Studies on the Characteristics of Water Adsorption
and Their Effects on Physical Properties of Soil
in Sea Land Reclamation Area

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Summary

The concept of water potential (p. F.), as the index to characterized the condition and the nature of the soil water, turned out to be of importance in dealing with the soil in sea land reclamation area.

The nature of water adsorbed at high p. F. range and its effects on physical properties of soil has been clarified using 75 samples in 16 sites from 4 different sea land reclamation areas.

The results obtained suggest that the surface charge represented by cation exchange capacity (C. E. C.) has definite effect on the adsorption of water at p. F. 6. 35, which in turn is considered to be the measure of specific surface area.

The effects of electrolyte concentration on the amount of adsorbed water at p. F. 4. 85 and 5. 51 was very significant.

The consistency limits were used to represent the physical properties of soil and the changes of these limits were interpreted in terms of change in the amount of adsorbed water at high p. F. range.

Significant correlation was found between the consistency limits and the amount of water adsorbed at p. F. 4. 85.

Introduction

The improvement of agricultual land in sea land reclamation area can be accomplished mainly by the following two practices (1) the removal of excess water as a result of evaporation and drainage (2) the removal of excess salt out of the soil by leaching.

The processes mentioned above associate, to a certain degree, with the water in the soil. Thus it is of importance to analyse and understand the behavior of soil with regards to the condition of water in the soil.

It has been generally understood that the soil is characterized by the amount of water it contains and water content has been used to express the condition of the soil. The Water content, however, is the quantitative concept and thus does not clarify the difference between the soil water in saturated condition and that in air-dried condition. Since the soil water near the clay particle is strongly attracted to the surface by the effects of the surface change of the particle and the dipole nature of water, the water near the particle and the water in bulk solution have different character.

In order to compensate for such unsatisfactory aspects of water content in understanding the characters of soil, the introduction of the concept which shows the status of water in soil is needed. Energy condition is often used to define the status

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of certain substance. The energy concept of soil water expresses the condition how the water is retained in the soil water system, thus is more suitable to predict the characteristics of the soil. Quantitative comparisons can be made on the basis of potential among soil properties which may vary with water content.

The soil in the sea land reclamation area contains large amounts of clay and this gives a peculiar characters to the soil in sea land reclamation area. Clay particles in soils are always hydrated, i. e., surrounded by layers of water molecules called adsorbed waters. The water molecules should be considered part of the clay surface when the behavior of clay soil is considered.

Plasticity, compaction, interparticle bonding and water movement in soils are all influenced by the water layers. The properties of clays change as the thickness of this hydration shell changes, and consequently the engineering characteristic of soil change. Thus, it is now clear that the study on the amount of adsorbed water, which is the water retained in soil at high p. F. range, in relation to other physical properties of soil is of significant importance. By knowing the relationship between the amount of adsorbed water and physical properties of soil, we will be able to predict the behaviors of soil through this parameter.

The purpose of this study is, therefore, to clarify the effects of adsorbed water on the physical properties of soil in sea land reclamation area.

Materials and Methods

1. 1. The area investigated

The investigation was made on four different sea land reclamation areas, namely Kojima, Kasaoka, Nakaumi, and Ariake polders. Seven sites in Kojima polder (A—1, A—2, B—1, B—2, C, D, and E), four sites in Kasaoka polder (1—1, 1—4, 3—1, and 3—4), two sites in Nakaumi polder (N—Y and N—I) and three sites in Ariake polder (A—M, A—A, and A—F) were selected for investigation.

In each site, soil profiles were classified by conventional way. Samples were collected from each profile and brought back to laboratory for experiments. Such basic physical properties as the consistency limits, particle size distribution, and specific gravity were determined by the methods described in J, I, S, A 1205, A 1206, 1204 and 1202, respectively.

The results are shown on Table 1. The date of Kojima polder are quoted from the investigation by BISHAY et al[1].

1. 2. Vapor pressure method[2,3,4,5]
1. 2. 1. Principle

In order to evaluate the energy status of soil water, the static vapor pressure method was employed. In this method, the samples under test are allowed to reach moisture equilibrium with a known humidity under certain temperature. The value of p. F. was obtained by the following formula,

$$\text{p. F.} = 4.04 + \log (2 - \log a) + \log T$$
$$\text{where } a = \text{relative humidity}$$

Table 1 (a) Physical properties of the soil investigated

Site	Specific weight	Particle size distribution*			*In situ* soil		
		Sand 0.02–2mm.	Silt .002–.02	Clay <.002mm	Consistency limits (%)		
					L.L.	P.L.	I.P.
Kojima							
A-1-1	2.58	25.0%	38.5%	36.5%	71.0	35.2	35.8
A-1-2	2.63	34.0	29.5	26.5	.94.1	33.0	61.1
A-1-3	2.69	36.0	41.0	23.0	92.6	34.1	58.5
A-1-4	2.63	38.0	39.0	23.0	83.1	30.1	53.0
A-2-1	2.57	22.0	42.0	36.0	73.3	35.7	37.6
A-2-2	2.66	28.0	48.0	24.0	79.2	33.4	45.8
A-2-3	2.69	46.5	34.5	19.0	93.0	33.9	59.1
A-2-4	2.70	42.0	39.5	18.5	78.0	32.0	46.0
B-1-1	2.62	27.0	46.0	27.0	56.9	28.1	28.8
B-1-2	2.66	52.0	41.5	16.5	71.6	26.5	45.1
B-1-3	2.67	60.0	72.0	12.0	50.0	25.5	24.5
B-1-4	2.66	61.0	22.5	16.5	53.5	24.8	28.7
B-1-5	2.63	61.5	10.5	18.0	46.7	24.8	21.9
B-2-1	2.62	33.0	40.0	27.0	47.1	29.3	17.8
B-2-2	2.64	35.0	38.5	26.5	58.5	28.2	30.3
B-2-3	2.64	40.0	41.0	19.0	66.0	32.1	33.9
B-2-4	2.65	55.0	31.0	14.0	62.4	29.4	32.9
B-2-5	2.69	40.0	46.0	14.0	52.2	27.7	24.5
C — 1	2.59	32.0	41.0	27.0	55.4	28.8	26.6
C — 2	2.70	43.0	39.0	18.0	57.0	25.8	31.2
C — 3	2.70	46.0	39.5	14.5	64.9	26.7	38.2
C — 4	2.71	52.0	34.0	14.0	63.2	22.9	40.3
C — 5	2.69	57.0	28.5	14.5	51.7	22.9	28.8
D — 1	2.63	25.0	41.0	34.0	68.0	29.4	38.6
D — 2	2.68	32.0	40.0	28.0	73.0	27.8	45.2
D — 3	2.71	36.0	43.0	21.0	89.4	27.3	62.1
D — 4	2.62	34.0	47.5	18.5	78.3	26.9	51.4
D — 5	2.63	42.0	38.5	19.5	71.9	28.2	43.7
E — 1	2.64	34.0	34.0	32.0	50.1	28.5	21.6
E — 2	2.65	32.0	34.0	34.0	52.9	25.9	27.0
E — 3	2.73	26.0	43.0	31.0	67.8	24.4	43.4
E — 4	2.7-	44.0	35.5	30.5	55.3	23.7	31.6
E — 5	2.71	63.0	80.5	16.5	54.8	22.5	32.3

* International Society of Soil Science

Table 1 (b)   Physical properties of the soil investigated

Site	Specific weight	Particle size distribution			In sisu soil Consistency limits (%)		
		Sand .02-2mm.	Silt .002-.02	Clay <.002mm	L.L.	P.L.	I.P.
Nakaumi							
Y—1	2.65	55.0%	32.5%	12.5%	94.4	27.2	67.2
Y—2	2.60	60.0	33.8	16.2	193.5	64.7	128.8
Y—3	2.60	40.0	39.8	20.2	200.5	52.7	147.8
I—1	2.64	47.0	43.0	10.0	81.2	34.0	37.2
I—2	2.65	34.0	56.1	9.9	103.3	37.5	65.8
I—3	2.70	25.0	64.7	10.3	101.5	30.9	88.6
Ariake							
M—1	2.56	18.0	48.5	33.5	132.4	52.3	80.1
M—2	2.58	14.0	52.5	33.5	144.4	50.8	93.6
M—3	2.59	18.0	51.0	31.0	146.0	51.6	94.4
M—4	2.60	29.0	44.0	28.0	147.7	46.9	100.8
F—1	2.59	8.0	67.0	25.0	119.5	51.7	67.8
F—2	2.56	12.0	56.0	32.0	146.6	50.0	96.6
F—3	2.56	2.0	64.5	33.5	138.0	53.6	84.4
F—4	2.58	10.0	59.0	31.0	130.2	45.5	84.7
A—1	2.57	6.0	59.0	35.0	101.1	41.4	59.7
A—2	2.59	4.0	69.8	26.2	132.6	48.8	83.8
A—3	2.60	2.0	74.0	24.0	119.3	54.4	64.9
A—4	2.63	9.0	71.0	20.0	109.6	49.8	59.8
Kasaoka							
1-1-1	2.67	25.0	65.0	10.0	97.2	41.4	55.8
1-1-2	2.64	25.0	63.0	12.0	107.9	37.7	70.2
1-1-3	2.65	35.0	53.8	11.2	92.6	33.5	59.1
1-1-4	2.70	30.0	60.0	10.0	88.5	28.7	59.8
1-4-1	2.66	44.0	42.0	14.0	94.9	39.2	54.8
1-4-2	2.68	31.5	56.5	12.0	108.4	40.6	67.8
1-4-3	2.68	31.5	56.5	12.0	105.6	35.5	70.1
1-4-4	2.67	49.0	38.2	12.8	101.1	38.8	62.3
3-1-1	2.64	32.3	50.2	17.5	96.5	40.5	56.0
3-1-2	2.66	35.0	56.0	9.01	10.3	37.7	72.6
3-1-3	2.72	28.5	63.3	8.2	112.5	38.3	74.2
3-1-4	2.68	43.8	42.7	13.5	91.2	33.5	57.7
3-4-1	2.67	35.0	49.8	15.2	74.4	31.9	42.5
3-4-2	2.68	27.5	56.5	16.0	82.7	33.6	49.1
3-4-3	2.70	36.0	41.5	12.5	66.1	27.1	39.0
3-4-4	2.64	50.0	40.0	10.0	45.8	—	—

Table 2 gives the relationship between relative humidity, the name of the chemical solution and the corresponding p. F. in equilibrium.

Table 2 The relation between the relative humidity and equivalent p.F. by different chemical solutions

Chemicals	R.H.	p.F.	Chemicals	R.H.	p.F.
$CaSO_4 \cdot 5H_2O$	98.0	4.46	NH_4Cl & KNO_2	72.6	5.65
$Pb(NO_3)_2$	98.0	4.46	$NaNO_2$	66.0	5.76
$NaHPO_4 \cdot 12H_2O$	95.0	4.85	$Mg(C_2H_3O_2)_2 \cdot 4H_2O$	65.0	5.77
$NH_4H_2PO_4$	93.1	5.00	$Na_2Cr_2O_7 \cdot 2H_2O$	52.0	5.95
$ZnSO_4 \cdot 7H_2O$	90.0	5.16	$NaHSO_4 \cdot H_2O$	52.0	5.95
$KHSO_4$	86.0	5.31	CrO_3	35.0	6.16
$(NH_4)_2SO_4$	81.0	5.46	$CaCl_2 \cdot 6H_2O$	32.3	6.19
NH_4Cl	79.2	5.51	$KC_2H_3O_2$	20.0	6.35

Determination of soil water potential by measurement of vapor pressure has many theoretical advantages. The vapor pressure is a well-defined thermodynamic quantity and it measures both the capillary and osmotic components of total potential.

1. 2. 2. Materials
The samples taken from each sites were dried in the room temperature for $2-3$ days so that the moisture content of the sample becomes appropriate for experiment, since too wet sample may affect the condition of relative vapor pressure or the time for measurement.
In the vapor pressure method, the water sorption is performed at high energy range, and thus the disturbance and the sieving of the sample do not affect the retentivity of the soil for water[2].
The soils were passed through 2 mm mesh sieve for faster reaction and used for experiments.

1. 2. 3. Experiments
In this study, the measurement was made on the desorption process, and the moisture content corresponding p. F. values of 4. 85, 5. 51 and 6. 35 was determined.*
The saturated chemical solutions used were $NaHPO_4 \cdot 12H_2O$, NH_4Cl, and $KC_2H_3O_2$, respectively. The apparatus for this experiment is shown in Fig. 1 .
Three to five gms. of soil were put in the measuring container and this container was placed in the vaccum dessicator containing saturated chemical solution, which maintains a definite vapor pressure. The air is evacuated from the dessicator to allow water molecules to diffuse rapidly, and placed in the constant temperature container, which is maintained at 25°C. After leaving the dessicator in the temperature container for about a week, the air was introduced slowly through the dessicating pipe containing P_2O_5 to the dessicator, and the weight of the measuring container was quickly measured. The procedures were repeated until the weight of the measuring container shows no fluctuation. Generally, it takes about a month untill the condition which is considered to be a close approach to the equilibrium value is reached.
The corresponding wet weight of the samples were determined. The samples were then transfered to the next p. F. value, and the same procedure mentioned above was

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* Three p.F. values are decided in an arbitrary manner with an equal interval.
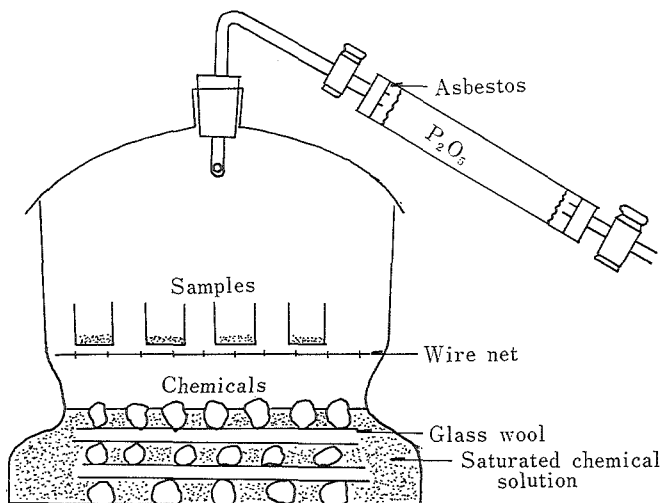
Fig. 1 Apparatus for experiment.

repeated. The moisture content corresponding to each p. F. value was calculated from the dry weight of the sample determined at the conclusion of the tests by oven drying.

Results and Discussion

2. 1. Factors affecting the amount of water adsorbed at high p. F. range

(a) Clay content

The general relation has been pointed out between the specific surface area and the clay content[6]. The amount of water adsorbed at p. F. 6. 35 can be assumed to be an index of the surface condition of the soil and thus, it is compared with the clay content ($<$0. 002mm) in the soil. This relation is shown in Fig. 2.

Obscure trends that the amount of water adsorbed increased as the clay content increased were found for each site investigated. Different slopes for each site indicate that for a unit increase of clay content the increase in the amount of water adsorbed at p. F. 6. 35 is different.

The slope was steepest for Kojima soils and lowest for Nakaumi soils. It is suspected that the different clay mineral or composition of clay minerals affect the differences in the slopes of the Fig. 2.

The deviation found in Fig. 2 for each site suggests that there might be another factor associated with the adsorption of water on the surface of the clay particle.

(b) Surface charge

The total amount of exchangeable cations that soil can retain is designated the "cation exchange capacity" (C. E. C.) and is a measure of surface charge of the soil particle[7].

Since the water adsorption is largely affected by the magnitude of surface charge, the relation between the C. E. C. and the amount of water adsorbed at p. F. 6. 35 is expected.

C. E. C. data were available only for Kojima soils[1] and they were compared with the amount of water adsorbed at p. F. 6. 35. The relation is shown in Fig. 3 and the significant correlation with the correlation coefficient of 0. 874 was obtained.

The deviations, pointed out in the previous section, in the relations between the amount of water adsorbed at p. F. 6.35 and clay content can now be explained as the difference in the surface charge of the clay particle. It is now understood that the dominant factor affecting the adsorption of water at p. F. 6.35 is the surface charge represented by C. E. C. of the soil.

Since the amount of water retained at p. F. 6.35 is related to the specific surface area, C. E. C. and somewhat to clay content, now it is possible to apply the amount of water retained at p. F. 6.35 as the index of the surface condition of the soil.

(c) Adsorption of water at different Electrolyte Concentration

Homogeneous soil from the subsurface layer in Kasaoka polder, which has not received drying and leaching effect, was sampled and utilized for this purpose of experiment.
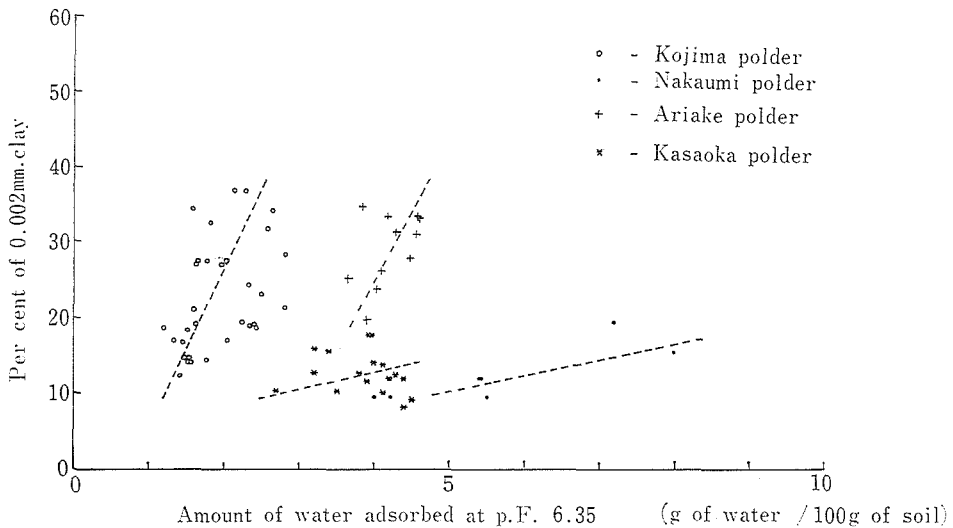
Fig. 2 Relation between clay content and the amount of adsorbed water.

Total amount of electrolyte present in each soil was determined by measuring the electrical conductivity of the soil solution extracted from the soil. The electrical conductivity has the dimention of mho/cm and 1 mho/cm= 1 milimho/cm$\times 10^3$. This measurement of conductivity gives a rough estimation of the salt content of the soil.

Conversion from electrical conductivity to concentration in miliequivalent/liter and p. p. m. can be made in the following manner[8].

$$\text{miliequivalent/liter} = 10 \times \text{E. C.} \times 10^3$$
$$\text{p. p. m.} = 0.64 \times \text{E. C.} \times 10^6$$
$$(\text{ E. C. } = \text{electrical conductivity in mho/cm })$$

Soils with various level of E. C. were prepared by centrifuging the sample in 3,000 rpm under ponded condition for different length of time. After centrifugation, the sample was oven dried and crushed. The extract from 1 : 2 soil water ratios was then utilized for measuring electrical conductivity.

The amount of adsorbed water under different electrolyte concentration was obtained at p. F. 4.85, 5.51, and 6.35. Some representative curves are shown in Fig. 4.

From this figure, it is clear that the decrease in the E. C. is accompanied by the
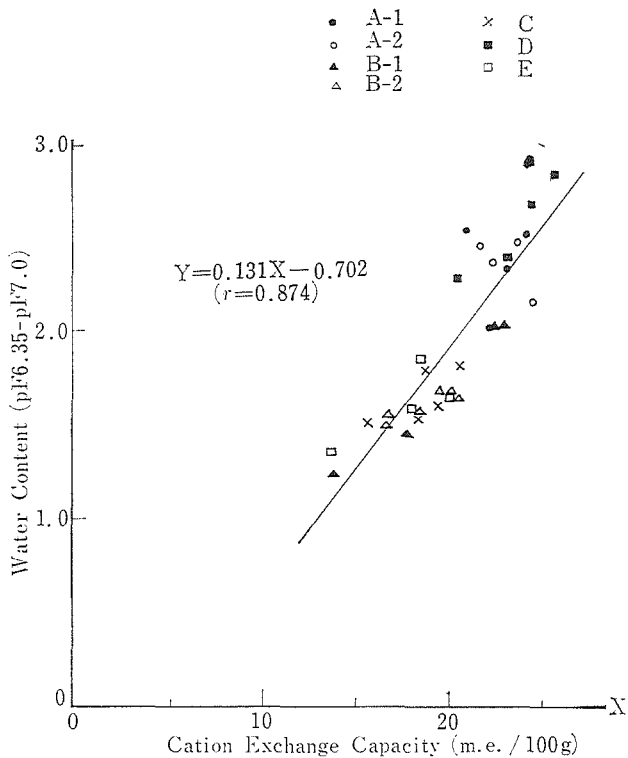
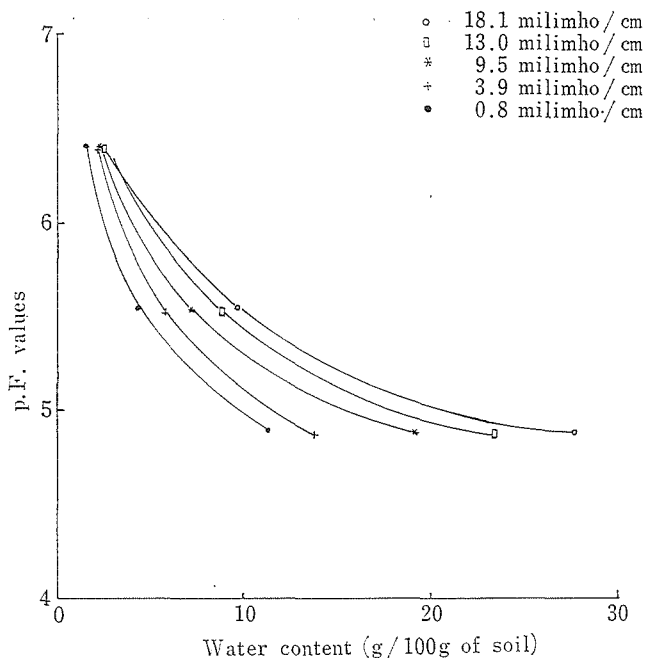Fig. 3 The Correlation between C.E.C. and the Adsorbed Water.

Fig. 4 The moisture characteristic curve at different E.C.

decrease in the amount of water adsorbed. The relationship between E.C. and the amount of adsorbed water was examined and plotted in Fig. 5.
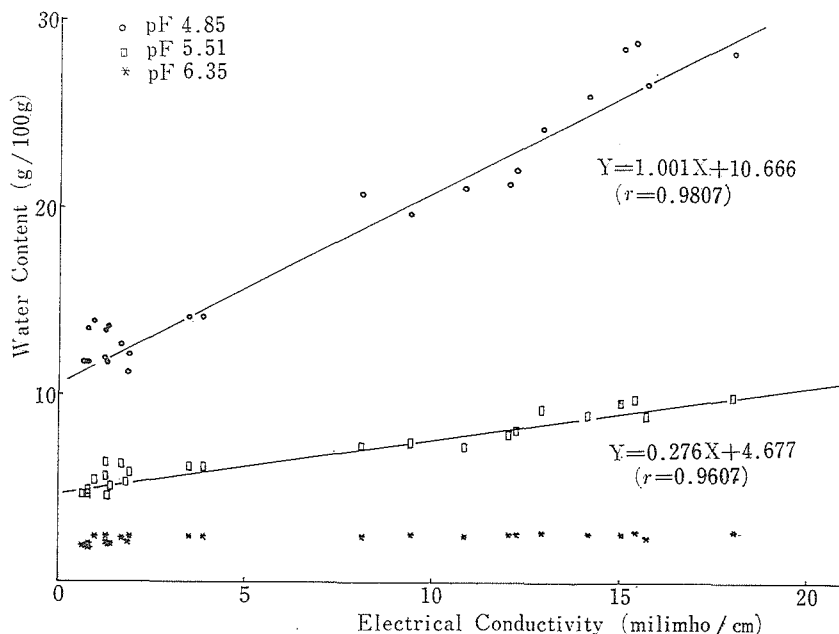

Fig. 5 Effect of E.C. on the adsorption of water.

The amount of water adsorbed at p. F. 6.35 was not much affected by the change in electrolyte concentration of soil. Since the water retained at p. F. 6.35 is considered to be the index of surface condition of soil, the result obtained indicates that the change in E.C. does not affect the surface condition of soil. However, the amount of water retained at p. F. 4.85 and 5.51 showed a decrease associated with the decrease in E.C. of soil. The correlation between them was very significant (r=0.9807 for p. F. 4.85 and r=0.9607 for p. F. 5.51).

It has been reported[9] that if we decrease the cation density in the soil solution, the density of the cations near the clay surface will decrease, and a thicker layer of cations will be needed to screen the negative charge on the clay particle, and the double layer will be thicker. Thus the decrease in the amount of water retained at p. F. 4.85 and 5.51 may be interpreted that the water near the particle become loosely held through the expansion of the double layer. In the region of interacting double layers between two adjacent particles, the concentration of ions is higher than in the external solution ; this causes a reduction in the water potential and a resultant affinity for water. As water enters, the particles are forced farther apart, and soil swells[10]. Thus we understand if E.C. of the soil decreases, the soil swells and dispersed and the affinity of soil for water decreases.

2. 2. The amount of adsorbed water and its effect on consistency limits

2. 2. 1. General remarks

The consistency limits were first described by the Swedish soil scientist ATTERBERG, who developed them to measure the plasticity of clays. Since that time they have found use in agriculture and engineering for measuring the water holding properties of fine grained soils. Soils containing more than about 15% clay exhibit plasticity, that is, pliability and the capacity to be moulded. This property is probably due to

the plate-like nature of the clay particles and lubricating through binding influence of the adsorbed water. As the water content of a soil is increased and the water films separating the soil particles become thicker, the water should be less resistant to flow or creep.

In addition, the attractive forces between the particles, which are inversely related to the distance of separation, should increase. As the water content increases, water is adsorbed between the particles and the soil becomes plastic. The water content at which pastticity becomes apparent is the plastic limit or lower plastic limit. When the water films are so thick that the outer-most water layers have nearly normal viscosity and the interparticle attractive forces are negligible, the soil will flow under a slight stress. The water content at which this occurs is liquid limit or upper plastic limit.

2. 2. 2. Experimental results and discussion

As has been mentioned in the previous section, adsorbed water plays an important role in the change in consistency limits. Thus the changes in consistency limits were interpreted in terms of the change in the amount of adsorbed water.

The comparison was made between the amount of water adsorbed at different p. F. values and the consistency limits.

Very significant correlations between the amount of water adsorbed at p.F. 4.85 and the consistency limits were obtained. These relations are shown in Table 3 and Fig. 6 and Fig. 7.

Table 3   Relation between the amount of water retained at p.F. 4.85 and
         consistency limits

Consistency limits	Amount of water retained at p.F. 4.85, X	Correlation coefficients
Liquid limit	L.L. $= 2.651 \cdot X + 23.95$	$r = 0.954$
Plastic limit	P.L. $= 0.663 \cdot X + 18.81$	$r = 0.859$

Since the water retention curve is the net result of interparticle attraction and repulsion[11], larger amount of water retained at p. F. 4.85 means that the total sum of the forces acting on that soil water system is bigger than that acting on the system with small amount of water retained at p. F. 4.85.

It is clear from the best fit curves in Fig. 6 and Fig. 7 that the plastic limit varies much less than the liquid limit. The reason for this is interpreted as follows ; the amount of water needed to add to change the net interaction of forces, represented by the amount of water retained at p. F. 4.85, is relatively smaller for the plastic limit than that for the liquid limit. In other words, the forces acting at p. F. 4.85 will be weakened by the addition of water and sufficient amount of water is needed to compensate the forces acting at p. F. 4.85 and bring it to the magnitude of forces associated with plastic limit and much more water is needed to weaken the forces acting at plastic limit and bring it to the stage of liquid limit.
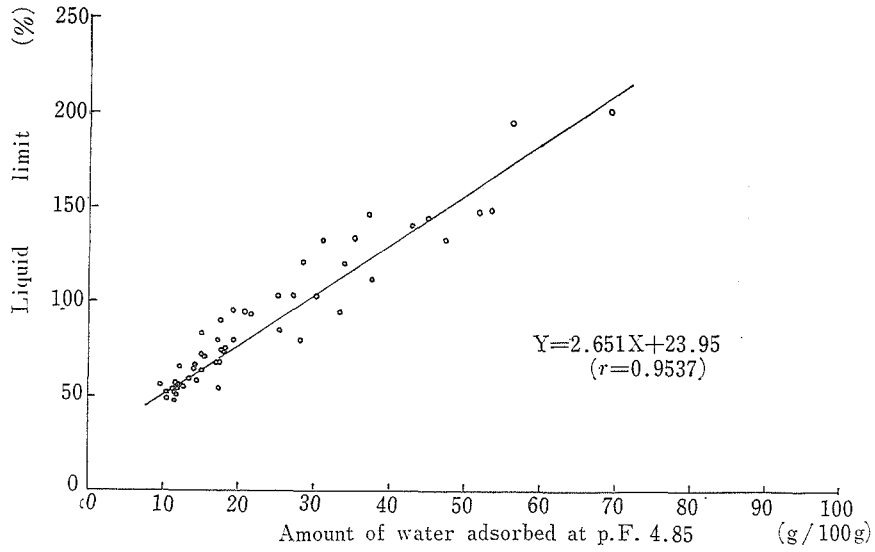
Fig. 6 Relation between amount of water adsorbed at p.F. 4.85 and liquid limit.
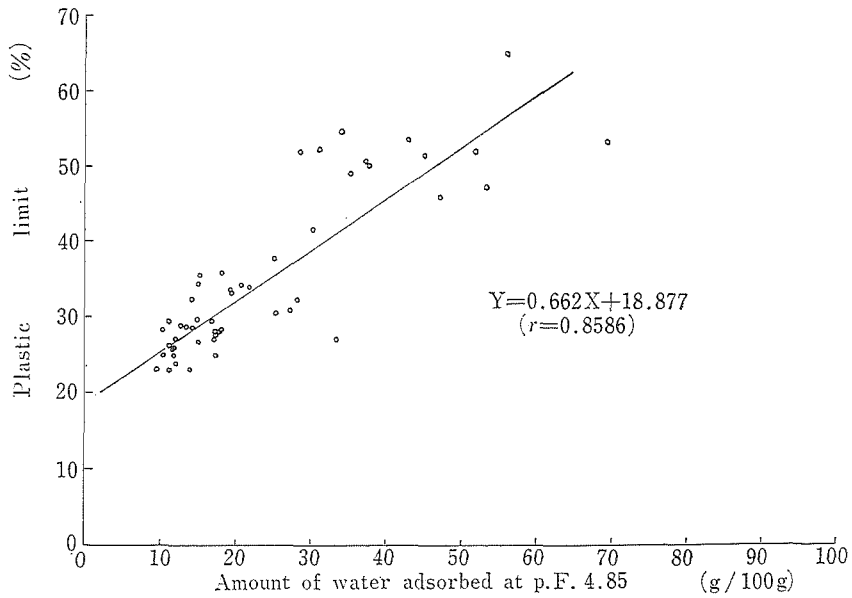

Fig. 7 Relation between amount of water adsorbed at p.F. 4.85 and plastic limit.

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干拓地土壌における水分吸着特性とその物理性への影響

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　干拓地土壌の特性を，4つの干拓地の75のサンプルについて，水分ポテンシャル (p. F.) の概念を用いて検討を行なった．

　その結果，高い p. F. 段階で吸着された水分量は土壌の物理性に大きな影響を持つことが明らかになった．p. F. 6.35の吸着水分量は，土粒子の表面特性を示すと考えられる陽イオン交換容量 (C. E. C.) と高い相関を示した．

　また，干拓地土壌の特性に影響を及ぼすと考えられる電気伝導度 (E. C.) とも高い相関を示した．

　さらに，土壌の物理性の種々の指標として用いられているコンシステンシー限界（液性限界および塑性限界）に対しても，高 p. F. 段階の吸着水分量が影響を及ぼしていることが明らかになった．

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