COMPARISON OF LONDON-VAN DER WAALS INTERACTIONS WITH THE SHEAR STRENGTH OF CLAYS

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INTRODUCTION

In the Institute of Hydroengineering (PAS) in Gdańsk since many years there are performed studies to find the physical reasons of the shear strength of saturated clays. Thermodynamic considerations of the mechanical process indicate, that in tension the change in potential energy of attractive forces should equal the work of external forces. In previous research of monomineral and homoionic clay there was found a good correlation between the cohesion measured (the part of shear strength independent of the normal stress) and the calculated dispersion, London-van der Waals interaction (further discussion of this problem is the subject of the other paper).

This encouraged to study natural clays. For the estimation of long-range particle interactions it is necessary to know the interparticle distance $2\,d$. For this purpose a water sorption test was developed, which gives the necessary informations upon the clay physical state and its mineralogical composition.

Those tests were performed for 113 samples of a clay from the sliding slope Dobrzyń therefrom the long-range London-van der Waals dispersion interaction was estimated and compared with the shear strength measured in the norwegian type triaxial test equipment with pore pressure measurement at constant axial strain rate $2^0/0$/hour.

DISPERSION INTERACTION PRESSURE

Van der Waals forces are very common in nature acting between all the atoms and molecules. Their reasons may be:

1. Orientation effect (Keesom effect) due to mutual orientation and attraction of two permanent dipoles;

2. Induction effect (Debye effect) due to mutual induction of dipole moment in interacting atoms and molecules resulting in attraction;

3. Dispersion effect (London effect) which is the most common and interesting. Due to the electron movement around the nucleus the atom has the properties of a fluctuating dipole, what means that the center of its positive charge does not coincide with center of its negative charge.

The interactions of two solid bodies are usually calculated for two parallel plates by summing up the interactions of separate atoms of both of them. Then the interaction energy is inversely proportional to the second power of the distance, whereas the interaction pressure p_A (force per unit area) is inversely proportional to the third power of the distance. The corresponding relations for interacting atoms are $V_A = f/R^{-6}$, $F_A = f/R^{-7}$.

As in all the systems, where atoms have a small dipole moment, also in clay minerals the most important seems to be the dispersion effect, e.g.in carbon oxide (CO) of the dipole moment $\mu = 0.11$ D this effect forms 99.9% of the total van der Waals interaction energy.

The analysis and comparision of formulas derived for calculation of the dispersion interaction was performed elsewhere [1, 2]. London equation was chosen to calculate the energy of interaction between atoms knowing their polarizability and characteristic frequency $\bar{\nu}$. Summing up the interactions over all the atoms in both interacting particles and considering the influence of neighbouring atoms (many-body interactions, or interaction of quasiatoms) the equation was obtained for the dispersion interaction pressure

$$p_A(d > \lambda_0) = -\frac{Cs_{cl}}{\bar{\varepsilon}^2(\omega)} \left\{ \frac{1}{d^3} + \frac{1}{(d+\delta)^3} - \frac{2}{\left(d + \frac{\delta}{2}\right)^3} \right\} \qquad (1)$$

here
  d — half the interparticle distance,
  δ — the particle thickness,
  $\bar{\varepsilon}(\omega)$ — the effective optical dielectric constant of the medium through which the interaction occurs,
  s_{cl} — the coefficient of many-body interaction of clusters (equivalent to interaction of quasi-clusters),
  C — a constant expressing the characteristics of atom in the crystal lattice being a function of polarizability α, characteristic frequency $\bar{\nu}$, number of ions in 1 cm³ of the crystal lattice q.

$$C = \frac{\pi q^2 \lambda s}{48},$$

s — the coefficient of many-body interaction of atoms (interaction of quasiatoms),

λ — a constant occuring in London equation for interaction energy V_A of atoms at the mutual distance R

$$V_A = -\frac{\lambda}{R^6} \text{ and } \lambda = \frac{3}{4} h\overline{\nu}a^2,$$

where h is the Planck constant.

The characteristic values used in p_A calculation are interrelated.

Between the polarizability a and the dielectric constant there is given the following Clausius—Mosotti relation:

$$a = \frac{\varepsilon - 1}{\varepsilon + 2} \frac{3}{4\pi q}.$$

The characteristic frequency $\overline{\nu}$ may be calculated from equation

$$\overline{\nu} = \frac{e}{2\pi} \sqrt{\frac{e}{m a}},$$

if the polarizability a and the oscillator strength f are known. The electron mass m and the elementary charge of the electron e are constant.

The dielectric constant is an additive property. The effective optical dielectric constant of the medium through which the interaction occurs may be calculated from the equation

$$\overline{\varepsilon}(\omega) = \frac{d \varepsilon(H_2O) + \left(\frac{\delta}{2}\right) \overline{\varepsilon} \text{ part}}{d + \frac{\delta}{2}},$$

where

$\varepsilon(H_2O)$ — the dielectric constant of water,

$\overline{\varepsilon}$ part — the dielectric constant of the clay particle.

The values used in calculation are presented in Table 1. The values of London—van der Waals dispersion interaction were calculated for montmorillonite, kaolinite and illite as the function of interparticle distance $2d$, assuming the particle thickness $\delta = 122.4$ Å determined for montmorillonite (Z.M. bentonite) and most probable values measured by X-day diffraction for illite and kaolinite ($\delta_{ill} = 200$ Å and $\delta_{KL} = 300$ Å, $\delta_{KL} = 700$ Å). Results are given in Table 2.

T a b l e 1

Values assumed for $-p_A$ calculation and calculation results

		Dioctahedral Montmorillonite	Intersheet water		Illite	Kaolinite
			$\rho\,\mathrm{I}=1.0\ \mathrm{g/cm^3}$	$\rho\,\mathrm{II}=1.27\ \mathrm{g/cm^3}$		
Number of oxygen atoms per 1 cm³ [cm⁻³]	q	$48.890 \cdot 10^{21}$	$33.44 \cdot 10^{21}$	$42.47 \cdot 10^{21}$	$50.927 \cdot 10^{21}$	$54.846 \cdot 10^{21}$
Particle thickness [A]	δ	122.4			200	300 and 700
Dielectric constant	ε	2.16	3.0	3.0	2.16	2.16
Oscillator strength (oxygen in crystal lattice	f	1.96	1.64	1.64	1.96	1.96
Polarizability [A³]	a	1.361	$n^2=1.77$ $a=1.47$	1.156	1.307	1.213
Characteristic freguency [sek⁻¹]	$\bar{\nu}$	$3.039 \cdot 10^{15}$	$2.675 \cdot 10^{15}$	$3.017.10^{15}$	$3.101 \cdot 10^{15}$	$3.219.10^{15}$
Planck constant	h		$6.625 \cdot 10^{-27}$ [erg/sek]			
Elementary charge	e		$4.803 \cdot 10^{-10}$ [j.E.s.]			
Electron mass	m		$9.108 \cdot 10^{-28}$ [g]			
Many-body interaction coefficient	S	5.846	6.670	6.670	6.077	6.119
Constant [erg cm⁶]	λ	$27.97 \cdot 10^{-60}$	$28.72 \cdot 10^{-60}$	$20.03 \cdot 10^{-60}$	$26.32 \cdot 10^{-60}$	$23.58 \cdot 10^{-60}$
Constant [erg]	C	$C_m = 2.558 \cdot 10^{-14}$	$C^{I}_{H_2O} = 1.402 \cdot 10^{-14}$ $C^{I}_{M} = 2.028 \cdot 10^{-14}$	$C^{II}_{H_2O} = 1.577 \cdot 10^{-14}$ $C^{II}_{M} = 2.108 \cdot 10^{-14}$	$2.7155 \cdot 10^{-14}$	$2.8407 \cdot 10^{-14}$

For estimation of London—van der Waals dispersion interaction in clay-water system there is necessary to know the interparticle distance. It was estimated as follows.

Table 2

$-p_A$ values for montmorillonite, illite and kaolinite

$\dfrac{d}{\text{Å}}$	Montmorilonite $\delta = 122{,}4$ Å		Illite $\delta = 200$ Å	Kaolinite	
	$\rho H_2O = 1{,}0$ g/cm³	$\rho H_2O = 1{,}27$ g/cm³		$\delta = 300$ Å	$\delta = 700$ Å
10	19.0291	19.7812	23.7834	38.2063	38.2448
20	2.2377	2.3261	2.9195	4.4663	4.6852
30	0,6192	0.6437	0.8520	1.2764	1.3622
40	0,2472	0.2570	0.3548	0.5111	0.5638
50	0.1317	0.1369	0.1797	0.2596	0.2843
60	0.0785	0.0816	0.1030	0.1465	0.1618
70	0.0488	0.0507	0.0643	0.0901	0.1005
80	0.0323	0.0336	0.0427	0.0591	0.0663
90	0.0225	0.0234	0.0298	0.0407	0.0459
100	0.0163	0.0169	0.0215	0.0292	0.0331

ESTIMATION OF INTERPARTICLE DISTANCE

X-ray diffraction measurement indicate that in a saturated clay-water system there may be assumed a linear relation between the water content and the interparticle distance $2d$

$$d = \frac{W - (W_c + W_{dead})}{\bar{S} \cdot \rho} \cdot 100 \, (\text{Å}), \tag{2}$$

here $\bar{S}$ is the external specific surface in m²/g, ϱ is the free liquid water density (1 g/cm³), W_c is the crystal phase water content in the investigated system. Basing on some experimental data it was assumed that it is equal to the sorbed water content at the relative water vapour pressure $p/p_0 = =0.95$, multiplied by $\dfrac{1.0 \, \text{g/cm}^3}{1.27 \, \text{g/cm}^3}$ This cofficient is supposed to be the ratio of crystal phase water density in the investigated system to this value in sorbed state. Its value should be checked what is discussed in the other paper *.

W_{dead} is the water content, which does not influence the interparticle

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* In recent study sorbed water density at $p/p_0 = 0.95$ is assumed as equal 1.0 g//cm³ and W_{dead} is estimated from the intercept of the linear relation $W_n - W_c = = f(\bar{S})$ or $W_f - W_a = f(\bar{S})$.

distance, e.g. capillary water. In montmorillonitic clays it is supposed to be equal to zero. It is assumed to be equal to the natural water content after extrapolation of the external specific surface to zero i.e. it is equal to the intercept of the straight linear relation $W_n = f(\overline{S})$. This may be derived in the following way.

Assuming $W = W_n$ in equation (2) it may be transformated into

$$W_n = d\overline{S}\varrho + W_c + W_{\text{dead}}.$$

If $\overline{S} = 0$ the soil can not contain clay minerals, thus $W_c = 0$ and

$$W_{\text{dead}} = W_n(S = 0).$$

Thus the estimation of interparticle distance and therefrom the particle interaction in a saturated clay-water system demands the knowledge of: 1. Water content of the system W; 2. Crystal phase water content W_c; 3 .External specific surface $\overline{S}$; 4 .Linear relation $W_n = f(\overline{S})$ and therefrom $W_{dead} = W_n(\overline{S} = 0)$, i.e. water content, which does not influence the interparticle distance.

Several methods of the external specific surface determination are known.

The BET method (Brunauer, Emmett, Teller) determines the adsorption isotherm of a nonpolar gas, usually nitrogen or krypton. The amount of gas is measured, which is necessery to cover the sorbent by a monomolecular layer and therefrom the specific surface is calculated.

From the X-ray diffraction or electron diffraction the estimation of particle thickness from the half width of the diffraction peak is possible but it may be done only in monomineral clays of rather regular crystal structure.

Heat of wetting measurement and ethylene glycol retention are often applied to determine the specific surface but it is not sure that in such a way the real specific surface is measured.

Most reasonable seems to be the determination of W_c and $\overline{S}$ from water sorption measurement [3], what is a very simple casy and unexpensive method.

WATER SORPTION TEST FOR ESTIMATION OF d

The water sorption test seems to supply extensive information on the physico-chemical state and mineralogical composition of investigated soil.

Water sorption is measured of the fraction less than 2 μm of natural clay, clay homoionic to Mg^{2+}, clay homoionic to K^+ and natural soil

samples dried and passed through a 0.09 mm sieve. Recent test indicate that in some soils both sieved and unsieved samples give similar sorption results. Water sorption is measured at the relative water vapour pressures: $p/p_0 = 0.5$, 0.95 and 1.0. From the water sorption test results the following values may be calculated:

a) External specific surface $\overline{S}$, internal $(S - \overline{S})$ and total (S) specific surface from water sorption of K-clay $(\overline{S})$ and Mg-clay at $p/p_0 = 0.5$. It is assumed that then on the external particle surface there is sorbed a bimolecular water layer of the density 1.27 g/cm³. In Mg-clay there forms also an incomplete bimolecular intersheet layer with a given number of vacancies.

b) Clay mineral content index C.M. as the ratio of water sorption of the natural sample to the water sorption of the Mg-clay fraction less than 2 μm, both at $p/p_0 = 0.5$.

c) Crystal phase water content from the water sorption of the natural sample at $p/p_0 = 0.95$ assuming the sorbed water density 1.27 g/cm³, dropping to 1.0 g/cm³ in clay-water system (increase in number of vacancies) see page 133.

d) Montmorillonite (and vermiculite) content index M, as the ratio of the measured internal specific surface $(S - \overline{S})$ to the theoretical specific surface of montmorillonite $(790-\overline{S})$.

e) Kaolinite (and/or chlorite) content index (Kl or Chl) from the weight loss ΔG at the temperature range 400°C to 800°C. For pure kaolinite $\Delta G = 13.9\%$ for chlorite $\Delta G \approx 10\%$, for pure montmorillonite and illite $\Delta G = 4.5\%$.

f) Illite content index, (Il) from the K_2O content assuming for pure illite 6% K_2O.

g) Organic matter index (O.M.) from the weight loss at the temperature range 200°C to 400°C introducing necessary corrections.

TEST RESULTS

Shear strength measurements were performed for 171 soil samples from Dobrzyń for practical purposes to check the reasons of the slope slide. The investigated samples could be devided into three groups: blue clay, silty clay and sandy loam. To compare the shear strength results with the calculated dispersion interaction, water sorption test was performed on 89 natural samples and 6 samples of the fraction less than 2 μm. These 6 samples were investigated by X-ray diffraction indicating montmorillonite, illite, kaolinite and/or chlorite (possible vermiculite) content, partly interstratified.

In the blue clay and silty clay the montmorillonite content index M,

Water sorptin test results for Dobrzyń

No. Baring dopth.	Soil	Exch. cation	Wa (dried 110°C) at p/p_0			Wm (driey 200°C) at p/p_0		
			0.5	0.95	1.0	0.5	0.95	1.0
1	2	3	4	5	6	7	8	9
111 9.1-9.3 m	Clay	nat	9.34	19.62	23.28	10.84	21.26	24.99
		nat<2 μm	9.16	19.42	23.01	13.43	24.09	27.82
		Mg<2 μm	14.51	28.88	35.76	26.84	42.75	50.37
		K<2 μm	4.73	35.71	64.27	8.32	40.36	69.90
		Ba<2 μm	10.58	37.48	62.74	11.60	38.75	54.15
111 12.6-12.8 m	Clay	nat	5.46	12.94	15.94	6.15	13.67	16.70
		nat<2 μm	9.07	21.42	29.64	15.33	28.38	37.0
		Mg<2 μm	5.11	24.36	35.85	15.86	37.08	49.74
		K<2 μm	5.31	37.61	48.71	10.43	44.31	55.95
		Ba<2 μm	11.32	35.14	48.50	12.73	36.86	50.30
104 19.6-19.8 m	Clay	nat	3.33	9.25	15.38	4.81	10.81	17.04
		nat<2 μm	5.73	30.56	51.41	11.79	38.04	60.09
		Mg<2μm	8.44	28.93	45.37	13.93	37.44	52.74
		K<2 μm	2.67	48.50	86.99	6.43	54.17	94.13
		Ba<2 μm	4.19	24.50	39.60	8.07	29.14	44.80
105 10.0-10.2 m	Silty clay	nat	3.29	9.84	13.02	6.13	12.86	16.13
		nat<2 μm	6.84	22.20	32.76	10.58	26.48	37.41
		Mg<2 μm	6.96	19.64	27.60	12.61	24.57	32.85
		K<2 μm	3.83	38.86	71.68	7.27	43.45	77.36
		Ba<2 μm	5.27	28.44	41.61	11.99	36.64	50.65
105 21.4-21.6 m	Silty Clay	nat	6.19	16.13	20.18	9.10	19.31	23.47
		nat<2 πm	8.40	29.62	56.71	15.55	38.17	67.04
		Mg<2 μm	5.83	19.42	26.86	14.18	28.84	36.60
		K<2 μm	5.12	25.03	39.65	8.29	28.79	43.86
		Ba<2 μm	3.79	53.02	57.06	10.47	62.89	67.17
104 15.2-15.4 m F<0.1 mm = 0.63	Sandy Loam	nat	0.38	2.38	3.04	1.19	3.21	3.86
		nat<2 μm	2.48	7.33	18.25	5.99	11.00	22.30
		Mg<2 μm	5.96	13.98	18.14	7.99	16.16	20.41
		K<2 μm	1.72	12.03	16.80	4.38	14.96	19.85
		Ba<2μm	1.14	7.96	14.35	3.12	10.07	16.55

* Heating in the oven. Remaining results taken from thermogravimetric.

clay representative samples

Table 3

$\bar{S} = \dfrac{Wa(K;0.5)}{0.0666}$ m²/g	$S-\bar{S} = \dfrac{Wm(0.5)-Wa(K;0.5)}{0.02015}$ m²/g	$S = \dfrac{Wm(0.95)}{0.0666}$ m²/g	C.M. $= \dfrac{Wm(nat)}{Wm(2<\mu m)}$ %	$M = \dfrac{S-\bar{S}}{790-\bar{S}}$ %	KL %	$\Delta G = \dfrac{G_{400}° - G_{800}°}{G_{400}°}$
10	11	12	13	14	15	16
			80.7	54.5	7.1	4.30*
	431.8			60.1	43.2*	8.56*
	485.3	641.8		67.5	20.3	6.41
71.0					20.6	6.44
CEC=0.693					—	
			40.1	29.6	18.3*	3.52*
	497.2			70.0	23.9	6.75
	523.5	556.7		73.7	26.1*	6.95*
79.7					19.3	6.31
CEC=0.778					23.6*	6.72
			40.8	30.4	10.1*	2.79*
	452.6			60.4	8.3*	5.28*
	558.8	562.1		74.5	19.1	6.30
40.1					29.7	7.29
CEC=0.392					—	4.04*
			57.9	34.5	9.4	3.49*
	335.0			45.7	22.9	6.65
	435.7	368.9		59.5	48.6*	9.07*
57.5					15.4	5.95
CEC=0.562					—	1.02*
			58.5	36.9	22.8	4.77*
	517.6			72.6	16.7	6.07
	450.0	433.0		63.1	—	4.17
76.9					13.2	5.74
CEC=0.751					29.8*	7.30*
			19.9	8.1	44.9	5.08
	211.9			27.7	46.4	8.86
	311.1	242.6		40.7	30.1*	7.33*
25.8					28.4	7.17
CEC=0.252					51.8*	9.3*

in the fraction less than 2 μm was high and amounted to 60—75%. The kaolinite content index Kl, was 13 to 30%. The external specific surface was $\overline{S} = 71$—$80 \frac{m^2}{g}$, the internal specific surface was $S — \overline{S} = 436$—$559 \frac{m^2}{g}$ the cation exchange capacity (from $\overline{S}$ measurement) was CEC $= 0.69$—$0.78 \frac{meg}{g}$ (CEC $= \frac{\overline{S}}{102.4 \, m^2/meg}$). The clay in sandy loam differed in properties from the remaining samples.

The water sorption test results for the investigated fraction less than 2 μm are presented in Table 3 together with the results for natural samples.

For all the remaining samples there were determined the parameters necessery for interparticle distance estimation, i.e. $\overline{S}$ and W_c using the water sorption test results and the average values obtained for the fraction less than 2 μm.

The correlations between the values obtained were calculated and the best results are prevented in Table 4. There was found a high value of the coefficients of correlation for following relations (Blue clay):

Table 4

The correlations between the obtained values

Blue clay		Silty day	
straight-line of regression	the coefficients of correlation	straight-line of regression	the coefficients of correlation
$W_n = 8.15 + 0.7138 \, \overline{S}$	$r = 0.994$	$W_n = 10.01 + 0.5467 \, \overline{S}$	$r = 0.459$
$W_n = 9.72 + 0.4815 \, M$	$r = 0.916$	$W_n = 10.42 + 0.4008 \, M$	$r = 0.442$
$W_n = 9.82 + 0.3770 \, C.M.$	$r = 0.928$	$W_n = 7.54 + 0.3911 \, C.M.$	$r = 0.498$
$W_c = 2.56 + 0.2547 \, C.M.$	$r = 0.8595$	$W_c = 2.80 + 0.2364 \, C.M.$	$r = 0.641$
$W_c = 3.24 + 0.3973 \, \overline{S}$	$r = 0.751$	$W_c = 4.42 + 0.3243 \, \overline{S}$	$r = 0.577$

$$W_n = f(\overline{S}), \quad W_n = f(M), \quad W_n = f(C.M.),$$

as well as for

$$W_c = f(\overline{S}) \quad \text{and} \quad W_c = f(C.M.).$$

No correlation was found between W_n and KL.

The natural water content is a parameter characterizing the investigated system and decisive of its properties, though there are some negative opinions concerning this value. Therefore a good correlation between this value of W_n and the values found by water sorption test indicates that the testing method chosen is correct.
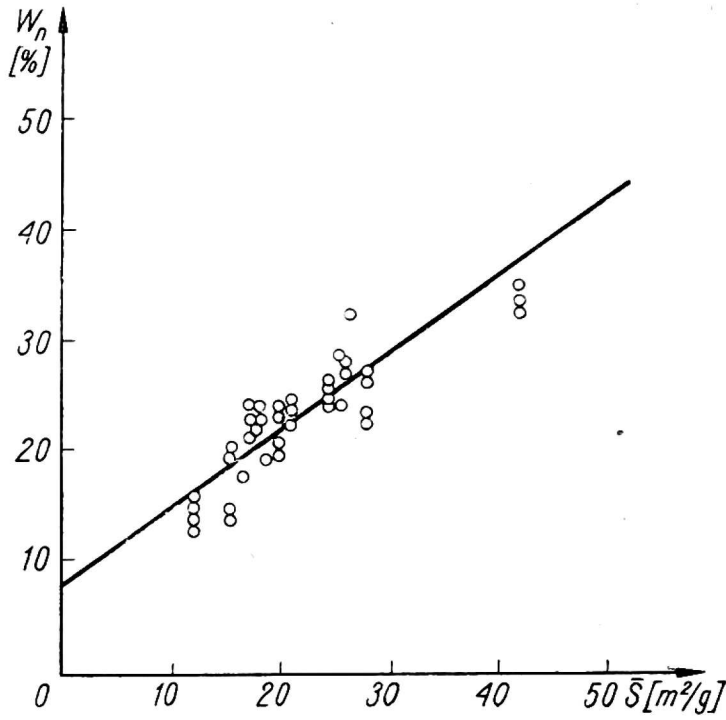
Fig. 1. The water sorption test results. $W_n = 8.15 + 0.7138\ \bar{S}$, $r = 0.984$ (blue clay)
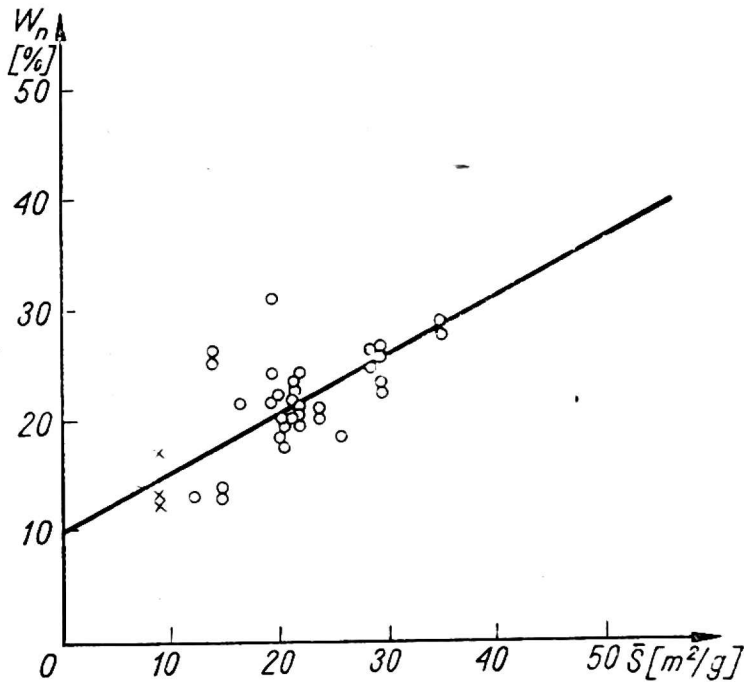

Fig. 2. The water sorption test results. $\odot\ F_{<0.90} > 90^0/o$, $\times\ F_{>0.09} > 10^0/o$, $W_n = 10.01 + 0.5467\ \bar{S}$, $r = 0.450$ (silty clay)

The estimated values of the particle dispersion interaction should have been compared to the measured shear strength. Therefore the average interparticle distance was estimated from

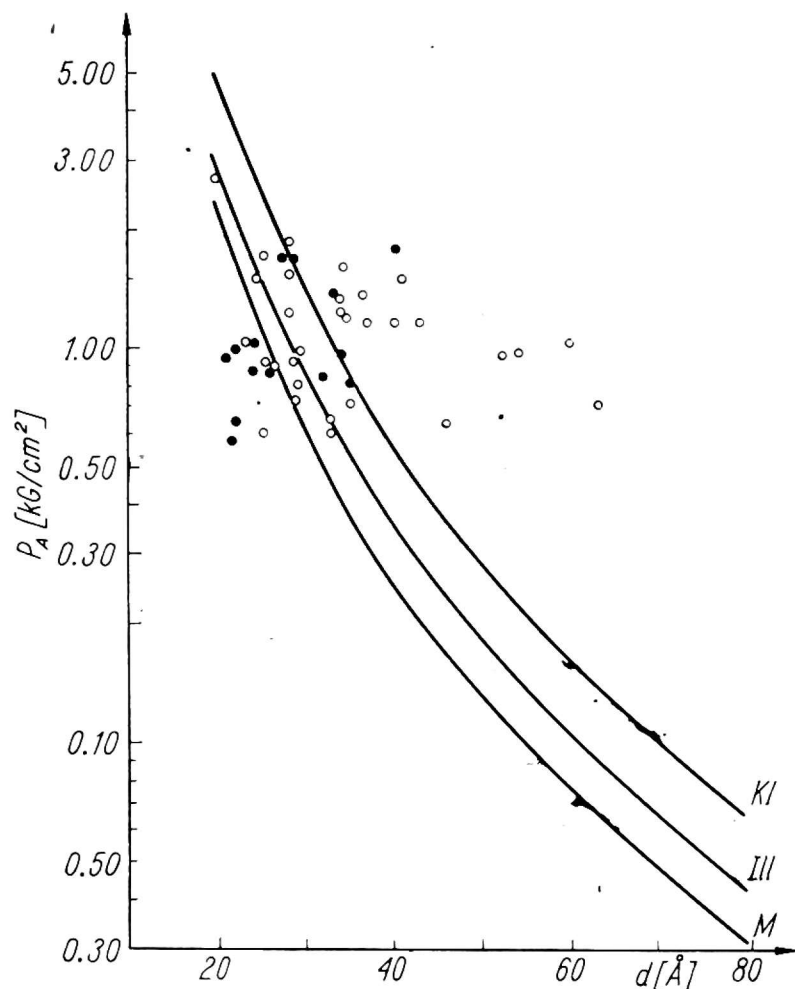$$d = \frac{W_f - (W_c + W_{daed})}{\bar{S} \cdot \rho} \cdot 100\ (\text{Å}),$$

Fig. 3. London—van der Waals dispersion-attraction pressure as compared with the shear strength. $\bigcirc$ — blue clay, $\bullet$ — silty clay

where

W_f is the water content in the sample at failure crystal phase water was calculated from

$$W_c = \frac{W_a(\text{nat}; 0.95)}{1.27},$$

W_{dead}, i.e. the "dead" water content not influencing the interparticle distance was estimated from the intercept of the line $W_n = f(\overline{S})$ as $W_{\text{dead}} = W_n(\overline{S} = 0)$ (see Fig. 1 and 2).

For blue clay $W_{\text{dead}} = 8.15^0/_0$, for silty clay $W_{\text{dead}} = 10.01^0/_0$.

The measured values of shear stength $\frac{1}{2}(\sigma_1 - \sigma_3)_f$ for the estimated interparticle disance $2d$ are indicated in Fig. 3 and they are compared to the dispersion interaction $-p_A = f(d)$ calculated for various clay minerals. Both values $(-p_A$ and $\frac{1}{2}(\sigma_1 - \sigma_3)_f)$ are of the same order of magnitude. The calculated values of $-p_A$ are in general smaller than the measured shear strength, what seems logical as there are also other

forces taking part in the shear strength, primarily contact stresses in the frictional shear strength component.

It should be emphasized that the Dobrzyń clay samples were fissured what resulted in great dispersion of test results. In spite of that a remarkable good correlation was found for samples:

a) containing more than $90^0/0$ of fraction less than 0.09 mm,

b) clay mineral content index higher than $20^0/0$,

c) water content determined (W_f) not differing pronouncedly from the regression line $W_n = f(\overline{S})$; change in water content by $1^0/0$ changes d by ~ 3.5 Å.

Test results for sandy loam were not analyzed as the coefficient of correlation was close to zero due to small number of samples tested.

PHYSICAL REASONS OF THE SHEAR STRENGTH OF SATURATED CLAYS

Of the several forces acting in the clay water system only the dispersion interaction was analyzed to prove that it is of the order of magnitude of the strength measured, and should not be neglected in the physical interpretation of the mechanical phenomena as it is the usual practice.

A complete interpretation of the shearing process demands the study of all the forces between clay mineral particles and consideration of those, whose magnitude of comparable to the applied load. These forces may be devided in two classes:

a) long-range forces, i.e. London—van der Waa's dispersion interaction pressure p_A and diffuse layer repulsive pressure p_R,

b) contact forces, i.e. primary valence bonds, secondary valence bonds, causing the particle cementation and the elastic properties of the crystallites as well as the ionic lattice attraction and edge-to-face attraction.

Various authors interpret the physical reasons of the shear strength in various ways [4]. These authors are of the opinion, that cohesion (normal stress independent part of the shear strength) is caused mainly by the long range interaction whereas the frictional component of the shear strength (normal stress dependent) is caused by contact interactions.

This problem may be and is studied by measuring the influence upon the shear strength of various parameters influencing particle interactions. For instance diffuse layer repulsion p_R depends on temperature, salt concentration, and static dielectric constant, whereas dispersion interaction p_A depends on the optical dielectric constant only. The influence of dielectric constant is complicated as also other forces, e.g.

edge-to-face attraction depend on it. Salt present in the soil water máy influence also particle flocculation and comentation.

Thus the problem is very difficult and complicated and may be solved by a stepwise approach both from the experimental and theoretical side.

As an interesting theoretical study it·should be mentioned, that the thermodynamic interpretation of the work performed in the shearing process indicates, that in pure tension the work of externally applied load should be equalized by the change in potential energy of attractive forces, whereas the change in potential energy of repulsive forces transforms into heat and dissipates in the mechanical process.

The results of this paper give support to the results of thermodynamic considerations.

REFERENCES

1. Stępkowska E. T.: Własności fizyko-chemiczne minerałów iłowych. Materiały z Konferencji pt. Problemy fizyko-chemii i dynamiki gruntów. Jabłonna, czerwiec 1973, PAN 1973.
2. Stępkowska E. T.: Calculation of the van der Waals interaction between clay mineral particles. Arch. Hydrot. t. XVII, Nr 3, 1970, 465—496.
3. Stępkowska E. T.: Water sorption test for particle interaction estimate. Proc. of. the Eighth Conf. on Soil Mech. and Found. Eng., Moscow 1973, 211—216.
4. Paszyc-Stępkowska E.: Próba fizyko-chemicznej interpretacji procesu ścinania nasyconych gruntów iłowych. Arch. Hydrot. t .XIII, nr 3—4, 1966.

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PORÓWNANIE ODDZIAŁYWAŃ VAN DER WAALSA
ZE ZMIERZONĄ WYTRZYMAŁOŚCIĄ
NA ŚCINANIE GRUNTÓW NATURALNYCH

Streszczenie

W pracy podjęto próbę fizycznej interpretacji procesu ścinania. Spośród wielu sił, działających w układzie woda-ił analizowano tylko oddziaływanie dyspersyjne w celu wykazania, że jego rząd wielkości jest taki sam, jak rząd wielkości zmierzonej wytrzymałości na ścinanie i że nie można tej siły zaniedbać przy fizycznej interpretacji zjawisk mechanicznych. Z pracy wynika, że spójność gruntu jest wywołana głównie przez oddziaływania dalekiego zasięgu (siły van der Waalsa i odpychanie warstw dyfuzyjnych), natomiast tarcie wewnętrzne jest wywołane przez siły kontaktowe (wiązania wartościowości, przyciąganie sieci jonowej i przyciąganie krawędzi płytkowych cząstek ilastych do powierzchni innych płytek).

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СРАВНЕНИЕ СИЛ ВАН ДЕР ВААЛЬСА С ИЗМЕРЕННЫМ СОПРОТИВЛЕНИЕМ СРЕЗУ ПРИРОДНЫХ ПОЧВОГРУНТОВ

Резюме

В труде предпринимается попытка физической интерпретации процесса срезывания. Среди многих сил действующих в система вода-ил анализировали только дисперсонное воздействие с целью установления, что его величины такого же разряда, как и величины измеренного сопротивления срезу и что не можно оставить вне учета этой силы в физической интерпретации механических явлений. Из содержащихся в труде данных следует, что связность почвогрунта обусловлена главным образом воздействованиями далекого захвата (силами ван дер Ваальса и отталкиванием диффузионных слоев), тогда как внутреннее трение происходит под влиянием контактных сил связи валентностей, притягивания ионовой сети, а также притягивания пластинчатых граней илистых частиц к поверхности других пластинатых граней.