NOTE ON EXPANSIVE SOILS, THEIR RECOGNITION AND THE FORECASTING OF THEIR BEHAVIOUR

NOTE SUR SOLS EXPANSIFS, SA RECOGNITION ET LA PREVISION DE SON COMPORTEMENT

О НАБУХАЮЩИХ ГРУНТАХ, ИХ РАСПОЗНАВАНИИ И ПРОГНОЗЕ ИХ ПОВЕДЕНИЯ

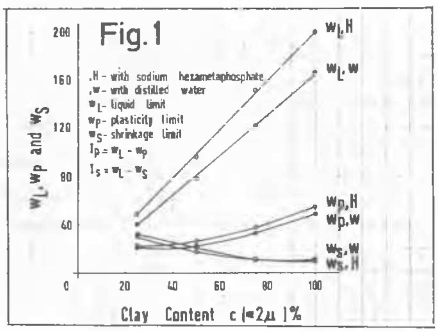
H. NOVAIS-FERREIRA, Research Engineer, Laboratório de Engenharia de Angola
J. A. HORTA DA SILVA, Specialist Geologist, Laboratório de Engenharia de Angola (Portugal)

SYNOPSIS-The present work deals with the behaviour of binary mixtures of soils of clay and sand exclusively referring the study of variation with clay-soil content *(C)* of the CBR, expansion *(ε)* and expansion pressure (p_e) for the compaction curve maxima, and the correlation between these values. The clay is a sub-tropical expansive soil; their properties are referred to.

1 - CHARACTERISTICS OF THE CLAY MATERIAL USED

1.1 - The clay material used in the tests comes from an expansive soil, dark grey and black in colour, occurring in the surroundings of Luanda and generally known as Cazenga Clay. It is a vertisoil showing tensile cracking and gilgay relief for most of the year. Its composition, origin and geotechnical behaviour in natural conditions were presented and discussed by Horta da Silva, (1967, 1969 and 1971a and b). The clay fraction of this soil comprises mainly dioctahedral smectites of the abnormal montmorillonitic type. Small quantities of kaolinite and quartz also form part of this fraction, as do occasional small quantities or traces of illite. The fractions above 2μ are mainly composed of quartz, to which are associated small quantities of calcite in some cases, and more rarely feldspars. The cation exchange capacity and the external specific surface of the ≤ 2μ fractions of some samples showed limiting values of 57.4me/100g to 92.86me/100g and 96m²/g to 121m²/g respectively, with an estimated 80 to 95% of smectites and never more than 15% of kaolinite. The clay is essentially saturated by divalent cations, mostly Ca^{++}, the montmorillonitic minerals showing a basal spacing of 15Å in the natural and dry conditions in air, which corresponds to two layers of interlamelar water. Notwithstanding its black colour the soil has very low organic material contents, less than 0.5%. The clay material used in the present paper was taken from this type of horizon.

1.2 - For a better interpretation of the plastic and shrinkage characteristics of the clay of the soil an appreciable quantity of ≤ 2μ fraction was isolated and mixed with a beach sand in proportions varying between 25%, 50%, 75% and 100% of clay. The liquid limits, plasticity limits and shrinkage limits were then obtained with distilled water in accordance with the standards and an aqueous solution of hexametaphosphate of Na^*. The results thus obtained are given in graph form in Fig. 1.



These results confirm the data presented by Dumbleton and West (1966a and b), Novais-Ferreira (1971) and Horta da Silva (1969) stressing the fact that both I_p and I_S undergo a considerable increase when the limits are determined with hexametaphosphate of sodium, proving that in natural conditions the material used does not occur in its potentially most active form. The peptising action of sodium hexametaphosphate, which complexes the divalent cations and forms Na^+ saturated clay, allows an increase of the specific surface of the clay material

* - The sodium hexametaphosphate was used in the same proportions as those given in ASTM standards for the particle size analysis by sedimentation.

and consequently an increase in the quantity of water adsorbed by the smectites, raising considerable the liquid limit in relation to the plasticity and shrinkage limits. Such results are reasonably consonant with Grim (1965) where the addition of soda ash to montmorillonitic clays is concerned, and also with the data by Bain (1971) as concerns the addition of sodium carbonate to calcic montmorillonites. These data are moreover in accord with the results given by Horta da Silva (1969, 1971), showing the interest in the then proposed definition for activity *(ultimate activity* = $(I_p'/(\% < 2\mu)'$ I_p' and $(\% < 2\mu)'$ *both determined by hexametaphosphate of Na).*

TABLE I - GRANULOMETRY AND DENSITY

	GRANULOMETRY (ASTM)							G
	Nº 4 4,76mm	Nº 10 2,00mm	Nº 40 0,42mm	Nº 200 74μ	5μ	2μ	M.G. (*)	
C	-	100,0	90,0	77,0	49,9	46,0	767,0	2,700
F	100,0	99,0	97,0	5,0	3,0	3,0	701,0	2,660

(*) - Sum of percentages of material passing ASTM sieves 1", 3/4", 1/2", 3/8", Nº 4, Nº 10, Nº 40 and Nº 200 (granulometric modulus)

2 - TESTS CARRIED OUT AND RESULTS OBTAINED

2.1 - The tests were carried out with clay mixtures *(C)* defined in 1 and fine sand *(F)*, (see Table I and II).

MIXTURES C/F	IDENTIFICATION RESULTS TESTS							OTHER TESTS CARRIED OUT
	w_L	w_P	w_S	I_P	I_S	S_V	R_L	
0/100	NP	NP	-	NP	-	-	-	CBR; E
2/98	NP	NP	-	NP	-	-	-	CBR
5/95	NP	NP	-	NP	-	-	-	CBR
10/90	NP	NP	-	NP	-	-	-	CBR; E
20/80	25,0	18,5	19,7	6,5	5,3	9,4	3,0	CBR; E
30/70	27,0	17,4	18,4	9,6	8,6	15,2	4,6	E
40/60	32,0	16,7	17,2	15,3	14,8	27,2	7,7	CBP; E
50/50	38,4	15,4	14,2	23,0	24,2	46,9	12,0	E
70/30	54,0	15,0	9,7	39,0	44,3	94,3	19,8	CBR; E
80/20	59,0	17,0	8,9	42,0	50,1	108,7	21,8	CBR
90/10	63,5	17,8	8,2	45,5	55,1	121,7	23,3	CBR
95/5	68,3	19,2	7,6	49,1	60,7	135,9	24,9	CBR
100/0	69,4	22,2	8,1	47,2	61,3	135,8	24,9	CBR; E

C - Clay soil
F - Fine sand
CBR- CBR test
E - Oedometric test
w_L - Liquid Limit
w_P - Plasticity limit
w_S - Shrinkage limit
I_P - Plasticity index
I_S - Shrinkage index ($I_S = w_L - w_S$)
S_V - Volumetric shrinkage
R_L - Linear shrinkage

2.2 - Each mixture was considered as one soil. In the compaction tests the general guidelines of the ASTM: :D 698-70 and ASTM:D 557-70 (ASTM Standard, 1970, Part 11), were followed, except where compaction energy was concerned (Table III). The oedometric tests were done on specimens prepared as nearly as possible in conditions of the maxima for the compaction curve (maximum dry bulk density, γ_M; optimum moisture content, w_M). The CBR tests were carried out on all the specimens made up during the compaction test. For each type or compaction energy were drawn diagrams: $1/\gamma_M = f_1(C)$; $w_M = f_2(C)$.

The diagrams obtained for the five types of compaction are similar. Only those corresponding to *24N* compaction (Table III) are shown (Fig. 2).

TABLE III - COMPACTION CONDITIONS

TESTS	OEDOMETRIC TEST	COMPACTION AND CBR TESTS			
Type of compaction	25 N	12 N	24 N	100 N	54 P
Mould (diameter)	4 in. (10,16 cm)	6 in. (15,24 cm)			
Rammer (weight)	5,5 lb. (2,5 kg.)				10 lb. (4,54 kg.)
Height of drop	12 in. (30,5 cm)				18 in. (45,7 cm)
Number of layers	3	5			
Blows by layer	25	12	24	100	54

2.3 - The oedometric tests (Novais-Ferreira, 1969) include consolidation in immersion (soaked test) and consolidation with the compaction moisture content (test in air), which are considered together as double oedometer test (Jennings and Knight, 1957), and the *virtual oedometric expansion pressure* was determined (p_{ev})- - a pressure which corresponds to intersection of the soaked test diagrams with those for the compaction moisture content ones. The mixtures with low percentage of clay soil - up to about 20% - in the diagram $e = f(\log p)$ show an initial zone $(p < p_{ev})$ which is common to the diagrams of saturated and in-air tests. The pressure $0 < p < p_{ev}$ seems to correspond to a zone of *oedometric indifference* relative to the sample moisture content, where there is neither expansion nor collapse.

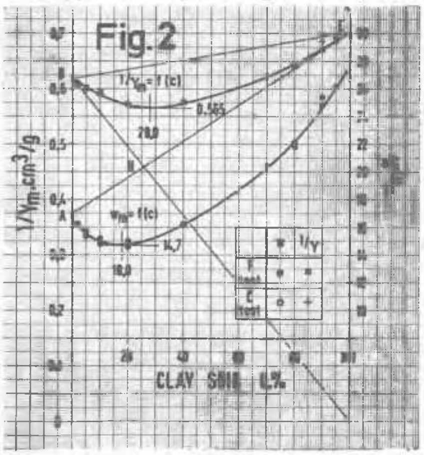
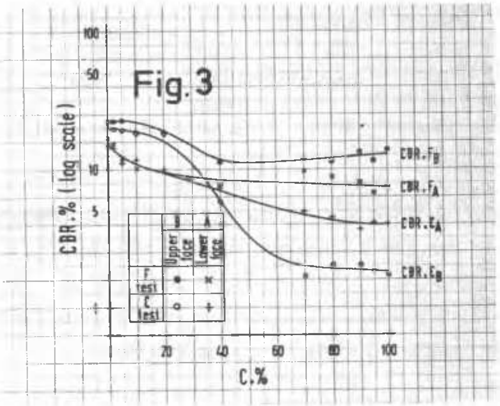


Fig.2

2.4 - For each mixture three new samples were consolidated at optimum compaction moisture content and at the pressures (p_{ev}, $1/2\ p_{ev}$ and $2\ p_{ev}$) the samples were saturated and the variation in voids ratio Δe was measured. With these results the diagrams for $\Delta e = f(\log p)$ were drawn, (Singh, A., 1967), and the *null expansion pressure* (p_{en}) corresponding to $\Delta e = 0$ was evaluated. The curves $p_{ev} = f(C)$ and $p_{en} = f(C)$ are similar in the shape, but some differences are observable.



2.5 - The CBR tests were carried out in two different ways: (a) in accordance with the ASTM:D 1883-67 specification -tests with free expansion - tests ε; (b) with impeded expansion (constant volume) - tests *F*. In the tests b) the *impeded expansion pressures* were read (p_{ei}) by means of dynamometer rings.

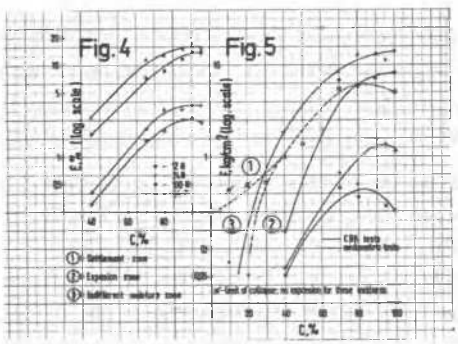
Subsequently the CBR was read on faces A (lower faces during soaking but upper during compaction),and upper ones,B. The CBR test obtained for each point of the compaction curves allow the tracing results curves *CBR= = f(w)* for each mixture (6),type of compaction (4) and type of test (2), in a total of 48 curves. From these curves were established the CBR's corresponding to the maxima of the compaction curves indicated. With those CBR corresponding to the maxima of compaction curves, diagrams of *CBR = f(C)* were drawn.Given the relatively similar shape of the diagrams *CBR = f(C)* for the four types of compaction, the means per type of test were compiled. Thus,mean curves were obtained(from the four compactions)for CBR measured: in the free-expansion samples on the face A - *CBR, εA;*ditto on the face B -*CBR, εB;* in the samples with impeded expansion on the face A - *CBR, FA;* ditto on the face B - *CBR, FB*. Fig.3 gives the diagrams of *CBR = f(C)* for the four cases.The behaviour of mixtures thus shows three different zones: the zone a) *(C ⩽ 20%)*mixtures have an incoherent behaviour since the main influence of CBR comes from the initial compaction. The best compaction conditions for sandy soils are found on the B faces underside during compaction. The soaking provokes slight expansion whereby there is little difference between the tests ε and *F* on face B and none at all on face A.

The zone b) *(20% ⩽ C ⩽ 70%)* is one of clear transition between the two types of behaviour,perhaps accepting *C = 40%* as the clay soil percentage at which the behaviour change takes place.

The zone c) *(70% ⩽ C)*the behaviour is clearly coherent. The best compaction is still found on face B (highest CBR for test *F*), but this effect becomes meaningless in view of the expansion, which is more detrimental on the upper face B (lowest CBR for test ε).

These conclusions agree with those obtained previously in shear tests (Novais-Ferreira, 1971).

2.6 - By analogy to the CBR results, curves were drawn for $\varepsilon = f(w)$ and $p = f(w)$ for each mixture and type of compaction, to a total of 24 curves for each property (ε and p) and the ε and p values corresponding to the compaction curve maxima were determined. With these values the curves of $\varepsilon = f(C)$ and $p = f(C)$ were drawn - - Figs. 4 and 5 respectively.



From Fig. 4 it will be seen that for *C ⩽ 20%* practically no expansion is evident; for *40 ⩽ C ⩽ 90%* the expansion grows with percentage of clay soil, *C*; for *90 < < C* the expansion remains constant or decreases when *C* increases (light compaction cases, *12N* and *24N*). In the zone *C ⩽ 20%* there exists the influence of the sandy skeleton to oppose the expansion. In the zone *90% < C* the soil dry density decrease with *C* and this effect counters the higher percentage of active element.The influence of compaction energy is considerable. The relation between ε from the *12N* and *54P* compacted specimens is about 1:6.

Fig. 5 gives rise to similar conclusions in the case of expansion pressure.

2.7 - In the same diagram the curve for p_{ev} and p_{en} obtained by oedometric tests was superimposed. In this case the forces above which settlement by soaking (collapse forces) occurs were marked, as were the forces up to which expansion takes place (expansion forces). As already mentioned (2.3) these two forces did not coincide in the zone of incoherent behaviour. Thus the zones of (a) settlement or collapse, (b) expansion and (c) indifference or of indifferent moisture content, are defined.

3 - CORRELATION BETWEEN PROPERTIES

In the free expansion tests the CBR shows negative correlation with ε, with the highest CBR values measured on face A (lower). In the impeded expansion tests (tests *F*) the CBR value is practically constant, those measured on the face B (upper) being the highest.

The correlation $p_{ei} = p(\varepsilon)$ (considered as an *SI* type correlation, Natrella, 1963: 5-31 et sequ.), obtained was *(r = coefficient of correlation)*:

$$\log p = 1{,}548 \log \varepsilon - 0{,}7706 \qquad (r = 0{,}9564)$$

The values considered were those corresponding to the compaction curve maxima. The equation given appears to be independent (in the first approximation) of the percentage of clay soil and the compaction energy.

The diagrams of CBR, ε and p_{ei} were drawn for mean values of the four compactions used as functions of liquid limit (w_L), plasticity index $(I_p = w_L - w_P)$ and shrinkage index $(I_s = w_L - w_s)$. The diagrams are similar. Also the diagrams are similar to those for CBR, ε and p_{ei} as function of the clay soil content.

4 - CONCLUSIONS

4.1 - The mixtures of clay and sand soil behave, in fact, as binary mixtures (Fig. 2) in what dry density is concerned.

4.2 - The mixtures show three zones of behaviour: *incoherent* up to just before the minimum of the $1/\gamma_M = f(C)$ curve, of for $C < 20\%$; *transition* from 20% to about 60 or 70% of clay soil, which covers the minimum zone in the diagram Fig. 3; *coherent*, for $C > 70\%$.

4.3 - The correlation of ε and p_{ei} (and also CBR) with the percentage of clay only have sense in the transition zone and depends on the compaction energy. The correlation of ε, p_{ei} and CBR with the limit, plasticity index and shrinkage index is similar to that obtained with the percentage of clay soil, given the fairly good correlation between the three properties with the percentage of clay.

4.4 - It appears suitable to define collapse pressure as that after which the soil settles if soaked. In the zone of incoherent behaviour the collapse force does not coincide with the expansion force. In the diagram $p_{ei} = f(C)$, three zones appear: settlement or collapse, expansion, and then a zone of indifference to variation in moisture content.

REFERENCES

1 - BAIN, J.A. - Clay Minerals, 9, 1971.

2 - GRIM, R.E. - *Applied Clay Mineralogy* - McGraw-Hill Book, New York, 1962.

3 - GRIM, R.E. - American Ceramic Soc., Bull. 44, 1965.

4 - HORTA DA SILVA, J.A.:

- Proc. 4th African Reg. Conf. Soil Mech. Found. Eng., Cape Town, I, Session 2, 1967.
- *Geology and Engineering Behaviour of Expansive and Collapsing Soils of Angola* -Dissertation, Imperial College of Science and Technology, London, 1969.
- 5th Reg. Conf. Africa Soil Mech. Found. Eng., Luanda, 1971, pp. 1-31.
- Bull. of the Laboratório de Engenharia de Angola, Luanda, (not published), 1971b.

5 - JENNINGS, J.E.B., and KNIGHT, K. - Transactions of the South African Inst. of Civil Eng., 7 (9): 285-291, 1957.09.

6 - NATRELLA, Mary G. - Experimental Statistics - National Bureau of Standards Handbook Insered, August, 1963.

7 - NOVAIS-FERREIRA, H.:

- 4th Reg. Conf. African Soil Mech. Found. Eng., Cape Town, I: 261-266, 1967.
- 7th Int. Conf. Soil Mech. Found. Eng., México, I: 317-325, 1969.
- Monografia 166, Laboratório de Engenharia de Angola, Luanda, 1970.
- 5th Reg. Conf. Africa Soil Mech. Found. Eng., Luanda, 1971, pp. 3-33.
- 5th Reg. Conf. Africa Soil Mech. Found. Eng., Luanda, 1971, pp. 5-35.

8 - SINGH, Alam - *Soil Eng. in Theory and Practice* - Asia Publish. House, London, 1967, pp. 658.