An investigation on dispersive clay and examination of different additives to reduce dispersive tendency

Une vérification en l'argile dispersive en examinant des différents additifs pour réduire sa sensibilité à être dispersif

J. Bolouri Bazaz
Civil Engineering Department, Engineering Faculty, Ferdowsi University of Mashad, P O Box 91775-1111 Mashad, Iran

H. R. Saghafi
Iran Ministry of Road and Transportation, Soil Mechanics and Strength of Material Laboratory Company of Khorasan Province, Khayam Avenue, Mashhad, Iran

ABSTRACT
Dispersive clay, with unique specification, is highly susceptible to erosion in certain circumstances. The erosion of the core of embankment dams in which dispersive clay are used can be usually led to hazardous occurrence. The primary factor contributing the susceptibility of a clay mass to erosion is the percent of sodium and other dissolved salts. The thickness of the double layer, which mainly depends on the type of clay soil, is another factor affecting the dispersivity phenomena. The existence cracks in dispersive clay core of embankment dams can also speed up erosion.

Replacement of dispersive soil with a non-dispersive one, with highly costs, may be considered as the first solution. To improve the resistance of compacted dispersive clay to erosion there are many methods, of which using additives such as lime is the most common one. Adoption a suitable filter in clay core can also reduce the susceptibility to erosion.

In the present research, different additives, including lime, sulfate aluminum and poly vinyl alcohol (PVA), are employed to examine the reduction of the dispersive tendency of three samples of dispersive clay, taken from different parts of North of Iran. It is shown that there is no unique solution for improvement of dispersive clay, but depends on the clay mineralogy and total dissolved salts (TDS) and sodium absorption ratio (SAR). It is also concluded that sulfate aluminum is more suitable than lime and PVA, since PVA is a very cohesive material in the presence of water and reduces the workability of clay soil.

RÉSUMÉ
L'argile dispersive avec spécification unique en certaine circonstance est très sensible à érosion. L'érosion du noyau des barrages étant construit par l'argile crée une situation dangereuse. Le premier élément qui cause la sensibilité de l'argile dispersif à érosion est le pourcentage de sodium et les autres sels. L'épaisseur de couche double qui dépend au type de l'argile est un autre élément de dispersement. Existence des fissures dans l'argile dispersif peut aggravé son érosion.

Remplacement de terre dispersif par une autre terre non dispersif peut être une solution très coûteuse. Pour améliorer la résistance de l'argile dispersive à érosion, on peut utiliser plusieurs solutions. L'utilisation de calcaire peut être une solution, et aussi l'utilisation d'un filtre convenable dans l'argile de noyau peut réduire la sensibilité à érosion. Dans cet article les différents additifs comme calcaire, aluminium sulfate et alcool polyvinyle (PVA) sont utilisé pour réduire la tendance de l'argile à dispersion. Trois échantillons sont choisis de différents endroits au nord de l'Iran, et on a montré qu'l n'y a pas une seule solution pour améliorer l'argile dispersive, mais la solution dépend à la minéralogie de l'argile et le total du sel dissolu (TDS), et au rapport de sodium absorption (SAR). On a conclu que l'aluminium sulfate est meilleur que PVA, parce que PVA devient une substance collante en présence de l'eau et réduise la rentabilité de l'argile.

Keywords : Dispersive, clay, erosion, improvement, additives, lime.

1 INTRODUCTION

In the last few decades it has become more clearly understood that there are certain clays, called dispersive, in nature that are highly erodible. The existence of this type clay has cleared much heretofore difficult-to-explain failure of earth slopes and embankment dams (Wan & Fell, 2004). The principal difference between dispersive clays and ordinary erosion resistance clays is the nature of the cations in the presence of water, when repulsive forces between clay particles exceed the attractive forces (Boucher, 2002). This results in progressively detachment of clay particles from the surface and immersing into suspension (Iran Large Dame Committee, 1995). The particle of clayey soil with this specification, called *Dispersive Clay*, will disperse and come out when small quantity of water flow through the soil particles. This, in turn, leads to gradual erosion and long term structural collapse (Askary & Fakher, 1994). Whereas, the contact between soil particles of non-dispersive clay will be stable in facing with water so as the hydrodynamic force has no efficient power to conquest the attraction force between particles. Sever erosion damages of earth dams by rainfall in the form of deep gullies have been reported by Sherard et al (1976). They found that certain soils in the nature are highly erodible and recommended different methods for identifying of dispersive soils. Figure 1, for example illustrates the erosion phenomena in the nature due to the dispersivity potential.

Figure 1. Erosion features in the form of gullies.

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There are many methods to improve this type of problematic soils, of which chemical and mechanical ones are more common. The objective of the present research is firstly to identify the dispersivity potential of soils in three sites in North of Iran, where the soil seems to be dispersive from field observations, and secondly is to examine the influence of different additives on these dispersive clayey soils and to study the degree of improvement.

2 EXPERIMENTAL INVESTIGATIONS

The potential of dispersivity, identification tests and also treatment methods to reduce dispersivity property of the soil samples are briefly described in the following sections.

2.1 *Materials*

The primary test results which were performed to identify, classify and determine the mechanical properties of the samples are summarized in table 1.

Table 1. Physical properties of the soil samples studied

Sample Number	1	2	3
G_s	2.73	2.70	2.70
Sand (%)	11.7	5.1	9.7
Silt (%)	63.2	83.7	68.7
Clay (%)	25.1	11.2	21.6
LL	45.6	23.9	24.8
PL	30.3	16.8	7.7
PI	15.3	7.1	17.2
Unified Classification	ML	CL-ML	CL
MDD [a] (gr/cm^3)	1.64	1.66	1.69
OMC [b] (%)	19.7	17.1	15.6

[a] Maximum Dry Density
[b] Optimum Moisture Content

2.2 *Test Methods and Test Results*

Sherard et al (1976) recommended the use of four tests for identifying the dispersive soils which are highly erodible. These four identification tests are:

a) *Chemical Test*: Dispersive clays have a preponderance of sodium, whereas ordinary clays have a preponderance of calcium and magnesium cations in pore water (Sridharan et al, 1992). The main reason of inter-particle repulsion of clay mass is the percent sodium in pore water, which is defined as

$$PS = \frac{Na}{(Ca + Mg + Na + K)} \times 100 \quad (1)$$

where Ca, Mg, Na and K represent the dissolved cation concentration in the pore water. The quantities of the four metallic ions (calcium, magnesium, sodium and potassium) in solution are referred to total dissolved salts (TDS) concentration. The TDS and sodium absorption ratio (SAR) of the pore fluid also influence the susceptibility of a clay mass to erosion. A high percent of sodium in pore water results in strong inter-particle repulsion, while a large TDS and SAR concentration suppress the inter-particle repulsion. For a great majority of clayey soils in nature, the percent of sodium, TDS and SAR can be a criterion for the distinction as to being dispersive, intermediate or non-dispersive.

To identify the chemical properties of soil samples in the present study, the specimens were analyzed for pH in 1:2 water suspensions by weight. Exchangeable calcium, magnesium, sodium and potassium ions were extracted. The chemical test results for three selected samples are inserted in the Sherard's plot and shown in Figure 2.

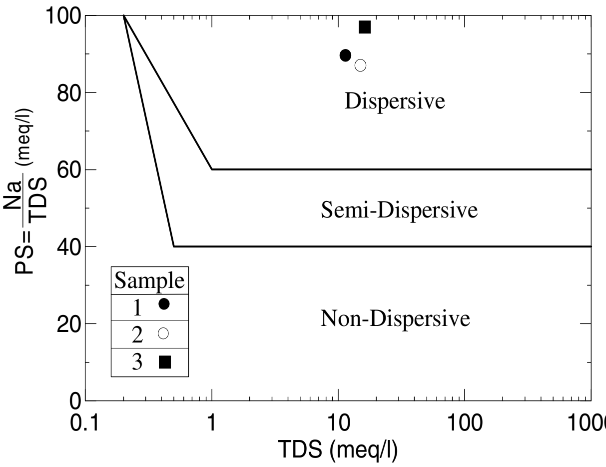

Figure 2. Dispersivity classification of samples based on soil chemistry test results.

As can be seen from the this Figure, based on chemical test all three samples are classified as dispersive soil.

b) *Pinhole Test*: the pinhole test procedure developed by Sherard et al (1976) was adopt to study the dispersivity of soil specimen as it is believed to be a reasonable approximation of the erosion environment for flow through a crack in an earth dam (ASTM D4647-87). To prepare specimens for pinhole test, a sample of soil was thoroughly mixed with distilled water to the respective standard Proctor optimum moisture content and equilibrated in a sealed polyethylene bag for 28 hours. Samples were then compacted to 95% of standard Proctor maximum dry density in erosion cell to dimension of 38 mm length and 25 mm in diameter. A plastic nipple was next pushed into the top of the compacted specimen with finger pressure and a hole punched through the nipple with a 1.0 mm diameter stiff stainless steel needle.

The apparatus was then assembled and distilled water percolated through the hole in the specimen under heads of 50 and 180 mm for 5 to 10 min at each head. For each specimen the quantity of flow was measured and the color of water was observed.

The ASTM D4647-87 recommends three methods, namely A, B and C for dispersive soil classification. Method C, which is used in this study, classifies the dispersive soils into 6 groups: dispersive (D1 and D2), low to moderate dispersive (ND3 and ND4) and non-dispersive (ND1 and ND2). The test results based on the pinhole test are given in table 2.

c) *Mineralogical Analysis*: One of the methods to identify dispersive soil is to determine the mineralogy of soil particles. Mineralogical Analysis was performed after giving standard chemical treatment to the clay-sized fractions of the specimens and recording the X-ray diffraction pattern with a Philip diffract meter. The test results are given in table 2. Sample 1 particle is Montmorillonite and is then highly dispersive. The particle of the sample 2 is Illite and is moderately dispersive in comparison with two other samples. Illite and Montmorillonite are the initial formation of sample 3, indicating the dispersivity of specimen.

d) *Double Hydrometer Test*: Double hydrometer test is another test method for dispersivity identification. In this method the sample is analyzed by standard hydrometer test and then analyzed by hydrometer test again. In the second test, however, no dispersion material was added to the water. The dispersivity percent is defined as the relation of soil particles smaller than 0.005 mm in standard hydrometer test to the amount of soil particles smaller than 0.005 mm in double hydrometer test. Based on this method the dispersivity percent of all samples are determined and gathered in table 2. The results indicate that sample 1 is highly dispersive and sample 2 and 3 are facing high dispersivity potential.

Table 2. Samples dipersivity conditions in different tests

Sample Number	1	2	3
Pinhole Test			
(dipersivity classification)	D1	D2	D2
Mineralogical Analysis			
(type of mineral)	Mte [a]	Ite [b]	Mte & Mte
Double Hydrometer Test			
(dipersivity percent)	82	83.7	68.7

[a] Mte: Montmorillonite
[b] Ite: Illite

3 TREATMENT AND IMPROVEMENT OF DISPERSIVE SOILS

The low permeability of clayey core of embankment dams plays an important role in preventing water flow through the dam and its stability. If this stability, for any reason, is jeopardized the probable damages can not be compensated. The presence of dispersive clay in clayey core may result in piping in core, leading to slope un-stability and dam collision. In this condition, it is most secure to replace the dispersive clay with non-dispersive one. This method, however, may highly cost in most occasions and there exists no economical and technical justification.

To improve the resistance of compacted dispersive clay to erosion there are many methods. Mechanical methods such as adoption a suitable filter in clay core are the most common one to reduce the susceptibility of clayey core to erosion. The chemical method, however, is to proper use of a chemical additive, such as lime [$CaCo_3$] and [Al_2 $(So_4)_3$] to reduce the dispersion tendency of dispersive soil. A non-organic agent such as lime which is the most common can reduce the dispersivity and stabilize the problematic soil. The use of synthetic organic polymers for improving stability of soil aggregates is well recognized in agricultural practice. For example, the effect of PVA (a class of uncharged linear polymers) in imparting stability to clay aggregates is well recognized (Greenland, 1963).

In the present research lime, Aluminum Sulphate and PVA are used as additives to examine effect of these additives on the degree of dispersivity. Since the magnitudes of stabilizer agent has a direct effect on improvement, lime and Aluminum Sulphate in the dry form and various dosages of 0.5, 1, 2, 3 and 4 percent were added to the soil samples. The samples were prepared in the same manner described in the previous section. The *chemical* and *pinhole* tests were adapted to measure the dispersivity potential of the samples. Due to the limited pages of the paper the detail of PVA is not described here.

a) *Chemical Test*: As described previously the improved soil samples were analyzed for pH in 1:2 water suspensions by weight. Exchangeable calcium, magnesium, sodium and potassium ions were again extracted. The chemical test results for samples 1 to 3 modified with a) lime and b) Aluminum Sulphate are illustrated in Figure 3 to 5.

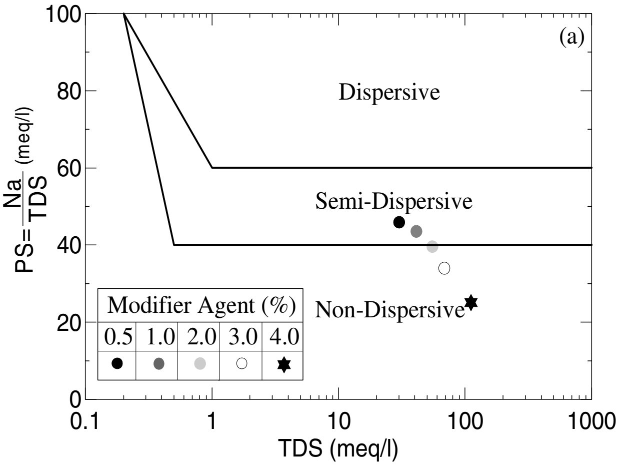

Figure 3. Dispersivity classification of sample 1, improved with a) Lime.

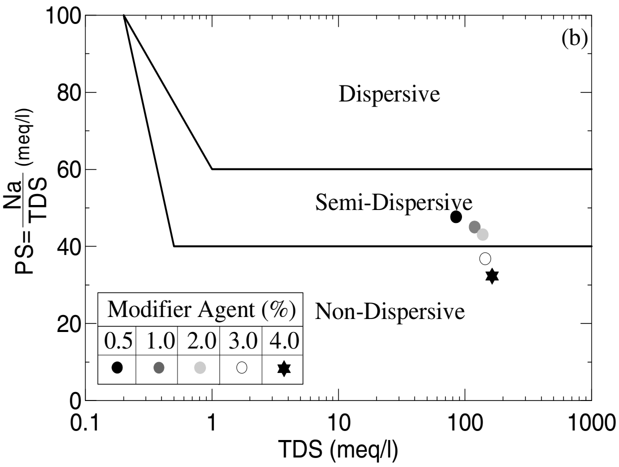

Figure 3. Dispersivity classification of sample 1, improved with b) Aluminum Sulphate.

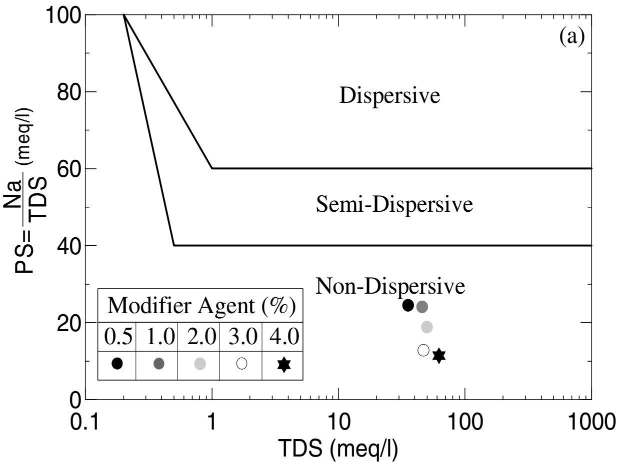

Figure 4. Dispersivity classification of sample 2, improved with a) Lime.

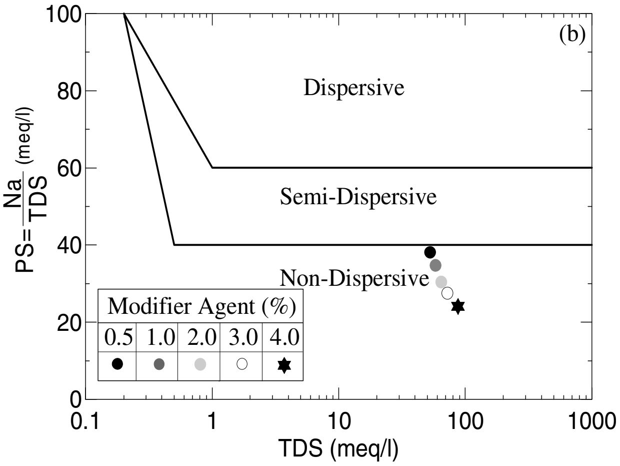

Figure 4. Dispersivity classification of sample 2, improved with b) Aluminum Sulphate.

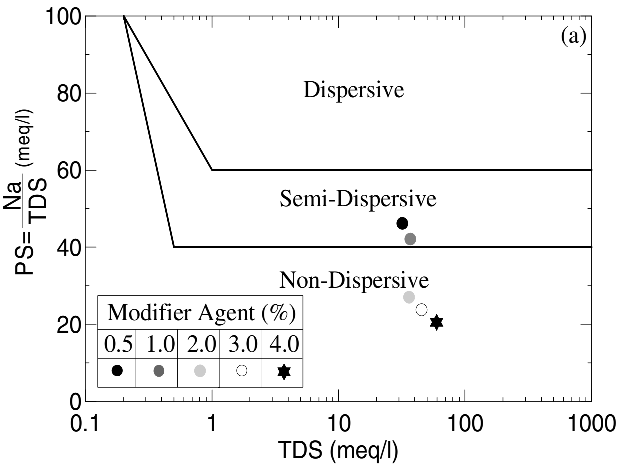

Figure 5. Dispersivity classification of sample 3, improved with a) Lime.

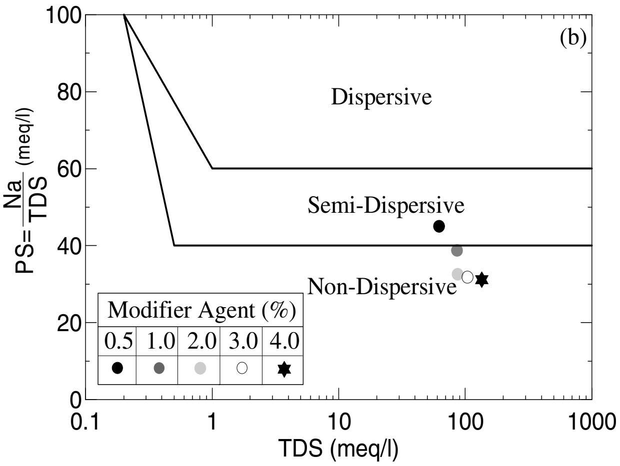

Figure 5. Dispersivity classification of sample 3, improved with b) Aluminum Sulphate.

b) *Pinhole Test*: the pinhole test was performed on the improved samples with different percents of additives. Table 3 summarizes the pinhole test results.

The results clarify the effect of modifier agents on reduction dispersivity potential. With using 3% lime or 3% Aluminum Sulphate the dispersivity potential reaches to lowest level (ND1), indicating the higher efficiency of Aluminum Sulphate in comparison with lime.

Table 3. Dipersivity classification of improved samples in pinhole test

Additive type	AP [a]	SN [b]1	SN [b]2	SN [b]3
Lime	0.5	ND4	ND4	ND4
	1%	ND4	ND4	ND4
	2%	ND3	ND2	ND2
	3%	ND2	ND1	ND1
	4%	ND1	ND1	ND1
Aluminum Sulphate	0.5	ND4	ND4	ND4
	1%	ND4	ND2	ND2
	2%	ND2	ND1	ND1
	3%	ND1	ND1	ND1
	4%	ND1	ND1	ND1

[a] AP: Additive Percent
[b] SN: Sample Number

4 CONCLUSIONS

A series of dipersivity classification tests were performed to investigate the potential of different samples from various parts of North of Iran to dipersivity. Four more common tests, including *Chemical*, *Pinhole*, *Double Hydrometer* and *Mineralogical* tests were conducted to identify the nature of the samples. These tests showed that all samples are dipersive, although the potential of dispersivity varies from sample to sample depending to the percent of sodium, TDS and SAR. The quantity of these parameters could be a criterion for the distinction as to being dispersive, moderate or non-dispersive soil.

Also the results revealed that for dispersivity improvement, lime and Aluminum Sulphate might be used to reduce and mitigate the dispersivity and erosion potential. The Aluminum Sulphate, however, has more workability in comparison with lime which is probably due to the presence of Aluminum ion in this material.

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