Soil susceptibility to dispersion

La susceptibilité des sols à la dispersion

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SYNOPSIS Association of dispersive clays with the failures of homogeneous earth dams has been recognized widely since the early 1970's. In this study, fifteen soils from eleven earth dam sites in Turkey were selected and subjected to double hydrometer, pinhole, chemical, crumb, and soil security tests in order to examine their dispersion characteristics. In soil security test, the effects of varying water content, lime treatment and presence of granular zones, as filters, on internal erosion were additionally investigated. The soils were also subjected to standard laboratory testing to obtain their index and mineralogical properties for their identification and for searching possible relationships between such properties and the dispersion characteristics.

INTRODUCTION

Some clay soils disperse in the presence of flowing water, therefore they are highly susceptible to erosion and piping. Such soils are structurally unstable and this is why they are easily dispersed and highly erodible. At the presence of water, when repulsive forces among clay particles exceed attractive forces, individual particles are progressively detached from each other and go into suspension. If the water is flowing, the dispersed clay particles are carried away causing internal erosion (Sherard et. al., 1976).

Although there have been no such incidents in Turkey, since large number of earth dams are under construction and planning recently, the internal erosion phenomenon would be a problem to be considered in more detail. In this study, fifteen different soils from eleven earth dam sites in Turkey were selected in order to examine their dispersion characteristics.

LABORATORY TESTING PROGRAM

Experimental work has been carried out in two stages. In the first stage eight soils from seven earth dams, namely Adigüzel, Alaca, Aslantas, Berdan, Camlidere, Kozlu, and Tercan, were subjected to double hydrometer, pinhole, crumb, and chemical tests in order to evaluate their dispersion characteristics, and standard laboratory tests were performed to obtain their index and mineralogical properties. In this group, two soils were considered for Aslantas Dam, since there were two borrow areas for that particular dam. All the tests of the first stage were conducted by Düzceer (1984).

In the second stage seven more soils from four other earth dam sites were investigated. Those dams were Atatürk, Cekmece, Camgazi, and Kayacik. Again, due to the existence of various borrow areas for Atatürk Dam, four soils were examined under that name. In this group, soil security test was additionally considered in evaluating dispersibility of soils, while chemical test was omitted. In soil security test, the influences of varying water content, lime treatment and presence of granular zones on dispersion characteristics were also studied. Moreover, index properties of soils were determined using standard procedures. No mineralogical analysis was carried out in this testing stage. All the tests of the second stage were conducted by Oud (1987).

TEST RESULTS

- Index Properties:

All fifteen soils were subjected to standard laboratory tests to obtain liquid limit (w_L), plastic limit (w_P), natural water content (w_n), specific gravity of solids (G_s), grain-size distribution, and compaction (standard Proctor) characteristics which are optimum water content (OWC) and maximum dry density (ρd_{max}). Then, plasticity index(I_p) and activity (A) values were determined and the soils were classified according to the Unified Soil Classification (USC) system. The results obtained are given in Table I.

- Mineralogical Properties:

Eight soils of the first stage were subjected to x-ray diffraction analysis in order to obtain their mineralogical compositions. The analysis was carried out on clay size fraction. Randomly oriented powder samples were examined air-dried, glycolated and heated up to 300°C and 550°C. Basic clay minerals detected are montmorillonite (MON), illite (ILL), and kaolinite (KAO). In Aslantas-1 soil, the clay fraction was identified as amorphous clay (AMC). The main nonclay minerals are quartz (QUA), calcite (CAL), and feldspar (FEL). Using the relative diffraction intensities the mineralogical compositions were

Table I. Various Properties of Soils Studied.

Testing Stage	Soil Sample	G_s	w_L (%)	w_P (%)	I_P (%)	Grain Size Distribution Gravel (%)	Sand (%)	Silt (%)	Clay (%)	A	w_n (%)	OWC (%)	$\rho_{d\,max}$ (kg/m³)	USC
I	ADIGÜZEL	2.80	50	15	35	3	47	23	27	1.30	23.6	17.3	1788	CL
	ALACA	2.75	56	23	33	7	21	28	44	0.75	25.2	26.6	1491	CH
	ASLANTAS-1	2.71	32	15	17	3	35	43	19	0.89	20.3	20.2	1703	CL
	ASLANTAS-2	2.79	74	26	48	2	18	30	50	0.96	36.4	28.7	1470	CH
	BERDAN	2.71	52	17	35	2	14	43	41	0.85	27.6	21.0	1634	CH
	CAMLIDERE	2.52	38	23	15	35	48	12	5	3.00	16.1	21.5	1554	SC
	KOZLU	2.72	29	16	13	1	40	35	24	0.54	22.2	15.3	1793	CL
	TERCAN	2.77	53	17	36	3	23	33	41	0.88	DRY	22.6	1602	CH
II	ATATÜRK-1	2.75	73	24	49	4	8	38	50	0.98	10.4	26.7	1508	CH
	ATATÜRK-2	2.77	70	24	46	2	7	40	51	0.90	9.2	25.0	1465	CH
	ATATÜRK-3	2.76	58	22	36	3	4	53	40	0.90	4.5	24.8	1524	CH
	ATATÜRK-4	2.73	33	17	16	3	14	55	28	0.57	4.0	19.3	1697	CL
	B. CEKMECE	2.71	NP*	NP	NP	18	48	18	16	NP	2.7	13.0	1850	SM
	CAMGAZI	2.78	80	30	50	5	14	38	43	1.16	10.5	33.5	1348	CH
	KAYACIK	2.77	68	20	48	2	10	41	47	1.02	7.6	24.0	1548	CH

(*) NP-Nonplastic

determined semi-quantitatively and are shown in Table II.

Table II. Semi-quantitative Mineralogical Compositions of Soils Studied.(*)

Soil Sample	MON	ILL	KAO	AMC	QUA	CAL	FEL
TERCAN	+++		++		+	+	
BERDAN	+++	+	++			+	
ALACA	++		++		+	+	
ASLANTAS-2	++		+++		++		
ADIGÜZEL	+	+	+			++	
ASLANTAS-1				+++			
KOZLU		+++	++		+++		
CAMLIDERE		+	++				+++

(*) +++ Abundant; ++ Moderate; + Minor

- Dispersion Characteristics:

i. Double Hydrometer Test

In this test soil is subjected to hydrometer analysis twice. Firstly, the soil is treated with a dispersing agent and subjected to mechanical agitation before testing. Then, it is examined without dispersing agent and mechanical agitation. According to U.S. Soil Conservation Service, the percent dispersion is calculated as the ratio of percentage of material less than 5 µm without dispersing agent and mechanical agitation to that measured with dispersing agent and mechanical agitation. Soils with percent dispersion values greater than 50 were classified as dispersive, less than 30 as nondispersive, and in between 30 to 50 as intermediate. Percent dispersion values and grading of all soils are given in Table V which compares the outcome of all dispersion tests.

ii. Pinhole Test

Pinhole test was carried out on all fifteen soils, using the procedure described by U.S. Bureau of Reclamation. In this method, flow rates can be evaluated quantitatively to grade the soils as dispersive (D1, D2), intermediate (ND3, ND4), nondispersive (ND1, ND2), and having swelling potential (SP) (Acciardi, 1982). Grading of soils in terms of flow rates obtained in pinhole tests are shown in Table V.

iii. Chemical Tests

Eight soils of the first stage were subjected to chemical analyses to determine the chemical parameters which indicate the dispersion characteristics. Soluble cations, cation exchange capacity (CEC), exchangeable sodium ($\overline{Na}$) were first measured, and then using these known values, total dissolved salts in saturation extract (TDS) and percent sodium (%Na) were calculated. Based on the criterion established by Sherard et. al. (1976), the soils were classified in the manner shown in Figure 1.

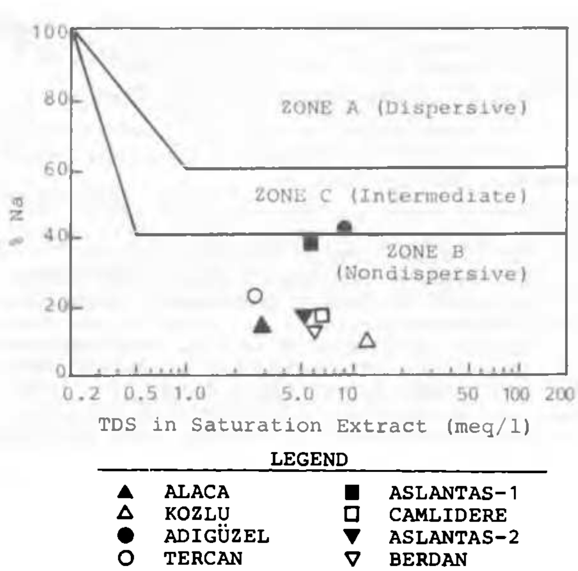

Figure 1. Results of Chemical Tests on Soils Studied.

iv. Crumb Test

Crumb test is used to determine dispersion potential qualitatively. A natural chunk of soil is set into the water and the tendency of the clay particles to go into colloidal suspension is described using the interpretative guide proposed by Sherard et.al. (1976). Grades suggested are: Grade 1- No reaction, 2- Slight reaction, 3- Moderate reaction, and 4- Strong reaction. All fifteen soils were subjected to crumb test and the grades given are 3 for Camlidere, 2 for Atatürk-3, Atatürk-4, and B. Cekmece, and 1 for the rest of the soils.

v. Soil Security Test

Soil security test, which is a relatively new test developed by Tadanier and Ingles (1985), is performed by filling a central hole in a compacted soil cylinder with distilled water and determining the failure time as suggested by Geomechanics Laboratory of the New South Wales Public Work Department. Compacted samples are cored axially to a depth of 85 mm using a sampling tube of 50 mm in diameter. The test enables one to grade the soils qualitatively according to the color of the flowing water. If the flowing water is visibly cloudy and does not become clearer with time, the soil is dispersive; with a slight cloudiness, it is intermediate; and in case of clear water without any noticable erosion, it is nondispersive. Seven samples of the second stage were compacted at the optimum water content and subjected to the soil security test. Results show that only Atatürk-4 has intermediate dispersion, while the rest are nondispersive.

Using the soil security test, influences of varying water content, lime treatment, and presence of granular zones on dispersion characteristics were also investigated. Five compacted specimens were prepared, using the standard proctor procedure, for each of the seven soils at different water content values, namely at i. optimum water content (OWC), ii. OWC+3%, iii. OWC-2%, iv. OWC-4%, and v. OWC-6%. Then, those specimens were subjected to the soil security test. To study the effect of lime treatment on dispersion, powder lime was added into the soils in ratios of 1%, 2%, and 3% of the dry soil by weight and mixed thoroughly before preparing the compacted specimens for the soil security test. The water contents of all the specimens tested were kept constant on the wet side of the optimum at OWC+3%. To study the influence of having granular zones on dispersion, coarse sand or medium to fine gravel was placed in the central hole in the compacted soil cylinder and soil security test was performed. Again, water content values of all samples were kept constant at OWC+3%. The results of all those soil security tests were utilized to classify the soils qualitatively in terms of dispersion as shown in Table III.

Here, an attempt was made to quantify the soil security test. Using the experimental data represented by Tadanier and Ingles (1985), it seems convenient to classify the soils according to the failure time. Test results and grading the dispersibility of soils in terms of failure time under the influence of varying water and lime contents and the presence of granular zones are presented in Table IV.

Table III. Qualitative Classification of Soils according to Soil Security Test.

Soil Sample	OWC (%)	Qualitative Classification(*)									
		Varying Water Content (%)					Lime Treatment			Presence of Granular Zones	
		OWC-6	OWC-4	OWC-2	OWC	OWC+3	1%	2%	3%	Coarse Sand	Gravel
ATATÜRK-1	26.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ATATÜRK-2	25.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ATATÜRK-3	24.8	I	I	I	ND	ND	ND	ND	ND	ND	ND
ATATÜRK-4	19.3	I	I	I	I	I	ND	ND	ND	ND	ND
CAMGAZI	33.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
KAYACIK	24.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
B. CEKMECE	13.0	I	I	ND	ND	ND	ND	ND	ND	ND	ND

(*) ND- Nondispersive; I- Intermediate

Table IV. Quantitative Classification of Soils according to Soil Security Test.(*)

Soil Sample	OWC (%)	Time of Failure, T_f (min)									
		Varying Water Content (%)					Lime Treatment			Presence of Granular Zones	
		OWC-6	OWC-4	OWC-2	OWC	OWC+3	1%	2%	3%	Coarse Sand	Gravel
ATATÜRK-1	26.7	1	4	31	38	167	130	42	23	258	206
ATATÜRK-2	25.0	1	3	4	7	154	30	29	14	336	198
ATATÜRK-3	24.8	8	12	18	30	146	>420	>420	>420	>420	>420
ATATÜRK-4	19.3	3	9	10	26	418	>420	>420	73	>420	>420
CAMGAZI	33.5	4	6	10	25	176	31	10	27	304	301
KAYACIK	24.0	2	5	19	54	>420	145	79	57	>420	>420
B. CEKMECE	13.0	8	9	12	19	86	53	>420	>420	180	172

(*) $T_f > 420$ (Nondispersive); $45 < T_f < 420$ (Intermediate); $T_f < 45$ (Dispersive)

Table V. Comparison of Dispersion Test Results and Overall Grading of Soils Studied.

Testing Stage	Soil Sample	MON	CEC $(\frac{meq}{100\,g})$	I_P (%)	SWP(*)	USC	Grading (**)							
							DH		PH	CR	CT	SS		Overall
							%	Gr.				Qual.	Quant.	
I	TERCAN	+++	32.2	36	H	CH	12	ND	SP	1	ND			ND
	BERDAN	+++	34.8	35	H	CH	18	ND	SP	1	ND			ND
	ALACA	++	38.3	33	H	CH	13	ND	SP	1	ND			ND
	ASLANTAS-2	++	33.7	48	H	CH	35	I	SP	1	ND			ND
	ADIGÜZEL	+	23.1	35	M	CL	31	I	ND1	1	I			I
	ASLANTAS-1	-	26.0	17	L	CL	42	I	ND2	1	ND-I			I
	KOZLU	-	14.9	13	L	CL	46	I	ND1	1	ND			ND
	CAMLIDERE	-	20.2	15	L	SC	100	D	ND1	3	ND			I
II	CAMGAZI			50	H	CH	10	ND	SP	1		ND	D	ND
	KAYACIK			48	H	CH	6	ND	SP	1		ND	D	ND
	ATATÜRK-1			49	H	CH	64	D	SP	1		ND	I	ND
	ATATÜRK-2			46	H	CH	21	ND	SP	1		ND	D	ND
	ATATÜRK-3			36	H	CH	2	ND	SP	2		ND	D	ND
	ATATÜRK-4			16	L	CL	49	I	ND1	2		I	D	I
	B. CEKMECE			NP	-	SM	15	ND	ND1	2		ND	D	ND

(*) SWP- Swelling Potential: H- High; M- Medium; L- Low
(**) DH- Double Hydrometer; PH- Pinhole: CR- Crumb; CT- Chemical Test; SS- Soil Security

INTERPRETATION OF EXPERIMENTAL RESULTS AND CONCLUSIONS

Comparison of dispersion characteristics of the soils, as obtained from various tests, can be made by studying Table V. In general, all agree with each other, except the quantitative interpretation of soil security test results. Time to failure is not yet a sufficiently sensitive criterion of soil security and obviously it requires further investigation. Grading the soils according to the results of all the tests, excluding quantitative evaluation of soil security test, concludes that Adigüzel, Aslantas-1, Camlidere, and Atatürk-4 soils are intermediately dispersive, while the rest are nondispersive.

In Table IV, it is observed that water content has a significant influence on dispersion, such that as it increases, the time of failure also increases, indicating that dispersion is more critical on the dry side of optimum water content.

The lime treated soil behavior depends on the physico-chemical properties of soil. This is why variable results have been obtained in the soil security test in different soils as presented in Table IV. Therefore, it seems significant to perform sufficient number of tests in selecting the best percentage of lime needed to improve soil properties against internal erosion.

Presece of granular zones as filters cause an increase in failure time as observed in all the samples subjected to soil security test (see Table IV), indicating that appropriate filters would help to control internal erosion.

Using the classification scheme proposed by Seed et. al.(1962), which is based upon percent clay size and activity, the soils were classified according to their swelling potentials as indicated in Table V. It is interesting to note that all the soils with high potential of swelling are nondispersive. It is known that swelling potential has a tendency to increase with increasing plasticity index, montmorillonite content and cation exchange capacity. The same trend has been observed in soils studied here. The soils with relatively higher plasticity index, montmorillonite content and cation exchange capacity were all classified as highly plastic clays (CH) and nondispersive. Therefore, it can be concluded that the susceptibility to dispersion seems more critical in soils with low plasticity and low swelling potential.

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