WATER PERMEABILITY AND PLASTIC INDEX OF SOILS

Yoshichika NISHIDA and Seishi NAKAGAWA

ABSTRACT

The coefficient of permeability of water in clay, on which the rate of consolidation settlement is dependent, can be approximately asked from its void ratio and plastic index through a simple formula.

RÉSUMÉ

Le coefficient de perméabilité de l'eau dans l'argile dont est dépendante la vitesse de tassement de consolidation peut être approximativement recherché par son indice des vides et son indice de plasticité par une formule simple.

INTRODUCTION

Land subsidence often is caused by the consolidation of the ground, which is due to water emerging from the soil under a load. Thus, the flow of water in the soil must have much influence on the settlement of the land surface, and it can be estimated by the coefficient of permeability of the soil. This coefficient is measured by a permeability test of the constant-head or falling-head type for the coarse-grained soils or the medium-grained soils, but such equipment is not useful for fine-grained clays. The coefficient of permeability of clay is obtained by analysis of consolidation-test results. This paper presents an experimental relationship to predict the coefficient of permeability of soils, particularly of clays, from their plasticity index, PI. The latter is one of the most simple tests, not requiring the permeability test or the consolidation test. A few comments on this idea were reported by one of the writers [1], and in this paper data on many kinds of clays are presented to confirm the relationship.

EXPERIMENT

According to many experiments, a linear relationship has already been formed between void ratio of a clay, e, and the logarithmic value of its coefficient of permeability, $\log_{10} k$, as follows:

$$e = \alpha + \beta \log_{10} k \tag{1}$$

where α and β are constants, depending on the kinds of clays, and k is in cm per sec.

Normal consolidation tests were carried out on each kind of clays and α, β and k in equation (1) were obtained by analysis of the test data according to Terzaghi's consolidation theory. Consistency tests also were carried out on many kinds of clays. Data were obtained from samples of undisturbed clays, of remolded clays, and of cation-exchanged clays soaked in different solutions. Some clays, air-dried at 20 °C and passing the 2-mm sieve, were soaked in the liquid acetete salts (Na, H, Ca, Mg, Al,) for 30 hours in order to exchange cations. The cation-exchanged clays were washed out with 80 percent methyl alcohol and air-dried. As cations in a clay are exchanged, the liquid phase around the clay particles makes a change in its characteristics and the thickness of the absorbed water. Then, the apparent size of particles is transformed and their consistency is altered.

A bentonite clay, which has high activity, was soaked in the electrolytes with different normalities in order to change the mutual forces acting between clay particles.

When clays were oven-dried at 11 °C, their consistency were different from the ones air-dried at 20 °C probably due to the change in apparent size of particles due to flocking.

TEST RESULTS

Figure 1 is the plasticity chart for the consistency tests on the clay samples used for the experiments. Table 1 shows the results of consolidation tests and consistency tests, to determine α, β, and the plasticity index. The data show that the value of α is nearly equal

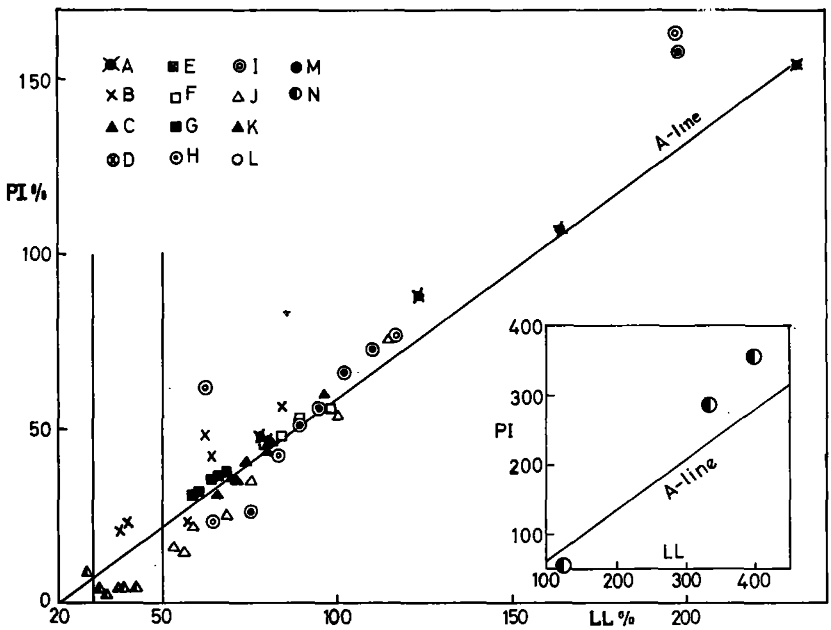

FIGURE 1. *Plasticity chart*

TABLE 1. *PI*, α and β of sample

Sample	*PI*	α	β	α/β	
A	46.9	6.2	0.6	10.3	undisturbed
	47.5	4.75	0.5	9.5	
	87.8	9.1[illegible]	0.88	10.4	
	106.8	15.0	1.7	8.8	
	154.7	13.4	1.5	8.9	
	223.1	20.1	2.1	9.6	
B	23.0	3.05	0.30	10.2	undisturbed
	32.4	3.95	0.40	9.9	
	41.5	4.84	0.48	10.1	
	47.5	3.85	0.45	8.6	
	58.4	3.10	0.25	12.4	
	20.7	2.74	0.28	9.8	

C	30.8	2.79	0.24	11.4	undisturbed
	35.3	3.64	0.38	9.6	
	36.4	3.76	0.38	9.9	
	40.0	3.54	0.33	10.7	
	43.0	3.65	0.36	10.1	
	48.9	2.52	0.22	11.5	
	60.3	4.49	0.48	9.4	
D	11.0	2.0	0.18	11.4	(Ref. 1) undisturbed vertical dir. for permeability
	14.0	2.3	0.23	10.2	
	18.0	2.5	0.25	10.0	
	21.0	2.8	0.26	10.8	
	22.0	3.0	0.27	11.1	
	23.0	2.9	0.26	11.2	
	24.0	3.1	0.30	10.3	
	30.0	3.7	0.36	10.3	
	35.0	4.0	0.39	10.3	
E	12.0	2.5	0.25	10.0	(Ref. 1) undisturbed horizontal dir. for permeability
	14.0	2.6	0.26	10.0	
	17.0	2.9	0.29	10.0	
	21.0	3.2	0.31	10.3	
	21.0	3.4	0.33	10.3	
	23.0	3.4	0.33	10.3	
	23.0	3.6	0.36	10.0	
F	55.8	6.41	0.58	11.1	Na — cation exchanged
	52.3	4.07	0.38	12.3	H
	47.9	4.80	0.41	11.7	Mg
	45.0	4.49	0.38	11.8	Ca
G	36.9	5.86	0.52	11.3	Na — cation exchanged
	35.4	4.27	0.35	12.2	H
	35.2	4.73	0.40	11.8	Mg
	31.7	4.14	0.33	12.6	Ca
	30.7	4.35	0.35	12.4	Al
H	158.0	13.8	1.33	10.4	Na — cation exchanged
	56.0	6.10	0.59	10.3	H
	65.9	6.57	0.69	9.5	Ca
	73.1	7.32	0.73	10.0	Mg
	26.0	4.08	0.35	11.7	Al
	50.8	4.86	0.44	11.1	original sample disturbed
I	42.8	7.30	0.75	9.7	H — dried in oven after cation exchanged
	22.5	4.35	0.44	9.9	Ca
	163.7	7.26	0.71	10.2	Mg
	–	3.76	0.35	10.7	Al
J	2.1	2.34	0.23	10.2	(Ref. 1) dried in oven
	4.1	2.35	0.25	9.4	
	4.5	2.58	0.22	11.7	
	4.9	2.27	0.21	10.8	
	5.2	2.53	0.22	11.5	
	8.6	2.78	0.32	8.7	

K	13.6	3.54	0.30	11.8	(Ref. 1) dried in oven
	15.6	2.87	0.28	10.2	
	21.6	3.93	0.38	10.3	
	25.0	4.10	0.40	10.2	
	34.9	4.90	0.49	10.0	
	76.2	6.23	0.36	11.1	
L	1.0	(10 β)	0.06	(10.0)	(Ref. 2) at denser state
	2.0	(10 β)	0.06	(10.0)	
	10.0	(10 β)	0.08	(10.0)	
	13.0	(10 β)	0.14	(10.0)	
	18.0	(10 β)	0.15	(10.0)	
	18.0	(10 β)	0.28	(10.0)	
	37.0	(10 β)	0.32	(10.0)	
M	1.0	(10 β)	0.27	(10.0)	(Ref. 2) at looser state
	2.0	(10 β)	0.06	(10.0)	
	10.0	(10 β)	0.16	(10.0)	
	13.0	(10 β)	0.17	(10.0)	
	18.0	(10 β)	0.25	(10.0)	
	18.0	(10 β)	0.31	(10.0)	
	37.0	(10 β)	0.50	(10.0)	
N	57.4	5.93	0.51	11.6	1 N — normality of NaCl Bentonite
	28.6	15.04	1.36	11.0	0.1 N
	35.3	28.1	2.58	10.9	0.01 N

to 10 times the value of β, and the coefficient β in equation [1] seems to be linear with the plasticity index. Figure 2 shows that the linear relationship between β and *PI* holds for each kind of clay. Those lines representing the relationships are parallel to each other, with a slope of about 0.01, and may be expressed for almost all kinds of clays as follows:

$$\beta = 0.01\,(PI) + \gamma \tag{2}$$

where γ is a constant depending on the kind of clay, which takes the value of -0.01 for a bentonite clay and of 0.3 for an oven-dried clay. Although a fine-grained clay of high consistency seems to have a smaller value (the negative value in some cases) for γ, while a coarse grained clay of low consistency has a larger value for γ, this conclusion about γ is not definitive and further studies should be made. Figure 3 shows the relationship for clays of much higher consistency, including those data in figure 2. It can be found in figure 3 that the average value of γ in equation [2] is 0.05.

If the void ratio of a clay and its plasticity index are known, the coefficient of permeability of the clay, k, in cm per sec, can be approximated by equation [1] and equation [2] using the values of 0.01 for β, 0.05 for γ and $\alpha \doteqdot 10$, because these values obtained from test results on many kinds of clays, covering an extensive range of plasticity index — from 2 percent to 350 percent.

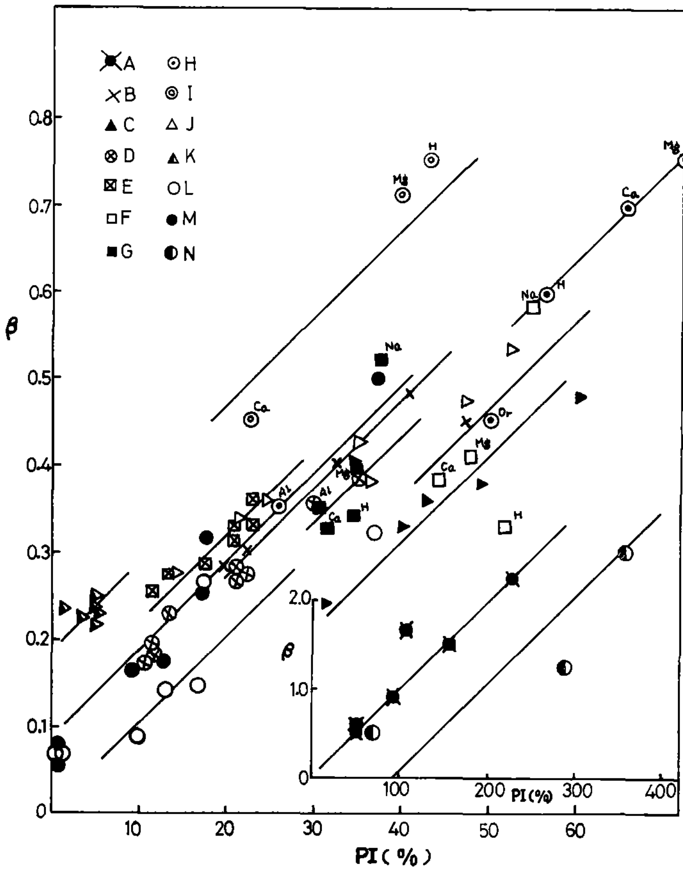

FIGURE 2. *β and PI in detail*

CONCLUSIONS

The following relationship is useful for prediction of the coefficient of permeability of water in clay.

$$e = \{0.01(PI)+0.05\}(10+\log_{10}k) \tag{3}$$

where

- e void ratio of clay;
- PI plasticity index of clay, in percent;
- k coefficient of permeability of clay, in cm per sec.

ACKNOWLEDGEMENT

The writers thank Mr. Hiroshi Koike who helped to carry out the experimental works.

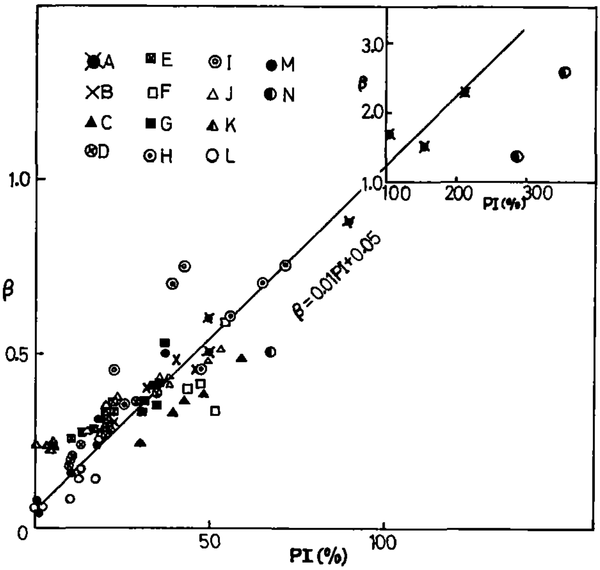

FIGURE 3. *β and PI*

DISCUSSION

Intervention by Mr. Arnold I. JOHNSON (USA):

Question:

I wondered if you ran tests of permeability on undisturbed cores of natural materials from the field or only on remolded or disturbed samples? If not, perhaps this is the reason you obtained as good a relationship as you indicated in your paper.

Answer of Prof. NIAHIDA:

We ran consolidation tests on undisturbed cores as well as on some remolded ones. Gathering up all data available, we are now carrying out a theoretical study: What I presented today are the experimental data. But I will say that en approximate relationship, linear relationship may be found between the plastic index by a very simple test.