Soil Erosion in Roads

Erosion des sols dans des travaux routiers

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SUMMARY

The authors investigate, on a set of 26 soils, a number of the mechanical, physical, and chemical properties that can influence a soil's resistance to erosion due to atmospheric actions. They conclude that, as regards resistance to erosion, soils can be classified by means of only two parameters. Therefore, they propose to adopt for the time being, a tentative selection criterion based on swelling and the grain size distribution curve (using the *a*-constant), the corresponding limit values being indicated.

SOMMAIRE

Les auteurs passent en revue, dans un groupe de 26 sols, les différentes proprietés mécaniques, physiques et chimiques, en recherchant une relation possible avec la résistance de ces sols à l'érosion par des agents atmosphériques. Ils constatent qu'on peut classifier ces sols en ce qui concerne leur résistance à l'érosion suivant deux paramètres seulement. Ils proposent un critère provisoire de sélection, fondé sur le gonflement et la courbe granulométrique (représentée par la constante *a*), tout en indiquant les valeurs limites respectives.

EROSION DUE TO ATMOSPHERIC AGENTS causes much damage every year to the slopes of embankments or cuts in roads, to earth or gravel pavements, and to shoulders and in adjoining areas, damage which often requires expensive repair or protective works. In the present paper, the authors have attempted to discuss some soil properties in relation to their resistance to erosion and to present tentative criteria for the identification of non-erosive soils.

The research work has been carried out on a set of 26 soil samples from slopes in the Northern Motorway outside Lisbon, along a section of about 20 km. The soils belong to Tertiary (Oligocene and Miocene) formations deposited in similar conditions in the sedimentary areas of the catchment basin of the Tagus River. The slopes have been under observation since early 1962, their behaviour being recorded from that date. Of the chosen sites, 8 presented evidence of good behaviour as regards resistance to erosion, 3 of fair behaviour, and 15 of bad behaviour.

It is intended, at a future stage, to extend this investigation to soils with different geologic characteristics, namely to African tropical soils from Angola and Mozambique, with a view to deriving more general criteria from the tentative rules that are proposed in this paper.

PROPERTIES STUDIED IN CONNECTION WITH SOIL EROSION

Of the literature available on the subject, particular attention was paid to Middleton's papers, especially to Middleton (1930), which seemed very promising. Unfortunately, as will be shown below, Middleton's erosion criteria proved unsuitable for the soils studied.

Thus it was necessary to examine other soil properties and they are listed in Tables I and II (in which, because of shortage of space, only the maxima and minima values of each characteristic are shown). Other soil properties were also investigated, but the results obtained were not retained as they proved of no interest for the problem under consideration.

As can be seen in Table I, the soils studied were of different natures, ranging from A-2-4 sandy soils to A-7-6 typical clays (PRA classification).

Specific gravity. Determined according to the ASTM standards, the values obtained were not significant in regard to erosion (Table I).

Grain size distribution curves. Also determined according to the ASTM standards, the results proving significant as expected. In addition to the percentages passing No. 10, 40,

TABLE I. IDENTIFICATION, MECHANICAL CHARACTERISTICS, AND ERODIBILITY OF SOILS (MAXIMA AND MINIMA VALUES)

Total number of samples	Behaviour	Specific gravity	Grain size distribution curve: Percentage passing 2.0 mm No. 10	0.42 mm No. 40	0.074 mm No. 200	<0.001 mm	a	Atterberg limits w_L	I_P	Classification (P.R.A.)	Compaction (heavy) γ_{max}	w_{opt}	C.B.R.	Erosion test per cent <200	per cent total
8	good	2.70	76	60	27	0	0.60	13	4	A-2-4	1.91	8.0	8	0.6	0.8
		2.81	100	96	80	37	0.92	32	17	A-6	2.13	13.0	74	5.0	8.8
3	fair	2.68	84	49	18	5	0.52	13	3	A-2-4	1.81	6.5	15	1.0	2.8
		2.71	100	93	22	17	0.73	28	14	A-2-6	2.13	14.0	55	5.0	28.5
15	bad	2.66	76	37	15	7	0.47	23	10	A-2-6	1.58	6.2	3	0.2	0.7
		2.86	100	100	95	70	0.99	68	36	A-7-6	2.16	25.0	70	3.0	6.5

TABLE II. PHYSICAL AND CHEMICAL CHARACTERISTICS (MAXIMA AND MINIMA VALUES)

Total number of samples	Behaviour	Swelling (per cent)	Surface area (sq. m./gram)	Centrifuge moisture eq. (per cent)	Suction w for pF = 0 (per cent)	Absorption limit (per cent)	CO_2 (per cent)	Organic matter (per cent)	Chemical analysis of the clay fraction ($\leqslant 2\mu$): SiO_2 (per cent)	Al_2O_3 (per cent)	Fe_2O_3 (per cent)	SiO_2/R_2O_3	Predominant clay mineral: Kaolinite	Illite	Montmorillonite	Middleton's parameters: Dispersion ratio	Ratio of coll. to moist. equiv.	Erosion ratio
8	good	4	20.5	12.2	34.0	26	0.00	0.00	43.65	25.19	3.90	2.0	2	6	—	33.2	0.25	21.3
		11	61.0	23.5	54.0	52	30.08	0.60	48.70	36.47	13.80	2.6	samples	samples		98.4	1.56	389.1
3	fair	2	28.5	9.2	39.0	26	0.06	0.02	44.87	26.73	3.47	2.0	2	1	—	61.3	0.53	56.2
		4	36.0	16.8	40.5	38	0.20	0.28	48.91	36.43	10.35	2.5	samples	sample		72.3	1.09	136.4
15	bad	8	26.0	15.9	40.5	36	0.06	0.04	43.53	20.10	4.49	2.0	1	13	—	31.0	0.36	20.2
		25	217.0	61.0	86.5	70	17.66	1.36	49.97	32.73	15.05	3.0	sample	samples		93.5	1.55	185.8

and 200 ASTM sieves and the percentage representative of the fraction less than 0.001 mm in diameter, values of the *a*-constant (Dos Santos, 1953, 1955) are also presented (Table I).

Atterberg limits. Determined according to the ASTM standards, the values of the liquid limit and of the plasticity index were recorded. For non-plastic soils, the values were determined by mixing with a reference clay (Dos Santos, 1955).

Compaction. The samples were compacted according to the ASTM standards for heavy compaction. The values obtained, although not significant for erosion analysis, were retained as subsidiary soil identification data (Table I).

CBR. The tests were carried out according to the U.S. Corps of Engineers standards after four days' soaking. The results obtained have been found of little interest with reference to erosion (Table I).

Erosion test in laboratory. In spite of its obvious limitations, the test described by Inderbitzen (1961) was used but with a CBR mould instead of the mould prescribed, a slope of 1:1½, and a rate of flow corresponding to a rainfall of 75 mm/hr. The soils were previously compacted to the maximum dry density and the optimum moisture content determined in the compaction test. Just after the erosion test, the samples were subjected to CBR and vane tests after smoothing the eroded surface, but the corresponding results of these tests were not found significant. With regard to the erosion test itself, it is to be noted that the percentages of eroded soil concern the weight of the top 5-cm layer of the sample. The values presented (Table I) are averages of at least three tests.

Swelling. Determined in the fraction of soils passing the No. 40 ASTM sieve according to the method described by de Castro (1963), this property proved of great interest for the investigation (Table II).

Surface area. Determined in the fraction passing the No. 40 ASTM sieve by the ethylene glycol retention method described by Bower and Gschwend (1952), this property (Table II), which also proved of interest with regard to resistance to erosion, presents a significant correlation with swelling (Fig. 1).

Centrifuge moisture equivalent. Determined according to ASTM standards this property proved of some interest. As it is well known, it corresponds to a point of the suction curves of the soils tested (Table II).

Suction curves. Determined for values of pF from 0 to 4.2, which seemed the interval of most interest for erosion behaviour. The suction plate method was used for values from pF = 0 to pF = 2.2 and the pressure membrane method for pF = 3 to pF = 4.2, according to techniques similar to those described by Croney, Coleman, and Bridge (1952). The drying curves obtained are presented in Fig. 2.

Because of their interest, the maxima and minima values of the moisture content for pF = 0 are presented in Table II.

Absorption limit (AL). This characteristic and its determination were described by Nascimento, de Castro, and Rodrigues (1963). Developed for studying petrifaction in

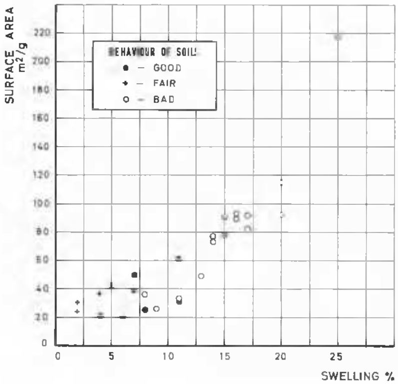

FIG. 1. Correlation of swelling and surface area.

tropical soils, this property is related to various other properties of soils, for example the moisture content for pF = 0 (Fig. 3).

Chemical analysis. The percentages of CO_2 and of organic matter in the whole sample were determined by the current methods. The SiO_2, Al_2O_3, and Fe_2O_3 contents were determined in the clay fraction obtained by sedimentation and from these values the SiO_2/R_2O_3 molecular ratios were calculated (Table II).

Mineralogic analysis of the clay fraction was carried out by X-ray diffraction and thermogravimetric analysis (Table II); this study is the object of a separate paper to be published—Figueiredo (in press).

Middleton parameters. The values determined by the methods described by Middleton (1930) did not confirm this author's conclusions concerning the group of soils studied. Neither the limit values indicated for separation of erosive and non-erosive soils, nor any others enabling a selection could be determined. Table II shows the maxima and minima values of the parameters.

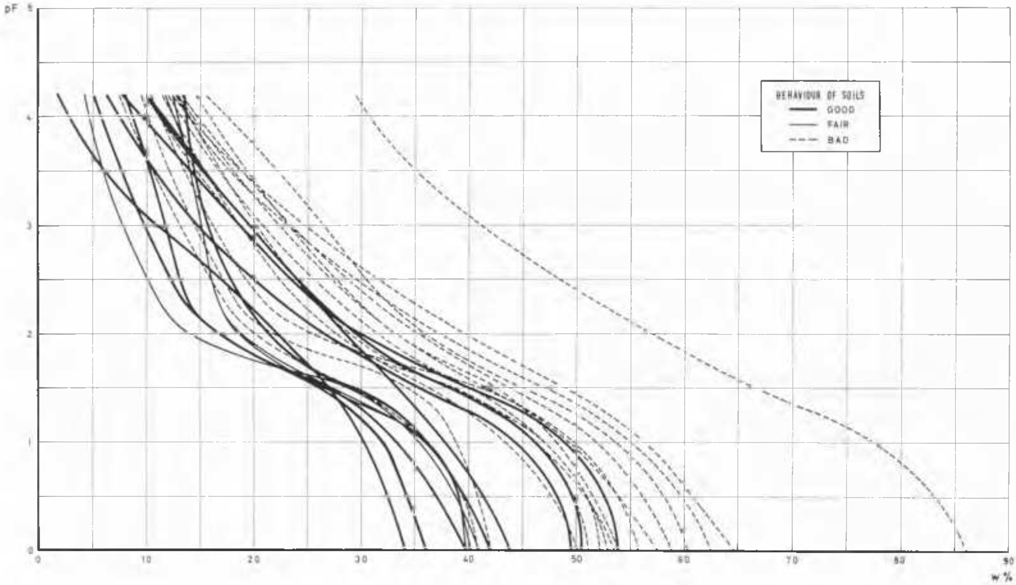

FIG. 2. Suction curves.

SELECTION CRITERIA FOR EROSIVE AND NON-EROSIVE SOILS

The limit values of the properties studied corresponding to soils with a good to fair behaviour in the field with regard to resistance to erosion are indicated in Table III. Choosing these limits so as to exclude soils exceeding them (below or

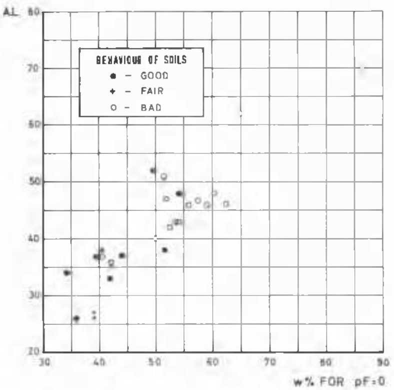

FIG. 3. Correlation of moisture content for pF = 0 and the absorption limit.

above), the same table shows (dark areas) the soils of bad behaviour identified by each characteristic, as well as their total number.

It is at once obvious that no property in itself enables every bad soil to be identified. The most significant criterion seemed to be swelling, identifying 12 out of 15 bad soils. The surface area follows, with 11 identified soils, all of which are included in the former group. Thus a superposition of effects is observed in the identification of bad soils by each of the two characteristics, which is hardly surprising bearing in mind the correlation demonstrated in Fig. 1. Nevertheless, the swelling test being simpler and quicker to perform, it seems advisable to retain it for establishing a selection criterion.

Notice that a similar superposition of effects is observed as regards the Atterberg limits (10 soils in all), the centrifuge moisture equivalent (6 soils), and the moisture content for pF = 0 (7 soils). For the latter values a correlation is shown to exist (Fig. 4) with swelling (similar correlation could also be found with the other properties just mentioned).

Results obtained with the SiO_2/R_2O_3 ratio (6 soils, all coinciding with those identified by swelling) do not make the retention of that property as a selection criterion advisable.

The grain size distribution curve, on the other hand, seems to complement the criterion based on swelling. In fact both the percentage passing the No. 40 sieve and the grain size a-constant identify the same 8 soils, including 3 not previously identified by swelling. This can possibly be explained by bearing in mind that in sandy soils the swelling of the fine fraction, which is scarce, is no longer the predominant factor in resistance to erosion. It is to be noted, that soils 23, 23-A, and 24, identified by grain size distribution curve values alone, are sands. Although the fraction passing the No. 40 sieve and the a-constant lead to the same results with regard to the soils studied, it seems more advisable to retain the a-constant, which is based on six points of the grain size distribution curve, instead of one. This does not exclude resorting occasionally to the criterion based on the percentage of material passing the No. 40 sieve when quick results are required.

TABLE III. CHARACTERISTICS OF SOILS RESISTANT TO EROSION AND THEIR LIMIT VALUES

LAB. NO. OF SAMPLE (BAD SOILS)	GRAIN SIZE DISTRIBUTION CURVE: % PASSING No. 40 SIEVE 49 – 96	% PASSING No. 200 SIEVE 18 – 80	a 0.52–0.92	ATTERBERG LIMITS: W_L ≤ 32	I_p ≤ 1.7	EROSION TESTS: % < 200 1.0 – 5.0	% TOTAL 2.0 – 28.5	SWELLING PER CENT ≤ 11	SURFACE AREA m2/g ≤ 61.0	CENTRIFUGE MOISTURE EQUIVALENT ≤ 23.5	W PER CENT FOR PF=0 ≤ 54	SiO_2/R_2O_3 ≤ 2.6
2				X	X			X	X		X	
9								X	X			X
15	X	X	X	X	X		X	X	X	X	X	X
16				X				X	X			X
23	X		X			X						
23A	X		X		X	X	X					
24	X	X	X			X						
26								X	X			
29	X	X	X			X		X				
30	X	X	X	X	X	X		X	X	X	X	
35				X	X	X		X	X	X	X	
37				X	X			X	X	X	X	
38	X		X	X	X			X	X	X	X	X
39	X		X	X	X			X	X	X	X	X
40				X	X			X	X			X
TOTAL NUMBER OF IDENTIFIED BAD SOILS	8	4	8	9	9	6	2	12	11	6	7	6
	8			10		7						

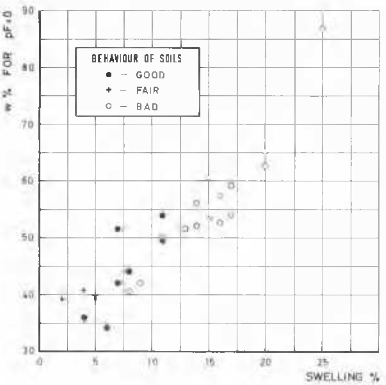

FIG. 4. Correlation of swelling and moisture content for pF = 0.

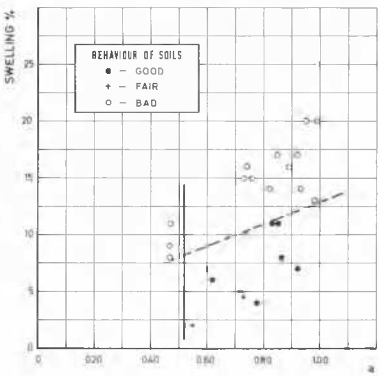

FIG. 5. Values of swelling *versus* a-constant.

Fig. 5 presents the relative position of good, fair, and bad soils in function of swelling and the a-constant. The border-line tentatively indicated by the dotted line must be accepted with much reserve as there are few points available for its definition. The vertical separating line corresponding to the lower limit assumed for a ($a = 0.52$) is also indicated in the figure.

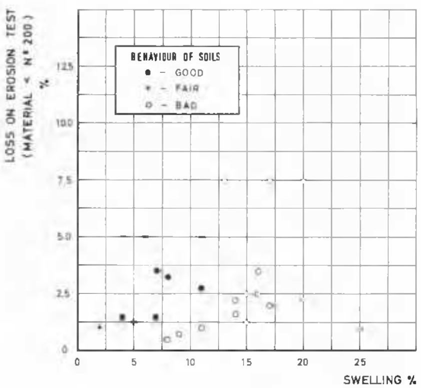

FIG. 6

On the other hand the erosion test in the laboratory (6 soils identified, taking into account the loss of the material passing in No. 200 sieve) does not seem clearly significant; nevertheless the possibility of obtaining experimental data for each soil by variation of the different parameters, as the rate of flow, slope, and compaction is under study.

From the above and bearing in mind the limitations due to the present stage of the research work, it is concluded that the soils studied can be separated in regard to their resistance to erosion in good (and fair) and bad soils by means of the following tentative criterion:

Swelling: $\leqslant$ 11 per cent

a-constant: from 0.52 to 0.92

As a quick, although less reliable, alternative for the latter it is possible to consider: fraction passing No. 40 sieve: from 49 to 96 per cent.

SECONDARY ASPECTS

The mineralogic analysis of the soils studied shows that, in the majority of cases, the prevailing clay mineral is illite, followed by kaolinite; montmorillonite, if present, is always scarce. From the five kaolinitic soils studied, only No. 24 proved erosive which may be due to its grain size distribution curve, with a deficiency of fines. From the predominantly illitic soils only those with a small percentage of clay ($\leqslant$ 16 per cent) proved resistant to erosion.

As for the carbonate content, which is not selective, it seems to exert a favourable influence when it is high, possibly due to a cementing action.

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