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CALCULATION OF CAPILLARY CONDUCTIVITY AND CAPILLARY RISE FROM GRAIN SIZE DISTRIBUTION

III. Air entry pressure and saturated conductivity calculated from grain size distribution and median grain size

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C O N T E N T S

1. INTRODUCTION

In an earlier paper it was shown how one summarizing parameter for the grain size distribution can be obtained from a grain size analysis. This parameter was called the grain size distribution index f and proved to be a convenient measure of the pore size distribution index which is a parameter in the formula of Brooks and Corey for the calculation of hydraulic conductivities (BLOEMEN, 1977b). It was suggested that the moisture tension curve which is generally used for this calculation could be replaced by a grain size analysis. The advantages are that a lot of time is saved, results can be given at much shorter notice and, as only disturbed samples are required instead of Kopecky cylinders, there is a possibility to get much better average samples. Apart from that the empirical approach to the exponent n in Brooks and Corey's formula through a relationship with grain size distribution saves the apparent necessity of adapting the value of n to all kinds of soil by theory (BLOEMEN, 1977a). There are however two other parameters in the Brooks and Corey formula. The formula is

$$k(\psi) = k_s \left(\frac{\psi_a}{\psi}\right)^n \qquad (1)$$

The exponent n is dealt with in two papers referred to above. The air entry value ψ_a and saturated conductivity k_s have also to be known. They can both be measured in undisturbed samples but than Kopecky cylinders have to be sampled again on every occasion and laboratory determinations have to be carried out again.

In this paper it is shown how the results of a finite number of determinations of ψ_a and k_s is transferable to all kinds of soil by way of establishing relationships between these parameters and the median as a measure of average grain size and the grain size distribution, expressed in the index f referred to above.

2. MEASUREMENTS OF AIR ENTRY PRESSURE

The air entry pressure is a measure of the maximum pore size forming a continuous network of flow channels within a medium (BROOKS and COREY, 1964, p.4). Measured values are generally not given in papers on hydraulic conductivity except in some cases (BROOKS and COREY, 1964, App. III, Watson, 1966). Still there has been a continuous attendance to the measurement of air entry pressures but mostly bearing on sand separates (f.i. ENGELHARDT, 1928; PURI, 1939; STAKMAN, 1966), sometimes on disturbed samples of soils of natural composition (PURI, 1939) and exceptionally on undisturbed samples (KUNTZE, 1969). VETTERLEIN and KOITZSCH (1964, table 2) report air entry pressures derived from relations between hydraulic conductivity and moisture tension in samples of homogeneous grain size. These agree very well with the values given by Engelhardt, Puri and Stakman for identical samples. In fig. 1 it is shown that these authors found similar relations between average grain size and air entry pressure. The disturbed samples of natural composition of Puri and the deducted values of Vetterlein e.a. fit in very well.

Whether the relationship in fig. 1 also holds for undisturbed samples is not disclosed in literature. According to KUNTZE (1969) 70% of the measured air entry pressures of undisturbed sandy soils was under 50 cm of water. In clay soils 40% was under 50 cm, 30% over 250 cm. Data on texture are unfortunately not provided. Consequently there is a lack of knowledge about the influence of texture on air entry pressure in undisturbed soils. Therefore air entry pressures were measured in 464 Kopekcy samples of different soil types, except peat soils. The samples were collected on 45 locations in 110 layers below rootzone. Every layer was sampled horizontally and vertically, generally in duplicate. From every sampled layer loose material was taken for a grain size analysis. A large part of the sampling was performed by the Soil Survey Institute (Stichting voor Bodemkartering).

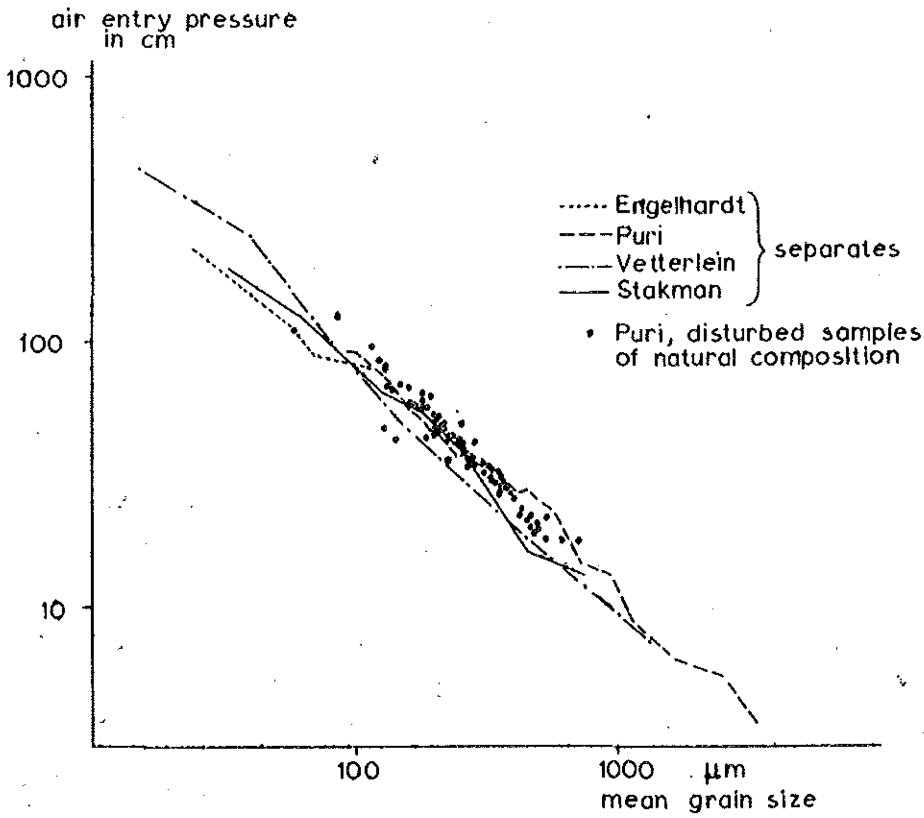

Fig. 1. Relation between air entry pressure and mean grain size, according to several authors

For the measurement of air entry values the apparatus described by STAKMAN (1966) was used, but with slight alterations. These were meant to prevent mechanical influences to damage the samples. The importance of this with respect to the reliability of the measurements is clear. Moreover the samples were to be used for the measurements of saturated conductivity afterwards. Chapter 4 reports on this subject.

3. RELATIONS BETWEEN AIR ENTRY PRESSURE AND TEXTURAL PROPERTIES

In Appendix I some data about texture of all sampled layers are given including the grain size distribution index f (BLOEMEN, 1977b). The means of air entry values measured in vertically and horizontally sampled cylinders are supplied, as well as total means. If these do not always agree with the mean of the other two means, it is because sometimes only one sample could be measured as the duplicate got lost while handling it.

The air entry values only show a moderate agreement between duplicate samples. Vertically sampled cylinders had a standard deviation of 16.1 cm, horizontally sampled cylinders of 22.7 cm. Regression between the averages of horizontally and vertically sampled cylinders satisfies the equation

$$\bar{\psi}_{a\ hor.} = 0.93\ \bar{\psi}_{a\ vert.} + 5.52 \quad (2)$$

The correlation coefficient is 0.77. The T-test of Student showed that the differences between horizontally and vertically measured values were not significant at a 95% level. Therefore the mean of both vertically and horizontally measured air entry values, hereafter denominated $\bar{\psi}_a$, was used to establish some empirical relationship with texture.

In fig. 2 $\bar{\psi}_a$ is plotted against the median grain size Md. In spite of the scatter a relation between the two properties is distinct.

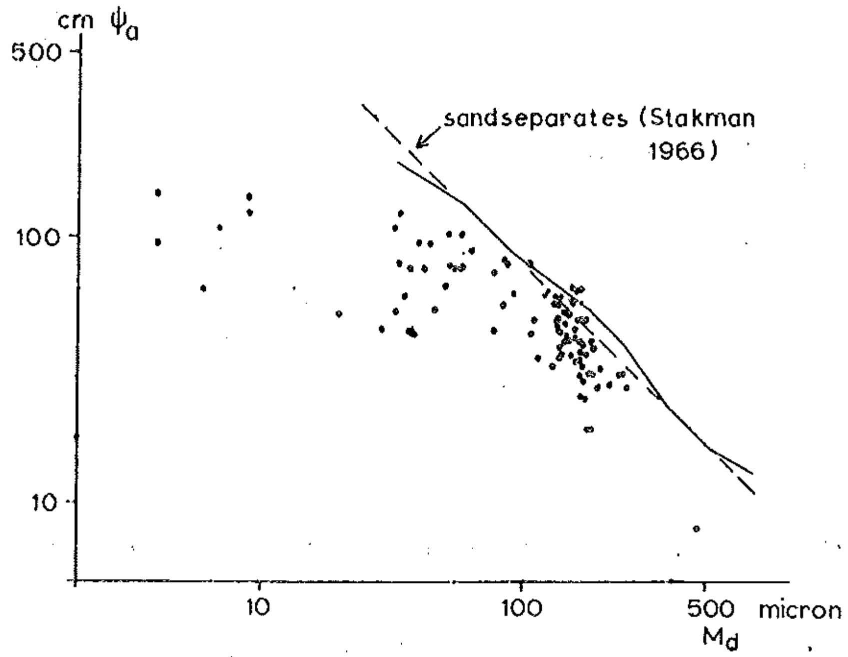

Fig. 2. Mean air entry values plotted against median grain size in natural soils

A curve representing a more or less complicated and unknown function would have to be fitted to the data points. It is for practical reasons however attractive to use convenient expressions, allowing easy calculation of $\bar{\psi}_a$ from texture properties. Interesting in this respect is that the straight line representing the relation between median grain size and air entry values on log-log scales as given by STAKMAN (1966, fig. 2) for sand separates with a sample height of 25 mm, is the upper boundary of the plot. As the separates have a very restricted pore size variety (STAKMAN, 1966, fig. 4), this line indicates that median grain size is closely related to a mean pore size which in the case of separates does not differ much from the largest pore size. There is good reason to suspect that the scatter in diagram 2 has something to do with grain size distribution in natural soils. This is confirmed in fig. 3. Here the ratio of calculated $\bar{\psi}_a$ for sand separates to measured $\bar{\psi}_a$ for soils is plotted against the grain size distribution index f. The calculated values were obtained from the expression

$$\bar{\psi}_a = 6441\ M_d^{-0.96} \qquad (3)$$

given by STAKMAN (1966) for sand separates.

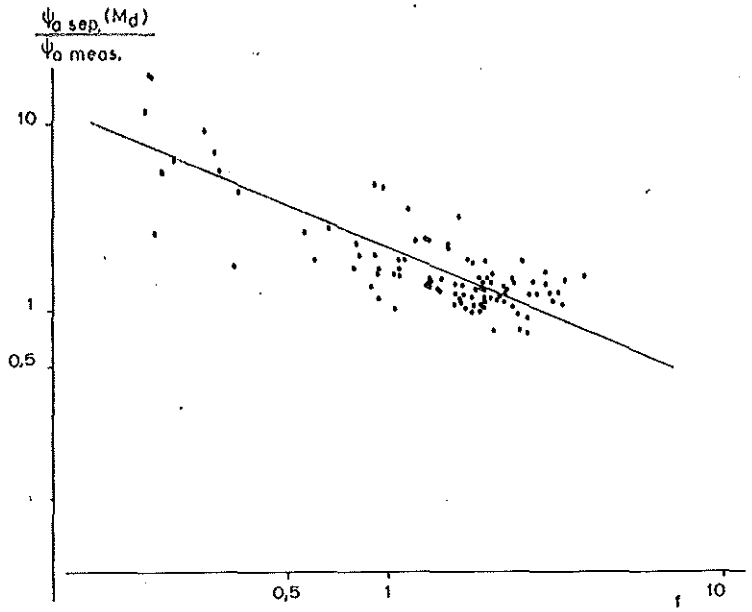

Fig. 3. Relations between index f and the ratio of calculated $\bar{\psi}_a$ for sand separates to measured $\bar{\psi}_a$ for natural soils

Fig. 3 shows that lower values of f go with increasing deviations of $\bar{\psi}_a$ measured in natural soils from $\bar{\psi}_a$ measured in sand separates. This agrees with an empirical relationship between grain size variety and pore size variety (BLOEMEN, 1977a) indicating that lower values of f go with a wider pore size variety. So with equal median grain size the largest pore size in porous media will be larger as the index f decreases. Fig. 3 has also been plotted on log-log scales since this appears to allow the relationship to be represented by a straight line, which satisfies the expression

$$\frac{\bar{\psi}_a(\mathrm{Md})}{\bar{\psi}_{a\ \mathrm{meas.}}} = 2.21\ f^{-0.79} \qquad (4)$$

The correlation coefficient was 0.84. Values of $\bar{\psi}_a$ for natural soils can be calculated as a function of median grain size and grain size distribution, because from equation (3) and (4) it follows that

$$\bar{\psi}_a = 2914\ f^{0.79} M_d^{-0.96} \qquad (5)$$

Fig. 4 is a graphical representation of eq. (5). It appears that

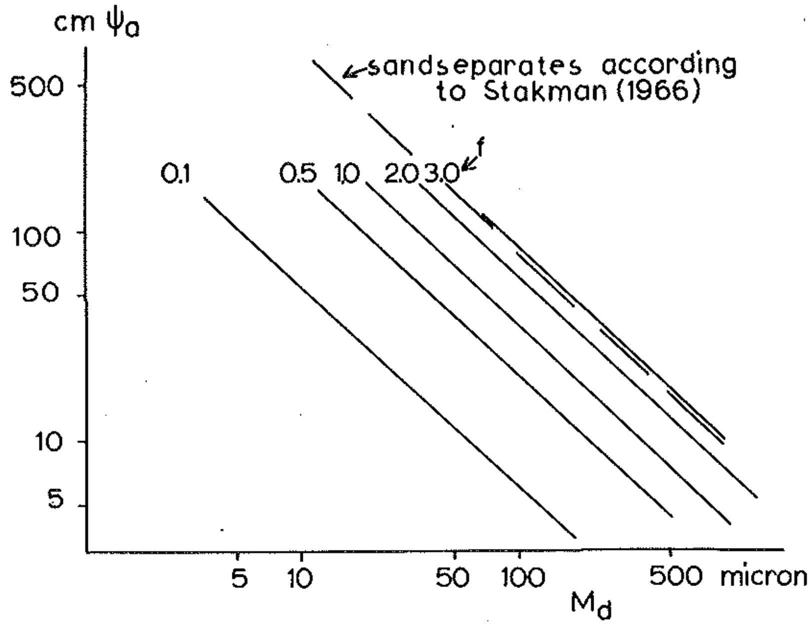

Fig. 4. Graphical representation of eq. (5). The heavy parts of the lines are relevant to natural soils

$\bar{\psi}_a$ of natural soils with f=3 equals $\bar{\psi}_a$ of sand separates with the same median grain size. On a former occasion f-values of separates were calculated (BLOEMEN, 1977b) which show that the mean f-value of the separates involved in Stakman's study was 9.7. This difference should indicate how little natural soils and separates with the same median grain size have in common.

It is evident that for soils with more than 50% < 2 micron the median grain size f cannot serve as a parameter for the calculation of $\bar{\psi}_a$. For that reason the elaboration which resulted in eq. (4) was repeated with the grain size read at the intercept with the cumulative curve of the 80 percentile ($\phi 80$). This met with equally good results. Because this elaboration is only relevant to a relatively small area of soils, it may suffice to state that $\bar{\psi}_a$ may also be calculated with

$$\bar{\psi}_a = 4637\ f^{0.37}\ \phi 80^{-0.93} \qquad (6)$$

The standard deviation between measured $\bar{\psi}_a$ and $\bar{\psi}_a$ calculated according to eq. (5) was 17 cm. This was very unfavourably influenced by a limited number of samples with very low values of f. When these samples are omitted, the standard deviation is only 12.7 cm.

4. MEASUREMENTS OF SATURATED CONDUCTIVITY

Many investigators have shown that soil texture is of major importance for the permeability of soils. ARONOVICI (1947) considers a mechanical analysis to be an index of subsoil permeability and gives data showing a relation between permeability and the percentage < 50 mm for undisturbed soils. DIEBOLD (1954), TALSMA and FLINT (1958) and DELVER (1962) show identical relationships for undisturbed soils of widely different origin. GUMBS (1974) found a significant correlation in undisturbed soils between clay content and permeability.

Much measuring has been done in disturbed samples. MASON e.a. (1959) and AMER (1960) demonstrate a relationship between permeability and the clay plus silt percentage. PILLSBURY (1950) and ZEIN EL ABADINE e.a. (1967) relate permeability and grain size measures. BEDINGER

(1961) found a straight line relationship between the logarithm of permeability and the median grain size diameter. KRUMBEIN and MONK (1942) included in their experiments grain size distribution together with the geometric mean diameter. MASCH and DENNY (1966) studied the influence of median grain size and a measure for grain size distribution on permeability. They gave a set of prediction curves showing increasing permeability with increasing median grain sizes and for a given median grain size, increasing permeability with increasing uniformity of grain size. Their approach is basically identical to what has been shown about relations between textural properties and air entry in chapter 3. The results cannot be applied to natural soil conditions however, because synthetically prepared samples were used.

To test median grain size and grain size distribution on their usefullness as a parameter for the saturated conductivities of natural soils, the samples in which air entry values were measured, were used afterwards for the measurement of k_s. The measurements were performed with apparatus described by WIT (1967).

The mean values of k_s measured in vertically and horizontally sampled Kopecky cylinders are entered in Appendix I, as well as the total means. The k_s measurements show considerable differences between duplicate samples. The standard deviation was 210 $cm.day^{-1}$ and 211 $cm.day^{-1}$ for respectively vertically and horizontally sampled cylinders. Regression between the means of horizontally and vertically sampled cylinders satisfies the equation

$$k_{s\ hor.} = 0.47\ k_{s\ vert.} + 128.75 \qquad (7)$$

The correlation coefficient is 0.66. The Student test showed that the differences between horizontal and vertical measured values are not significant at a 95% level. Therefore the overall means, having a standard deviation of 105 $cm.day^{-1}$ and denominated $\bar{k}_s$, were used to establish an empirical relationship with texture.

5. RELATIONS BETWEEN SATURATED CONDUCTIVITY AND TEXTURAL PROPERTIES

Regression between $\bar{k}_s$ and $\bar{\psi}_a$ satisfies the equation

$$\bar{k}_s = 6225660\ \bar{\psi}_a^{-2.85} \qquad (8)$$

The correlation coefficient is 0.76. In fig. 5 $\bar{k}_s$ and $\bar{\psi}_a$ are plotted. The relationship is close enough to expect that the influence of median grain size and index f on $\bar{\psi}_a$, shown in chapter 3, extends to $\bar{k}_s$ too.

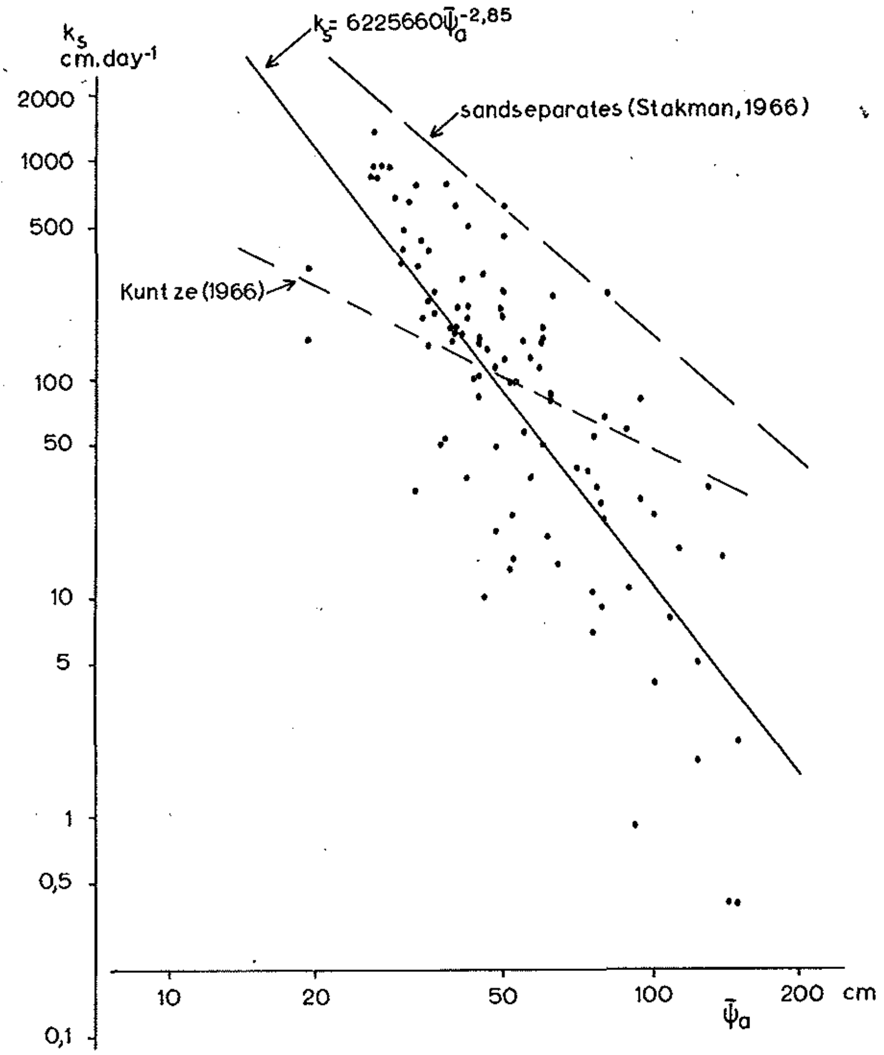

Fig. 5. Relation between air entry pressure and saturated conductivity in natural soils

In fig. 5 the regression line according to eq. (8) is drawn as well as the regression line given by KUNTZE (1966) for natural soils. The two lines don't agree, though they intersect in a point close to the geometric mean of the data. The line representing the expression

$$k_s = 1148100 \quad \psi_a^{-1.93} \qquad (9)$$

which is given by STAKMAN (1966) for sand separates is also drawn in fig. 5. Equation (8) and (9) represent diverging lines. As in the case of air entry values the pore size distribution, represented by grain size distribution, is responsible for this divergence which demonstrates differences between sand separates and natural soils. This is shown in fig. 6. The regression line is satisfying

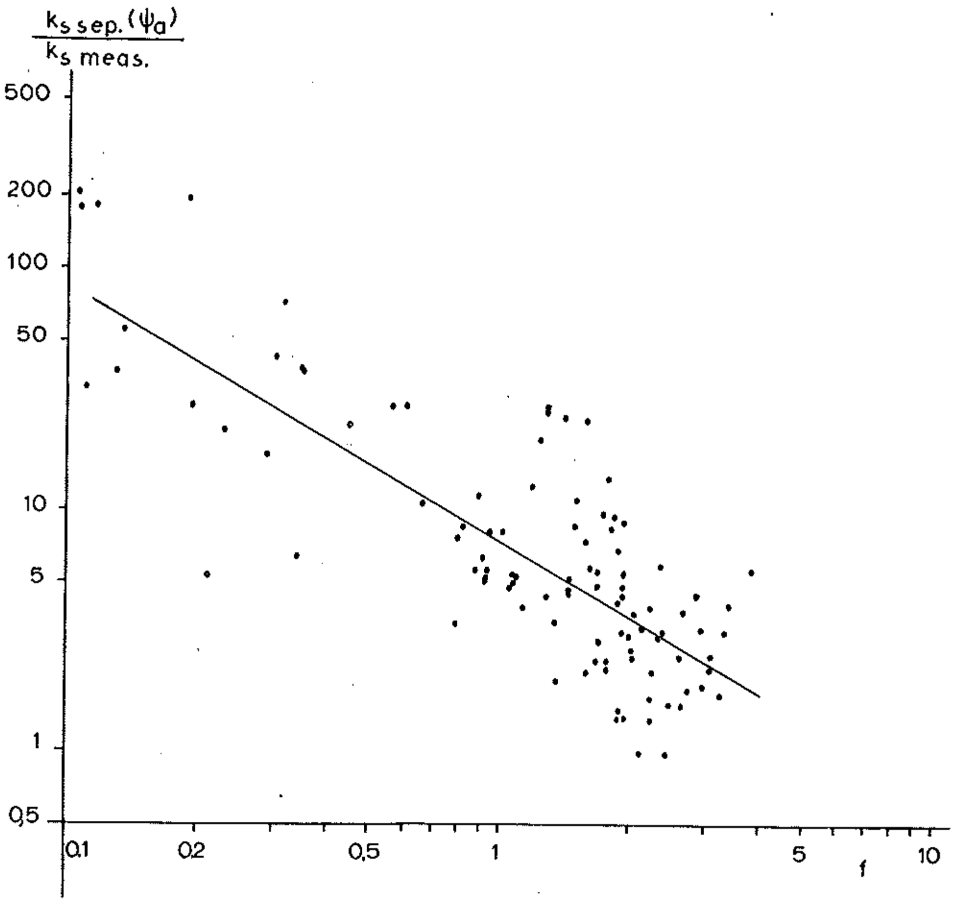

Fig. 6. Relation between grain size distribution index f and the ratio of saturated conductivity calculated for sand separates from air entry pressure to measured saturated conductivity for natural soils

$$\frac{k_{s\ sep}(\psi_a)}{k_{s\ meas.}} = 7.4\ f^{-1.09} \qquad (10)$$

The correlation coefficient is 0.81.

The value of k_s for natural soils can now be calculated from the value of $\bar{\psi}_a$, calculated for sand separates with eq. (5), and a correction for grain size distribution of natural soils, according to eq. (9) and (10) as

$$\bar{k}_s = 155148\ \bar{\psi}_a^{-1.93}\ f^{1.09} \qquad (11)$$

This calculation has the disadvantage of the risk of a propagation of error in $\bar{\psi}_a$, whether calculated or measured, into $\bar{k}_s$. However, if the median grain size is justly considered to be a measure for some or another mean pore size, there will also be a relation between median grain size and $\bar{k}_s$. In fig. 7 this is shown. The regression line satisfies the equation

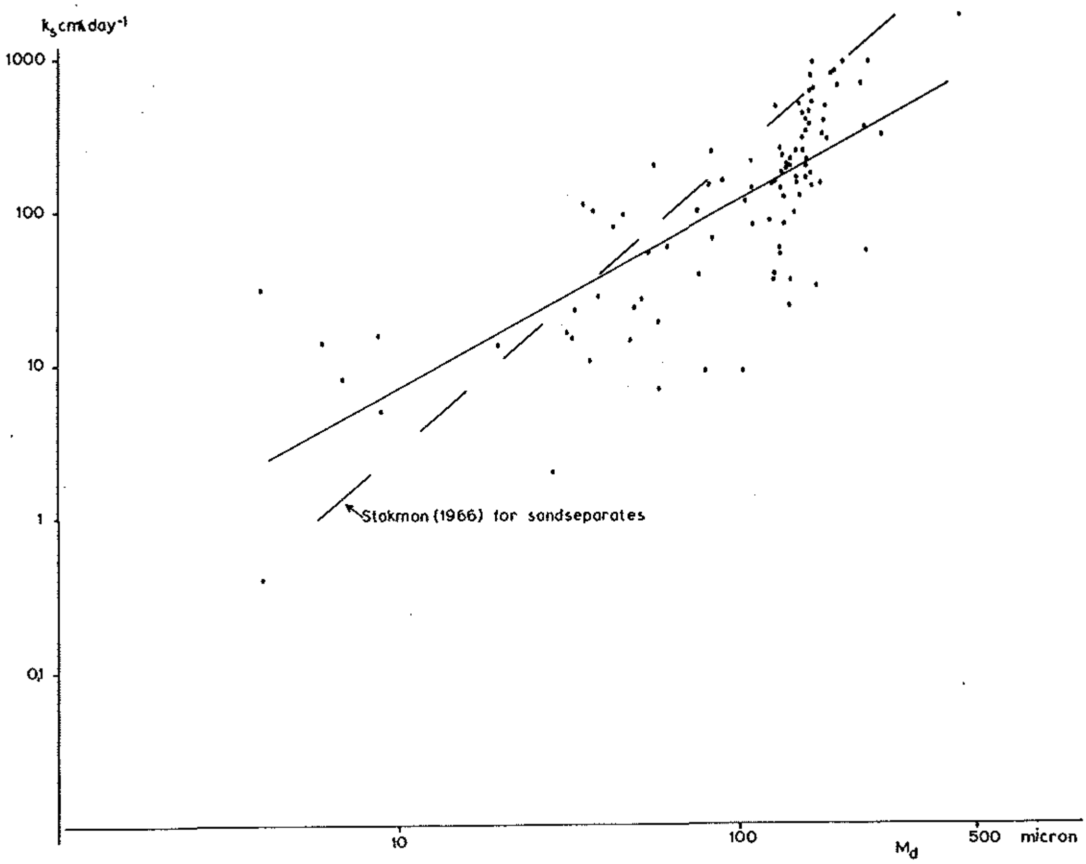

Fig. 7. Relation between saturated conductivity measured in natural soils and median grain size

$$\bar{k}_s = 0.434\ M_d^{1.219} \quad (12)$$

The correlation coefficient is 0.76.

STAKMAN (1966) gives for sand separates

$$\bar{k}_s = 0.032\ M_d^{1.93} \quad (13)$$

In fig. 7 the two lines are crossing and since a lower median gives a lower $\bar{\psi}_a$ for natural soils than for sand separates (fig. 2) and a lower $\bar{\psi}_a$ gives a higher $\bar{k}_s$ for natural soils than for sand separates (fig. 5), a lower median will give a higher $\bar{k}_s$ for natural soils than for sand separates. In fig. 8 it is shown that the ratio's are related to grain size distribution, but the correlation coefficient is only 0.24 and the correlation is not significant. Nevertheless a line was calculated to fit the data points in fig. 8, which represents as good as possible the obvious though widely scattered influence of grain size distribution on the ratio between k_s calcu-

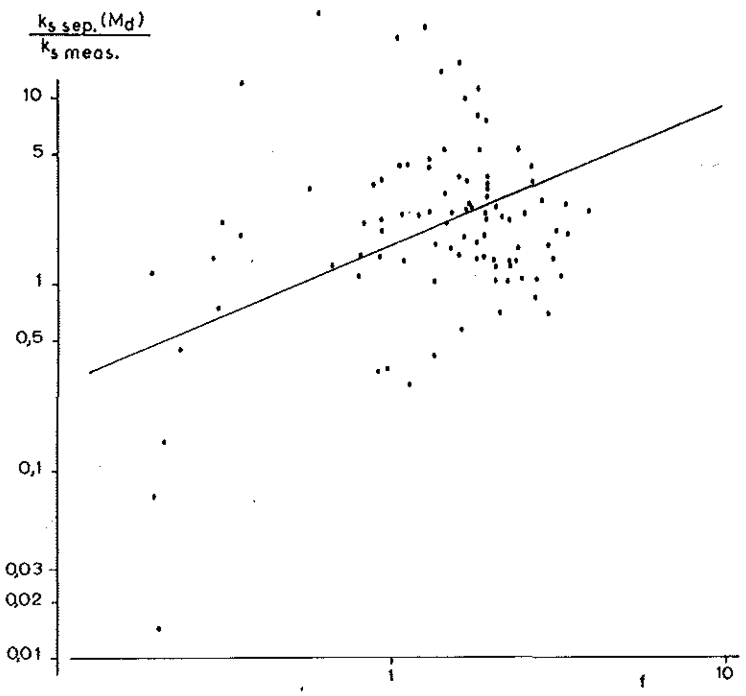

Fig. 8. Relation between grain size distribution index f and the ratio of saturated conductivity calculated for sand separates from median grain size to saturated conductivity measured in natural soils

lated for sand separates with eq. (13) and measured $\bar{k}_s$ for natural soils. This line is a straight one through both the geometric mean of all the data points in fig. 8 and that of only the data points with lower values than 0.4 on the abscissa. It is described with the expression

$$\frac{\bar{k}_{s\ sep}(M_d)}{\bar{k}_{s\ meas.}} = 1.58\ f^{0.74} \qquad (14)$$

From equations (13) and (14) it follows that $\bar{k}_s$ for natural soils can be calculated as

$$\bar{k}_s = 0.02\ Md^{1.93} f^{-0.74} \qquad (15)$$

Determination of how $\bar{k}_s$ can be calculated from grain size distribution and f.e. the 80 percentile was omitted because in those cases that the median would be < 2 micron and therefore undetermined, $\bar{k}_s$ can be calculated with eq. (11).

When calculation of $\bar{k}_s$ with eq. (15) or, when necessary, with eg. (11) is performed for the samples in Appendix I, the standard deviation between measured and calculated $\bar{k}_s$, computed as the totalled square of the differences over twice the number of samples, was 146 $cm.day^{-1}$.

6. SUMMARY AND CONCLUSION

In this paper it is shown how air entry pressure and saturated conductivity, parameters in a formula of Brooks and Corey for the calculation of hydraulic conductivities, can be obtained from median grain size and grain size distribution. These textural properties together give an indication of the pore volume and how it is distributed over pores of various diameters. To allow for easy calculation such relations between parameters and textural properties were determined as can be represented by straight lines on log-log scales. The obtained values seem to be more accurate for air entry pressure than for saturated conductivity. This is comprehensible enough for air entry pressure is closely and directly related to the largest pores in the medium, while saturated conductivity, though generally considered to be related to the volume of large pores, will also be governed by properties not related to the granular composition, such as pore geometry and particle shape.

Since the exponent in the Brooks and Corey formula has on a former occasion been shown to follow from the grain size distribution, it is now possible to calculate capillary conductivities and capillary rise for any soil, provided an adequate granular analysis is available. A following paper will deal with such calculations for a number of Dutch soils.

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Appendix I. Specification of samples and results of measurements

	percentages			micron			ψ_a cm			k_s cm.day^{-1}		
	< 2 µm	< 16 µm	< 50 µm	Md[1)]	Q80[2)]	f[3)]	4)	5)	6)			
1	3.9	4.7	17.5	140	230	0.94	31	41	36	167	239	203
2	2.0		15.1	130	275	1.10	24	40	32	-	339	-
3	1.2		14.6	111	210	2.01	45	53	49	144	282	213
4	4.0	6.0	46.7	50	150	1.30	61	69	65	12	17	14
5	4.0	7.0	79.1	32	55	1.52	115	100	107	17	16	16
6	3.0	5.0	47.0	53	75	1.76	99	57	78	20	33	27
7	0.4	0.6	1.2	465	590	1.51	8	8	8	1712	2048	1880
8	1.2		2.3	178	280	1.30	28	10	19	168	131	150
9	2.5		9.7	135	240	1.46	47	45	46	136	140	138
10	1.5		3.3	180	390	1.21	22	16	19	220	412	316
11	3.2	7.3	14.2	152	275	0.89	34	50	42	164	139	152
12	2.8	3.2	6.4	143	190	1.61	57	48	52	22	26	24
13	4.3	4.9	16.9	108	162	1.08	58	30	49	52	180	116
14	3.3	6.1	20.1	243	400	1.26	38	-	38	53	-	53
15	3.0	5.8	18.9	271	450	1.44	33	-	33	304	-	304
16	0.9	2.2	5.3	208	350	1.33	19	38	28	1425	451	938
17	3.7	4.4	60.4	44	63	1.79	87	103	95	87	72	80
18	6.5		12.1	138	370	0.94	22	48	35	95	361	228
19	3.8	4.6	54.8	47	68	1.63	73	31	52	52	143	97
20	5.1	13.2	66.7	37	150	0.91	26	46	36	-	-	-
21	6.8	14.8	68.8	38	105	0.87	108	-	-	10	-	-
22	7.5	12.9	75.2	36	58	1.14	50	68	59	164	60	112
23	8.0	13.7	69.3	38	69	0.97	40	46	43	126	75	100
24	1.1	1.3	1.9	160	208	2.37	-	34	34	-	431	431
25	0.8	1.2	1.6	180	225	3.42	-	31	31	-	388	388
26	2.0	2.3	3.7	170	232	2.46	-	50	50	-	620	620
27	0.7	1.2	2.1	185	215	3.35	-	41	41	-	285	285
28	2.6	3.9	7.9	163	208	1.68	37	44	40	120	213	166
29	1.5	1.9	4.4	138	194	1.85	45	43	44	66	100	83
30	2.1	2.8	6.5	131	185	1.71	61	60	60	204	295	250
31	1.0	1.6	3.4	165	215	1.92	24	29	27	318	375	347
32	0.9	1.8	4.3	164	221	1.90	46	19	33	257	409	333
33	2.3	2.8	5.5	136	186	1.91	62	49	55	69	45	57
34	1.1	1.7	2.9	132	179	2.27	55	41	48	335	638	487
35	1.0	1.5	2.8	142	190	2.16	46	50	48	316	85	200
36	0.8	1.1	2.0	171	225	2.28	45	30	37	263	735	500
37	8.2	12.4	56.5	34	99	0.67	65	95	80	25	19	22
38	11.3	13.9	42.7	55	77	1.09	67	95	76	106	5	55
39	5.1	6.1	10.8	86	105	2.08	80	81	80	90	55	67
40	10.4	12.4	30.9	63	87	1.34	112	66	89	20	98	59
41	6.3	9.2	34.0	78	138	0.81	45	43	44	32	173	102
42	7.9	10.3	18.9	77	99	1.59	83	65	74	38	39	38
43	12.4	16.5	64.1	40	66	0.92	95	96	95	18	37	28
44	3.9	5.1	9.2	92	123	2.03	71	50	61	94	224	159
45	5.0	6.3	11.3	85	103	2.12	82	80	81	226	266	246
46	8.6	11.1	35.3	58	78	1.34	-	90	-	255	145	200
47	1.1	1.9	3.0	242	345	1.96	28	35	31	362	328	345

Appendix I. continued

	percentages			micron			ψ_a cm			k_s cm.day^{-1}		
	< 2 μm	< 16 μm	< 50 μm	Md	ϕ80	f						
48	0.5	1.1	1.5	186	249	2.99	26	36	31	364	610	482
49	0.5	1.0	1.6	200	270	3.08	26	38	32	624	675	650
50	1.0	2.2	9.4	144	201	1.42	55	29	42	13	58	35
51	1.0	1.7	3.1	161	234	1.93	42	57	50	210	183	197
52	0.9	1.3	2.3	167	207	2.67	47	33	40	554	645	600
53	1.8	2.3	3.3	150	206	1.94	38	44	41	152	170	161
54	2.3	3.2	8.9	174	288	1.03	63	91	77	61	4	32
55	3.7	6.8	28.8	113	190	0.83	34	35	35	146	139	142
56	1.6	2.3	6.1	150	233	1.47	31	41	36	278	212	245
57	1.3	3.3	11.2	168	282	1.11	44	44	44	116	178	146
58	2.9	4.7	9.6	134	188	1.52	-	33	-	-	433	-
59	2.3	2.9	5.1	141	197	1.91	31	37	34	180	201	190
60	1.9	2.4	6.2	137	188	1.80	56	44	50	113	402	257
61	1.4	2.2	3.8	166	220	1.90	44	57	50	495	399	447
62	1.8	2.1	2.8	248	415	1.60	27	28	27	1050	829	940
63	4.5	8.3	38.8	84	174	0.80	35	76	55	201	52	126
64	3.5	4.9	25.2	112	180	0.94	71	53	62	51	107	79
65	3.2	4.4	18.5	126	204	1.06	54	69	62	90	80	85
66	1.2	1.3	2.1	235	345	1.67	28	32	30	625	745	685
67	2.2	2.6	7.9	143	209	1.30	50	33	42	129	255	192
68	1.2	1.7	4.0	139	190	1.95	50	50	50	85	165	125
69	1.2	1.7	6.1	131	189	1.69	46	42	44	51	210	130
70	0.8	1.1	2.0	156	193	3.23	45	40	42	460	535	498
71	0.7	1.6	1.9	189	325	2.23	31	45	38	969	587	778
72	2.4	2.6	5.9	145	188	2.24	44	40	42	135	301	218
73	2.6	3.3	5.3	155	190	2.65	47	67	57	157	104	127
74	2.9	4.4	7.1	135	193	1.82	63	58	60	58	47	52
75	3.7	5.4	8.8	155	192	2.09	64	67	65	-	-	-
76	1.8	2.7	4.3	160	240	2.50	59	68	63	239	247	243
77	1.5	2.3	3.7	160	193	3.11	47	43	45	339	260	300
78	4.1	6.1	11.3	130	178	1.82	59	52	57	24	58	36
79	2.8	4.4	6.6	150	189	2.41	52	52	52	95	100	97
80	3.7	5.5	8.7	130	186	1.67	88	51	70	25	53	39
81	2.4	3.1	4.6	165	199	2.63	76	52	65	150	218	173
82	1.9	3.1	5.0	195	272	2.07	27	27	27	707	930	818
83	2.7	3.9	5.4	137	183	3.89	38	40	39	140	206	173
84	2.6	3.5	5.1	165	199	2.83	51	30	40	107	320	214
85	2.1	8.2	8.9	163	199	2.40	31	39	35	310	465	388
86	1.4	4.9	5.3	171	202	2.99	36	22	29	855	1030	943
87	1.7	7.1	7.8	173	207	2.55	32	18	25	-	-	-
88	1.8	7.4	8.0	168	199	2.73	41	25	33	608	910	759
89	12.7	26.9	65.6	37	83	0.57	87	65	76	4	17	10.5
90	35.1	68.4	94.0	7	24	0.29	101	117	109	7	9	8
91	15.1	31.2	48.1	59	210	0.35	61	122	92	6	8	7
92	17.5	36.4	49.4	52	185	0.34	105	100	102	4	44	24
93	13.1	27.6	36.4	121	258	0.45	47	73	60	25	6	19
94	57.8	80.7	88.9	< 2	15	0.12	127	174	150	0.5	0.3	0.4

Appendix I. continued

	percentages			micron			ψ_a cm			k_5 cm.day^{-1}		
	< 2 µm	< 16 µm	< 50 µm	Md	φ80	f						
95	60.6	80.7	89.5	< 2	15	0.11	106	75	90	1.5	0.7	1.1
96	61.6	82.1	90.2	< 2	15	0.10	100	89	93	1.3	0.5	0.9
97	65.6	88.2	95.3	< 2	11	0.11	140	165	152	0.4	4.0	2.2
98	62.6	88.8	94.6	< 2	11	0.13	102	103	202	2.8	6.7	4.1
99	60.1	86.8	92.3	< 2	13	0.13	136	120	128	2.5	1.5	1.8
100	27.4	43.4	57.3	29	163	0.32	44	46	45	2.0	18	10
101	27.2	41.4	54.6	33	166	0.35	63	42	52	5	25	15
102	23.5	32.7	42.4	105	183	0.61	55	105	80	16	1.5	9.0
103	40.1	68.7	86.1	4	31	0.20	104	85	95	0.2	63.6	32
104	43.9	73.0	89.4	4	24	0.19	109	182	145	0.5	0.3	0.4
105	30.3	47.7	62.1	20	125	0.30	48	54	51	21	6.2	13.6
106	36.4	59.1	74.5	9	76	0.21	130	146	141	0.1	23.5	11.8
107	35.8	58.6	74.6	9	89	0.23	162	86	124	6.5	3.5	5

1) median grain size
2) 80 percentile
3) grain size distribution index
4) mean of generally two vertically sampled cylinders
5) mean of generally two horizontally sampled cylinders
6) mean of vertically and horizontally sampled cylinders