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DISPERSIVE SOILS: PROPERTIES, IDENTIFICATION, CLASSIFICATION AND STABILIZATION

DISPERZIVNA TLA: SVOJSTVA, IDENTIFIKACIJA, KLASIFIKACIJA I STABILIZACIJA

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Abstract

The application of dispersive soil can result in various types of damage, and even the collapse of embanked buildings if it is not identified. Dispersive soils cannot be uniquely identified by visual identification in the field, or by usual standard methods used for soil identification in the geomechanical laboratory. The paper presents the results of laboratory geomechanical tests aimed at identifying and classifying erodible dispersive fine-grained soil. The tests were carried out using the crumb test, the double hydrometer test (SCS), and the pinhole test on samples: sandy clay embankment dams of 'Rovni', loess from different locations (Zemun, Novi Beograd, Titel, Kelebija, Srbobran, Slankamen, Ruma, Mali Iđoš) and kaolinite sandy clay deposits Grabež - Aranđelovac. The possibility of improving dispersive soil by adding fly ash was also analyzed. Pinhole tests on dispersive soil samples with the addition of 10, 30 and 50 % ash showed that there was a decrease in dispersivity of natural soil for one to two dispersion classes.

Ključne reči

- disperzivna tla
- opit grudvice
- opit duplog hidrometrisanja
- 'pinhole' opit
- stabilizacija

Izvod

Primena disperzivnog tla za posledicu može imati pojavu različitih vrsta oštećenja, pa čak i rušenja nasutih objekata ukoliko ono nije identifikovano. Disperzivna tla se ne mogu jednoznačno prepoznati vizuelnom identifikacijom na terenu, ili uobičajenim standardnim metodama koje se koriste za identifikaciju tla u geomehaničkoj laboratoriji. U radu su prikazani rezultati laboratorijskih geomehaničkih ispitivanja u cilju identifikacije i klasifikacije erodibilnog disperzivnog finozrnog tla. Ispitivanja su sprovedena metodom grudvice tla, metodom duplog hidrometrisanja (SCS test) i metodom strujanja vode kroz formiranu cilindričnu poru (pinhole test) na uzorcima: prašinastih glina iz jezgra nasute brane 'Rovni', lesa sa različitih lokacija (Zemun, Bežanijska kosa, Titel, Kelebija, Srbobran, Slankamen, Ruma, Mali Iđoš) i kaolinitske peskovite gline ležišta Grabež-Aranđelovac. Analizirana je i mogućnost poboljšanja disperzivnog tla dodavanjem elektrofilterskog pepela. Ispitivanja pinhole opitom na uzorcima disperzivnog tla dodavanjem 10, 30 i 50 % pepela, pokazala su da je došlo do smanjenja disperzivnosti prirodnog tla za jednu do dve klase disperzivnosti.

INTRODUCTION

Dispersive clays are a special type of fine-grained soils, where clay particles disperse (deflocculate) in the presence of water, forming a colloidal dispersion system. The behavior of clayey soils is closely related to particle size (1-100 nm) and their electric charge. The water that flows through dispersive clay can freely rinse individual clay particles, which 'loosens' clay structure, the density decreases, and for a relatively short time appear to internal erosion. For this reason dispersive clays are unfavorable for building in earth structures, particularly core earth dams, hydraulic and road embankments. The use of these clays ultimately may result in different damage or even destruction of some of earth structures, /1/.

This behavior in dispersive clay was first observed in agriculture for more than 100 years and their basic nature is rather well studied by agricultural engineers /2, 3/. In civil engineering practice, this phenomenon was not recognized until the 60's of the last century. Then Aitchison and Wood's (1965) numerous studies have proven that the cause of damage and leakage of small earth dams in Australia lies in the nature of clay dispersion, /4/.

Sherard's (1976) has shown that the main difference between dispersive and undispersive clays lies in the nature of cation pore water clay structure. Dispersive clays are the dominant cations of sodium, while the other are dominant cations of calcium, potassium, and magnesium, /5, 6/.

In the study of dispersive soils, one of the main problems is the identification of such soil /6/. Dispersive soils can not be identified by the standard-classification tests: graine size analysis, Atterberg limits etc. The main methods used for testing the dispersion are the crumb test, the double hydrometer test (SCS), the pinhole test and chemical test for the determination of dissolved sodium in pore water (ESP and SAR). Here are presented the results obtained by the crumb test, the double hydrometer test, and the pinhole test, /7/.

When soil is classified as dispersive, it does not mean that it is completely unusable. By applying appropriate remedial measures, the dispersible soil can be improved to non-dispersible soil, which can later be used for filling, /8, 9/.

Soil dispersivity tests conducted to date have shown that ash has a significant effect on dispersivity /9, 10/. Namely, dispersivity decreases with increasing content of fly ash and sample curing time.

For all the above reasons, experimental testing was undertaken for the first time in Serbia to assess the practicability of using fly ash to reduce the dispersion of the natural soil embedded in embankments, /7/.

TESTS FOR IDENTIFICATION DISPERSIVE SOILS

The crumb test

The crumb test, which is also called the Emerson Crumb Test /12/, was developed as a simple fast test for identification of dispersive soil in the field, which can be used in the laboratory as well. Observing a few cubical specimens of soil submerged in a glass of distilled water (ASTM D6572-06) and 0.001 M sodium hydroxide (BS 1377-5:1990, No. 6.3) in time intervals defined by the class sample /13, 14/. Visual observation of the reaction follows the pattern: the shape of the sample, changes in the structure, color and turbidity of the water, forming a colloidal 'cloud' or clustering of colloidal particles. Depending on the reactions registered, there are four classes of dispersion (Table 1).

Table 1. Dispersion classes depending on the reaction in the crumb test (Emerson, 1967).

Class	Dispersive	Reaction/Description
1	Non-dispersive soils ND	Soil without any reaction: The crumb soil aggregates can slake, lose shape, form little heaps on the bottom of the cup, but there is no sign that changes color. The water is clear.
2	Slight dispersive soils SD	Soils with low to slight reaction: The fine barely visible traces of blur in water, slightly blurring around the surface of the colloidal samples or fine colloidal layer at the bottom of the cup.
3	Medium dispersive soils MD	Clearly visible colloidal cloud around crumb of soil.
4	Highly dispersive soils HD	Strong reaction in the form of a dense cloud solution, colloidal turbidity covers the entire bottom of the glass, and frequently appears on the walls. In extreme cases, a solution of water is turbid.

The crumb test gives good results in terms of identification of dispersive soil. Sometimes, it can happen that some dispersive soil does not show a reaction, which was later proved in other tests (e.g. the pinhole test). However, if the crumb test indicates that the dispersive soil, the soil is generally dispersive in other tests, /6/.

Double hydrometer test (SCS-Soil Conservation Service test)

Laboratory testing of dispersive clays via double hydrometer is the oldest method for assessing dispersion developed by Volk in 1937. Namely, grain size distribution is examined on two identical (duplicate) soil samples. The first sample is implemented with standard hydrometer test in distilled water with a strong mechanical agitation and a chemical dispersant /14, 15/. Parallelly, the second sample is tested in distilled water without mechanical agitation and without chemical dispersant. The percent dispersion D is determined by the ratio: percent of particles smaller than 0.005 mm without mechanical agitation and chemical dispersant and percent of particles smaller than 0.005 mm with mechanical agitation and chemical dispersant.

Depending on the percent dispersion of the soil can be classified /16/ as shown in Table 2.

Table 2. Degree of dispersion depending on percent dispersion (Kinney, 1979).

Percent of dispersion	Degree of dispersion
D < 35 %	non-dispersive soils (ND)
35 < D < 50 %	intermediate soils (ID)
D > 50 %	dispersive soils (D)

The pinhole test

The pinhole test presents physical method of direct identification of dispersibility and colloidal erodibility of fine-grained soils, by causing water to flow through a small hole (cylindrical pore) formed in specimen, /14, 17/.

In the pinhole apparatus, a compacted soil specimen is installed with formed (punched) hole diameter of 1 mm, through which distilled water passes at different hydraulic heads 50, 180, 380 and 1020 mm (hydraulic gradients of approximately 2, 7, 15 and 41) simulating the flow of water through pore space. During the test, flow rate, effluent turbidity and pore size in the samples are registered and recorded at the end of the test. These parameters are used for determining the dispersion class. Dispersion classes are given in Table 1.

If the soil is dispersive, with classes D1 and D2, distilled water that passes through the pore formed in the sample is turbid colloid, a pore diameter after the test has spread d > 1 mm. Nondispersive soils of classes ND1 and ND2 are the soils in which the distilled water is clear after testing, and the pore diameter is the same d = 1 mm. The soils ND3 and ND4 are medium dispersive soils, where the distilled water is slightly to moderately dark, and the pore diameter is d ≥ 1.5 mm, /13, 16/.

PERFORMED LABORATORY TESTS

Dispersive tests were carried out on samples of fine-grained soils of different origins which were used for the purpose of filling various objects: silty clay core earthfill dams 'Rovni', loess from different locations: Bežanijska Kosa, Zemun Gornji grad, Ruma, Titel, Kelebija, Mali Iđoš, Srbobran, Slankamen, and kaolinite sandy clay deposits 'Grabež' Aranđelovac.

The dispersion tests that were carried out are: crumb test, double hydrometer test, and pinhole test (Tables 3, 4, 5, 6). Common identification-classification testing was done previously: determination of moisture content, particle size distribution (sieving and hydrometer method), plasticity and standard Proctor's compaction test. Soil classification was made according to the Unified Soil Classification System (USCS).

Based on the results of conducted tests, the identification and classification of fine-grained soil samples in dispersion terms was done. In order to establish dependencies between dispersion and the degree of compaction, the pinhole tests were performed on samples with different degrees of compaction Sz: 90, 92, 95, 98, 100 and 102 % compared to the compaction of the resulting standard Proctor compaction energy (Table 5).

In samples of high-dispersion (K-1) there have been implemented measures to improve the soil by adding fly ash landfill power plants ‘Nikola Tesla A’ in Obrenovac (TENT A). In order to find optimal ash content additive, the samples were prepared with different percentages of ash (10, 30 and 50 %) and there after examined parameters that define the dispersion (Tables 7, 8). The aim of the research was to define the influence of the applied remedial measures to reduce dispersible obtained materials.

RESULTS AND ANALYSES

The results of testing dispersive fine-grained soil by crumb test did not show significant differences depending on the test methods i.e. whether the sample immersed in distilled water or a solution of 0.001 M NaOH. Only the sample ZGG-1 showed strong different reaction in distilled water nondispersive reaction (ND), and in a solution of 0.001 M NaOH, a highly dispersive reaction (HD). The sample U-1 had a smaller difference in reactions in distilled water nondispersive reaction (ND), and in a solution of 0.001 M NaOH, a slight dispersive reaction (SD).

Soil samples T-1 and K-1 that showed dispersive reaction during the crumb test, double hydrometer test, and in the pinhole test show the same reaction. Also, soil samples MI-1, SV-1, SV-6 and SJ-4, that during the crumb test are classified as slight-medium dispersive class (SD-MD), that corresponds to the pinhole test with class dispersion ND2 and ND3.

Determination of dispersive soil by double hydrometer test showed that tested samples have the same dispersion class independent of the applied standards: ASTM D 4221-99 or BS 1377-5: 1990 (except sample SV-6).

The double hydrometer test results show that the soils in which the percent of dispersion PD < 35 % and classified as non-dispersive soils, have the same non-dispersive reaction in the crumb test and pinhole test, e.g. U-1.

The soils in which the percent of dispersion is between 35-50 % (samples U-2, R-1, SV-6) and classified as intermediate dispersive soils in the double hydrometer test, show nondispersive to medium dispersive reaction in pinhole test (ND1, ND2 and ND3), whereas certain deviation are noticed in the classification crumb test.

For soils with the percent of dispersion PD > 50 %, there is a great inconsistency in the results obtained by double hydrometer and pinhole tests, especially in soils classified by pinhole test, as medium dispersive soils classes ND2 and ND3. For soils that are classified by double hydrometer test as dispersive class D, the pinhole test confirmed the class.

Table 3. Results of crumb test and double hydrometer test.

Sample	Type of soil	Soil classification (USCS)	Crumb test		Double hydrometer test			
			BS 1377-5:1990, 6.3	ASTM D 6572-00	BS 1377-5:1990, 6.4		ASTM D 4221-99	
					D (%)	class	D (%)	class
U-1	silty clay	CL	SD	ND	24	ND	21.5	ND
U-2	silty clay	CL/CH	ND	ND	39.5	ID	49	ID
R-1	loess I	CL	SD	SD	31	ID	37.5	ID
T-1	loess I	CL	HD	HD	70	D	94	D
K-1	loess I	CL	HD	HD	83	D	96	D
ZGG-1	loess I	CL	HD	ND	57	D	69	D
MI-1	loess I	CL	SD	SD	61.5	D	86	D
KGA-1	sandy clay	CL	HD	HD	111	D	115	D
SV-1	loess I	CL	SD	SD	72	D	85	D
SV-6	loess I	CL	SD	SD	41	ID	63	D
SJ-1	loess I	CL	MD	MD	43	ID	35	ID
SJ-2	loess I	CL	MD	MD	67	D	86	D
SJ-4	loess I	CL	MD	MD	76	D	85	D
BK-1	loess I	CL	SD	SD	62.5	D	67	D

* D is percent of dispersion

Table 4. Results of crumb test.

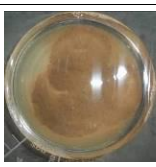
Sample	U-2	R-1	SJ-1	K-1
ASTM D 6572-00 (Distilled water)				
BS 1377-5:1990 6.3 Solution 0.001 M NaOH				
Dispersive classification	ND	SD	MD	HD

Table 5. Results of pinhole test.

Sample	Type of soil	Soil classification (USCS)	Pinhole test ASTM D4647-98; BS 1377-5:1990, 6.2					
			Degree of compaction (%)					
			90	92	95	98	100	102
U-1	silty clay	CL	ND1	ND1	ND1	ND1	ND1	ND1
U-2	silty clay	CL/CH	ND3	ND3	ND3	ND2	ND2	ND2
R-1	loess I	CL	ND2/ND3	ND3	ND3	ND1	ND1	ND1
T-1	loess I	CL	D1	D1	D1	D1	D1	D1
K-1	loess I	CL	D1	D1	D1	D1	D1	D1
ZGG-1	loess I	CL	D2	D2/ND4	D2/ND4	ND3	ND3	ND3
MI-1	loess I	CL	ND3	ND3	ND3	ND3	ND3	ND3
KGA-1	sandy clay	CL	ND3	ND3	ND3	ND3	ND3	ND3
SV-1	loess I	CL	ND2/ND3	ND2/ND3	ND2/ND3	ND2/ND3	ND2/ND3	ND3
SV-6	loess I	CL	ND2/ND3	ND2/ND3	ND2/ND3	ND2/ND3	ND2/ND3	ND3
SJ-1	loess I	CL	D1	D1	D1	D1	D2	D1
SJ-2	loess I	CL	D1	D1	D1	D1	D1	D1
SJ-4	loess I	CL	ND3	ND3	ND3	ND3	ND3	ND3
BK-1	loess I	CL	ND1	ND1	ND1	ND1	ND1	ND1

Tabela 6. The appearance of the samples, after performed pinhole test.

Sample	BK-1	U-2	SJ-4	SV-1	SJ-1	K-1
Q (ml/s)	2.25	> 3.7	3.66	3.23	1.18	1.41
Cloudiness of flow at end of test	clear	clear		clear		
Output surface						
Longitudinal cross-section						
Hole size after test, d (mm)	1	2-5	2	2.5-6	5-9	7
Dispersive classification	ND1	ND2	ND3	ND2/ND3	D2	D1

Table 7. Results of stabilization of dispersive soil.

Sample	Type of soil, mixture of loess : ash	Soil classifi-cation (USCS)	Crumb test		Double hydrometer test		Pinhole test
			BS 1377-5:1990, 6.3	ASTM D 6572-00	BS 1377-5:1990, 6.4	ASTM D 4221-99	D4647-98; BS 1377-5:1990, 6.2
LP-50	50:50	SM	MD	MD	D	D	ND2
LP-30	70:30	SM	SD	SD	D	D	ND4
LP-10	90:10	SM	SD	SD	D	D	D1

Table 8. Results of pinhole dispersivity test of ash and loess mixtures.

Sample	LA-10	LA-30	LA-50
Cloudiness of flow at end of test			
Output surface			
Longitudinal cross-section			
Hole size after test, d (mm)	6-12	5-12	3-5
Dispersive classification	D1	ND4	ND2

STABILIZATION OF DISPERSIVE SOILS

When the identification-classification tests identify that the soil is dispersive, it does not mean that it is completely unusable for use in the construction of earthfill dams, embankments or waterproof barriers. By applying suitable remedial measures dispersive soil can be improved by non-dispersive soil, which could be used for the filling.

Based on previous studies and from the point of consideration to improve the characteristics of dispersive soil using fly ash (class F) effects were examined with additions of ashes 10, 30 and 50 %. For stabilization of dispersed soil, the selected soil has showed the most intensive dispersion reaction, specimen K-1, which represents the silty clay of low plasticity (according to USCS classification) in this specific case I loess horizon borrow pit near Kelebia.

After adding fly ash, class of dispersion, based on the results of the crumb test, changed for two, i.e. the soil of high dispersive class - HD has taken the dispersive class of slight soils - SD. Percentage share of ash had an impact on improving the dispersion properties and classification according to the double hydrometer test. The applied method for determining the double hydrometer percent dispersive mixture of loess and ash in order to improve the dispersive soils did not produce anticipated results (Table 6).

Tests carried out in pinhole test on samples of dispersive soil treated with 10, 30 and 50 % of ash showed that the material subsequently became nondispersive. Adding a larger amount of ash lessens the effect of dispersion. By adding 10 % of ash, dispersive soil does not change the soil class, with 30 % ash dispersion soil changes class in a dispersive medium soil to ND4, and adding 50 % ash in a non-dispersive soil, to ND2.

CONCLUSION

The crumb test and the double hydrometer test are very simple to perform in the field and in the laboratory, and can be used for a preliminary assessment of dispersive soils. If the crumb test found that the soil is non-dispersive, it is non-dispersive in other tests as well. However, many dispersive soils show no dispersion reaction in the crumb test. Since the crumb test is based on visual identification of soil, this test carries a high degree of subjectivity. Pinhole test gives very clear results in the classification of dispersive soils classes D1 and D2 and nondispersive soil classes ND1 and ND2. Tests have shown that in the class of medium-dispersive soils ND3 and ND4, doubts may occur in classification. These doubts occur because of the lack of defined criteria of class, especially when it comes to low value flow rate. In such cases, it is necessary to complemented the tests by using chemical tests. Testing dispersion by pinhole test on prepared samples with the degree of compaction Sz = 90, 92, 95, 98, 100 and 102 % showed that the degree of compaction has no significant influence on the class of dispersion.

By applying suitable remedial measures, dispersive soil can be converted into a non-dispersive soil, which could be used for backfilling. In order to evaluate the possibilities of application of dispersive soils has led to the discussed possibility of improving dispersion properties of the soil fly ash and gave satisfactory results.

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