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Correlation of Water Contents of the Clay Minerals, Derived from the Liquid Limit, and Viscosity of the Media

By

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with 1 Table and 6 Text-figures

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ABSTRACT: Water contents of some clay minerals kneaded with several kinds, and concentration, of some salt solutions have been measured in the case of the liquid limit with use of the apparatus prepared specifically for the present experiments and compared with those obtained from viscosity of the media corresponding to the solutions provided ordinarily for measurement of the liquid limit. It has thus become remarkable that continuity between the data recognized in both cases is considerably apparent even though with a slight discrepancy but to certain extent, that careful considerations on the liquid limit of the clayey materials are necessary in relation to the kinds of their own and those of the electrolytes, and that measurement of viscosity in solution suspending the clayey materials is more easily replaceable with that of the liquid limit and applicable to a part of the soil mechanics.

CONTENTS

I. INTRODUCTION

Plenty of the procedures suggestive for the physical or mechanical properties of the sediments and soils have hitherto been proposed by many authors and especially on the basis of JIS rule in Japan even though for the industrial purpose. According to HABARA (1965), LL (liquid limit), one of the ATTERBERG limit used in the soil mechanics, is in a close relation to the mineral species as well as to the surrounding media while it has also been reported by KAZDA (1961) that the limit in question for kaolinitic and montmorillonitic clay is variable with content of cations in solution and specifically its variation for the latter is more complicated due to its inner structure.

The works given by many authors such as MERING (1946), BARSHAD (1949), CARROLL (1959) and HAVLICEK and KAZDA (1961) have also made it public that mechanical property of the clay mineral is markedly influenced with absorbed quantity of cations, anions and organic substances, though of course different in grade from one another owing to the mineral species. The relation of shear strength of the clayey materials to their ion-exchange capacity in the clay-water-electrolyte system has been pointed out by ROSENQVIST (1955), the amount of cations contained in the clay-water system has been ascribed to concentration of the valence electrons disposed on the surface and specific area of the clay mineral under consideration by BOLT (1956) and its swelling pressure has been formulated by CHILINGAR (1960), the void ratio representing the quantity of water contained in the sediment has been expressed by MEADE (1963) statistically as a formula combined with the grain size, the quantity of salt and the absorbed amount of Na, a remarkable difference in the extracting process of cations from the sediment under the lower and higher pressure has been connected with ion exchangeability of the clayey materials by ENGELHALDT (1963) and the related studies have been carried into effect by several authors such as SKEMPTON (1945), WELLER (1959), LEONARDS (1961), MOUM and ROSENQVIST (1961) and as forth.

In view of the investigations mentioned above, the present authors have aimed to find out certain factors other than those alluded to previously with special emphasis on the relationship between mechanical characteristics of the mineral species and their inner structures controlling, and controled by, the surrounding environments. As the first step for this purpose, the results obtained for the values of the liquid limit through the test used ordinarily in the soil mechanics as well as those passing over the former in the term of viscosity, measured by a sort of viscometer, of the media in which the clayey particles were dispersed have been inspected and compared with each other.

II. EXPERIMENTS

In order to approach to the objective several kinds of experiments have been carried into operation.

A. MATERIALS PROVIDED for EXPERIMENTS

The specimens used in the experiments are the Hōjun bentonite, the Murakami sericite and the Shōkōzan dickite researched in detail through the röntgenographic and chemical analyses, infrared spectroscopy, electron microscopy, grain-size analysis and the tests for consistency, of which the X-ray diffraction data are cited in Table 1. The results of analysis obtained for the particles of more than 200 mesh in size are given in the figure 1.

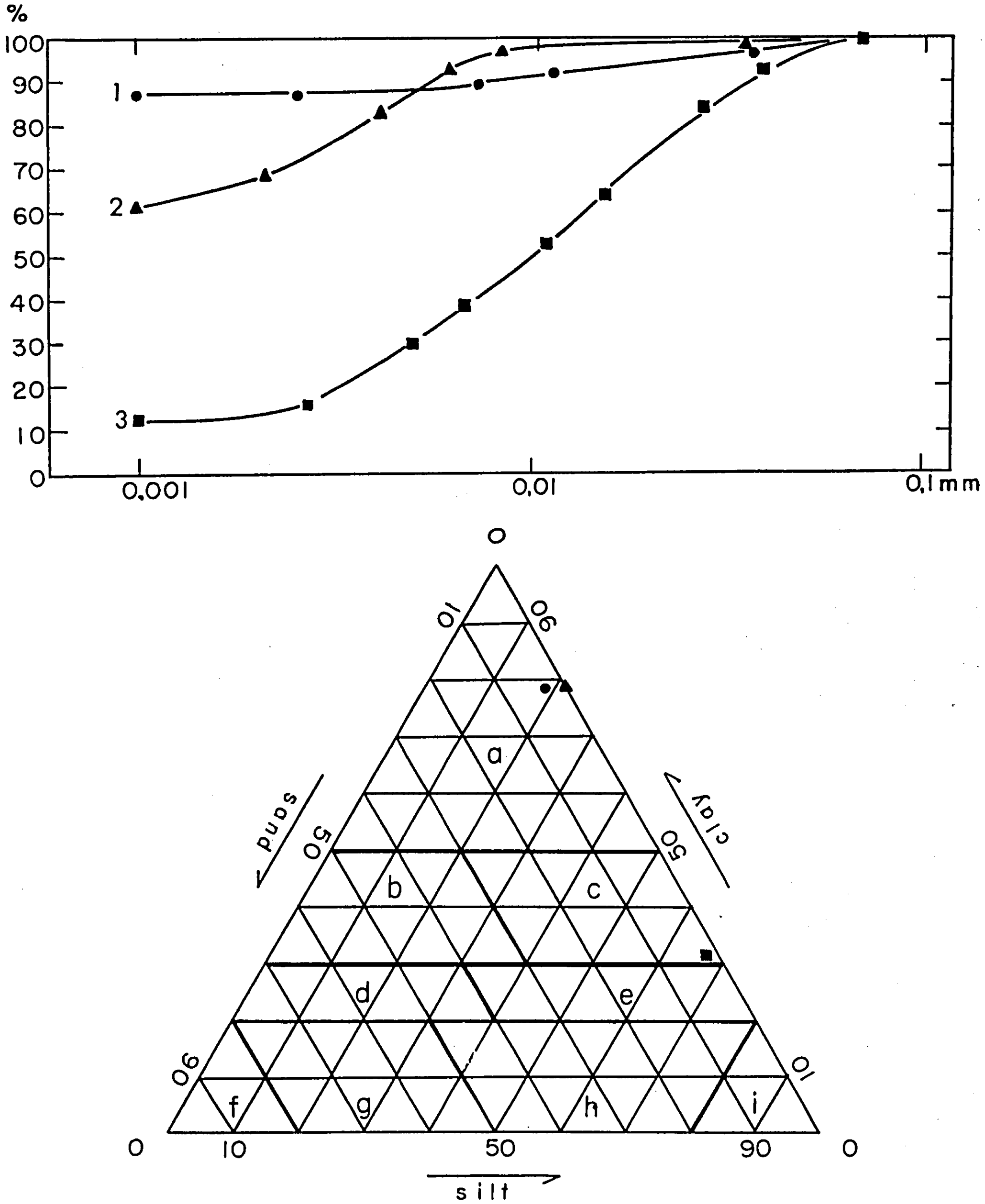

Fig. 1 Analysis of grain-size distribution

1 ● Bentonite
2 ▲ Sericite
3 ■ Dickite

The areas of mixtures classified with predominant grain-size are respectively represented by:

a: Clay, b: Sandy clay, c: Silty clay, d: Clayey sand, e: Clayey silt, f: Sand, g: Silty sand, h: Sandy silt, and i: Silt

TABLE 1. COMPARISON OF X-RAY DIFFRACTION DATA FOR SOME MINERALS.

Bentonite (Hōjun)		Sericite (Murakami)				Dickite (Wanibuchi)			
I	d(A)	I	d(A)	I	d(A)	I	d(A)	I	d(A)
35	14.4	19	10.06	13	2. 13	3	9.18	17	2.50
		2	7.22	9	1.980	12	7.96	45	2.39
			7.16	17	1.818	90	7.22	10	2.36
17	4.46	10	4.99	6	1.671	43	4.71	36	2.33
44	4.06	9	4.47	4	1.662	15	4.45	5	2.21
3	3.34	50	4.26		1.650	21	4.37	4	2.13
8	3.11	2	3.71	17	1.541	14	4.26	3	2.11
6	3.03	90	3.34	4	1.496	23	4.13	4	2.08
14	2.91	3	3.09	2	1.454	68	3.99	5	1.97
6	2.56	9	2.56		1.451	18	3.80	3	1.89
9	2.50	17	2.46	7	1.385	90	3.58	6	1.85
		3	2.38		1.382	14	3.43	20	1.79
		9	2.28	9	1.374	8	3.35	20	1.65
		6	2.24	11	1.372	4	3.10	3	1.63
		5	2.23	3	1.288	3	3.07		
						6	2.94		
						6	2.80		
						13	2.56		

(HABARA, 1965)

B. PREPARATION of the STARTING MATERIAL

Inasmuch as it is most probable that different results are producible even through the same procedure due to instability of the starting material with easily variable composition or at least pH ensued from abrasion, standardization or the best conditioning for holding the initial state of the specimens as constant as possible prior to experiments is indispensable specifically in the case of clay minerals with ion exchangeability or absorbability for the substances contained in the media. As a method 0. 5g of the specimen of bentonite has been dispersed and stirred in 100c.c. of 0. 005N HCl for definite hours and the final point for washing effect or of exchange reaction of cation absorbed in the specimen with hydrogen ion has been discerned through the end of variation of pH in the solution. The data obtained are presented in the figure 2. In these experiments the specimens held for 24 hours have been taken out through the centrifugal separator and then one fraction of them has been dispersed again in 100c.c. of distilled water while the remainders have been subjected to treatment with 100c.c. of 0.005N HCl. For furthermore 24 hours variation of pH in the media containing suspension has been continuously measured. The similar procedures referred to above have been repeated again in 100c.c. of distilled water and of 0.005N HCl for furthermore 24 hours (totalized 72 hours from the initial state), resulting in constant value of pH$\approx$7 revealed in solution. As the result, it has become clear that

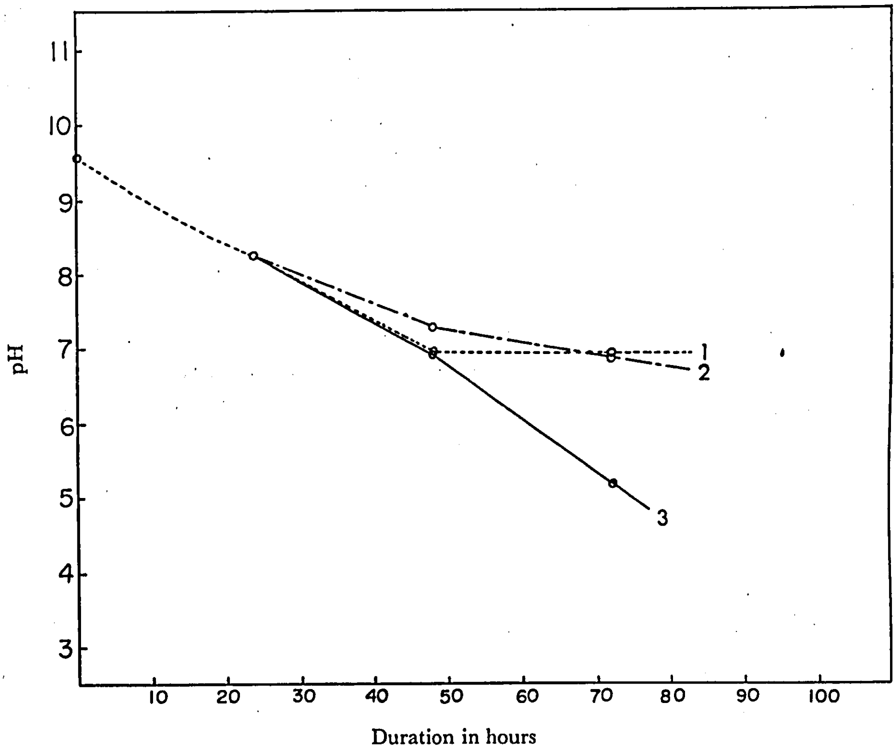

FIG. 2 pH variation in solution with suspension of bentonite (montmorillonite associated with a little amount of cristobalite).

1. stirred in 0.005N HCl for more than 72 hours.
2. stirred in 0.005N HCl for 48~72 hours after immersed in distilled water for 24~48 hours.
3. stirred in distilled water for 48~72 hours after immersed in 0.005N HCl for 48 hours.

the specimens treated with 0.005N HCl for 48 hours are considered as the sample useful as the standard for the starting material.

C. TESTING PROCESS

1. *Measurement of LL.*

The instrument used for measuring LL of the clayey substances has been modified to that with diameter of 7cm smaller than that of JIS scale and regulated to move with a constant vibration of two strokes per second by means of motor. After the specimen revealing LL with the above apparatus has been held in the electric air-bath at 90°C for 24 hours, its content of water has then been weighed.

2. *Measurement of viscosity.*

The viscometer of B8M type useful specifically for the materials with higher viscosity, manufactured by *Tokyo Keiki K.K.*, has been provided for the experiments of reading viscosity represented by torks yielded on the rotating tube in the viscous madia. The viscosity has been measured for 50～200g of the clayey material suspended in 500c.c. of distilled water and various kinds of electrolytes after definite stirring for 10 minutes with mechanical stirrer and then the water content has been determined through the procedure similar to that carried out in the above case.

III. EXPERIMENTAL RESULTS

A. LIQUID LIMIT

The data for LL are concerned with the untreated and washed bentonite (treated with various manipulations alluded to already) kneaded with various concentration of NaCl and $CaCl_2$ solution, as are illustrated in the figure 3. Inspection of the figure naturally indicates (1) difference in LL value due to concentration of NaCl, (2) that derived from whether the clayey material has been preliminarily subjected to certain treatment or not, (3) almost similar value of LL for the untreated and treated materials in the case of 0.2N solution and (4) the higher value for the treated material in the case of higher concentrated solution. The similar tendency is recognizable in the figure 4 except the lower value obtained in $CaCl_2$ solution than in the case with NaCl solution, indicating the identity with the data given by KAZDA (1961).

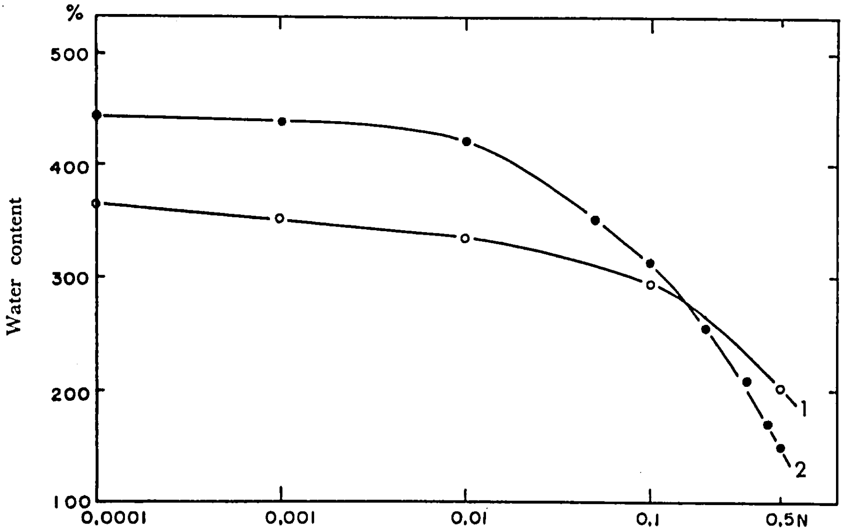

FIG. 3 Variation of the liquid limit of with use bentonite of variously concentrated NaCl solution.
1. Washed specimen. 2. Untreated specimen.

B. VISCOSITY

The results obtained in the preceding are accountably related to the upper limit of

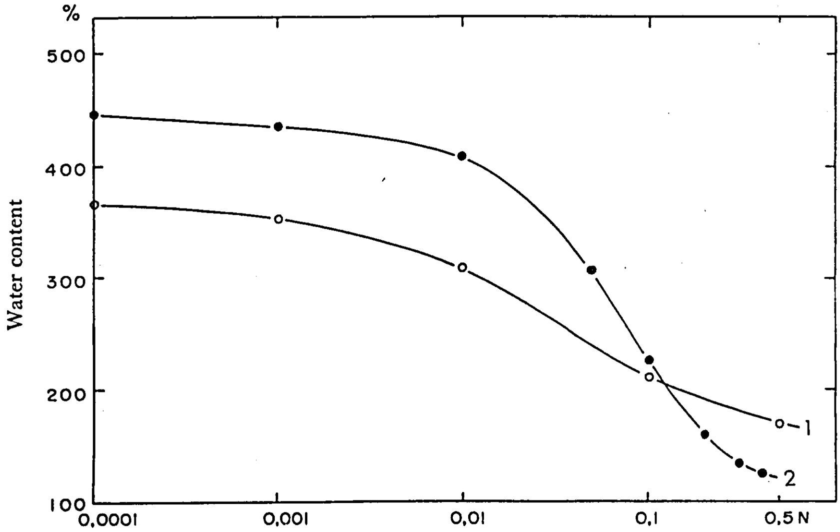

FIG. 4 Variation of the liquid limit of bentonite with use of variously concentrated $CaCl_2$ solution.
1. Washed specimen. 2. Untreated specimen.

plasticity for the paste of the clayey materials. To clarify their behaviors above this limit and to ascertain whether some continuity between them may present or not, the viscosity of electrolyte solution containing various amount of the clayey materials as well as the possibility of pursuing the relation of viscosity in suspension to LL in the upper range of plasticity have been scrutinized in detail. As for this regard, it has become obvious that difference in viscosity is caused due to the sort of clayey minerals, as are clearly demonstrated in the figure 5. The similar results have already been reported by HABARA (1965), according to whom the LL values are considerably different from the highest content of water for measuring viscosity in the term of water content: e.g. about 200% for bentonite, about 300% for sericite and about 30% for dickite. The fact attained in the present experiments is however that the resembling data have been obtained for water content in the cases of LL and viscosity measurement in the system including the clay minerals. As far as the bentonite is concerned, it seems evident that viscosity for the washed specimen is remarkably less than that for the untreated and the similar tendency is also observable in LL value. On the other hand, a considerable difference in viscosity due to content of the electrolyte represented by sea water is markedly conspicuous in comparison with use of the distilled water. As is recognizable in the figure 5, it is the reality that variation in viscosity of the bentonite is most noticeable. As is apparent in the figure 6, the experiments concerning the effects of kinds of electrolyte with some concentration on viscosity of bentonite have been carried into execution, yielding the miscellaneous results together with variation ascribed to concentration.

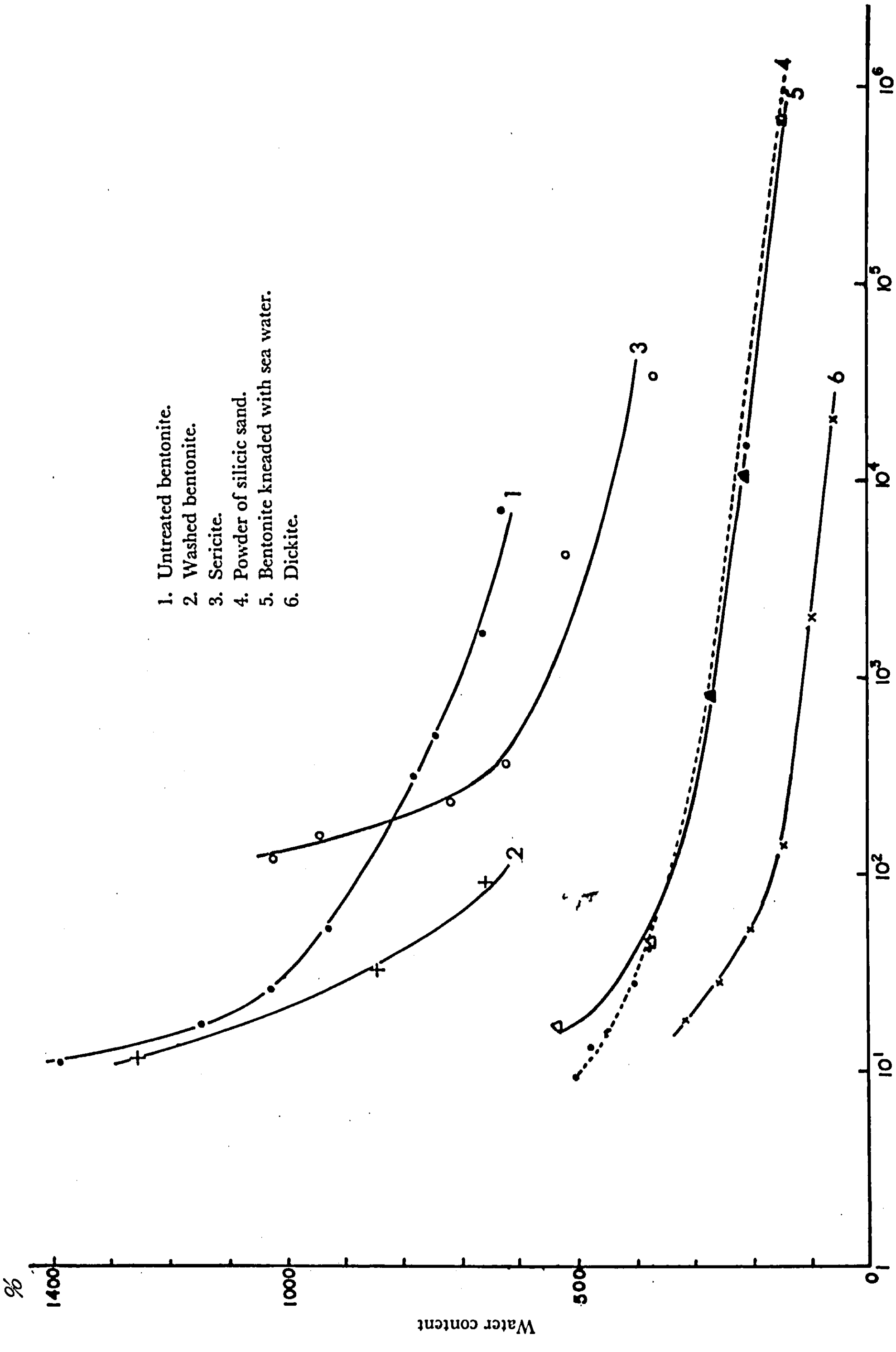

FIG. 5 Difference of viscosity owing to water content with the kinds of clayey minerals.

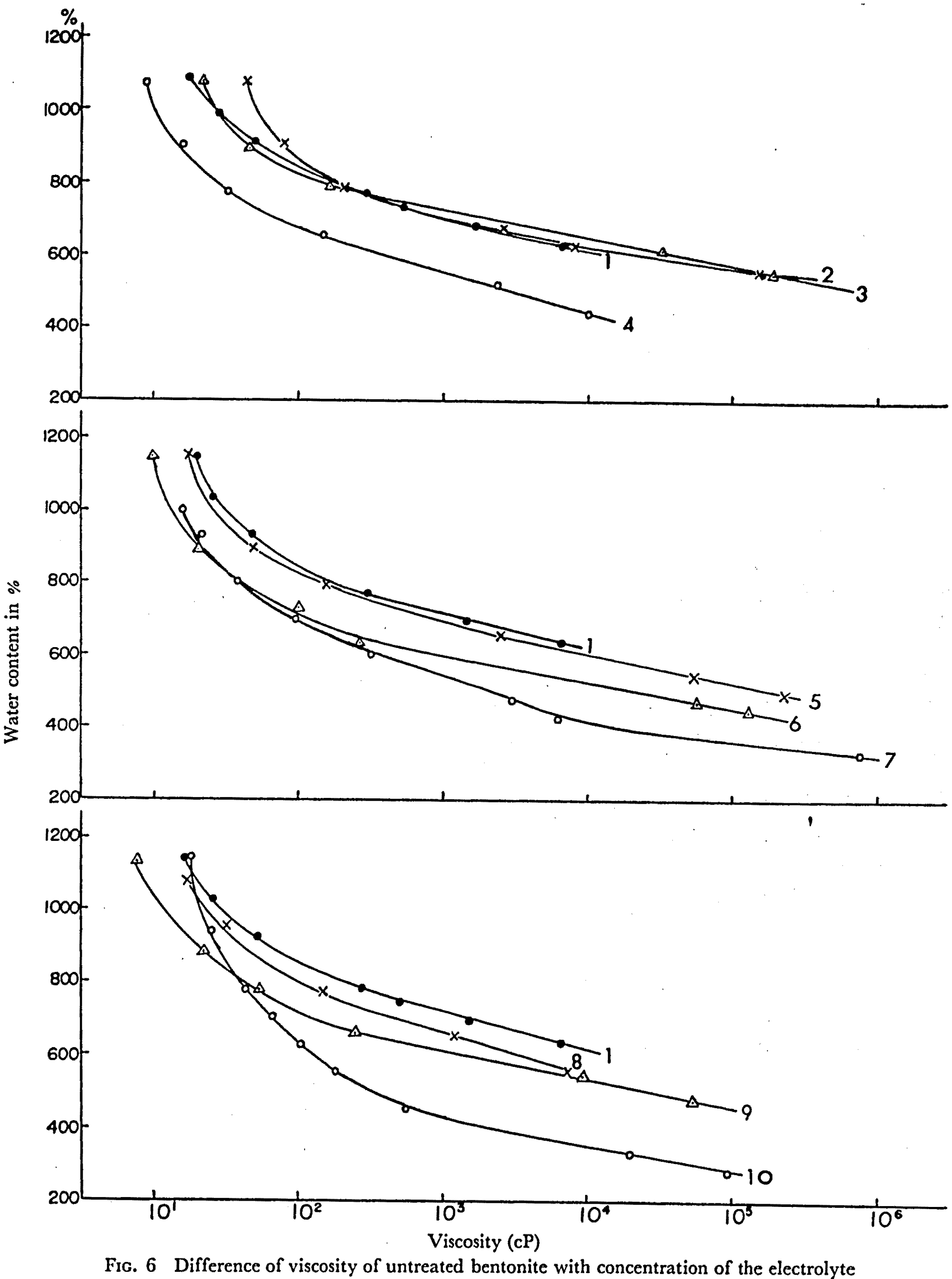

FIG. 6 Difference of viscosity of untreated bentonite with concentration of the electrolyte solutions.
1. distilled water 2. 0.001N KCl 3. 0.01N KCl 4. 0.1N KCl 5. 0.001N NaCl
6. 0.01N NaCl 7. 0.1N NaCl 8. 0.001N $CaCl_2$ 9. 0.01N $CaCl_2$ 10. 0. 1N $CaCl_2$

IV. SUMMARY

In general, the liquid limit reflecting a part of mechanical property of the sediments is liable to be measured without regard to their mineralogic and chemical compositions as well as their secondarily obtained characteristics, e.g. ion exchangeability and the absorbed or adsorbed contents of the coming-in materials in correspondence to the media. Similarly as for viscosity of solution containing suspension of the clayey materials as well as the analysis of particle size according to STOKES' rule, difference appearing in the specimens with or without treatments of standardization for the starting material is to be remarked to a considerable extent because of the gap occurring in both cases. From the data obtained for the untreated and washed materials (denoted hereunder the former and the latter respectively) in the cases with use of NaCl and $CaCl_2$ solution it has become clear that:

(1) difference of LL value for the untreated and washed materials is estimated about 80%.

(2) that of the value for the former kneaded with distilled water amounts to about 300% in the cases of being kneaded with 0.5N solution of NaCl and $CaCl_2$.

(3) that of the value for the latter amounts to 170～200% with the similar treatments.

(4) when kneaded with 0.2N solution of NaCl and $CaCl_2$, LL values for the former are not so much different from each other.

(5) when kneaded with 0.2～0.5N solution of NaCl and $CaCl_2$, LL values for the latter are commonly greater than those for the former.

(6) LL values treated with $CaCl_2$ solution are less than those kneaded with NaCl solution.

In relation to viscosity measured in the range above the upper limit of plasticity, the following results have been ascertainable.

(7) viscosity curve for the untreated bentonite is situated within the area of water content higher than those for sericite, silicic sand and dickite whereas that for the last is in the lowest area and that for the second bears the special characteristic in habit, distributing in the area somewhat higher than the last.

(8) it is surely general that the value of viscocity of the washed bentonite is less than that of the untreated.

(9) from all of the facts mentioned above it is deducible that the estimate of the absorbed quantity of cations on the clayey materials, discernible by some of the indirect procedure such as measurement of variation of pH and electric conductivity or resistivity, makes it possible to compare or to compute LL values, that the relation of viscosity within the range of suspension to the absorbed amount of cations determined through some other procedure enables to calculate the LL values and, in addition, that compression of the clayey materials, no matter whether it might have been caused artificially or naturally, is quantitatively determinable through analysis or any other means for estimating the ions extracted out into the surrounding media.

One of the purpose of the present work was, as alluded to already, to find out the clue to obtaining difference in mechanical property in connection with mineralogic or chemical composition together with the features obtained secondarily from their essential characteristics and, in consequence, it is believed to reach somewhat satisfactory conclusion even though as the first trial.

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