CALCULATION OF INTERPARTICLE ATTRACTION FOR CLAY SOILS FROM WATER RETENTION CURVES

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ABSTRACT

The nature of the water retention curve for a clay soil is determined by interparticle forces. It is possible, with some assumptions of undetermined validity, to calculate the value of interparticle attraction from the measured water retention curve. If water retention is assumed to be the net result of interparticle attraction and repulsion, and if repulsion is measured or calculated, the attraction can be determined. The values for interparticle attraction obtained in this way are consistent with other known physical properties. Relative values of interparticle attraction were also calculated for different soils from the increase in interparticle attraction under different levels of sample compaction during preparation. It is suggested that interparticle attraction calculated from the water retention curve can become an important property for characterizing soils.

INTRODUCTION

One of the important properties of soils is that the constituent particles are held together in a porous structure. The extent to which the particles resist movement into a less porous arrangement is an aspect of aggregate stability. However, we know little about the forces which hold soil particles together. Organic matter and sesquioxides are important, but there are also interparticle bonds between clay particles. The absence of interparticle bonds for silt-size particles explains many of the undesirable physical properties of high-silt soils.

There is no direct method for measuring interparticle attraction. The various indirect methods are unsatisfactory. Aggregate stability or resistance to slaking measure interparticle attraction but are also dependent upon other factors.

In this paper an attempt is made to calculate interparticle attraction from measured water retention curves. Several methods are suggested, but they all depend upon the concept that the water retention curve has components due to attraction and to repulsion between clay particles. A separation of these components results in a calculated value of the magnitude of the force of interparticle attraction.

The strength and coherence of a clay aggregate is the net result of attraction and repulsion between clay particles. This is expected from the predicted behavior of a model of interacting clay particles, and has been shown experimentally by Emerson's (1952) method of measuring aggregate stability by gradually increasing interparticle repulsion until the aggregates break. For a saturated swelling clay soil, the water retention curve is also a volume change curve, i.e. the change in water content results in a change in volume (Warkentin, 1962). The force of attraction which limits swelling therfore also limits water retention. The volume change and water retention curves are identical if the soil remains saturated. If the precent saturation decreases, the volume change in less than the water content change. The water retention curve is a fundamental property of the soil, since it is determined by the interaction between soil and water. It is, therefore attractive in principle to use the water retention curve to calculate other soil properties which depend upon soil-water interaction. Usually we use the general shape of the curve in a qualitative way to characterize soils, although the high suction end of the curve has been used for quantitative analysis of adsorbed water (van Olphen, 1963). In this paper, the water retention curve in the range of 1 to 10 bars suction will be analyzed quantitatively

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Since the volume increase on swelling, and hence the volume of water retained, is limited by the force of attraction it is in principle possible to use the water retention curve to get a measure of an interparticle attraction. Three different approaches will be used in this paper. In the first two it is assumed that the water retention curve is the net result of interparticle repulsion and attraction. Repulsion is obtained by a theoretical calculation or by experimental measurement. In the third approach, increases in interparticle attraction are calculated from changes in the water retention curve on increasing compaction of a soil sample. All three methods have assumptions of unknown validity. Despite this, the values calculated are reasonable and appear useful in characterizing soils.

RESULTS AND DISCUSSION

1. Calculated and Measured Repulsion

For saturated clays we will assume that the measured water retention curve is the net result of repulsion and attraction between particles. This has been discussed by several authors, for example Childs (1956) and Warkentin (1962). The repulsion can be assumed to equal the measured swelling pressure, or the repulsion can be calculated. The only model for a swelling clay which can be used to calculate the amount of swelling is the diffuse ion-layer model (Yong and Warkentin, 1975). The diffuse ion-layer model is quantitatively applicable only to certain end-member systems, such as sodium or lithium saturated montmorillonite. But since it is the only model which allows a calculation, it will be usel here. Any values calculated for force of attraction will be in error by the error in the calculated repulsion.

The values for interparticle (**Table** 1) were calculated from the water retention and swelling curves shown in **Figure 1.** This figure is taken from Warkentin (1962), where the measurements and calculations of swelling pressure are detailed.

Table 1 Interparticle Attraction, in bars, for Leda Clay

	Suction (bars)			
	0.01	0.1	1	3.2
Calculated repulsion	0.5	0.6	0.6	0.7
Measured swelling pressure	1.2	1.5	2.0	0.7

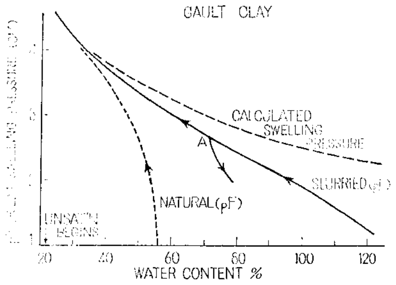

Fig. 1 Measured Water Retention Compared with Measured and Calculated Swelling Pressure for Lead Clay. (from Warkentin, 1962.)

The calculation of interparticle attraction is as follows. At a given water content the measured suction from the water retention curve is subtracted from the measured or calculated swelling pressure. This was done for water contents corresponding to suctions of 0.01, 0.1, 1 and 3.2 bars on the water retention curve.

The interparticle attraction using the calculated repulsion (**Table** 1) is constant, with an average value of 0.6 bar or 6×10^5 dynes/cm^2. Using the measured swelling pressure gives a range of values from 0.7 to 2 bar. The uncertainties in obtaining values for interparticle repulsion from the measured swelling pressure are at least as great as those from the calculated repulsion. The force of attraction would be expected to increase only slightly with increasing suction as interparticle distance is decreased, because this is an undisturbed soil sample.

The results of a similar calculation from **Figure** 2 also taken from Warkentin (1962) are given in **Table 2.** The first row gives the calculated force of attraction for the undisturbed soil using calculated repulsion. The values increase slightly with increasing suction, which is typical of swelling clays as will be discussed in the next section. The average value of 2.9 bar is considerably higher than that for the Leda clay in **Table 1.**

The third row gives the calculations for the slurried sample using calculated repulsion. There is

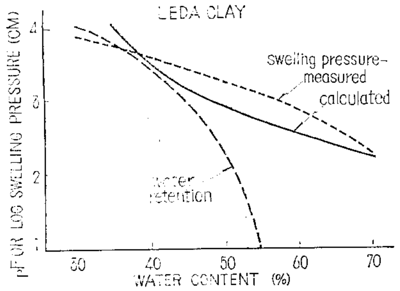

Fig. 2 Measured Water Retention of Sample with Natural Structure and a Slurried Sample Compared with Calculated Swelling Pressure for Gault Clay. (from Warkentin, 1962)

Table 2 Interparticle Attraction, in bars for Gault Clay

	Suctian (bars)				
	0.01	0.1	1	3.2	10
Undisturbed -calculated repulsion	2.5	2.9	3.0	3.2	3.3
-slurried	2.3	2.7	2.2	2.1	2.0
Slurried -calculated repulsion	0.2	0.2	0.8	1.1	1.3

an increase in the force of attraction as the suction increases. This would be expected for this disturbed sample because the particles are being brought closer together as drying proceeds. On a second cycle of drying the interparticle attraction should increase again and eventually reach the average value of 2.9 after many cycles of drying. The difference between 2.5 for the undisturbed sample and 1.3 bars for the slurried sample at 10 bars is a measure of the bonds broken by slurrying which remain broken after one cycle of drying.

The middle line gives the calculated attraction on assumption that slurrying breaks all the interparticle bonds of attraction. These calculated values of attraction for the undisturbed soil are 10—40% lower than those obtained using the calculated repulsion. This change in interparticle attraction on slurrying may be a useful measurment in characterizing soils.

The valuees for the slurried sample at low suction, 0.2 bar or 2×10^5 dyne/cm^2, are at the upper end of the range of 10^4 to 10^5 dyne/cm^2 measured by Norrish et al. (1963) for sodium montmorillonite.

2. Compacted Samples

Another way of measuring differences in interparticle attraction for different soils is from water retention curves of soil samples compacted under different stresses. Four soils with different volume-change characteristics were chosen for this experiment. Air-dry samples were ground to pass through a 0.25mm sieve, and then compacted under static loading of 50, 1000, and 10,000 pounds per square inch (3.5, 70 and 700kg/cm^2). The samples ware wetted and the water retention curve measured. The water content-suction values from th adsorption part of the curve were then used to calculate the forces of attraction created by increased loading from 3.5 to 70kg/cm^2 and from 70 to 700kg/cm^2. The measured water retention curves for adsorption for the low-swelling Ste. Rosalie clay soil are shown in **Figure** 3. The calculated values for force of attraction due to compaction from 3.5 to 70kg/cm^2 are given in **Table** 3. The soils are rated for swelling behavior from lowest to highest as:—

Ste. Rosalie$=$Lamothe$<$Macamic$\ll$Barbados

The first soil is derived from Champlain Sea sedimimets near Montreal, the next two from Lake

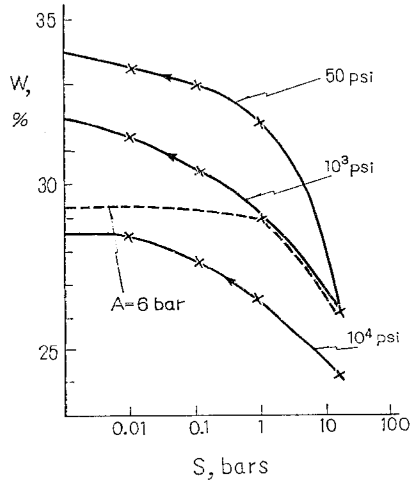

Fig. 3 Measured Water Retantion Curves for Ste. Rosalie Clay Samples Compacted at 50, 10^3 and 10^4 psi (3.5, 70 and 700 kg/cm^2). Dotted Curve is Calculated Water Retention Curve with Constant Force of Attraction of 6 Bar.

Table 3 Attraction Calculated from Difference between Swelling Curves for 70 and 3.5kg/cm² Compaction

Suction (bars)	Ste. Rosalie	Lamothe	Macamic	Barbados
0.01	1.8	3.6	0.3	0.4
0.1	3.2	5.0	0.5	0.9
1	6.0	7.0	1.4	2.5
3.2	6.7	8.7	2.4	3.1
10	5.0	7.8	—	3.0

Barlow-Ojibway sediments near Abitibi, Qnebec and the fourth from flysch deposits in Barbados, W.I.

The values for attraction for all soils (**Table** 3) decrease with decreasing suction from 3.2 to 0.01 bar. This is interpreted as indicating that interparticle bonds are broken on swelling, and hence attraction is lower at lower suction. The largest decreases are below 1 bar suction, the values between 1 and 10 bar are not too different. The values at 10 bar are lower than those at 3.2 bar. This is probably due to inaccuracy in drawing the water retention curves between the measured points.

The low-swelling Ste. Rosalie and Lamothe soils have a much higher force of attraction at all suction values compared with the Macamic and Barbados soils. Also, the decrease in attraction with decreasing suction is proportionally lower in the low-swlling soils.

The water retention curve which would result for the Ste. Rosalie clay if the force of attraction remained constant at 6 bar is shown in Figure 3. The logarithm plot usually used for water retention curves distorts a visual appreciation of the forces of attraction.

The calculated values for interparticle attraction are summarized in **Table** 4. For the Ste. Rosalie and Macamic soils, the compaction from 70 to 700 kg/cm² produced a larger interparticle attraction than did the compaction from 3.5 to 70kg/cm². These materials would likely form strong shales. The high-swelling Barbados soil shows only a small increased attraction between 70 and 700kg/cm² compaction. This distinguishes the Barbados soil from the lower-swelling Macamic.

Table 4 Summary of Attraction Calculations

	Ave. (1-10bar)		Ratio 3.2/0.01	
	70-3.5	700-70	70-3.5	700-70
Ste. Rosalie	5.9	14.7	3.7	8.8
Lamothe	7.8	7.3	2.4	8.4
Macamic	2.4	9.2	8.0	16
Barbados	2.9	1.8	7.0	10

The ratio of interparticle attraction at 3.2 bar to 0.01 bar is higher for all soils for compaction from 70 to 700kg/cm² compared with compaction from 3.5 to 70kg/cm² (**Table** 4). This indicates the greater proportion of bonds broken on swelling.

SUMMARY

The interparticle forces of attraction calculated for the different soils are consistent with other known properties of the soils, such as swelling behavior. Whether or not such calculations will provied useful characterization of soils will be decided when the method is used widely for different soils.

Water retention curves have been measured for many soils, although usaually only the desorption arm of the curve is measured. A number of these curves would likely be suitable for use in calculating interparticle attraction. The compilation of data on interparticle attraction should be useful in our study of stability of soil structure.

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