The moisture characteristic of heavy clay soils

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In dealing with problems of flow of water in unsaturated soils, there is need for a relationship between the volume fraction of water and an appropriate component of the water potential. In rigid soils, the relation between the matric potential, p_m (Pa), and the volume fraction of water θ (m^3 water per m^3 bulk soil), is named the moisture characteristic (MC) or retentivity curve of the soil. If the soil air pressure is atmospheric (which usually is the case) p_m can be replaced by p_t, i.e. the pressure as can be determined experimentally with a tensiometer. Apart from hysteresis, the p_m-θ relation is a unique one. It shows the soil's capacity for water uptake or release, $d\theta/dp_m$ and also the p_m range for which the soil remains saturated, i.e. $d\theta/dp_m = 0$.

For heavy clay soils the concept of the MC is more complicated. The tensiometer pressure (of which the gradient together with the gradient of the gravitational potential forms the driving force for water flow as in rigid soils) now consist of two component pressures, i.e. the wetness pressure p_w and the envelop pressure p_e. The latter is the result of a load P on the soil. Because of the absence of sufficient contact points between solid phase particles, there will be insufficient reaction forces between those solid particles which implies that a load P on the clay will influence the pressure potential (i.e. p_t) of the water.

If one measures the MC of a heavy clay soil with the equipment normally used for rigid soils, one obtains a p_t-ν curve for load P=0 as schematically given in fig. 1.

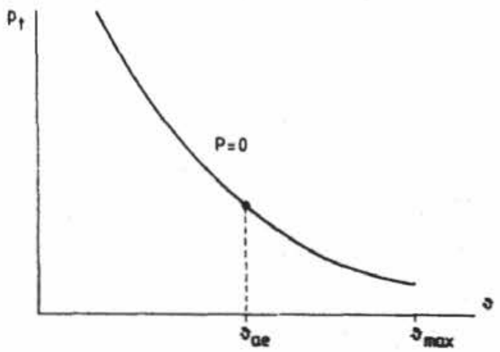


Fig.1 The Moisture Characteristic of a heavy clay soil. ν is the moisture ratio (m^3 water per m^3 solid phase), p_t is the tensiometer pressure (Pa).

The above MC is named the unloaded MC. There is a maximum ν value at which p_t is still < 0. This indicates that there is a remainder of the swelling pressure π which is not able to let the clay swell further due to crosslinking forces between the clay plates.
Another typical aspect of this MC is the shrinking of the soil matrix. In 'drying' from ν_{max} to the air entry value, ν_{ae}, the soil remains saturated. Note that in this range $d\nu/dp_t$ is not equal to zero as is the case in rigid soils. This type of shrinkage is named proportional or normal shrinkage. Shrinkage continues (i.e. the void ratio, e, (m^3 voids per m^3 solid phase) decreases) upon further drying below ν_{ae}. This is named unsaturated shrinkage. Obviously, this MC applies only for P=0, e.g. at the soil surface.
As to the situation below the soil surface where P≠0, the relevant information may be obtained with two different experimental methods, viz.

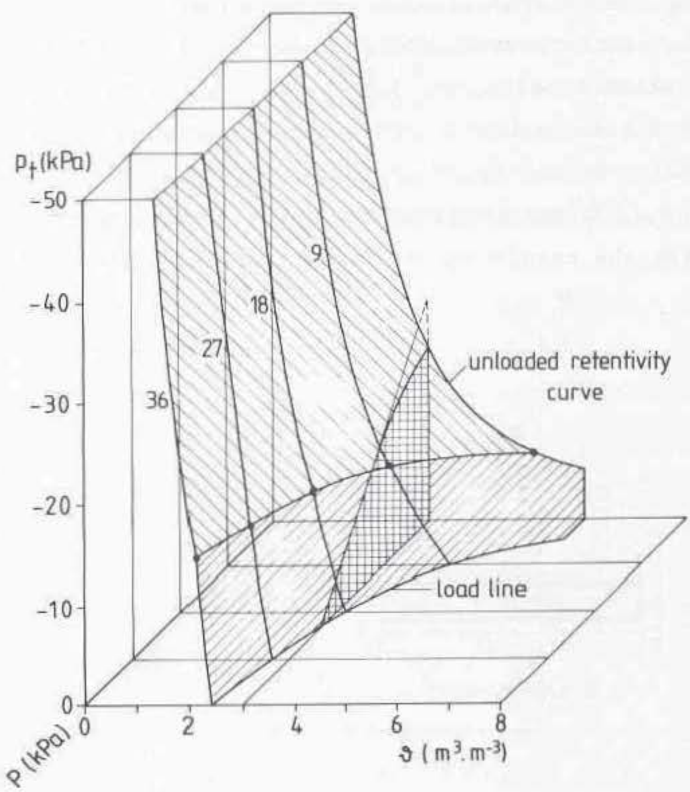


Fig. 2. Three-dimensional representation of a hypothetical family of retentivity curves.

a) One measures (p_t- ν) curves for many P values. The complete MC then consists of a $\nu(p_t$-P) plane as shown in fig. 2.
A special feature of the above MC is the $(\nu-P)_{p_t=0}$ curve which is named the load line, i.e. the reaction of ν on load under the outflow of free water (p_t=0). This is a curve commonly determined in civil engineering. As with 'drying' the soil, loading the soil also causes shrinkage of the soil matrix. In the extreme case of the load line (p_t=0), this shrinkage is named consolidation. If the full $\nu(p_t, P)$ plane is measured, the contribution of the load P to the tensiometer pressure p_t is automatically taken into account. This is shown in fig. 2 where a cross-section for =3 illustrates the phenomenological expression for p_e, i.e.
$p_e = \int_o^P \left(\frac{\partial p}{\partial P}\right)_\nu d\alpha$. The above implies that the MC plane is also fully determined if besides measurement of the unloaded MC, $p_e(\nu, P)$ is obtained from a separate measurement. This leads to the second experimental technique for the determination of the MC plane.
b) It was proven thermodynamically by Groenevelt and Bolt (1972) that p_e can also be written as: $p_e = \int_o^P \left(\frac{\partial e}{\partial \nu}\right)_\nu d\alpha$ sothat the e(ν,P) plane which is named the Shrinkage Characteristic (SC) provides the same information as the extension of the $(p_t - \nu)_{P=0}$ curve into a $\nu(p_t, P)$ plane. A hypothetical e(ν,P) plane is given in fig. 3 (as a projection on the e(ν) plane, showing the result for different values of the overburden P).

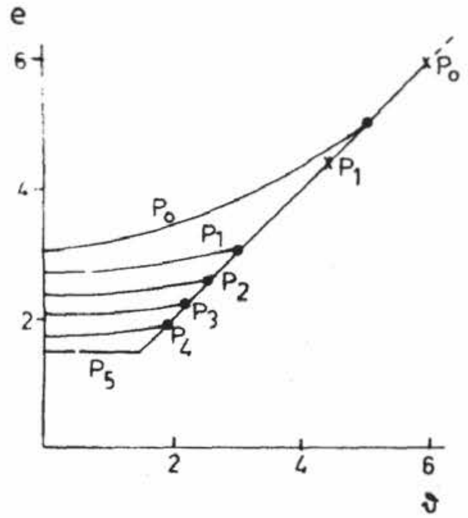
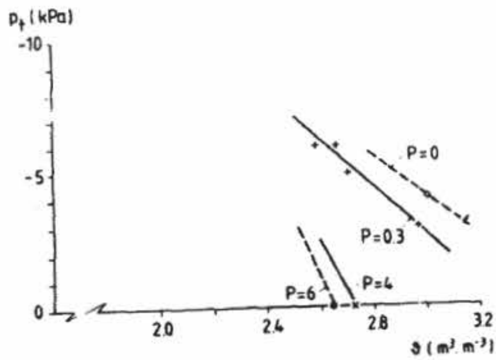


Fig. 3. Hypothetical shrinkage characteristic. •——x: Part of curve, for constant P, where normal shrinkage prevails. P=0 is indicated as P_0.

The above has made clear that there are 4 variables which describe shrinkage and drying of heavy clay soil: ν, p_t, P and e. The plane of the MC includes the effect of P on p_t. However, if the unloaded MC is known, the complete MC can also be obtained from a measured SC. The latter measurement has the advantage that also information about e is obtained sothat then all variables are sufficiently known.
It was tried to measure both the MC and the SC of a margalite clay (Koenigs, 1961) in order to verify that both give the same effect of P on p_t, i.e. p_e. The MC was measured on small samples 4.5 cm in diameter and 1 cm high. These were covered with a course porous plate on which a weight could be placed. The sample was then placed on a fine porous plate. The matric potential of the water in the pores of that plate could be decreased by means of a hanging water column. Some preliminary results are given in fig. 4.

The SC of the margalite clay was determined on samples of 12 cm in diameter and 3 cm high in an experimental set-up shown in fig. 5. The samples in this set-up were dried in an oven at 50°C during 12 days. On 8 days non-destructive measurements of ν and e were made using a double-beam gamma scanner (Stroosnijder and De Swart, 1974). Results of an unloaded and a loaded sample are given in fig. 6 and 7 respectively.



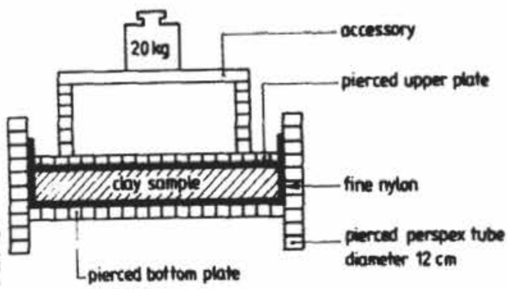


Fig. 4. Some points from the retentivity curve of margalite clay.

Fig. 5. Cross section of a ring used to estimate the shrinkage characteristics.

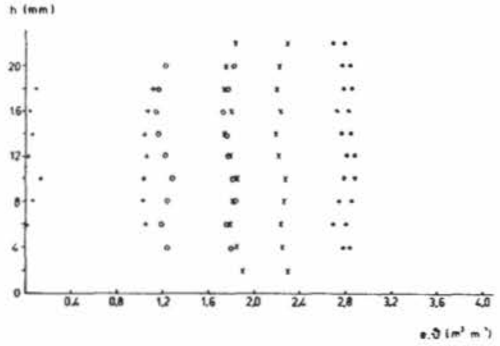


Fig. 6. Drying of an unloaded margalite clay. Points for e are on the right of those for ν.
•: Initial situation. x: After drying for 1 d at 50°C.
o: After drying for 2 d. +: After drying for 7 d.

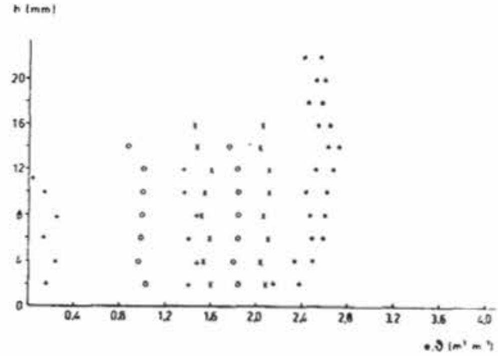


Fig. 7. Drying of a margalite sample under load, P = 17.8 kPa. Key as in Fig. 6.

The SC which could be calculated from the results as given in fig. 6 and 7 is presented in fig. 8. At ν = 1.8 the curves for P = 0 and for P = 17.8 kPa cross. This is not conform theoretical expectation. The latter is due to the fact that the measured e consisted of the total of small voids between the clay plates and which probably are still saturated and a circular crack that circumferenced the shrunken sample. If this crack is not included in e, the curve for P = 17.8 drops and will lie below the curve for P = 0 as theoretically is expected. The need for such a correction clearly shows the 'problem' that cracks give in theoretical considerations.

The above measurements are only preliminary and do not suffice for a true verification of the theory as presented above. Further experimental data are planned with an instrument as shown in fig. 9 where the MC and the SC can be measured simultaneously. With piston 2 a load P1 can be apllied on the soil sample 1 which is on a water saturated porous plate 3 sothat with a gas pressure P2 the tensiometer pressure p_t can be regulated. ν and e can be measured simultaneously and non-destructive with dual gamma transmission. If water can flow both out of and into the sample also hysteresis can be measured with the above instrument.

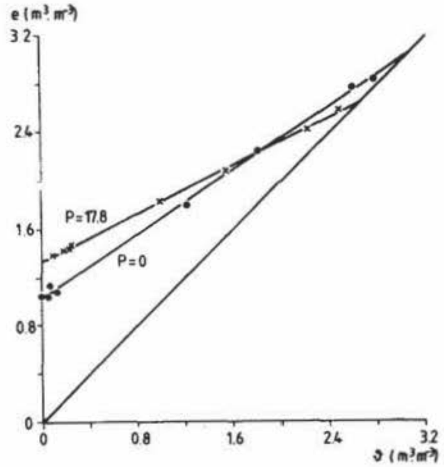


Fig. 8. The shrinkage characteristics of margalite clay as calculated from Fig. 6 and 7.

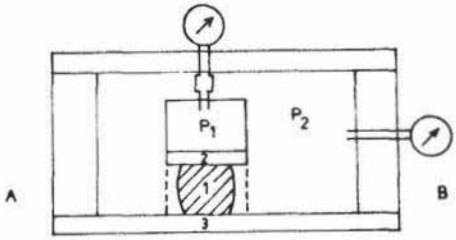


Fig. 9. Scheme of an instrument for estimating retentivity curves of swelling soils. 1: Soil sample. 2: Air-tight piston 3: Pourous membrane. P1: Air pressure estimating envelope pressure. P2: Air pressure estimating tensiometer-pressure. AB: Direction of gamma transmission estimating e and ν continuously.

References.

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