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BY

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Shrinking and Swelling Properties of two Canadian Clays

Propriétés de retrait et de gonflement de deux argiles canadiennes

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Summary

Dimension/water-content relationships were measured during shrinkage and after saturation on wetting for a low swelling marine clay from the Ottawa - St. Lawrence River valley, and a high swelling lacustrine clay from Central Canada. The marine clay showed about equal horizontal and vertical total shrinkage. Swelling was reduced with decreasing water content to which the samples were dried and with the number of dry-wet cycles. Undisturbed samples with random particle orientation showed higher swelling than remoulded samples where parallel orientation would exist over small distances. In the lacustrine clay, vertical shrinkage exceeded horizontal shrinkage by a factor of three. Swelling was highest for the undisturbed sample and was greater in the vertical than horizontal direction. Remoulding destroyed the natural orientation and decreased swelling. Swelling as a function of particle orientation for the two clays is discussed.

Sommaire

On a mesuré les relations dimensions-teneur en eau d'une argile marine à faible gonflement extraite de la vallée Ontaonais-St.-Laurent et d'une argile lacustre à fort gonflement en provenance du Canada central. Les mesures ont été faites durant le retrait de ces argiles et après leur saturation par mouillage. L'argile marine a révélé un retrait total à peu près égal dans la direction horizontale et dans la direction verticale. Le gonflement a été réduit à mesure qu'on diminuait la teneur en eau des échantillons et selon le nombre des cycles de séchage et de remouillage que l'on effectuait. Des échantillons non perturbés ayant des particules orientées au hasard ont fait preuve d'un plus grand gonflement que des échantillons remoulés où les particules étaient orientées parallèlement sur de petites distances. Dans le cas de l'argile lacustre le retrait vertical était trois fois plus important que le retrait horizontal. Le gonflement était le plus fort dans l'échantillon non perturbé et il était plus élevé dans la direction verticale que dans la direction horizontale. Le remoulage détruisait l'orientation naturelle et augmentait le gonflement. On explique comment le gonflement est fonction de l'orientation des particules dans les deux types d'argiles.

Introduction

This paper describes results of a laboratory investigation of the volume changes associated with water content changes in clay soils. Shrinkage was studied in relation to total volume change and degree of saturation. Swelling on rewetting was measured to determine the total amount of regain and the factors such as arrangement and cementing between clay particles which control this regain. This work is part of a broader program of field studies of volume changes in Canadian soils.

Shrinkage and Swelling

Most of the concepts of shrinkage of clay soils are based upon the work of Haines (1923) on shrinkage of remoulded clays. When a saturated sample is slowly dried, curved interfaces which have a lower pressure on the convex side are formed in the pores on the outside of the sample. Water moves from inside the mass to the curved interface and the soil mass shrinks. Shrinkage is resisted by the forces of hydration of the clay particle surface which cause swelling. The first increments of volume decrease are equal to the water content loss. On further drying a point is reached when the soil structure resists further significant shrinkage, and the soil becomes unsaturated. Further losses of water are accompanied by much smaller decreases in volume. Finally a water content is reached below which no shrinkage takes place. Shrinkage characteristics of a soil depend upon grain-size distribution, type of clay, and arrangement of particles with respect to one another.

Swelling or increase of volume on wetting results from forces of hydration (Grim 1953). For the first increments of water taken up, the forces are associated with hydration of exchangeable ions and of the clay mineral surface. Large volume increases are due to osmotic forces associated with the exchangeable ions (Bolt 1956). Swelling increases with increasing surface area of the clay, with decreasing salt concentration in the pore water, and with decreasing valence of the exchangeable cation. It is influenced by type of clay, arrangement of particles, and the presence of any materials which can cement the particles together.

Volume-change characteristics of clay soils have been measured by a number of investigators. Horizontal and vertical shrinkage for samples of black cotton soil were measured by Sen and Wooltorton (1942). Swelling and shrinking of natural soils and of laboratory samples are given for several Australian soils by Aitchison and Holmes (1953). In connection with engineering problems a symposium on expansive clays was held in South Africa, 1957. Baracos and Bozozuk (1957) have previously reported such problems in Canada.

Experimental Samples

Two geologically different clays were chosen for this study. Samples of Leda clay from Ottawa, Ontario, were selected as representative of the marine clays of the Champlain Sea (Eden and Crawford 1957). Samples from Seven Sisters, Manitoba, were used as representative of the lacustrine deposits of glacial Lake Agassiz in Central Canada (Bozozuk 1954). Properties of these samples are given in Table 1.

Table 1
Soil Test Summary Record

Sample Number	*Description of Soil*	*Depth ft*	*W* %	S_L %	L_L %	P_L %	*Grain Size*		*Void Ratio e*	p_c tsf
							Silt %	*Clay* %		
50-141	Grey Leda clay (marine) from Ottawa, Ontario	18	75	27	70	28	30	70	2·23	2·5
83-27	Grey Leda clay (marine) from Ottawa Ontario.	16	65	27	55	26	30	70	1·94	1·9
88-9	Brown (lacustrine) clay from Seven Sisters, Manitoba	14	62	20	104	41	20	80	1·73	0·5

W Water content in percent of dry weight of soil.
S_L Shrinkage limit.
L_L Liquid limit.
P_L Plastic limit
p_c Maximum preconsolidation load as determined by laboratory tests.

Ottawa Leda clay retains a high water content which is characteristic of clays which settle out in a flocculated structure with a particle arrangement in which edge-to-face contact is dominant (Rosenqvist 1959). It exhibits large shrinkage on drying with limited swelling on rewetting. The clay-size fractions are mostly illite (Lambe and Martin 1955) with an exchange capacity of about 20 me/100 gm. It is largely calcium and magnesium saturated, indicating a material with only moderate osmotic swelling.

Seven Sisters clay was deposited in fresh water (Elson 1957) and a more parallel arrangement of particles would be expected. The clay minerals are montmorillonite and illite (Lambe and Martin 1956) which indicates that osmotic swelling would be high. It has a natural water content which is an equilibrium of swelling against overburden, and exhibits a more nearly reversible shrinking and swelling on drying and wetting.

Experimental Methods

Samples, trimmed from large blocks of clay, retained the vertical and horizontal orientation as existed in situ. Volume changes were measured in two ways. In one series of tests undisturbed samples were trimmed to form cylinders about 4 cm in diameter and from 4 to 6 cm high. Diameter and height of these " cylinder " samples were measured with precision calipers. In a second series of tests thin samples 4 by 30 by 30 mm were cut and placed in protective holding frames. Crosses were marked on one side near the centre of each edge of these " wafer " samples and the distance measured with a travelling microscope to the nearest 0·003 cm. Moisture contents were calculated from the weight of the samples at the time the dimensions were measured.

To measure volume change on shrinkage the samples were allowed to dry at constant temperature. Rate of drying was reduced by enclosing them in a small space. These were not equilibrium values but, with the slow drying rate, the moisture gradients should not be large.

In measuring volume change on swelling the samples had to be moistened carefully to prevent cracking and disintegration. They were first stored for several days in a humid room at a relative humidity of 90 per cent then moistened by placing them on filter paper dipping into water, and finally completely submerged in distilled water.

Readings of dimensions and water content for wafer samples were taken after the sample had been allowed to swell for several days. The cylinder samples were allowed to soak for one week. Limited swelling continued beyond this time.

Some tests were performed on completely remoulded materials to determine the effect of different particle orientation. Tests were also carried out on remoulded samples from which the cementing materials were removed. These samples were first treated with acid to remove carbonates, then with hydro-sulphite to remove iron and aluminum oxides. They were washed free of the excessive acid and salts by centrifuging and decanting, and finally filtered under air pressure through ultra filters.

Results and Discussion

(1) *Shrinkage Characteristics.*

(a) Ottawa (Leda) clay

Shrinkage measurements on cylindrical samples of Leda clay are shown in Figure 1. Initially the horizontal shrinkage is greater than the vertical which may be due to the shape of the sample, but total vertical shrinkage is somewhat greater than horizontal shrinkage.

Measured dimensional shrinkage for the wafer samples of Leda clay (No. 83-27) gave curves similar to those obtained by Haines (1923) and Keen (1931). Within the variation caused by differences between samples, total vertical and horizontal shrinkage were equal. The shrinkage limit decreased from 27 per cent for the undisturbed clay to 20 per cent for a remoulded sample. This indicated a probable breakdown of the edge-to-face particle arrangement during remoulding to a more parallel arrangement over small distances resulting in closer packing of the particles. The oven dry densities, which average 1·64 and 1·77 gm/cm^3 for undisturbed and remoulded samples respectively, corroborated this closer packing.

(b) Seven Sisters clay

Dimensional shrinkage measurements for wafer samples of clay are shown in Figure 2. Total volume shrinkage is about the same as for the Leda clay, but vertical shrinkage exceeds horizontal shrinkage by a factor of three. Dimensional

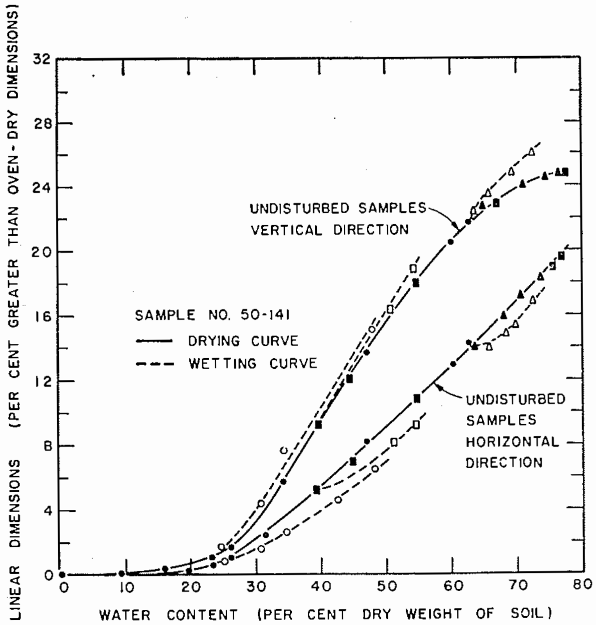

Fig. 1 Dimensional changes in Ottawa clay due to one cycle of drying and rewetting.
Changements dimensionnels dans l'argile d'Ottawa, dû · à un cycle de séchage et de remouillage.

shrinkage with decrease in water content is not linear. Vertical shrinkage is relatively greater at high water content : where the slope of the vertical shrinkage line decreases, the rate of horizontal shrinkage increases. The plate-shaped clay particles have a preferred horizontal orientation, and because the force of repulsion between particles is greatest perpendicular to the flat surfaces, the distances separating the particles are greater in the vertical than horizontal directions.

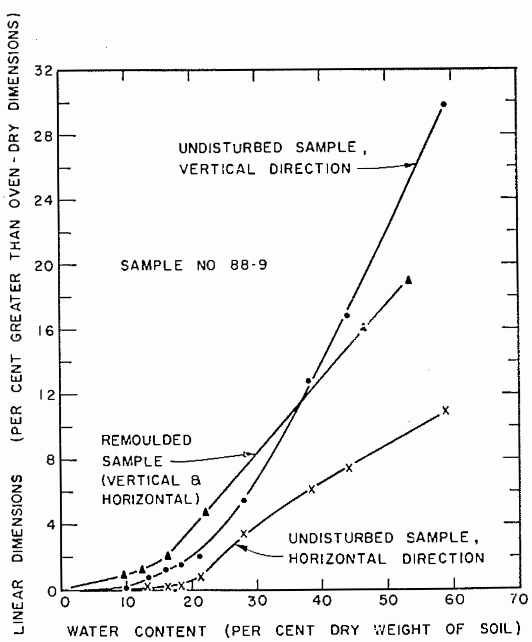

Fig. 2 Dimensional shrinkage curves for Seven Sisters clay.
Courbes de retrait pour l'argile " Seven Sisters ".

When dimensional shrinkage is converted to volume shrinkage, the shrinkage limit is found to change from 20 per cent for the undisturbed to 18 per cent for the remoulded clay. Partial parallel orientation of particles already exists in the undisturbed clay as shown in Figure 2. Therefore remoulding does not result in significantly closer packing of the particles on shrinking as it does for Leda clay.

(2) *Volume and Water Content Regain on Wetting*

(a) Ottawa (Leda) clay

The Leda clay samples did not regain their original water content or dimensions on rewetting after drying. The water content to which they were dried and the structure of the samples both influence the amount of regain. The dimensional recovery for cylinder samples, as shown in Figure 1, decreased on rewetting with the decreasing water contents to which they were dried. Some particle rearrangement must have occurred in drying which resulted, on rewetting, in greater swelling in the vertical than in the horizontal directions. Figure 3

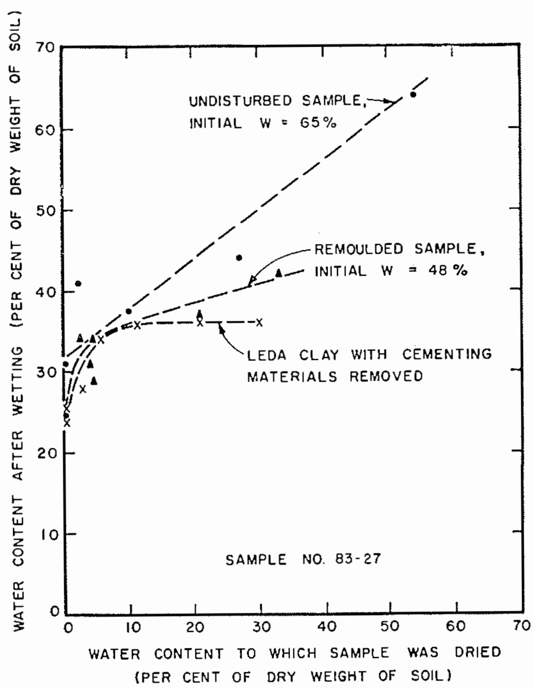

Fig. 3 Water content regain of Ottawa clay samples on wetting after drying.
Récupération de la teneur en eau d'échantillons d'argile d'Ottawa mouillés après séchage.

shows water content regain for wafer samples of clay treated in different ways. There is considerable scatter in the results but a definite pattern exists. The undisturbed samples show an almost linear decrease in the maximum rewetting water content as the samples were dried to lower and lower water contents. The disturbed sample with cementing materials removed shows an almost constant water regain until dried below 10 per cent water, after which regain decreases sharply. The remoulded sample falls between these two extremes.

Volume regain showed the same pattern as water content regain. Differences between samples are due to different particle arrangement. An undisturbed marine clay has a nearly random arrangement of particles separated by large voids filled with water. When it shrinks on drying the particles approach each other more closely, becoming more parallel over distances smaller than their lengths. As the diffuse layers of exchangeable ions of two particles overlap, a swelling force is exerted perpendicular to the flat surface of the particles. This osmotic swelling is small but can result in some volume increase when the sample is in contact with water. Most of the water, however, may still be held by surface tension forces in the voids. Additional drying moves the particles into a more parallel arrangement and water regain becomes dependent more on the small osmotic swelling, and less on the surface tension forces in the voids. The influence on regain of the water content to which the sample is dried is due to this changing structure on drying.

The remoulded samples, especially those with cementing materials removed, have a more nearly parallel particle orientation over small distances (Mitchell 1956). The initial water content for each of the samples is that at which the sample was sufficiently firm to be trimmed and handled. As the structure was more completely destroyed this water content decreased and approached a value attributable to reswelling of the clay particles rather than to pores present because of particle arrangement. With cementing materials removed the samples are more thoroughly remoulded. There was no evidence, however that cementing materials restricted swelling in this clay.

If the drying and wetting cycle is repeated, the water content regain decreases further. These results are shown in Figure 4 for cylinder samples of undisturbed Leda clay dried

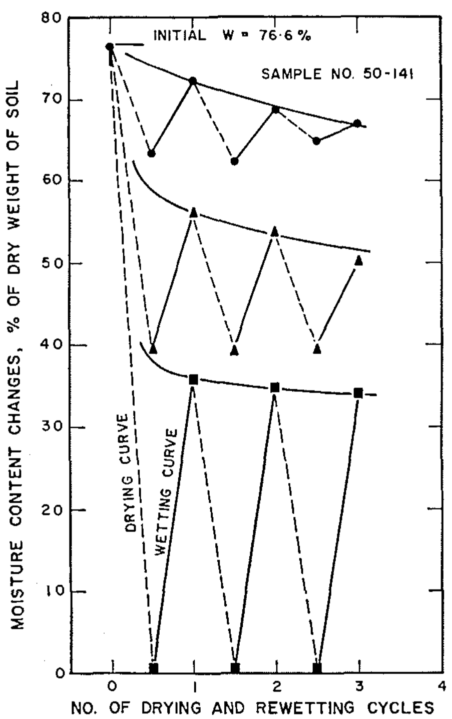

Fig. 4 Effect of drying and rewetting on the ultimate moisture content of Ottawa clay.

Effet du séchage et du remouillage sur l'ultime teneur en eau de l'argile d'Ottawa.

to three different water contents. The net loss after each cycle is small and could be due to further orientation of particles with each drying cycle. After many cycles the volume change should be reversible.

Cylinder samples that had been subjected to $2\frac{1}{2}$ cycles of drying and wetting were allowed to soak in distilled water for an extended period. A typical result for sample 50-141 shows that the water content had increased from 29 per cent to 34 per cent after one day and to 37 per cent after thirteen days on a wet filter paper. The sample was than submerged in distilled water and the water content increased to 40 per cent at fifteen days, 41 per cent at fifty days, and 42 per cent at five hundred and five days, indicating that prolonged osmotic swelling is small.

(b) Seven Sisters Clay

Dimensional recovery for the lacustrine clay samples is shown in Figure 5. The undisturbed samples swell beyond

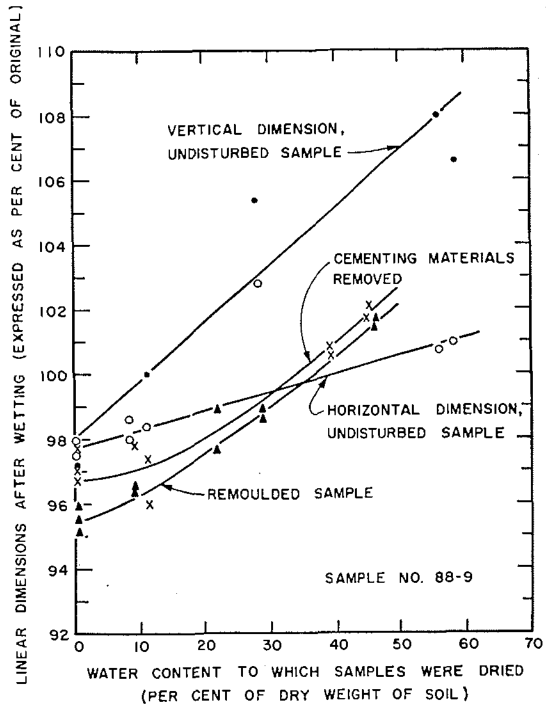

Fig. 5 Dimensional regain of Seven Sisters clay samples on wetting after drying.

Récupération dimensionnelle d'échantillons d'argile " Seven Sisters " par mouillage après séchage.

the original dimensions except when they are dried to low water contents. Vertical swelling is greater than horizontal swelling because the particles are oriented parallel to the horizontal axis. The disturbed samples with less orientation showed a lower regain. After oven drying, the samples with cementing materials removed had a slightly higher regain than the remoulded samples, but there was little difference in swelling from other water contents.

In contrast to the marine clay, this material has the characteristics of a high-swelling clay where the largest water content and volume regain occur for parallel orientation of clay particles. Remoulding results in a decrease of this particle orientation. However, remoulding a marine clay with its initial random particle orientation results in a partial parallel orientation. The swelling force responsible for the high water content is exerted perpendicular to the particle surface, and is proportional to the total surface area. Parallel orientation of particles allows interaction over the maximum area.

Conclusions

(1) Particle orientation had an important influence on swelling and shrinking characteristics of the clays studied.

(2) Random particle orientation accounts for the high undisturbed water content of the low-swelling Leda clav. It

is suggested that the change to more parallel orientation on drying and remoulding explains the subsequent low volume regain upon rewetting.

(3) With Ottawa clay, drying and wetting cycles caused further small decreases in the volume regained on swelling. The increase in water content on extended soaking of a rewetted sample was small.

(4). Undisturbed Seven Sisters clay with a parallel particle orientation regained its initial water content and volume on wetting after drying. Remoulding decreases the volume regain. Remoulding disrupts the parallel particle orientation and hence decreases the effective swelling force in the high-swelling clay.

(5) Cementing materials had little influence on the swelling of the clays studied.

(6) The measurements support the view that the engineering problems created by soil movements are due to shrinkage in marine (Ottawa) clay, and to cyclic shrinking and swelling in lacustrine (Seven Sisters) clay.

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