INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

No. D-5 LONG DURATION CONSOLIDATION TESTS

J. H. van der Burght, Engineer of the
"Rijkswaterstaat" and the Laboratory of Soil Mechanics, Delft

The subsoil of the isle of Marken--situated at 15 km. north-eastward from Amsterdam--Fig. 1--consists of a clay-layer, thick 1.5 - 2 m, under which a peat layer thick 4 - 4.5 m, which rests upon a sandy underground. Around the island is an embankment of about 8 km. length, with a mean height of 1.50--2.20 m above soil surface.

The peat layer under this embankment has been consolidated as Fig. 2 indicates till about 2 m below the peat surface in the neighbourhood.

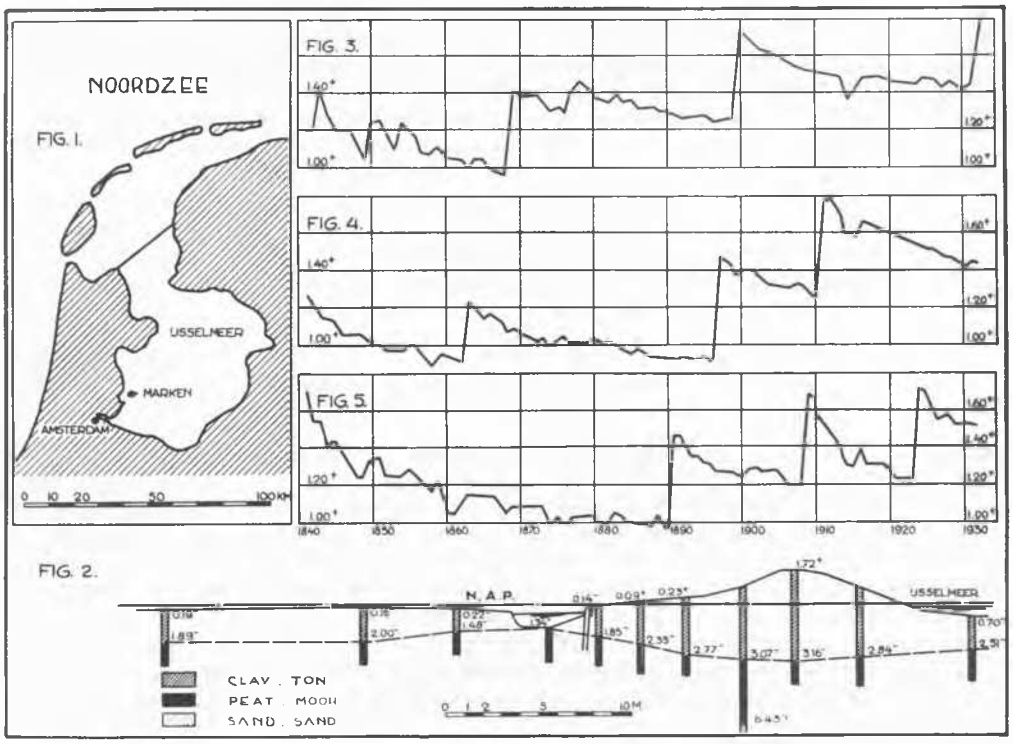
Since 1841 the top of the embankment has been surveyed every year in profiles at distances of 100 m, apparently while a regular settlement of the top had been observed and thus the embankment should be heightened regularly. This was necessary in order to prevent, that the island, before the enclosure of the Zuiderzee, being inundated with high storm floods average once a year, also by common storm-floods should not be inundated.

The embankment of Marken is very old already and has been heightened in the course of ages gradually to greater heighth, by which lateral displacement of the peat practically has not occurred.

The system of loading which the peat has undergone is very simple, and practically comparable with a sideward enclosed mass, which underwent exclusively a vertical compression.

While the loads gradually increased the shearing resistance; the resistance against equilibrium disturbance of the peat also could increase gradually.

The peat is still compressed--mean 8 mm annually which prove the diagrams of Fig. 3, 4 and 5, which give the time-settlement diagram of the top from 1841-1932 of some profiles of the dike.



Figs. 1, 2, 3, 4 & 5.

No. D-6 THE CHEMICAL NATURE OF CLAYS

Prof. Dr. K. Endell and U. Hoffmann, Technische Hochschule, Berlin

Introduction. The physical characteristics of two apparently identical clays may, as is well known, be very different. In the failure to recognize the essential differences doubtless lies the cause of many accidents which occur in connection with structures built on clay, such as the excessive or unequal settlement of buildings, earth slides, etc.

Beside the so-called clay fraction, which will be discussed in detail below, all clays contain variable amounts of non-plastic material of different grain-size, such as quartz, mica, calcite, feldspar, and rock particles, and frequently humus. The amount of water contained in a soil under a given pressure depends on the humus content, the type of clay mineral or minerals present, and on the material chemically dissolved in the soil (dissolved in the water?)

Nature of Clays. The usual practice of designating as clay the fraction smaller than 2 μ is not justified by our present knowledge of the subject. In the past few years, clays from Germany, Denmark, Holland, the

United States, Canada, Argentina, Egypt, West Afrika, Java, and the Philippines have been investigated by röntgenographic and colloid-chemical methods, which have indicated the presence of crystalline clay minerals in all of them.(S.B. Hendricks u. W.F. Fry: The results of X-ray and microscopical examinations of soil colloids. Soil Science 30 (1930, 447. W.P. Kelley, W.H. Dore u. S.M. Brown: The nature of the base exchange material of Bentonite, soils and zeolites, as revealed by chemical investigations and X-ray analysis. Soil Science 31 (1931) 25. K. Endell, U. Hofmann und D. Wilm: Über die Natur der keramischen Tone. Ber. deutsch. Keram. Ges. 14 (1933) 407. U. Hofmann, K. Endell und D. Wilm: Über die eindiemensionale Quellung des Montmorillonits. Z. Krist. 86 (1933) 340 und dieselben Röntgenographische und kolloidchemische Untersuchungen über Tone. Z. angew. Chem. 47 (1934) 539.)(P. Vageler: Der Kationen und Wasserhaushalts des Minéralbodens. Berlin 1932. K. Endell, H. Fendius und U. Hofmann: Basenaustauschfähigkeit von Tonen und Formgebungsprobleme in der Keramik (Giessen, Drehen, Pressen) Ber. Deutsch. Keram. Ges. 15 (1934) 595. F. Alten und B. Kurmies: Die physikalisch-chemischen Gesetzmässigkeiten beim Kationenaustausch in Mineralböden und A. Jakob, U. Hofmann, H. Loofmann und E. Mägdefrau: Chemische und röntgenographische Untersuchungen über die mineralogische Sorptionssubstanz im Boden. Z. angew. Chem. 48 (1935) 584 und Beiheft Nr. 21 (1935) derselben Zeitschrift.) In contrast to the non-plastic constituents (quartz, feldspar, calcite, etc.) which may also occur in the fraction smaller than 2μ , the clay minerals are responsible for the swelling and the plastic flow of clay soils. (K. Endell: Beitrag zur chemischen Erforschung und Behandlung von Tonböden. Die Bautechnik 1935, 226. R. Seifert, J. Ehrenberg, B. Tiedemann, K. Endell, U. Hofmann, D. Wilm: Bestehen Zusamme nhänge zwischen Rutschneigung und Chemie von Tonböden? Mittl. Preuss. Versuchsanstaltf. Wasserbau u. Schiffbau Berlin Heft 20, 1935, 34 S.)

Colloid-chemical investigations have shown that all clay minerals are so fine-grained, and have, therefore, such a large specific surface, that certain small quantities of exchangeable kations (positive ions) attached to the surface may be determined quantitatively by chemical or electrochemical methods. Fig. 1 is a diagrammatic representation of a crystal of a clay mineral to whose surface kations are attached. By their capacity to attract and hold water in a partially fixed state, and their tendency to dissociate from the clay mineral crystal, they determine the most important properties of clay soils, such as swelling capacity, and the angle of internal friction.

The sum of the exchangeably bound kations is designated as the S-value, and is determined in milliequivalents per 100 grams of dry material, by means of replacement with ammonium chloride. The S-values of clays consisting largely of certain of the clay minerals lie between the limits given below:

Kaolin (kaolin clays),	3-15	milliequivalents
Bentonite (Montmorillonite clays),	40-100	"
Unknown clay minerals	20-50	"

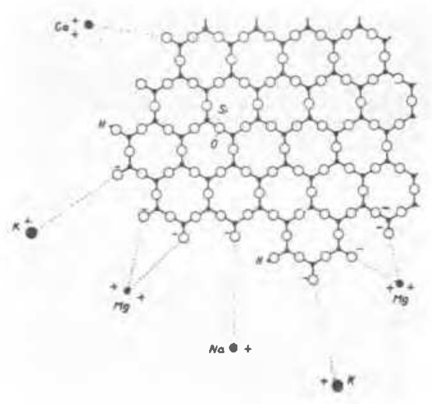


Fig. 1. Diagrammatic representation of the exchangeable kations on the edge of a Si-O layer of a clay-mineral crystal.

The univalent ions, such as Na are highly dissociated (loosely bound). Na has also the capacity of holding large quantities of water. The bivalent ions Ca and Mg are somewhat more firmly attached to the clay particles, but can hold a certain amount of water. In contrast to these are the very slightly dissociated hydrogen ion (H) and the trivalent kations like aluminium and iron, which are firmly bound and can hold very little water. In addition to the crystalline structure and the type and amount of exchangeable kations bound to the particles, the alkaline or acid character of the water in the soil plays an important part in the determination of the swelling capacity of the clay mineral in water.

By röntgenographic methods the following minerals may be determined in clays, even though, as often happens, they occur together in the same soil:

1. Kaolinite	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$
2. Montmorillonite	$Al_2O_3 \cdot 4SiO_2 \cdot xH_2O$
3. Unknown clay minerals	not yet exactly known.

While the individual layers of the space-lattice of kaolinite are rigidly attached to one another, as in the case of practically all other crystals, those of montmorillonite may increase or decrease their distance from one another, as water from the surroundings enters the crystal. The amount of water so absorbed, and thus the distance between the individual layers, is a function of the humidity of the environment. Since montmorillonite, the typical mineral of all bentonites, occurs much more frequently in clay soils than has previously been supposed, this fact is of importance in connection with the present problem. However, the intracrystalline change in the space-lattice plays only a minor part in the visible swelling of clays which is caused chiefly by the fixation of water by the kations attached to the surfaces of the clay particles.

The following Table I gives some important properties of kaolin and bentonite, which consist largely of kaolinite and montmorillonite, respectively, two of the most important constituents of all clays.

TABLE I

Some Important Properties of Kaolin and Bentonite

Group	Kaolin	Bentonite		
crystal structure	kaolinite, rigid	montmorillonite, expanding, accordion-like		
exchangeable kations a) quantity in milliequivalents per 100 gm dry clay	small, 3-15	large, 60-100		
b) kind	Ca, natural occurrence	Na, artificial product	Ca, natural	Na, natural
water content at the liquid limit (Casagrande apparatus)	60	50	150	500-700
conspic. thixotropic gel if mixed in clay: water ratio	ca. 1:1	ca 1:2	ca 1:3	1:10 to 1:20

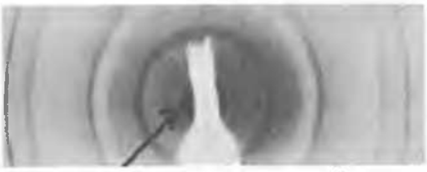


Fig. 2a. Debye-Scherrer X-ray diagram of kaolin. The inner ring indicated by the arrow corresponds to the rigid layers of the space-lattice, and is always located at the same distance from the center of the diagram, indicating a constant distance between the layers.

Fig. 2b. Debye-Scherrer X-ray diagram of montmorillonite. The inner ring indicated by the arrow corresponds to the movable layers of the space-lattice; its distance from the center depends on the water content of the system, indicating that the distance between the layers of the space-lattice vary.

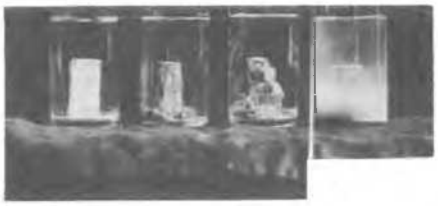


Fig. 3. Disintegration of various clays and soils after 15 minutes' immersion in water.

TABLE II

Essential Characteristics of Disintegrating Clay Specimens Shown in Fig. ~~2~~ 3

No.	Description	Essential Constituent	Accessory	Original water-content	S-value	Na-value
					in milliequivalents per 100 gm dry clay	
1	washed, non-plastic kaolin	kaolinite	10-20% quartz	30	4	0
2	plastic Westerwald clay	kaolinite	about 10% quartz	45	10	0
3	bentonite (bleaching clay)	montmorillonite	5% quartz	100	60	1
4	marine sediment, nr. Hamburg, (Na-clay)	montmorillonite	5% quartz	60	26	6

Fig. 2 shows the Debye-Scherrer röntgen diagrams for the two minerals. Beside kaolinite and montmorillonite, one or more unknown clay minerals have been frequently encountered in clays. Their properties lie between those of kaolinite and montmorillonite.

A thixotropic gel is one which may be liquified by a mechanical disturbance alone, without temperature change, and becomes solid again after the disturbance has ceased. The fact which has been observed and investigated by A. Casagrande that many soils have a smaller bearing capacity in a disturbed than in an undisturbed state is probably to be explained at least in part by the thixotropic properties of the clays.

Since the univalent, (Na and K) and to a smaller extent, the bivalent, bases (Ca and Mg) which are loosely bound on the surfaces of the clay particles, tend to unite with water, all dry clays swell more or less in water and tend to disintegrate into their constituent particles or into lumps or flakes. In Fig. 3 are shown a few characteristic pictures of clay specimens disintegrating in tap water, and Table II gives some data concerning these clays.

Fig. 3, in connection with Table II, shows very clearly that disintegration becomes more marked with increasing amounts of exchangeable bases. There is a very marked difference between the Ca-bentonite No. 3 and the Na-clay No. 4 in that the water surrounding the former is quite clear, owing to the flocculating effect of the Ca-ion, while that surrounding the Na-clay is cloudy.

If it were possible to destroy this swelling capacity of clay immersed in water, plastic flow of clay could be prevented. The electrochemical nature of the attachment of the exchangeable bases suggests that this may be accomplished by means of an electric current. Another abstract by the present writers presents the results of some investigations which have been carried out in this direction.

No. D-7 THE SHEARING RESISTANCE OF SATURATED SOILS AND THE ANGLE BETWEEN THE PLANES OF SHEAR

Dr. Karl v. Terzaghi, Professor at the Technische Hochschule in Vienna

The stresses in any point of a section through a mass of earth can be computed from the *total principal stresses* n_I', n_{II}' and n_{III}' which act in this point. If the voids of the earth are filled with water under a stress n_w, the total principal stresses consist of two parts. One part, n_w, acts in the water *and* in the solid in every direction with equal intensity. It is called the *neutral stress*. The balance, $n_I = n_I' - n_w$, $n_{II} = n_{II}' - n_w$ and $n_{III} = n_{III}' - n_w$, represents an excess over the neutral stress n_w and it has its seat exclusively in the solid phase of the earth.

This fraction of the total principal stresses will be called the *effective principal stresses*. For equal values of the total principal stresses, the effective stresses depend on the value of n_w. In order to determine the effect of a change of n_w at a constant value of the effective stresses, numerous tests were made on sand, clay and concrete, in which n_w was varied between zero and several hundred atmospheres. All these tests led to the following conclusions, valid for the materials mentioned:

A change of the neutral stress n_w produces practically no volume change and has practically no influence on the stress conditions for failure. Each of the porous materials mentioned was found to react on a change of n_w *as if* it were incompressible and *as if* its internal friction were equal to zero. All the measurable effects of a change of the stress, such as compression, distortion and a change of the shearing resistance are *exclusively* due to changes in the effective stresses, n_I, n_{II} and n_{III}. Hence every investigation of the stability of a saturated body of earth requires the knowledge of both the total and the neutral stresses.

If a saturated soil fails by shear, the normal stress on the surface of failure also consists of a neutral and an effective part. The relation between the normal stress n and the corresponding shearing resistance t_s is usually determined by means of shearing tests. In order to obtain from such tests not more than *one* value of t_s for each value of n the following conditions must be satisfied. All the specimens subjected to the test must have the same initial water content and in *all* the tests of the same series the normal pressure n must either be increased from zero to its ultimate value or *all* the tests must have been preceded by consolidating the samples under the same pressure $n_o > n$. If these conditions are satisfied and if the neutral stress n_w has been kept equal to zero, the test results can be expressed by an empirical equation

$$t_s = c_s + f_s\,(n) \qquad (1)$$

wherein c_s is a constant and $f_s\,(n)$ is some function of n. By plotting the values of n as abscissae and the values of t_s as ordinates we obtain a curve such as $M_s\,N_s$ in Fig. 1a. It is called the *basic line of rupture*. In most cases this line is almost straight.

Since the shearing resistance depends exclusively on the effective normal stress, a neutral stress n_w has no influence on t_s. Since the effective stress is equal to the difference between the total normal stress n' and the neutral stress n_w, we can replace equation (1) by

$$t_s = c_s + f_s\,(n' - n_w) \qquad (2)$$

The following discussions concerning the angle between the planes of rupture refer exclusively to the basic line of rupture represented by equation (1). According to Mohr's rupture hypothesis this line is identical with Mohr's envelope. The reasoning which led to Mohr's hypothesis is illustrated by Fig. 1b.