離散土의 物理的·化學的 特性에 관한 研究

A Study on the Physical and Chemical Characteristics of Dispersive Soils

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要 旨

타일랜드 北東部 세 地域에서 나타나는 離散土에 대한 物理的·化學的 特性에 對한 試驗이 實驗室과 現場에서 遂行되었다.

離散土의 粘土含量과 離散性과의 關係를 糾明하기 爲하여 室內에서 離散土中의 粘土를 分離한 後 人爲的인 粘土含量比로 흙을 다시 만들어서 pinhole 試驗을 遂行하였는데, 離散土는 粘土含量比에 關係없이 쉽게 離散되었다.

또한 흙의 抽出水와 貯水池 물에 대한 化學的 特性을 밝히기 위하여 SAR, ESP 및 pH 값들이 決定되었는데, 離散土는 1.8~6.7 SAR, 1.4~7.9 ESP 및 5.4~9.0의 pH 값을 나타내어서 一般的인 흙에 比하여 높은 SAR, ESP 및 pH 값을 보였다.

Abstract

Tests for the physical and chemical properties on the dispersive soils from the 3 selected sites in the northeast region of Thailand were carried out in the field and laboratory.

In oder to find out the relationship between clay contents and dispersivity of the soil, some specimens are artificially mixed with a certain amount of clay in the laboratory and tested by means of pinhole tests. The artificial soils are dispersed in pinhole tests regardless of their clay contents.

Chemical properties on the soil saturation extract and reservoir water are also determined by means of sodium adsorption ratio(SAR), exchangeable sodium percentage (ESP) and pH. The dispersive soils in the region have ranges of 1.8~6.7 SAR, 1.4~7.9 ESP and 5.4~9.0 pH value. Namely, the dispersive soils studied have somewhat higher SAR, ESP and pH value than those of ordinary soil.

I. General

Many of the hydraulic structures and highways containing dispersive soils or on dispersive soils have suffered by any or combination of forms of piping, jugging, gully erosion, slickspots, tunnels and surface erosion, because the dispersive soils disperse easily and rapidly in slow-moving or even quiet water by individual colloidal clay particles going into suspen-

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sion.

The soils encountered in the northeastern Thailand have distinct pseudokarstic topography and the color of water in small puddles or ponds on the dispersive soils is cloudy yellow or brownish yellow. The common soils in the region are silty clay, sandy clay, sandy silt and clayey silt of Quarternary age with the underlying bedrocks of sandstone and shale of the Mesozoic age.

II. Literature Review

The dispersion occurs when the repulsive forces(electrical surface forces) between individual clay particles exceed the attractive forces(van der Waal attraction) so that when the clay mass is in contact with water, individual clay particles are progressively detatched from the surface and go into suspension.[1] The tendency toward dispersion is usually caused by a decreasing of the electrolyte concentration, ion valence and temperature and by increasing of the dielectric constant, size of hydrated ion, pH and sodium content in the soils[2]. The dispersive soils generally have an exchangeable sodium percentage greater than two to ten, and the same soil can be made dispersive or nondispersive status depending upon chemistry of the eroding water i.e. eroding water with pH less than 4 or greater than 11 caused a change from dispersive to nondispersive behavior[3].

The typical dispersive soil piping failure in homogenous dams has started with a very small initial leak which eroded in a few hours to a tunnel of substantial diameter.[4] According to Aitchson & Wood (1965)[5], it was determined that 8.7% of the earth dams constructed in Australia failed by piping or have been badly damaged by vertical erosion tunnels from rainfall. Parker & Jeene(1967)[6] described the current and potential damage of piping and surface erosion to the highways in the western U.S.A, and pointed out some ways in which this damage might be minimized. They showed that the dominant type of piping damaging highway structures in the western dry land originated from desication cracks. And they observed a number of sites where highways, bridges, culverts, and other highway structures are imperilled by piping.

Cole, et al. (1977)[7] studied the dispersive soils which were obtained from several sites of irrigation dams in the northeastern region of Thailand, which have failed or suffered by the erosion. They found the average percent sodium of 66～80 %, the percent dispersion of 29～49 % and major clay minerals of quartz, kaolinite, illite, and montmorillonite from the 122 samples of dispersive soils. Shie (1981)[8] studied the engineering properties of the dispersive soils in the Lam Sam Lai dam site, and found that the major clay minerals are 50～60 % kaolinite and about equal amounts of montmorillonite and illite, i.e., 20～25 % each. Kim (1982)[9] found that the major clay minerals in the soils of the Lam Sam Lai dam are 50 % of montmorillonite and 40 % of kaolinite, and the soil from the Lam Chieng Krai dam has 90 % of montmorillonite.

III. Experimental Investigation and Result Presentation

1. Site Description

The Lam Sam Lai dam which has a maximum height of 14m, a crest length of 2.5km, failed by piping during the first reservoir filling, and the embankment has suffered very severe tunnel and gully erosion as shown in Figs. 3.1 and 3.2. The soils encountered in the site are yellow and brownish yellow silty clay and sandy clay of Quarternary age.

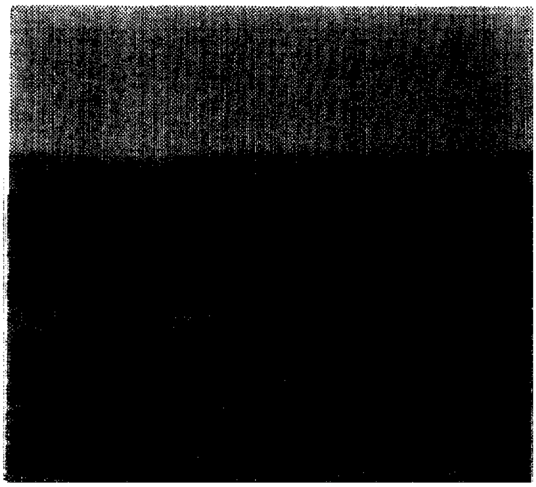


Fig. 3.1 Typical Pseudokarst

Fig. 3.2 Typical Gully Erosion

The Lam Chieng Krai dam has a maximum height of 10m and a crest length of 3.2 km, and its embankment section is virtually homogeneous. When unusually heavy rain filled the reservoir quickly, the embankment leaked by piping in three different locations. The soils encountered are brown to dark brown clayey sand, silty sand, silty sand, or clayey silt with some gravels.

The embankment of a small pond in the Ban Sawai village, has suffered by the sink hole, gully and tunnel erosion as shown in Figs. 3.3 and 3.4. The soils in the area are reddish brown to light purple or yellow silty clays.

2. Laboratory Experiments and Result Presentation

(1) Index Test

Some of the index properties on the soil

Fig. 3.3 Severely Eroded Embankment

Fig. 3.4 Typical Sinkholes and Tunnels

Table 3.1 Index Properties of the Dispersive Soils Studied

Site	W(%)	Wl(%)	Wp(%)	PI	G	<.005mm (%)	% Clay
Lam Sam Lai	6.0	35.1	13.3	21.8	2.68	35.0	32.0
Lam Chieng Krai	4.8	18.0	13.2	4.8	2.55	13.5	12.0
Ban Sawai	7.9	39.5	19.6	19.9	2.64	42.0	39.0
Sukhothai (*)	1.3	24.8	13.4	11.4	2.63	25.0	22.0

(*) Nondispersive Soil

samples were determined to understand the physical character of the soils. The results are tabulated in Table 3.1, and the grain size distributions are shown in Fig. 3.5.

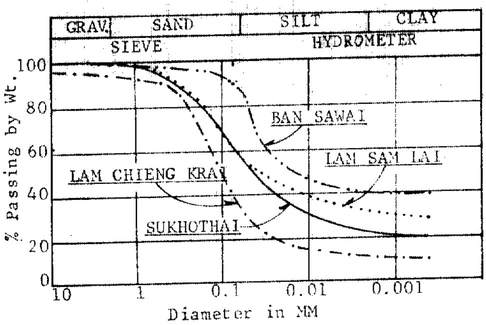


Fig. 3.5 Grain Size Distribution of Soils

As shown in Table 3.1, and Fig. 3.5 the physical properties of the dispersive soils are not distinguishable from the ordinary soils. According to the Unified Soil Classification System, the soils in the Lam Sam Lai dam site and Ban Sawai area are classified as inorganic clays of low to medium plasticity (CL), and the soil in the Lam Chieng Krai dam site is classified as poorly graded silty sand to clayey sand (SM-CM).

(2) Crumb Test

A crumb of soils less than 1.0 cm in diameter was dropped in the distilled water in a beaker. The dispersivity of the soil was observed after 5 to 10 minutes using the following interpretation guide.

Grade 1 : No Reaction (No sign of cloudy water)

Grade 2 : Slight Reaction (Bare hint of cloud)

Grade 3 : Moderate Reaction (Easily recognizable cloud)

Grade 4 : Strong Reaction (Colloidal cloud covers bottom)

The results of crumb tests indicated that the soils in the three studied sites were dispersive soils of which grades were between 3 and 4, moderate to strong reaction, with the distilled water as shown in Table 3.2.

For the soil in the Lam Chieng Krai dam site, although the recognizable cloud of colloids in suspension was observed in the crumb test, and the crumb was collapsed easily in the water, it was classified as Grade 3 because the cloud was not so dark as those of other sites. A few samples of the soil in the Ban Sawai area showed Grade 4, but mostly they were of Grade 3. Half of the samples of the soil of the Lam Sam Lai dam site showed Grade 4 and another half could be classified as Grade 3.

Table 3.2 Results of Crumb Tests

Site	Grade	Sample Number	Water Content	Description
Lam Sam Lai	3~4	12	5~7 %	Becomes cloudy
Lam Chieng Krai	3	6	4~6 %	Cloudy but not dark
Ban Sawai	3~4	10	7~9 %	Becomes cloudy

(3) Pinhole Test

The standard apparatus (Fig. 3.6) and procedure which was described by Sherard, et al. (1976a)[1], were employed for the pinhole tests. The standard method followed is briefly described below, and the criteria for evaluating result are shown in Table 3.3.

(i) sieve with No. 10 (2 mm) to remove coarse grains, and determine the natural water content,

(ii) bring to about the plastic limit by adding distilled water,

(iii) the 1.5 in. long specimen is compacted in the mold on top of pea gravel and wire screen in 5 layers with 16 tamps each layer using a 6.8 kg spring with Harvard miniature compaction test tamper,

(iv) the nipple is pushed into the top of the compacted specimen with finger pressure and the hole is punched through the nipple with a steel pin of 1 mm diameter,

(v) after an apparatus is assembled, distilled water is percolated through the hole under 2 in. head, for a duration of 10 minutes (or 5 minutes) by observing the rate and color of flowout through the side of flask,

(vi) at the end of the successive flow tests, the apparatus is dismantled and the specimen is extruded from the mold, and

(vii) the size of hole is measured by comparing with the pin used for punching the hole.

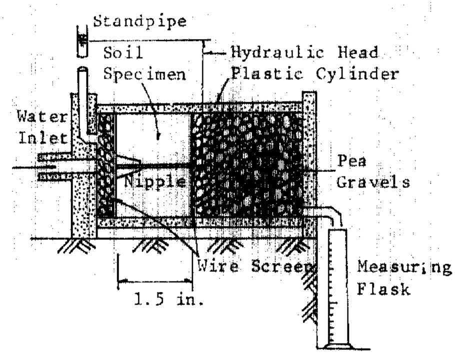


Fig. 3.6 Pinhole Test Apparatus

(a) Pinhole Tests on the Natural Soils

Pinhole tests on natural soils were carried out in the laboratory and their results are shown in Table 3.4 and Fig. 3.7. In all cases, the soils were easily eroded under 2 in. head of eroding water. The soil of the Lam Chieng Krai dam site was seriously eroded in the test due to its low clay content.

Table 3.3 Criteria for Evaluating Pinhole Test Results

Class	Head (in.)	Time (min)	Flows (ml/s)	Cloudiness	Hole Size increment
D 1	2	5	>1.5	Very Distinct Cloud	>2 Times
D 2	2	10	>1.0	Distinct to Slight Cloud	2 Times
ND 4	2	10	<0.8	Easily Visible Cloud	1.5 Times
ND 3	7~15	5	>2.5~3.5	Easily Visible Cloud	2 Times
ND 2	40	5	>5.0	Barely Visible Cloud	2 Times
ND 1	40	5	<5.0	Crystal Clear	1 Times

Table 3.4 Results of Pinhole Tests on Natural Soils

Site	Test No.	Water Content	Flows (ml/s)	Color	Hole (mm)	Class	Remark
Lam Sam Lai	L1~L4	14.1%	1.3~1.8	Very Distinct	4~5	D1	
Lam Chieng Krai	Lc1~Lc3	9.8~14.3%	1.6~2.8	Very Distinct	7~30	D1	5 Min.
Ban Sawai	B1~B4	20.2%	1.3~1.8	Very Distinct	3~5	D1~D2	

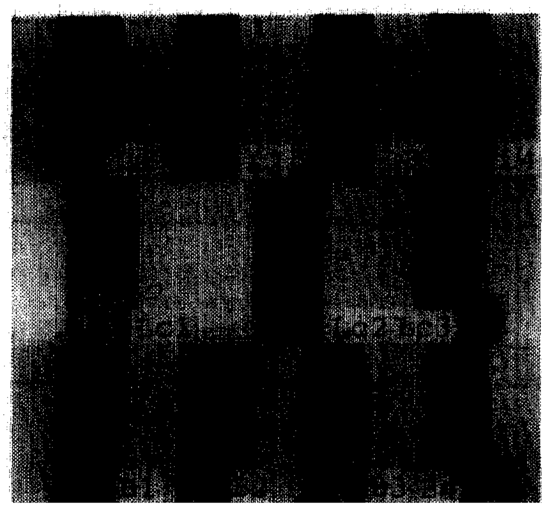
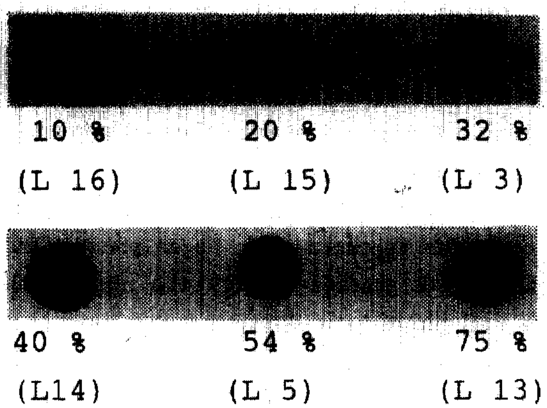


Fig. 3.7 Pinhole Test Results on Natural Soils

(b) Pinhole Tests on the Reconstructed Soils

Two series of pinhole tests on the reconstructed soils was carried out in the laboratory and the results are shown in Table 3.5 and Fig. 3.8 and 3.9. Regardless of the amount of clay particles in the soils the specimens are eroded easily. The higher content of clay seemed to decrease the erodability of the soil, but the specimen with a high clay content was seriously fractured during the drying as shown in figures. The most serious erosion occurred at the lowest clay content in the specimen. The lower clay content would be a cause of small attractive force between grains, and pore space of the soil with small amount of clay would be bigger than that of the soil with high clay content; as a result, the permeability would be higher. These high permeability and low attractive



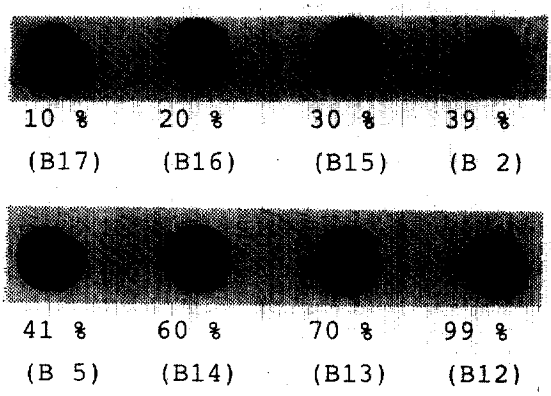
(Lam Sam Lai Dam Site)

Fig. 3.8 Pinhole Test Results on Reconstructed Soils

Table 3.5 Results of Pinhole Tests on Reconstructed Soils

Site	Test No.	% of Clay	Water Content (%)	Flows (ml/s)	Color	Hole (mm)	Class
Lam	L 16	10	6.7	2.6	Very Distinct	20	D1
Sam	L 15	20	10.7	2.6		8	D1
Lai	L 3	32	14.1	1.8		5	D1
Dam	L 14	40	13.6	2.4		8	D1
	L 5	54	14.7	2.0		6	D1
	L 13	75	21.7	2.6		6	D1
Ban	B 17	10	10.4	2.6	Very Distinct	18	D1
Sawai	B 16	20	10.9	2.3		8	D1
Area	B 15	30	12.3	2.4		6	D1
	B 2	39	20.2	1.3		3	D1/D2
	B 5	41	20.3	2.2		5	D1
	B 14	60	20.8	2.5		4	D1
	B 13	70	22.2	2.7		4	D1
	B 12	99	27.1	2.3		3	D1

force are the causes of serious erosion of the soil with low clay content. The natural soils in the both cases showed the least erosion in the test.



(Ban Sawai Area)

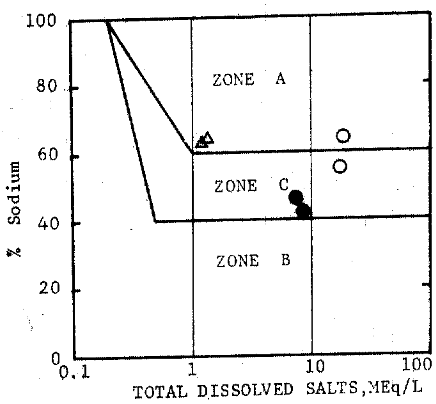
Fig. 3.9 Pinhole Test Results on Reconstructed Soils

(4) Chemical Test

In order to determine the Sodium Adsorption Ratio (SAR), the amount of calcium plus magnesium was measured by EDTA titrimetric method, and a flame photometer was used for measuring of amount of sodium. The equations used are Eq. 3.1 and Eq 3.2 and the procedures followed are those recommended by Richards (1954)[10].

$$Ca^{++}+Mg^{++}(meq/l)=(ml \text{ of EDTA used} \times \text{Normality of EDTA} \times 1000)/10 \quad \text{(Eq. 3.1)}$$

$$Na^{+}(meq/l)=(50\times meq/l \text{ of Na from calibration curve})/10 \quad \text{(Eq. 3.2)}$$



Zone A : Dispersive, Zone B : Nondispersive, Zone C : Intermediate

● : Lam Sam Lai Dam Site,

○ : Lam Chieng Krai Dam Site

△ : Ban Sawai Area

Fig. 3.10 Relationship between Dispersivity and Dissolved Salts

Table 3.6 Results of Chemical Analysis

Site	Test No.	$Ca^{++}+Mg^{++}$ MEq/l	Na^{+} MEq/l	SAR	$Ca^{++}+Mg^{++}+Na^{+}$ MEq/l	ESP (%)	% Sodium	pH
Lam Sam Lai	Ls 1	5.68	3.9	2.3	9.58	2.1	40.7	8.1
	Ls 2	4.32	3.8	2.6	8.12	2.3	46.8	8.2
	Lw1	2.74	0.5	0.4	3.24	—	15.4	7.5
	Lw2	2.84	0.4	0.3	3.24	—	12.3	7.3
	Lw3	1.37	0.9	1.1	2.27	0.4	39.7	6.6
Lam Chieng Krai	Lcs 1	10.0	12.6	5.6	22.60	6.5	55.8	8.9
	Lcs 2	9.26	14.4	6.7	23.66	7.9	60.9	9.0
Ban Sawai	Bs 1	0.53	0.9	1.8	1.43	1.4	63.1	5.4
	Bs 2	0.53	0.9	1.8	1.43	1.4	63.1	5.4
	Bw 1	5.47	0.4	0.2	5.87	—	6.8	7.5
	Bw 2	2.11	0.5	0.4	2.61	—	19.2	7.0
	Bw 3	6.84	0.4	0.2	7.24	—	5.5	7.5

(*) Ls, Lcs, Bs; Soil Samples
Lw,Bw; Water Samples

The pH-meter used to determine the pH of the reservoir water and the soil suspension, was PYE UNICAM model 290. Three readings were taken on each sample and the average was considered as representative value. The procedure described by the Standards Association of Australia (1966) was employed.

As shown in Table 3.6, the SAR of the reservoir water (eroding water) is extremely low (less than 0.5) and that of the soil is greater than 1.8. The highest SAR of the soil is 5.6~6.7 in the Lam Chieng Krai dam site, and its pH value is about 9.0. And Fig. 3.10 shows a reliable relationship between the chemistry and dispersivity of soils. Even though it falls in zonc C, the soil of the Lam Sam Lai dam site is highly dispersive. The soil of the Lam Chieng Krai dam site falls in zone A and C, and the Ban Sawai soil belongs to zone A, i.e., area of a dispersive behavior.

The difference of total ionic concentration between the pore water in the soil and the storage water is a cause of the difference of the osmotic pressure between two, i.e., the osmotic pressure of the pore water is higher than that of the storage water, so that the soil would absorb the storage water to attain equilibrium. As a result, the soil will swell and the attractive force will decrease. By this procedure, the soil mass will be dispersed.

The pH value of the dispersive soils are somewhat high except the Ban Sawai area. At high pH, the proton concentration is low and the net surface charge is negative and high. The greater surface charge density at high pH results in a greater concentration of ions in the diffuse swarm and a consequently greater repulsive interaction between the particles. Although the soil in the Ban Sawai area has only 1.8 SAR and 5.4 pH value, it was a easily dispersed in pinhole tests and the surface of the embankment of the pond has seriouly suffered.

IV. Conclusions

From the field and laboratory experimental investigations the conclusions of this study can be summarized as follows;

(1) Index properties of the dispersive soils were not distinguishable from those of the ordinary soils. And the soils in the Lam Sam Lai dam site and Ban Sawai area were classified as CL, and the soil in the Lam Chieng Krai dam site was classified as SM-CM according to the Unified Soil Classification System.

(2) All the dispersive soils studied were easily eroded in pinhole tests and classified as D1 or D1-D2.

(3) The clay content of the dispersive soils slightly affected the erodability of the soil in pinhole test. Soils with low clay content (such as Test No. L 16 & B 17 in Table 3.5) were eroded more easily than the high clayey soils, but it may not be classified as dispersive soil because the amounts of clay particles are too small to control the erodability of soil. And severe cracks were developed on the specimen with higher clay content during drying after test.

(4) The dispersive soils had 1.8~6.7 SAR, 1.4~7.9 ESP and 5.4~9.0 pH. High values of SAR, ESP and pH seemed to be more dispersible in pinhole tests.

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(接受 : 1984. 11. 22)