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CONFINED COMPRESSION TESTS ON SOIL AGGREGATE SAMPLES

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1. Introduction

As was discussed in another lecture*, soil compaction is likely to be an important cause of structure deterioration. Therefore it is reasonable to base stability measurements on it. On the other hand it will be necessary to measure properties related to the mechanical behaviour when comparisons between different soils with respect to soil cultivation are to be made.

For this reason a simple method for soil compression tests was developed. Up to now it was used only for clayey soil types.

2a. Method

Soil compressibility will depend on many factors. For a certain soil the most important factors will be : moisture content, apparent density, compression rate and the way in which these quantities varied with time before the moment at which compressibility is determined.

Moisture content of the soil is so important, that compressibility should be determined as a function of moisture content. Other factors should be standardized or described to get reproducible results.

2b. Preparation of the samples

The samples are made air dry by slow drying on plates indoors. Then the samples are crushed till as great a part as possible is brought into the fraction 3,4 — 4,6 mm. Metal rings of 50 cm^3 and a height of 5 cm with a bottom of nylon are filled with air dry aggregates. The rings are held for a few seconds on a vibrator (50 cycles/sec.) to get a reproducible density and then filled to the

(*) Kuipers, H. : „Some remarks on pore space and pressure on marine clay soils".

rim and placed in an exsiccator in which the pressure is decreased to about 1/20 of an atmosphere. All the rings of one soil, are filled with the same amount of soil. After waiting for a quarter of an hour water is let in till it stands some millimeters above the feet of the rings. About one hour is allowed to get saturation, and then the samples are brought to certain pF-values by a suction method. They are dried further if necessary by means of a slow air stream, at about 30° C, that is led through the samples, giving a loss of water of about 0.5 cm^3 per hour.

If the samples are dried in the last way, a week is allowed to reestablish a homogeneous distribution of the water left in the soil. Whether this full week is quite necessary is not yet examined.

Compression tests are done by means of a balance on which the soil samples are placed. They are covered with a metal plate fitting loosely in the ring. By turning a wheel this plate is pressed down and if the speed is not chosen too high a rather constant compression rate can be obtained.

Pressure and compression are read in such a way that they can be plotted against each other.

3. Evaluation of compression curve

If z is the decrease in height of the sample (cm's) and p is the pressure (kg/cm^2) it appears that the relation between them can be described by $z = A - \frac{1}{a + bp}$ (1). This is an empirical function in which A, a and b are constants if there is not a too small air content in the soil, let us say not smaller than 5 %. It shows that the maximum compression is A and that the pressure has a linear relation with the reverse of the decrease in height that still can be established (A — z). However when the pressure is zero, compression is not zero, so the formula will not hold at very small compressions and forces as could be expected.

From formula (1) can be found, that if z_k, p_k is an arbitrarily chosen point on the curve, the relation between $\frac{z - z_k}{p - p_k}$ and p will be a straight line, from which the constants A, a and b can be calculated easily. In fig. 1 this straight line is shown for 2 samples of the same soil compressed at a rate of 1 mm/min.

To separate the two lines the values belonging to the vertical axis are increased by 0,1 kg/cm^3 for one line. Along the horizontal axis p is represented till $p = 1$ kg/cm^2, as here the soil still contains enough air. In fig. 2 the same straight lines are shown, but now p ranges from 0 to 5 kg/cm^2.

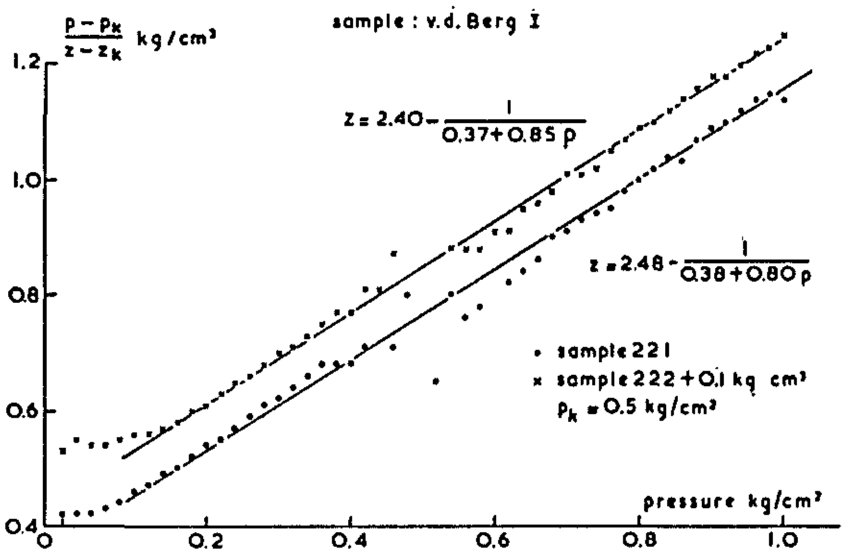

Fig. 1

Example of compression curves after transformation into a straight line for p between 0 and 1 kg/cm²

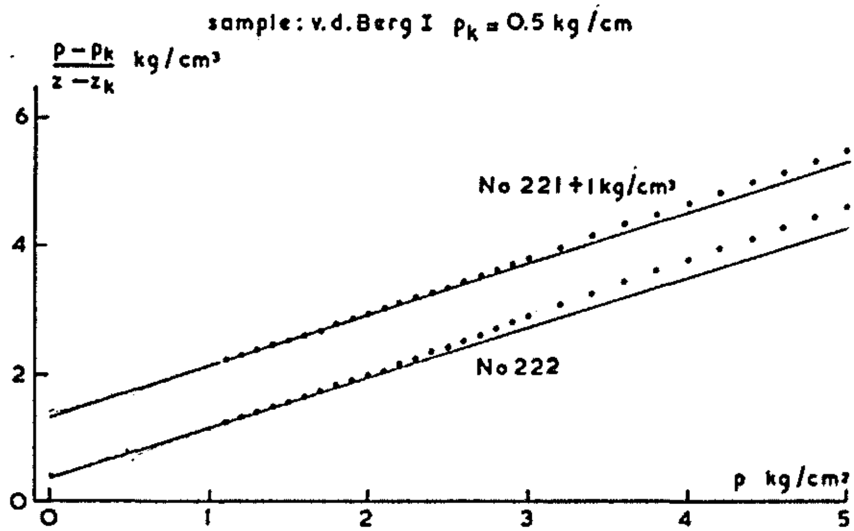

Fig 2

Example of compression curves after transformation into a straight line for p between 0 and 5 kg/cm²

We see that at pressures between 2 and 3 kg/cm² the observations begin to deviate from the line. Here air content becomes so small that water is pressed out of the soil. This new process however also seems to give a rather straight line.

Fig. 3 shows the original measurements of one of these two samples indicated by dots; the lower curve in the range between p = 0 and p = 1 and the upper one between p = 1 and p = 5. The crosses are calculated from the formula found by the rectilinear adjustment.

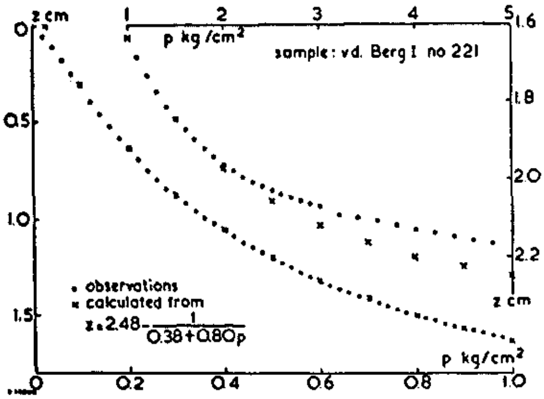

Fig. 3

Example of original compression curve in comparison with the results of rectilinear adjustment

In this graph too can be seen that at a pressure between 2 and 3 kg/cm² compression is restricted.

The constants A, a and b are also easily calculated from three points of the curve if one of the coördinates of the three points form an arithmetic or geometric series. Of course the three points must be chosen in the right part of the curve.

Formula (1) remains of the same type if z and p are interchanged, if z represents the relative compression (decrease in height devided by original height) or % pore space.

A, a and b are related to clay- and organic matter content of the soil. A has a positive correlation with both, and b a negative one. As all three parameters have a positive influence on z it is not easy to see what is the influence of clay and humus content of the soil on the compressions studied. The same holds for the influence of moisture content and therefore the method described below was followed.

4. Soil compression and moisture content

Soil compaction can be harmfull by restricting aeration when the soil is wet. The soil can be called wet at a pF of about 2. Water movement becomes difficult when the soil is drier and a higher water content normally will soon decrease as the water will drain under influence of gravity. So for practical purposes soil compression tests should be compared with regard to moisture content at pF 1.9.

For this purpose on a set of identical samples moisture content at pF 1.9 is determined and from this moisture content and the specific gravity of the soil the percentage pore space corresponding to air contents of 0, 5, 10, 15, 20 and 25 % of volume at pF 1.9 is calculated. From these pore spaces the height of the samples required can be determined.

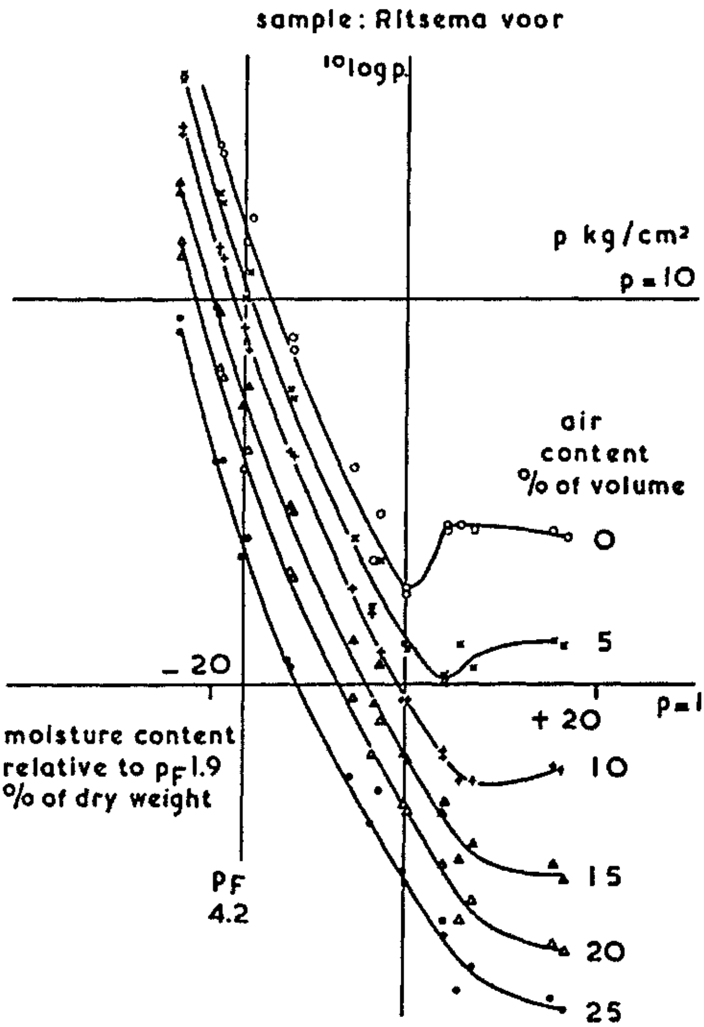

Fig. 4

Example of compression test in relation to moisture content of the soil.

At a constant rate of 1 cm/min. the samples are compressed and pressure readings are taken when the pore space corresponds to air contents at pF 1.9 of 0, 5, 10, 15, 20 and 25 % of the total volume. For one soil the result is plotted in fig. 4.

On the horizontal scale we find moisture content relative to moisture content at pF 1.9 in % of dry weight and on the vertical scale the logarithm of the pressure.

At the right some irregularities are to be seen. They are caused by the fact that at moisture contents higher than pF 1.9 water should be pressed out of the soil to get low pore spaces. At lower moisture contents there is a curvilinear relationship, which sometimes approaches a linear one. In the 10 cases examined up to now it was clear that in the range between pF 1.9 and pF 4.2 the relation was sufficiently described by a straight line. In fig. 4 pF 4.2 is indicated. The range between pF 1.9 and 4.2 will be the most important one, as higher moisture contents normally soon disappear and lower moisture contents do not exist at some distance below the surface.

This relation can be characterized by 3 figures : the amount of water available for plant growth, and the force at a certain pore space at pF 1.9 and 4.2. This certain pore space we calculated from the condition that air content at pF 1.9 should be 10 %.

Table 1 shows the results for 10 soils, ranged according to clay content and percentage organic matter.

TABLE 1

Results of confined compression tests at different moisture contents

Sample	percentage			p (kg/cm^2) at			moisture content pF 1.9-4.2 % dry weight	1000 × log. p / m.c.
	part. < 16 μ	org. matt.	$CaCO_3$	pF 1.9	pF 4.2	lower plastic limit		
Weert h. . . .	14.1	1.7	0.4	1.23	6.0	1.23	18.7	39
Rietema Jr. .	16.0	3.9	1.8	1.86	5.6	1.79	21.3	23
Huizinga . .	25.3	1.6	0.0	1.00	7.6	1.33	19.0	46
Biewenga . .	23.0	3.4	0.6	1.41	5.5	1.51	20.9	27
Ritsema voor	36.6	2.0	0.5	0.91	7.2	1.62	17.0	53
v.d. Bergdijk	35.7	2.7	13.0	1.20	7.1	1.66	19.6	39
Westmaas 35	40.3	1.9	7.5	1.00	8.7	1.60	16.3	58
Gdl. 4033 . .	43.3	5.6	1.1	1.38	6.3	1.54	22.7	29
Rwp. voor	72.1	3.2	10.0	1.41	6.6	1.78	16.6	40
Buist	63.9	8.2	0.0	3.80	14.1	3.19	18.2	32

It appears that at pF 1.9 medium textured soils with normal humus content are compressed easiest. Organic matter raises soil strength at this moisture content. At pF 4.2 however the soils high in organic matter are less hard than those with normal humus contents, except the last soil, which is the only one where the high content of organic matter is due to peat formation. At a moisture content corresponding to the lower plastic limit there is a small increase of the strength with clay content. The amount of available moisture is hardly affected by clay content, but does show a positive influence of humus content. As a linear relationship was found between moisture content and the logarithm of the force at a certain pore space under compression, it is clear, that a relatively small change in moisture content in the dry region will give a rather great change in the force. Strength in a relatively dry state often will not be such an interesting quantity as the change in strength at changing moisture content. So in the last column the slope of the line relating log p and moisture content is given. Here it is very clear, that a higher content of organic matter gave a smaller slope.

5. Further development

These determinations are not necessarily restricted to aggregate samples, nor to the compression rate used. For comparisons with practical conditions it should be kept in mind that there the soil can move in more directions and that the rate of compaction used is rather slow. When the critical pore space, based on 10 % air, is reached the pressure rises with about 0.05 $kg/cm^2/sec.$ at pF 1.9 and about 15 times quicker in an air dry condition. So under wet conditions loading will be much quicker in practice.

SAMENVATTING

Druktest door celproeven op bodemaggregaten

Daar het samendrukken van de bodem zeer belangrijk is bij het optreden van structuurverval wordt een druktest door celproeven als methode voorgesteld, tot het bepalen van de stabiliteit van de aggregaten. Luchtdroge bodemaggregaten (fractie 3,4 — 4,6 mm) worden onder vacuum en in ringen van 3,6 cm doormeter en 5 cm hoogte bevochtigd. Door uitzuigen of uitdrogen laat men de monsters op het gewenste vochtgehalte komen, waarna de druk wordt gemeten die nodig is om een bepaalde constante samendrukking te bekomen.

Is z de samendrukking in cm, en p de benodigde kracht in kg, dan bestaat tussen deze grootheden een betrekking die bij benadering kan uitgedrukt worden als $z = A - \frac{1}{a + bp}$ (waarin A, a en b constanten zijn). Het verdichten van kleigronden is vooral kritiek bij veldcapaciteit (pF 1,9) daar het luchtgehalte dan kritisch is.

Als practische maatstaf voor het verdichten van klei wordt voorgesteld de druk te nemen, nodig voor het samendrukken van de grond met een snelheid van 1 cm/minuut tot een luchtgehalte van 10 volumepercenten bereikt wordt bij een watergehalte overeenstemmend met pF 1,9. Er werd gevonden dat het verband tussen het logarithme van deze druk en het watergehalte, althans voor watergehalten overeenstemmende met pF-waarden gaande van 1,9 tot 4,2, dikwijls kan voorgesteld worden door een rechte. Dit verband kan dus aangegeven worden door 3 parameters nl. : het beschikbaar water tussen pF 4,2 en 1,9 en de drukking bij de pF-waarden 1,9 en 4,2.

RESUME

Tests de compression triaxiale sur les agregats du sol

Etant donné que la compacité d'un sol est un critère fort important pour caractériser la détérioration de la structure, nous proposons une méthode pour déterminer la stabilité des agrégats, basée sur des tests de compression triaxiale (ou essais cellulaires). Des grumeaux séchés à l'air (fraction de 3,4 à 4,6 mm), contenus dans des anneaux de 3,6 cm de diamètre et de 5 cm de haut, sont humectés au vide. Ensuite on réalise la teneur en eau désirée par une méthode de succion ou par évaporation. La compression réalisée est constante pour tous les échantillons et on mesure la pression correspondante.

Si z est la compression en cm et p la force nécessaire en kg, nous obtenons la relation $z = A - \frac{1}{a + bp}$, qui donne une bonne approximation (A, a et b sont des constantes).

La compacité des argiles devient critique au moment où la „field capacity" est atteinte (pF 1,9), étant donné que l'aération à ce moment est un facteur critique. Comme mesure pratique de la compacité des argiles nous proposons la valeur de la pression requise (à une vitesse de compression de 1 cm/min.) pour tasser un sol jusqu'au moment où le volume d'air atteint 10 % du volume total, le sol ayant une teneur en humidité correspondant à un pF de 1,9.

Il apparait que la relation entre le logarithme de cette pression et la teneur en humidité est souvent caractérisée par une droite entre les pF 1,9 et 4,2. On peut donc caractériser cette relation par trois paramètres : l'eau disponible (pF 4,2 — pF 1,9) et les pressions au pF 1,9 et 4,2.

ZUSAMMENFASSUNG

Zusammendrückungversuche bei verhinderter Seitenausdehnung auf Bodenaggregatsproben

Da die Bodenverdichtung bei dem Zerfall der Bodenstruktur scheinbar sehr wichtig ist, wird der Oedometerversuch als Methode zur Bestimmung der Aggregatstabilität vorgeschlagen.

Lufttrockene Bodenaggregate (Fraktion 3,6 — 4,6 mm) werden unter Vakuum in Ringen von 3,6 cm Durchmesser und 5 cm Höhe befeuchtet. Die endgültige Feuchtigkeit wird durch Absaugen oder Eintrocknen hergestellt. Die Zusammendrückung wird konstant gehalten und der Druck gemessen.

Ist die Zusammendrückung in cm = z und die Kraft in kgr = p, dann ergibt die Formel : $z = A - \frac{1}{a + bp}$ einen guten Annäherungswert (A, a und b sind konstanten).

Die Verdichtung der Tonböden wird bei Feldkapazität (pF 1,9) einen kritischen Wert erreichen, weil dann der Luftgehalt ausschlaggebend ist. Als praktische Bestimmung der Verdichtung wird vorgeschlagen : Der Druck, der (bei einem pF = 1,9 entsprechenden Feuchtigkeitsgehalt des Bodens und bei einer Geschwindigkeit des Druckstempels von 1 cm/min.) in dem Augenblick erreicht ist, wo der Luftgehalt der Probe 10 Vol. % beträgt.

Es hat sich ergeben, dass das Verhältnis zwischen dem Logaritmus dieses Druckes und dem Feuchtigkeitsgehalt manchmal durch eine gerade Linie zwischen den pF Werten 1,9 und 4,2 gekennzeichnet werden kann.

Dieses Verhältnis kann also durch 3 Parameter angegeben werden, nämlich durch das verfügbare Wasser zwischen pF 4,2 — 1,9 und den Druck bei pF 1,9 und bei pF 4,2.