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Behaviour of a tropical soil under saturated conditions

Comportement d'un sol tropical dans des conditions saturées

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ABSTRACT
The paper reports laboratory investigations carried out in a tropical soil profile to study critical state and yield conditions and their variation with depth. The soil profile is composed of a reddish lateritic layer underlain by a saprolitic soil in which a number of block samples were taken. Compression tests and drained and undrained triaxial tests were conducted at depths between 1.0m and 7.0m, and also in the exposed saprolitic soil. The test programme carried out consisted of compression and strength tests under saturated conditions.

RÉSUMÉ
Le papier rapporte des investigations de laboratoire effectuées dans un profil tropical de sol à l'état critique d'étude et yied des conditions et leur variation par rapport à la profondeur. Le profil de sol se compose de couche lateritic rougeâtre étée à la base par un sol saprolitic dans lequel un certain nombre d'échantillons de bloc ont été pris. Les essais de compressibilité et vidangé et undrained les essais à trois axes ont été conduits aux profondeurs entre 1.0m et 7.0m, et également dans le sol saprolitic exposé. Le programme d'essai a effectué les essais composés de compression et de force dans des conditions saturées.

1 INTRODUCTION

Tropical soils occur in large regions and have been less studied than soils from temperate climates, particularly with respect to critical state and limit state conditions. The tropical soil studied here is a residual soil from gneissic rock from Ouro Preto, Southeast Brazil.

This paper presents the laboratory behaviour of the Ouro Preto tropical soil based on studies carried out by Futai (2002) on block samples collected at various depths. Compression and shearing tests have been conducted and strength, critical state and limit state conditions have been determined. Futai (2002) investigated soils under saturated and unsaturated conditions, the latter by means of suction controlled tests, as well as tests at the natural water content. However, this paper presented only tests in the saturated conditions.

2 SOIL PROFILE

The tropical soil studied is composed of a reddish top (horizon B) layer about 2.0m thick followed by a saprolite soil (horizon C) which may reach depths up to 40m. The water level is found at about 20m depth. The present study is concentrated in the top 7.0m in which block samples were taken at regular depths, samples were also tested from the nearby saprolite slope, which had been exposed due to erosion and associated stability problems.

Results of index tests are summarized in Figure 1. Water content is between plastic and liquid limit. The amount of clay is greater in horizon B and grain size analyses have revealed that all clay is in the flocculated state. Mineralogical studies revealed that kaolinite is the main clay mineral, but gibbsite is also present. The amount of quartz, which is approximately constant with depth, is consistent with the proportion of sand with depth is relatively constant. Scanning electron microscopy studies suggested a meta-stable structure for the horizon B soil.

3 TESTS IN SATURATED SPECIMENS

3.1 *Compression tests*

Data of oedometer compression tests on intact flooded specimens are summarized in Table 1. Values of the compression index C_c for horizon B are greater than for horizon C and may result (Futai, 2002) from the porous cemented structure of horizon B. The compression index (C_c) for horizon B does not vary much with depth, as seen in Table 1. Isotropic yield stress p'_o is shown in Table 1 together with yield stress σ'_{vm} and compression index C_c determined in oedometer tests. Oedometer yield stresses σ'_{vm} increase with depth.
Isotropic and anisotropic ($K = \sigma'_3/\sigma'_1$ equal to 0.5 and 0.75) compression tests on intact flooded specimens have been performed and the data from the test with K=0.5 are shown in Figure 2.

Anisotropic compression tests were carried out with control of strain, with measurement of the major principal stress and continuous adjustment of the minor principal stress by a feedback control program.

3.2 *Triaxial shear tests*

Isotropic consolidated triaxial tests have been performed on intact soils from block samples of the whole profile, plus the exposed saprolite, with the objective to get a complete understanding of the stress-strain-strength behaviour. Undrained and drained tests have been performed in each block, thus 16 sets of tests (strength envelopes) were determined.

Saturation of each specimen was ensured by water flow followed by application of back-pressure. Radial and base drainage were adopted and 95% consolidation was obtained in less than 2 minutes. The adopted rates of shearing were 0.05 and 0.013 mm/min, respectively, for undrained and drained tests, about 10 times slower than calculated rates (Bishop and Henkel, 1974).

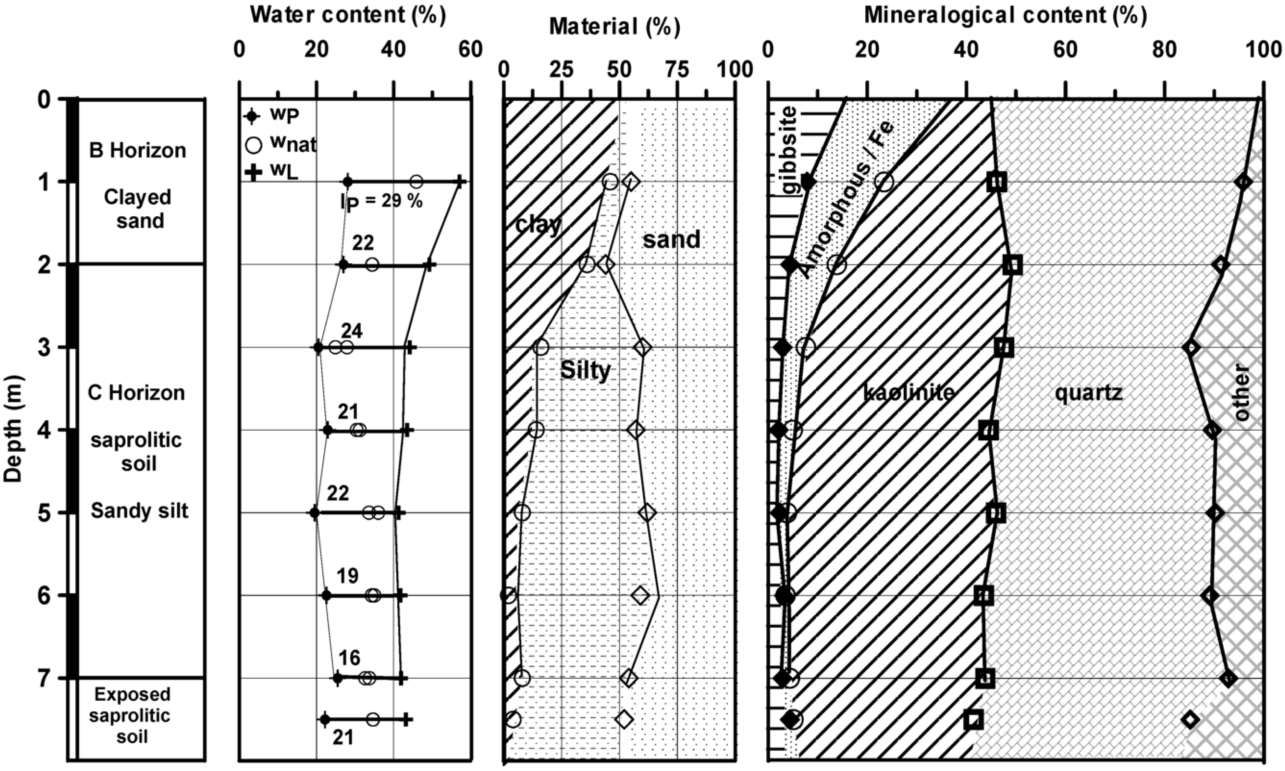


Figure 1 - Site characteristic profiles (Futai et al., 2004).

Table 1 – Compressibility parameters – saturated specimens

Depth (m)	C_r	C_c	σ'_{vm} (kPa)	e_o	p'_o (kPa)
1	0,03	0,44	60	1,34	100
2	0,05	0,41	100	1,02	120
3	0,05	0,27	200	0,88	140
4	0,04	0,29	250	0,93	-
5	0,05	0,30	400	0,88	300
6	0,03	0,28	450	0,90	-
7	0,04	0,42	500	1,05	400
exposed	0,03	0,33	400	1,25	340

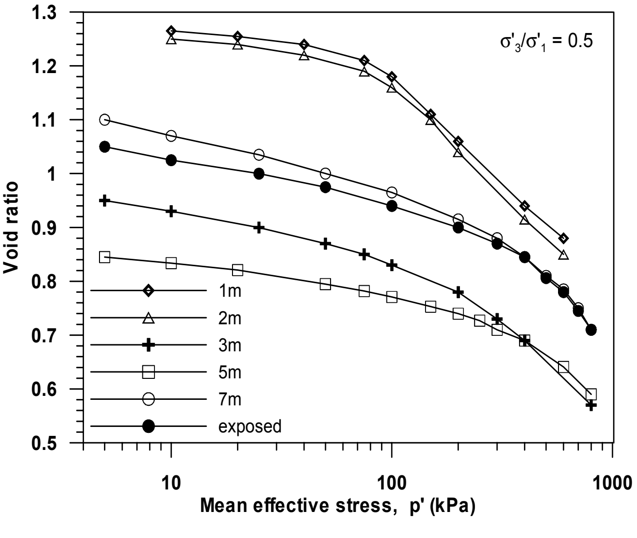


Figure 2 - Anisotropic compression curves - saturated specimens.

The piston load was measured by an internal load cell and the change in volume by an automated volume change device. Pore pressures in the undrained tests were measured at the triaxial cell base.

3.3 *Critical state parameters*

Critical state parameters have been determined for each depth using data of drained and undrained tests close to critical state conditions. In some tests critical state conditions could not be achieved, thus large strain data close to critical state conditions were used. Figure 3 shows critical state lines in the Cambridge q:p’ and e:p’ spaces. The non-linearity of the critical state line in q: p’ stress space may be noticed, in Figure 3-a particularly for less weathered soils.

The influence of the weathering may be seen in the plot of voids ratio e, against mean effective stress p’, Figure 3-b. However, this influence is clearer in the $\Delta e/e_o$:p’ plot shown in Figure 4, where Δe is the change in voids ratio during both consolidation and shearing and e_o is the initial voids ratio at the start of test.

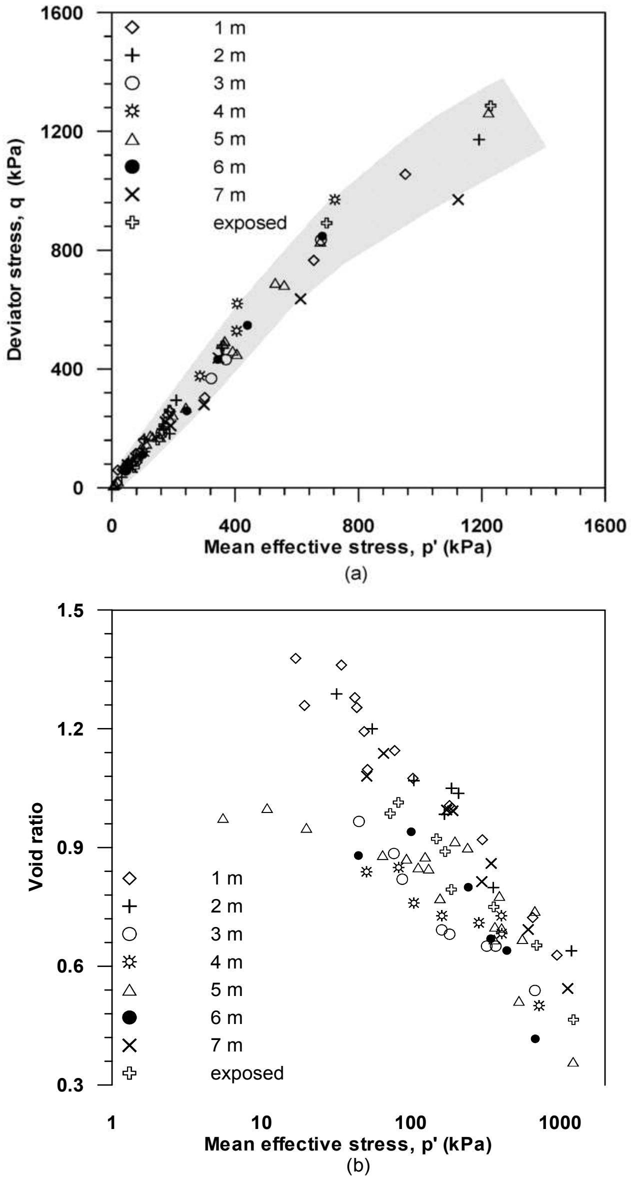
The $\Delta e/e_o$:p’ plot made it possible to establish two ranges for the critical state line, one for horizon B and the other for horizon C, as seen in Figure 4.

The linear regression is convenient, but is not necessarily the best fit. Table 2 shows data of the critical state parameters M, Γ and λ (Atkinson and Bransby, 1978; Wood, 1990) for the 8 soils tested. There is not a clear trend of the variation of M (or other critical state parameter) with depth.

3.4 *Limit state curves*

Limit state curves have been determined by a number of tests chosen in order to define limit state conditions by probing different directions in the q:p’ space.

Isotropic and anisotropic compression tests were used to define yield conditions and triaxial drained and undrained tests were used to define failure states, as exemplified in Figure 5.



(a)

(b)

Figure 3 - Critical state - saturated specimens.

Casagrande's criterion was used to define yield for hydrostatic and anisotropic compression conditions. For triaxial tests, the assessment proposed by Graham et al. (1988) was adopted to define the inflexion point in arithmetic, semi-log and bi-log scales All approaches suggested similar yield states.

Results shown in Figure 5 for the soil at 5.0m depth allowed the definition of three limit state conditions: Region 1, where yield is achieved below the critical state line; Region 2, the Hvorslev-type failure envelope with well defined plane and dilatant behaviour; and Region 3, defined by the tensile cut-off by means of the special triaxial tests.

All limit state curves are combined in Figure. 6 and the expansion of the limit state curves with the increase of depth is quite clear. It is shown that limit state curves for soils from depths 1.0 and 2.0m in horizon B are centred on the hydrostatic axis. However, limit state curves of soils from horizon C are not centred on the hydrostatic axis, which may be due to the remaining 'mother' rock anisotropy, which could still be intact despite weathering.

Limit state curves were normalized for each depth with respect to the yield stress measured in isotropic compression tests (p'_o).

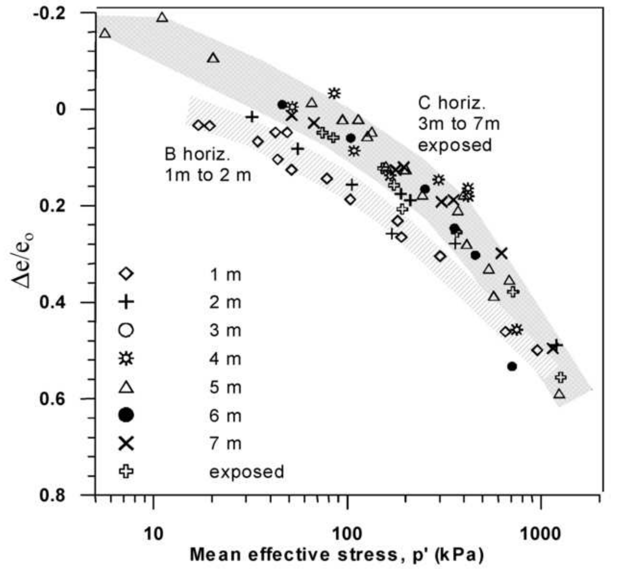


Figure 4 - Critical state condition in Δe/eo:ln(p') plane - saturated specimens.

Table 2 –Critical state parameters – saturated specimens

Depth (m)	M	Γ	λ (*)
1	1,14	2,89	0,176
2	1,03	2,93	0,182
3	1,20	2,51	0,151
4	1,36	2,27	0,104
5	1,01	2,34	0,111
6	1,25	2,70	0,183
7	1,08	2,80	0,182
exposed	1,12	2,78	0,177

(*) λ = slope of the critical state line in the e:lnp' plot

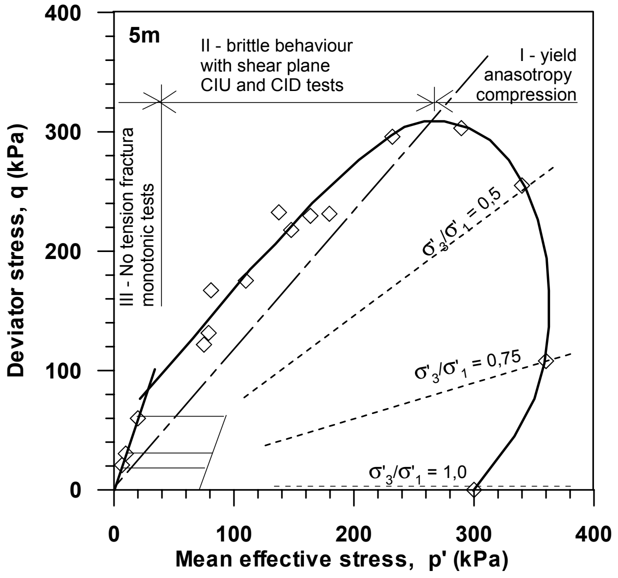


Figure 5 - Limit state curve at 5m depth.

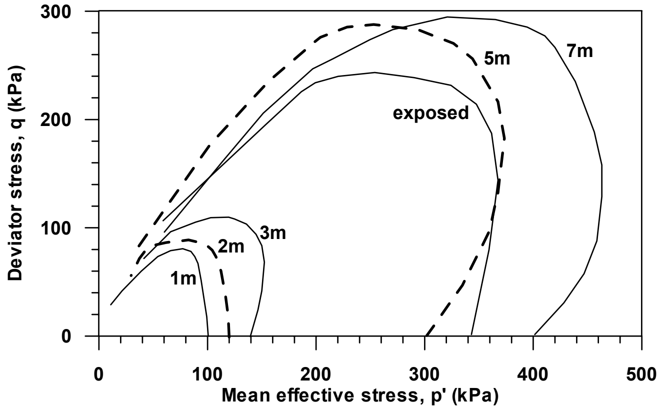


Figure 6 - Limit state curves at all depths.

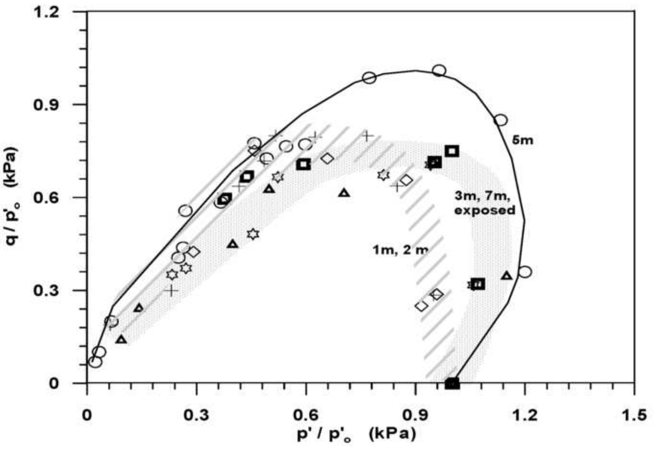


Figure 7 - Normalized limit state curves.

The normalized limit state plot is shown in Figure. 7, and two patterns of curves emerge, one for horizon B (soils at 1.0m and 2.0m) and another for horizon C. The limit state curve of the soil at 5m depth does not fit into the general pattern observed for horizon C. Visual analysis of this soil in the laboratory indicated that it was out of the pattern of horizon C. It appeared less weathered than soils of 6.0 and 7.0m depths. However this qualitative evaluation was not confirmed by chemical and mechanical tests.

4 CONCLUSIONS

The tropical soil studied herein is composed of a clayey reddish horizon B layer about 2.0m thick underlain by a saprolitic gneissic residual soil - horizon C - soil. Laboratory tests were carried out under saturated and unsaturated conditions on block samples collected at depths 1.0 to 7.0m. Isotropic and anisotropic compression tests and triaxial tests were conducted at every meter to study critical state and limit state conditions.

The studies under unsaturated conditions were carried out on samples collected at depths 1.0m (horizon B) and 5.0m (horizon B). Isotropic and anisotropic compression tests and CID triaxial tests were carried out under controlled suction. Constant water content triaxial tests in air dried specimens were also carried out.

For saturated specimens a non-linearity in the critical state line in q:p' stress space was noticed, but linear regression was used to obtain critical state parameters. The plot of $\Delta e/e_o$:p' made it possible to establish two ranges for the critical state line, one for horizon B and the other for horizon C. The expansion of the limit state curves with increasing depth was quite clear. Limit state curves for soils from horizon B are centered on the hydrostatic axis but the shape of limit state curves for horizon C suggested anisotropic behaviour.

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