the root system.

Concern this aspect, De Ploey (1981) refers to the ambivalent effect of some erosion factors, through a great number of examples, amongst which, the referring one to a specific type of «hidrophobic» organic matter that make difficult the infiltration of water in the ground, thus favoring the overland flow.

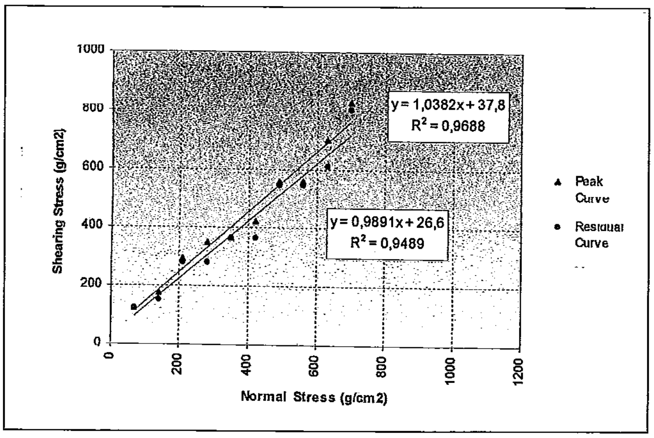

FIG. 5 - Shear strength of weathering material (C horizon) in North face of «Morro do Tinga», base of Caraguatatuba scarps, sample point n. 4.

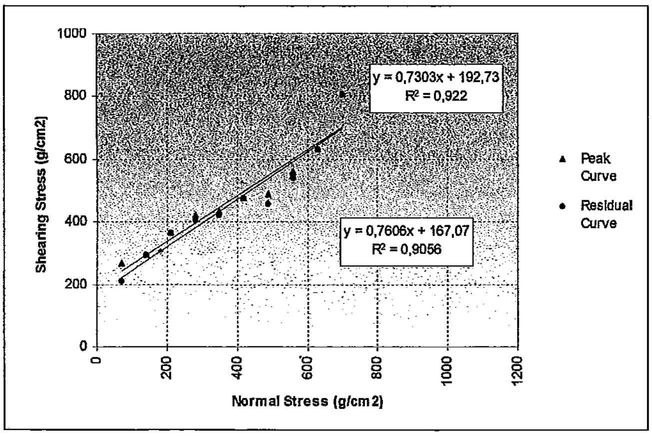

FIG. 6 - Shear strength of 1967-Debris Talus, base of Caraguatatuba scarps, sample point n. 5.

THRESHOLDS OF DECLIVITY

For determine the hillslope stability conditions, the concept of factor of safety utilized here is the same by Chowdhury (1978), which establishes a ratio between the actual shear strength (S) and the mobilized or required shear strength (Sm). The mobilized shear strength is equal to the shear stress (τ). The aim of the limit equilibrium analysis is to establish the thresholds of declivity for the stability condition. For to reach this goal is necessary to consider the properties of the autochthonous weathered, colluvial and soil materials. It must be known too, as Vargas (1968) proposed: texture, porosity, humidity rate, conditions of saturation and the activity index of the materials (tab. 1 and 2). The thresholds of declivity, empirically established by Cruz (1975) for scarped areas, as in the «Serra de Caraguatatuba», are at approximately 22° (40%), gotten

TABLE 1 - Thresholds of declivitys and mechanical parameters of sample points of «Serra de Caraguatatuba»

Site	Sample Point	Textural Composition: Sand (%)	Silt (%)	Clay (%)	Plasticity Index (%)	Shear Strength: Cohesion c' g/cm.	Friction ϕ'	Threshold of Declivity Satured Material
Morro do Tinga - East	1	28	4	68	53	331	46.	27.
	2	48	30	22	23	176	48.	29.
Morro do Tinga - North	3	27	8	66	38	255	39.	22.
	4	52	23	25	15	38	46.	27.
Debris Talus	5	39	34	27	11	193	36.	20.
	6	67	10	23	11	179	45.	26.

TABLE 2 - Thresholds of declivitys and mechanical parameters of sample points of Paraibuna Plateau

Site	Sample Point	Textural Composition: Sand (%)	Silt (%)	Clay (%)	Plasticity Index (%)	Shear Strength: Cohesion c' g/cm.	Friction ϕ"	Threshold of Declivity Satured Material
Bairro Rio Pardo	7	25	6	69	51	377	46.	27.
	8	27	37	35	29	323	40.	23.
Landslide 091	9	45	17	38	20	332	46.	28.
	10	46	26	28	15	237	44.	26.
Landslide 131	11	43	9	48	33	428	42.	24.
	12	43	29	28	20	216	45.	27.
Ponte Rio Pardo	13	52	4	44	26	561	36.	21.
	14	65	7	28	10	200	35.	20.

from the superposition of the declivities and the landslides maps. These results are in agreement with the results gotten with the done assays of shearing later (decade of 80, see table 1, last column). In the mounts and ridges of Paraibuna and Paraitinga plateaus, the declivity thresholds, gotten of applied the fast essays of field to the «limit equilibrium analysis» indicate values of 18°, 20° and 22°, respectively on hillslopes with rocky basements micaxists, migmatits and granite-gneiss (Colangelo, 1990, 1995 and 1996).

Another objective of this work is to compare the results, from the application of the thresholds declivity analysis of the superficial materials on the base of steep hillslopes of the «Serra de Caraguatatuba» with those of Paraibuna plateau. In this way, the topo-geomorphic constraints, the mechanical properties of the materials and the surface hydrodynamics are take in account.

MASS MOVEMENTS AND EXPERIMENTATION

Much has been studied regarding the hillslope processes for to understand its genesys and evolution mechanisms, observing, measuring, and making experimentation. The aim of experimentation is to test a pair of variables, under

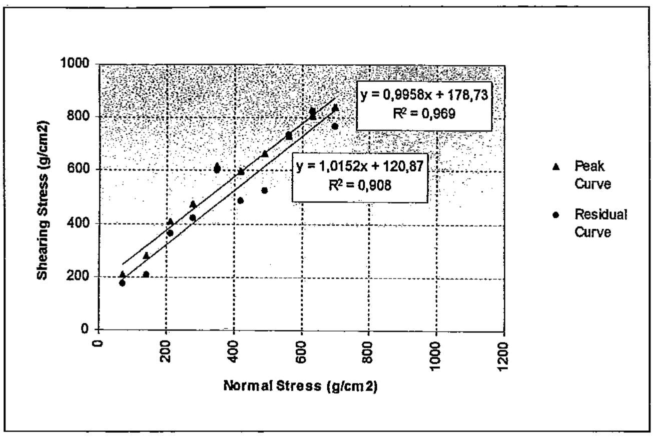

FIG. 7 - Shear strength of 1967-Debris Talus, base of Caraguatatuba scarps, sample point n. 6.

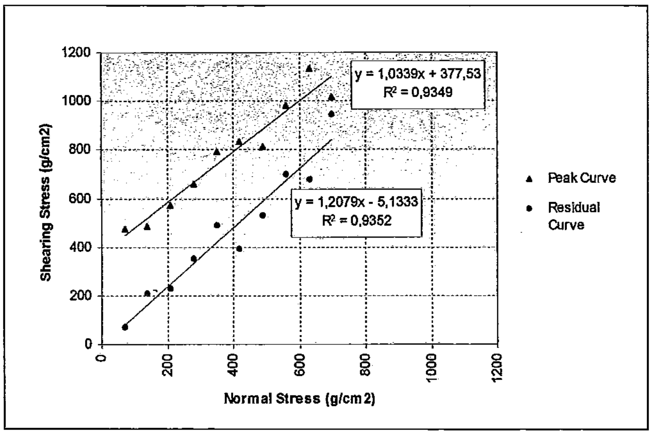

FIG. 8 - Shear strength of «Rio Pardo» coluvium (B horizon) , Paraibuna plateau, sample point n. 7.

control of the other ones, for to try to get the possible algorithm that unite them, and to thus be able to make disgnostic and prognostics. From the fast field essays, carried through with the device «Cohron Sheargraph» , in wheathering materials and coluvium, the parameters cohesion (c') and the apparent angle of internal friction (ϕ') was measured. The experiment consists in produce rupture of the material for the application of a shearing stress (τ) at one known level of normal stress (σ). The experiment is repeated for ten distinct levels of normal stress in mode that, from simple linear regression, gets it curve of the shear strenght. These curve represents the resistance envelope of Mohr-Coulomb (fig. 2 up to 14).

With the application of the results of these experiments in a «limit equilibrium method», and on the basis of the «infinite slope analysis», is possible to determine the thresholds of declivity of the hillslopes, from which there is imminent risk of occurrence of landslides. In this analysis, it's possible to evaluate the different stability conditions and its thresholds of declivity, for distinct conditions of subsurface flow. Supposing to be the material in the imminence to suffer rupture, the cohesion in this case must be next to zero value (Skempton & Delory, 1957 apud Carson, 1975). A detailing on the adopted method can be found in Colangelo (1995 and 1996).

According to De Ploey, Cruz & Modenesi (1978), the threshold of declivity of slope, for the limit equilibrium condition, considered the constraints above related and a parallel subsurface flow, percolating the superficial materials of the hillslope, is given by:

$$\beta t = \arc \tan \{(1 - m.\gamma w/\gamma s)\tan \phi'\}, \text{ where:}$$

βt = threshold of declivity;
m = relative position of the saturation level
(m=1, full saturation; m=0, full drained material);
γw = specific weight of the water;
γs = specific weight of humid soil material;
ϕ' = angle of apparent internal friction;
tan ϕ' = apparent friction index.

In the steep hillslopes of the «Serra de Caraguatatuba», many assays had been accomplished during the eighties, in accessible and available points, chosen in function of the presence of coluvium and «in situ» weathering materials, being realized preferentialy in B horizons of the soils. In the C horizon materials, when their degree of weathering is low and/or their textural composition exhibit great amounts of particles bigger than 4 mm, in general did not allow the accomplishment of the tests. In Paraibuna and Paraitinga Plateaus, the assays come being effected until the current days. Certainly, the excellent material for their execution are those that are very poor selecteds, with more than 30% of fine particles (silte + clay + iron) and with a certain percentage of humidity next to the Atterberg plasticity limit. From there the necessity of proceeding to an artificial moistening of the material, if it is very dry up.

ANALYSIS OF RESULTS

Amongst the multiple assays accomplished on superficial materials, we choose ones effected in mid and footslopes of east and north «Morro do Tinga», in the base of scarps of Caraguatatuba, on basement of oftalmics migmatites. These ones has been confronted with those refered to talus coluvium and dedris fans in the plain of «Santo Antonio» river, formed for occasion of the bebris avalanche ocurred at 1967, and to the referring ones to the plateau of Paraibuna (fig. 1). Although the curves of linear regression show both the thresholds of peak and residual shear strenght, in this paper however only the values of peak had been analysed. The curves demonstrate a diferentiated behavior of the shear strenght, expressed in terms of apparent cohesion and angle of internal friction, in function of

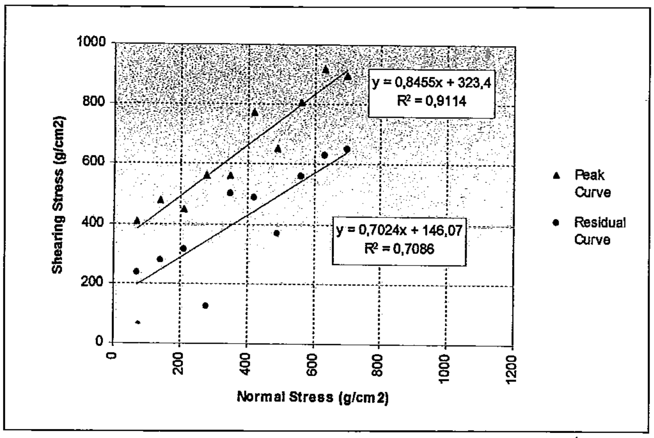

FIG. 9 - Shear strength of «Rio Pardo» coluvium material (B horizon), Paraibuna plateau, sample point n. 8.

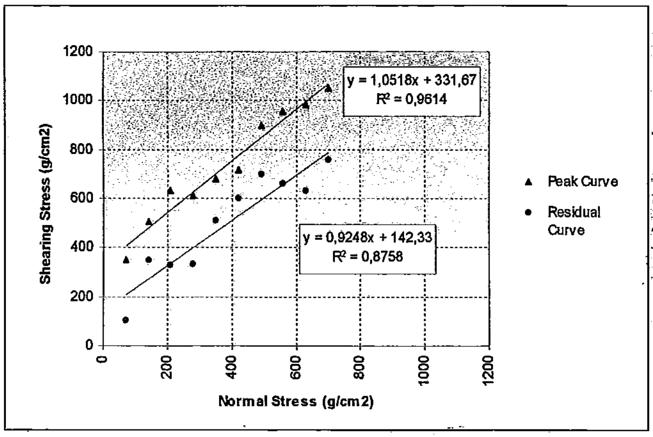

FIG. 10 - Shear strength of landslide 091 coluvium material (B horizon), Paraibuna plateau, sample point n. 9.

the textural and structural composition of the materais in the contacts between soil horizons and between the weathered material and coluvium. It had been made assays generally in the cuts of mid and footslopes, collected removed samples of the shear head of sheargraph and of the soil profiles for determine moisture content, grain size distribution and liquid and plastic Atterberg limits.

The curves referring to the materials in the east face of the «Morro do Tinga» watershed show their bigger shear strenght, in both the cohesion and angle of internal friction components, when compared with those of the west face. In the top of interfluve, the bigger cohesion can be attributed to the great amount of fines (72%), chiefly clays (68%; point n. 1; figs. 1 and 2; tb. 1). The biggest angles of internal friction in the east face (46° and 48°) must be associates by presence of a certain amount of granules (points n. 1 and n. 2, figs. 2 and 3). In this east face, oriented to the sea, the weathering material presents a greater cohesion (176 g/cm^2, fig. 3) if compared with these of the north face, that presents cohesion of 38 g/cm^2 (fig. 5). Such fact would be explained by the bigger clay content of material and depper points of assays, 7 meters: in the north face the essays had been less deep (5 meters), therefore the material is more weathered. In the other hand, on the two faces coluvium and B horizons materials are more cohesives (330 and 255 g/cm^2) that those of weathering (176 and 38 g/cm^2), but they present smaller angles of internal friction (46° and 39°) when compared with weathering materials (48° and 46°). This in consequence of the bigger amounts of sandy fraction (48% and 52%) in these C horizons. When compared, textural and mechanical variables in the points 1, 2 and 3, 4 in table 1, which are respectively B, C and B, C horizons, invariably present, in the C horizons, bigger amounts of sand, smaller cohesion and bigger angles of internal friction, so that the point 4 presents the biggest amount of sand (52%), the smallest cohesion (38 g/cm^2) and higth value of effective angle of internal friction (46°).

These results are in agreement with the thesis presented by Colangelo (1995 and 1996) about the existence of one possible compensation mechanism in the nature, so that the a relative in the steep hillslopes is guaranteed for to prevent or reduce the hazard of ocurrence of landslides in the humid tropical climate conditions. According to this concept, for the maintenance of stability the amount of shear strenght must be equivalent that referred of shear stress in in the two types of materials, B and C soil horizons, even so different of the qualitative point of view. When the weathering material (C horizon) offers a smaller value of apparent cohesion (c') and greater value of apparent angle of internal friction (ϕ'), the colluvies and/or B horizons presents greater cohesion and smaller angles of internal friction.

Two assays carried through the debris fans, deposited for the 1967 debris avalanche, show that these material is less resistant when compared with the coluvial deposits in the talus hillslopes (figs. 6-7 and tb. 1): its recent deposition is certainly responsible for its lesser cohesion. The measure in point n. 6 (fig. 7) presents 179 g/cm^2 of cohesion and high amount of sand (67%), having to be this last value responsible for an angle of internal friction of 45°, well bigger that of the point n. 5, which presents minor amount of sand (39%) and friction of 36°. It is that the shear strenght in these debris fans are strongly associate with textural composition of materials, differentiated in function of the location of the assays; in accordance with the pitches of deposition between the low hillslopes and the distal part of these slopes: the fine material tend to move away and to spread in the plains.

In the valley of Pardo river of plateau of the Paraibuna, still in oftalmics migmatites, the coluvial material presents itself more resistant to shear, with cohesion raising of 561 g/cm^2, as at point n. 13, however with a very lower value of angle of internal friction (36°) and bigger figures of average moisture content (28%) if compared to those (20%) of the hillslopes of the «Morro do Tinga», (fig. 14 and tb. 2). The weathering material (fig. 15; tb. 2 point n. 14), in turn

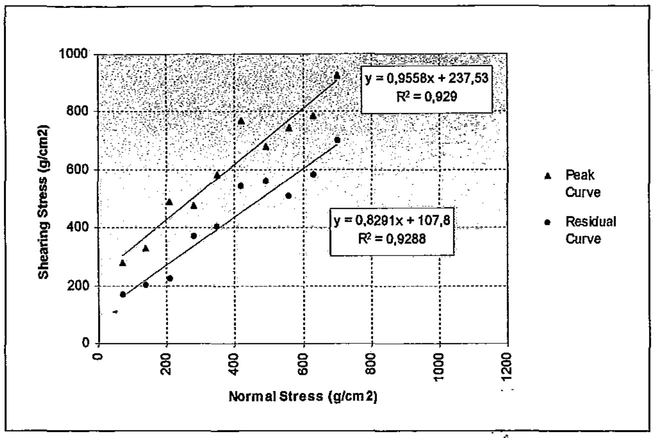

FIG. 11 - Shear strength of landslide 091 weathering material (C horizon), Paraibuna plateau, sample point n. 10.

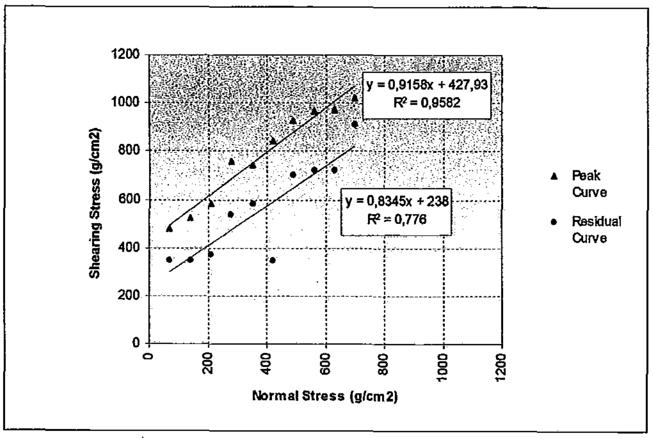

FIG. 12 - Shear strength of landslide 131 coluvium material (B horizon), Paraibuna plateau, sample point n. 11.

presents well lesser cohesion but with equivalent angle of internal friction (200 g/cm^2, 35°). In plateau (tb. 2; points n. 7 to 12), the materials are presented more cohesive than the materials in scarps of Caraguatatuba. This, no in consequence of a importante rise in average clay rate (38% and 40%) but probably on account of either removal of the forest canopy changed by grassland and a strongly compacted superficial soil material by cattle pasture. On the other hand, as well as it occurs in scarps, the more superficial materials in general have more cohesion than in depth. Such materials correspond generally to soil B horizons, being more clayey than the deeper, being able to have been also developed in coluvies. Although less clayey, it was inferred that the types of clay present in the weathering materials (C horizons) are mechanicaly more active, what must compensate, in part, in that relates to hillslope stability, a textural discontinuity, which under other circumstances, would put these materials in the imminent condition to suffer risk of collapse, even under habitual amounts of rain (Colângelo, 1995).

In relation to the thresholds of declivity for hillslope stability, considering the occurrence of extreme rain events with full saturation of soil materials, is important to point out that in scarps of Serra de Caraguatatuba, where had been found thresholds values between 20° and 29°, as much in plateau of Paraibuna, where they are between 20° and 28°, the maximum and the minimum thresholds values are in the same range. With respect of hillslope stability thresholds, this means that are the two relief systems subdued to the same set of climatic constraints parameters? This is a hypothesis that this being tested by Colangelo.

Important factors as rainfall, surface and subsurface flow, kind of soil material, root systems and declivity help us to understand the differences in the dynamic types between different geomorphic systems, in scarps and plateaus. The scarps present abrupt declivities and are affected by high magnitude and frequency rain events. This favors the hazard of mass movements inducing a lowering of cohesion in the case of «arena» over oftalmics migmatites. In this case, high friction index are necessary so that the materials are not put into motion. With great and intense rain events and with a predominance of strong declivities, the scarps of the Serra de Caraguatatuba become a permanent risk area, even if recovered for the tropical rain forest.

Observing the data presented in table 2, for plateau, we notice that the clay rate and the plasticity index are bigger for the B horizons materials, when compared with the ones of C horizons, what it is in accordance with the high argila/silte indexes observed in those horizontes. In relation to the declivity thresholds, when we compare the results gotten for scarps of the scarps and plateau, we observe that it has an inversion: while in scarps the materials of B horizons, in full saturation state, presents lower thresholds (27°, 22°, 20°) than of the C horizons (29°, 27°, 26°), in plateau its values are generally higher (27°, 28°, 21°) than the presented for C horizons (23°, 26°, 20°). These high values in the thresholds of declivity of C horizons in relation to B horizons in scarps, must be atributed to a bigger sand and granules rates (48%, 52%, 67%) when compared with the sand rates in the C horizons materials of plateau (27%, 46%, 65%). This is in accordance with the extreme conditions of declivity and rainfall found in the scarps. However, the clays that compose C horizons is always mechanicaly more active, as already related with relation to the scarps. In plateau, the results presented for Colangelo (1995): 18°, 20° and 22°, had been gotten from the regression curves that relate the apparent angle of internal friction to the moisture content for the weathering materials in micaxists, migmatits and granites. With the subsequent plot of values of the plasticity limits in these curves, is possible to obtain the respectives angles of internal friction. Then, from the application of this «limit equilibrium method» matched at the «infinite slope analysis» on these friction data, the author arrived at the values of the thresholds of declivity above related. With the application of this methodology, the declivity thresholds are lower than the

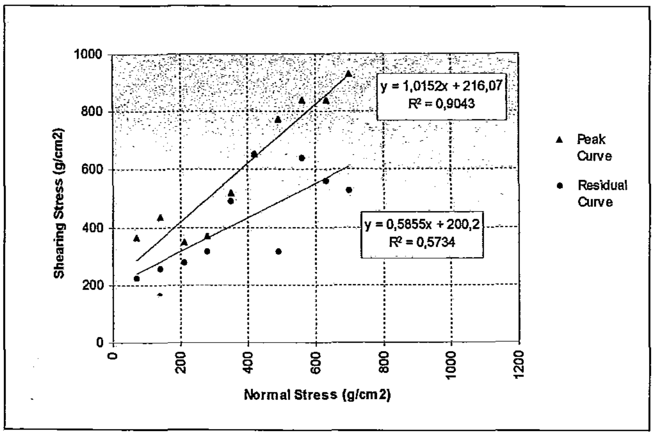

FIG. 13 - Shear strength of landslide 131 weathering material (C horizon), Paraibuna plateau, sample point n. 12.

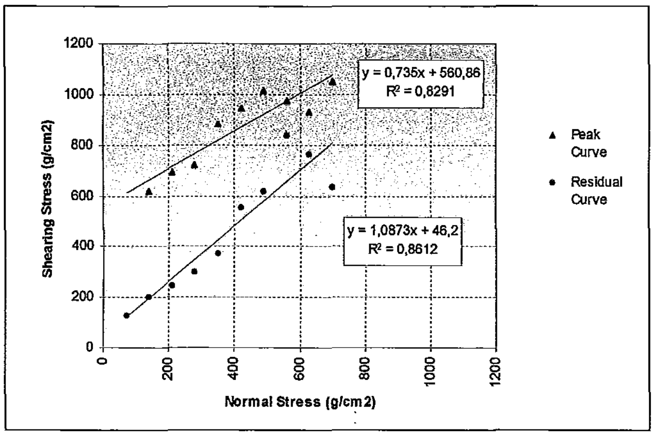

FIG. 14 - Shear strength of «Bairro Rio Pardo» coluvium material (B horizon), Paraibuna plateau, sample point n. 13.

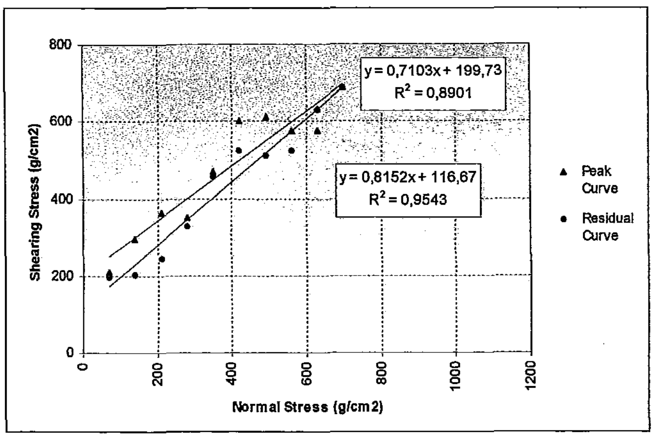

FIG. 15 - Shear strength of «Bairro Rio Pardo» weathering material (C horizon), Paraibuna plateau, sample point n. 14.

ones presented for the traditional method. The validity of this methodology still is being tested from the confrontation with the emergent cases, in the study area.

Is know that good part of the landslides, mainly the planar slide, in scarped humid tropical areas, has its surfaces of rupture in the contact between B and C horizons (Cruz, 1974 and 1975, De Ploey & Cruz, 1979), for the strong discontinuities of mechanical, textural and structural character, existing in the pass between cited horizons. For this reason the assays of shear strenght had been made in these horizontes, as well as the collection of samples for the assays of texture and Atterberg Limits (Liquid and Plasticity). Is interesting to remenber that the results gotten for Cruz (1975), from the overlapping of declivities and landslides charts, are very next (22° or 40%) to the gotten ones with the field assays made by the «Cohron Sheargraph».

Of the textural point of view, all the materials had been presented very poor selected, with sand content between 25% and 67%, silte between 4% and 37% and clay between 22% and 69%. The B horizons always is presented richer in clay when compared with C horizons, even so the fine amounts (silte + clay + iron) are equivalents. Applying the argila/silte index, also we may observe a direct and proportional relation between this index, the cohesion and the ratio of reduction (angular coefficient) of the apparent angle of internal friction in function of a increase, either in the moisture and fine contents. Although less clayey, the C horizon material, in general, possess clay types with bigger physical and chemical activity, as in the case of the vermiculites or the montmorilonites (Colangelo, 1990, 1995), what it compensates in part, their low contents (tb. 1 and 2).

The materials referring to the area of plateau are presented, in general, more resistant to the shearing, mainly with respect to the cohesion, because the coluvies B horizons are sufficiently clayeys.

The great incidence of landslides in scarps of the Serra de Caraguatatuba must possibly be due to a convergence of factors, of which must stand out: bigger humidity, rainfall and energy of the surface and subsurface waterflow. Other important factor is the parent material formed by oftalmic migmatite, which presents as weathering product, very little consistent material («arena»). In this comparison of units of relief, we must remember that the morphologic differences, for conditioning the surface and subsurface waterflow, the behavior of the declivity of the hillslopes and the type of draining surface in the hillslopes, also control, in great part, the texture, structure and composition of the inconsistent superficial materials and the your mechanical behavior (Colangelo, 1995). In the steep hillslopes with very long rectilinear sectors and little deep B horizons profiles (1 metre), the landslides are planar slides. In the plateau, when the relief is «mamelonado», strongly convex or in half orange, with deeper soil profiles (>2 metres), the landslides are slumps.

Therefore, the models to apply in each in case that they must contemplate the morphology of the geomorphic system in question. In this work we consider chiefly the planar slides either in scarps or in the plateau.

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(ms. received 31 October 1999; accepted 31 March 2000).