Improvement of Dispersive Soils by Using Different Additives

by

S. Chandra*

C.G.L. James**

Introduction

A number of earth dams in northeast Thailand have suffered serious surface and subsurface erosion problem from water and several have failed during the first reservoir filling. In 1972, the failure of the La Escondida dam took place in Mexico by the dispersive piping of the clay containing high Total Dissolved Salt (TDS). This behaviour is typical of dams containing dispersive clay. Preventing the failures caused by the dispersibility of the soils, is one of the major concerns of Geotechnical engineers these days. The recent trend of research has shown chemical stabilization as an effective means to improve the strength and the erosion resistant properties of these soils.

Most of the dispersive soils are found in flood-plain deposits, slope wash, lake bed deposits and weathered loessial deposits. Dispersive soils are present in various parts of northeast Thailand and substantial deposits of these soils have also been recognized in United States, Australia, Mexico, Brazil, South Africa and Vietnam. Hence it can be anticipated that the dispersive soils may be found anywhere in the world. In recent years, dispersive soils and consequently their erosion problems have been found to exist in humid climates in various locations in many countries.

Dispersive soils contain a clay fraction which has a high potential to be in a dispersive state when the soil mass is in contact with water. Wood et al (1964) and Ingles (1972) showed that the failure by piping and erosion of earth structures containing dispersive soils is often due to the interaction between stored water and the soil which induces a greater seepage flow.

Sherard et al (1972) described that the dispersion occurs when the repulsive force (electrical surface forces) between individual clay particles exceeds the attractive force (van der Waals attraction) so that when the clay mass is in contact with water, individual clay particles are progressively detached from the surface and go into suspension. The repulsive forces depend on the thickness of the double layer which is increased by decreasing the concentration or the valence of absorbed ions, or by increasing the dielectric constant. The attractive forces, however, are independent of these adsorbed ions and the dielectric constant. This is the reason that the repulsive forces exceed the attractive forces.

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* Assistant Professor Geotechnical & Transportation Engineering Division, Asian Institute of Technology, Bangkok, Thailand

** Formerly Graduate Student,

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Holmgren (1977) said that the dispersive condition is an evidence that sodium is present in the system and that the effectiveness of sodium as a dispersing agent is related to its ionic charge of plus one. Sodium ion promotes dispersion by creating a greater osmotic potential for water movement into the space between particles and also by increasing the long range repulsive double layer interaction of the particles, which causes greater soil dispersivity.

For identification and understanding of dispersive soils, various tests in the field and in the laboratory are used. Sherard et al (1976) developed a test called as Pinhole test. In this test, distilled water is caused to flow through a 1.0 mm diameter hole punched in a 25. 4 mm long specimen of clay. The test is quite simple and carried out easily on disturbed or undisturbed soils.

The SCS laboratory dispersion test or Double hydrometer test was developed by Volk (1937) and has been widely used by the U.S. Soil Conservation Service since 1940. This test is simple, short in test duration and easy to understand by Engineers. The Soil conservation service has concluded that clays having a degree of dispersion greater than about 40 per cent are susceptible to erosion and set up a criterion for classifying soils.

Crumb test is a useful method of field identification of the dispersive soil. Rallings (1966) after study of dam failures concluded that crumb test identified dispersive soils as well as any other test then available and that a dilute Na0H solution (0.001 N: = 1.0 meq/l) worked better than distilled water.

Ryker (1977) suggested a reliable field test for determining the degree of dispersion, also called as the modified hydrometer test. The test is made by comparing the turbidity of a fractional part of an artificially dispersed soil-water suspension with the turbidity of an aliquot of an untreated soil water suspension. This method requires a test history to develop ranges in turbidity ratio that correlate with the laboratory test. Potentially dispersive soils should be examined by determination of a sodium absorption ratio and exchangeable sodium percentage. In order to measure the sodium absorption ratio (SAR), the method was developed by the United States salinity laboratory in 1954.

According to Australian researches, the clay with exchangeable sodium percentage (ESP) of 7 to 10 are moderately dispersive and have been associated with piping failures in clay dams when the reservoir water is relatively pure. Clays with ESP of 15, or more, have serious piping potential.

The physical erosion test (PET) was developed by Haliburton, et al (1975). This was a new method to identify dispersive soils. The test was carried out in the normal field conditions by using a Harvard-miniature-sized cylinder (diameter 3.33 cm (1.31 in.), length 7.39 cm (2.91 in.)) compaction method for different moisture conditions. Artificial cracks or notes were drilled longitudinally through the cylinder so that a most internally erodible soil mass could be simulated. The dispersion of clay is caused by distilled water passing through the specimen. The holes also provided a channel to flush dispersive clay out of the mass and provide relatively pure water for continuous clay dispersion. The flushing and removal action was included to simulate intermittent water flow conditions found in the field.

The value of Percent Erosion is believed to give better results than other chemical and engineering property tests currently used to identify potentially dispersive soils.

Improving Dispersive Soils by Chemical Additives

Soil-lime treatment—The effectiveness of lime is due to several factors. One factor is the increase in Ca cation exchange with the increase in soil *pH*. Another factor is compression of the ionic atmosphere around the clay particles. Pozzolanic reactions between the lime and clay particles may also cause an increase in strength, and the cementation reduces major erosion. The addition of lime to soil initiates several reactions. Cation exchange and flocculation-agglomeration reactions take place rapidly and produce immediate changes in soil properties.

Sodium chloride treatment—The presence of sodium chloride causes the concentration of sodium cations to increase on the clay surface as the absorbed anions are replaced and a flocculated structure results. This acts as a compaction aid, promoting higher densities.

Sodium chloride acts to reduce the freezing point and to increase the boiling point of the soil water, and it is for this reason that it improves frost resistance. For this purpose, it is the best available stabilizer at a very low price. The principal disadvantage is that, being soluble. salt is leached from the soil by subsequent rains and the treatment may need frequent renewal unless a surface seal is quickly applied. Soils with high liquid limit (montmorillonite type) generally respond quite well, since subsequent leaching out is minimal in these soils.

Flyash treatment—Flyash belongs to a class of material known as pozzolanas. The pozzolanic activity of the flyash depends on the quality of its grain size distribution and coarse flyash admixture leads to failure. The flyash quality can be greatly improved by grinding, but this is seldom economical (Kezdi, 1979).

The flyash particles may have an electric charge, which is rather detrimental to compaction, so a suitable discharge technique must be sought.

Gypsum—Ghosh (1973) indicated that gypsum was found to improve considerably the compressive strength of stabilized soil using flyash at both 7 and 28 days when the concentration of gypsum was 1 percent by weight of the stabilized soil. When, 1 percent gypsum and 15 percent lime flyash mixture was used, it was found that there was an improvement in strength in soil lime flyash system by the addition of gypsum. This might be attributed to accelerated formation of ettringite.

Sherard et al (1976) indicated that percentage sodium usually decreases as additional calcium cations are generated by solution of gypsum and other partially soluble calcium compound. So gypsum is a good material to improve soil and avoids dispersion.

Results and Discussions

In this study, the results of the laboratory tests carried out on dispersive soils for identification and understanding the behaviour of these soils are presented. Approximately 250 specimens were tested. The samples were tested to obtain physical properties, permeability and compression characteristics before and after mixing chemical additives. For the identification of dispersive soils, pinhole test, crumb test and chemical analysis test were carried out. Tests like *X*-ray diffraction and *pH* measurement were also carried out to understand the behaviour of these soils.

The samples tested in this study were collected from Lam Sum Lai dam site in the Lam Prakong village, Pak-Thongchai District, Nakhon Rachasima Province and the Khon Kaen University site in Khon Kaen town, Khon Kaen Province in North Eastern Thailand. The Lam Sum Lai dam failed by piping during the first fiilling and a section of embankment about 50 *m* wide was washed out. There is considerable evidence available at the site of dispersive erosion.

The Khon Kaen area mainly comprises of broad river terraces and flood plain. The weathered Khon Krat Clay, which was sampled at the borrow pit in front of the central library, is exposed as a gradation zone overlying the Khon Krat shale and underlying the unconformity in the stratigraphic section (Montree, 1977). It is reddish brown, indurated, loose silt and shale beds mottled with white Kaolinite, the thickness is approximately 1 m. The soil properties and the results of chemical tests are summarized in Table 1.

TABLE 1

Physical and Chemical Properties of Raw Soil

Item		L.S.L	K.Y.	K.O.
Natural water content.%		10.41	4.92	9.71
Liquid limit, %		25.00	21.02	24.30
Plastic limit, %		13.75	13.37	13.84
Specific gravity		2.635	2.633	2.634
< 0.005 mm, %		30	20	28
< 0.002 mm, %		29	18	26
Unified Soil Classification		Silty-clay CL	Silty-clay sand SM-S	Silty-clay CL
pH		7.81	7.36	7.50
K	meq/l	0.05	0.20	0.30
Na	meq/l	3.57	2.52	4.09
Ca+Mg	meq/l	1.33	0.80	1.50
TDS	meq/l	4.95	3.52	5.62
SAR		5.38	3.98	4.72
Zone		A	A	A
Classification			Dispersive	

The relationship between dry density and water content obtained from standard proctor compaction test on Khon Kaen old type of soil shows an optimum water content obtained as 10.4% and the corresponding maximum dry density as 1.95 t/m^3.

Effect of Various Additives on Strength

Effect of lime on strength of soil—The effect of adding lime on the plasticity of Khon Kaen old type of soil was studied. There is not a marked change in liquid limit by addition of lime, however, the plastic limit increased from 16.14 to 20.30% by addition of lime increasing from 1 to 3%. However, as the percentage of lime added increased, the rate of reduction decreased.

Hilt et al (1961) observed that there is an optimum percentage of lime to be added beyond which additional increments of lime produced no appreciable increase in plastic limit. It was hypothesized that excess calcium cations derived from the lime, in some fashion 'crowd onto' the clay particles and cause them to become 'electrically attractable' which results in flocculation with weak bonds between the flocs. Additional lime, which produces calcium cations in excess of those which could crowd onto the clay, produced no further change in the plastic limit. This results in a rather sharp decrease in plasticity index. The observation mentioned above on the Khon Kaen soil supports this hypothesis.

The dose of lime was limited to less than 5% as Herrin and Mitchell (1962) had showed that lime in excess of a relatively limited amount, of the order of 5 percent by weight of soil, generally produced little additional increase in the optimum moisture requirement. So 4% of lime additive is nearly the most optimum quantity to be added.

To study the effect of adding lime on the compaction characteristics of Khon Kaen old soil, tests on specimens were carried out using Harvard miniature compaction, with varying doses of lime viz. 1%, 2%, 3% and 4% of lime by weight. The compaction was done using a spring of 20 *lb* force, divided in 5 layers and each layer was given 16 tamps. Soil lime mixtures have a lower maximum density than the original untreated soil and the maximum density normally continues to decrease as the lime content is increased. The optimum moisture content increases with increase in lime content. The lower density is due to the flocculation of the fines and due to formation of an open structure. The higher optimum water content results from the consumption of water by the quick lime.

To study the effect of lime on compressive strength of soil, tests were carried out on soil specimens prepared by compaction in Harvard miniature compaction mould. The unconfined compression test was carried out by using strain controlled type of unconfined compression machine. The tests were conducted on specimens with different lime contents immediately after compaction in the first stage and after curing for 2,7,14 and 21 days in the second stage. The tests were carried out on specimens in soaked and unsoaked conditions. The *pH* value was also measured after curing the sample. The results of these tests are presented in Table 2. The effect of curing time on the compressive strength of the samples can be seen from Table 3.

TABLE 2

Effect of Chemical Addition on Physical Properties and Strength

Additives	After test γ_d (t/m³)	After test w (%)	Unsoaked Compressive Strength (t/m²)
Ca0–1%	1.83	8.99	19.02
Ca0–2%	1.80	9.30	22.19
Ca0–3%	1.78	9.53	22.96
Ca0–4%	1.77	9.86	24.60
Gypsum–3%	1.85	9.63	26.24
Gypsum–5%	1.87	9.21	27.84
Gypsum–7%	1.84	8.74	22.69
Gypsum–10%	1.82	8.75	23.77
Flyash–1%	2.0	10.00	21.23
Flyash–2%	2.0	10.15	24.64
Flyash–3%	1.95	10.02	26.50
Flyash–4%	1.96	9.90	35.20
Gypsum–1% Flyash–3%	1.87	10.09	40.45
Gypsum–1% Flyash–6%	1.85	9.70	49.70
$Al_2(So_4)_3$–0.5%	1.99	9.98	14.70
$Al_2(S0_4)_3$–1%	1.98	10.28	12.70
NaCl–1%	2.01	10.02	11.70
NaCl–2%	1.99	10.08	11.35
NaCl–3%	1.97	10.40	10.30
NaCl–4%	1.96	10.43	8.24

Effect of flyash on strength of soil—The tests were conducted on specimens with different flyash contents immediately after compaction in the first stage and after curing for 2, 7, 14 and 21 days in the second stage. The tests were carried out on specimens in unsoaked condition. The results of these tests are presented in Tables 2 and 3.

TABLE 3

Effect of Curing on Physical Properties and Strength

Additives	Curing time (days)	After test γ_d (t/m³)	After test w (%)	Unsoaked Compressive Strength (t/m²)	pH
CaO—1%	2	1.81	9.90	21.58	12.32
	7	1.84	9.96	26.86	11.85
	14	1.82	9.57	32.94	11.25
	21	1.84	9.48	39.97	11.00
CaO—3%	2	1.79	9.39	23.56	12.39
	7	1.85	9.31	33.65	12.30
	14	1.82	9.25	37.50	11.55
	21	1.83	8.90	39.10	11.30
Flyash 5%	2	1.85	8.71	127.45	
	7	1.87	9.28	121.10	
	14	1.88	9.21	170.43	
	21	1.87	8.68	171.30	
Gypsum 3%	2	1.97	9.72	22.30	
	7	1.99	9.99	27.14	
	14	1.96	9.54	27.80	
	21	1.95	9.49	28.70	
Gypsum 1%	7	1.85	9.33	89.82	
Flyash 3%	28	1.89	8.63	225.92	
Gypsum 1 %	7	1.83	8.8	106.44	
Flyash 6 %	28	1.85	8.81	285.07	
$Al_2(SO)_3$ 0.5%	2	1.97	10.40	14.40	
	7	2.01	10.08	14.10	
	14	1.98	10.02	17.40	
	21	1.99	9.99	18.40	
NaCl 1%	2	2.01	10.03	10.07	
	7	1.99	9.97	14.20	
	14	1.98	10.03	13.30	
	21	1.98	9.59	17.50	

From Table 2, it can be seen that 5% flyash content is an optimum content to get maximum strength. Due to addition of flyash, there is a decrease in the dry density obtained after the test with increase in flyash content.

The effect of curing time on compressive strength of the sample for flyash content of 5% can be seen from Table 3.

Effect of gypsum on strength of soil—The tests were conducted on specimens with different gypsum contents. The results of these tests are presented in Tables 2 and 3.

From the tables, it can be seen that the unconfined compressive strength of unsoaked samples increases when the gypsum content is increased from 1 to 4%. The maximum deformation at failure decreases with increasing gypsum content. Thus indicating that the samples show a more brittle behaviour due to addition of gypsum. The water content value obtained for samples after curing 2, 7, 14 and 21 days, present approximately same value, and also the dry density remains more or less constant. The compressive strength increases from 16.40 t/m^2 to 21.70 t/m^2 when the curing time is increased from 2 to 21 days. The water content and dry density values are more or less constant and do not get effected by curing.

Effect of flyash-gypsum mixture on strength of soil—The flyash-gypsum mixtures were used as a chemical stabilizer in these tests. Two different proportions of gypsum and flyash were tried viz. (*i*) 3% flyash+1% gypsum and (*ii*) 6% flyash+1% gypsum. The samples obtained with these mixes of gypsum and flyash were cured for 7 days and 28 days to study the effect of curing time on strength. The results of these tests are presented in Tables 2 and 3.

Comparing the behaviour of gypsum-flyash mixture with the behaviour of flyash and gypsum separately, it is seen that the mixture is found to be more effective.

Effect of aluminium sulphate on strength of soil—To study the effect of aluminium sulphate on compressive strength of soil, tests were carried out on soil specimens with varying doses of aluminium sulphate viz. 0.5%, 1% and 2% of aluminium sulphate by weight. The results of these tests are presented in Table 2 and 3.

From Table 2, it can be seen that the unconfined compressive strength decreases when the aluminium sulfate content increases. It can be said that 0.5% of aluminium sulphate is optimum content to get maximum strength. The water content increases with increase in the content of aluminium sulphate, and dry density shows no change with addition of aluminium sulphate. The maximum deformation increases with increase in the content of aluminium sulphate. Thus indicating that addition of aluminium makes sample more plastic.

The effect of curing time on the compressive strength of the samples can be seen from Table 3.

Effect of salt on strength of soil—To study the effect of salt on compressive strength of soil, tests were carried out on soil specimens with varying doses of salt viz. 1, 2, 3 and 4% of salt by weight. The results of these tests are presented in Table 2.

From Table 2, it can be seen that the unconfined compressive strength decreases when the salt content is increased from 1 to 4%. It can be said that 1% of salt is optimum to get maximum strength. The dry density reduces with addition of salt, and water content increases with an increase in addition of salt. The maximum deformation inreases with increase in the content of salt indicating that there is a softening of soil taking place due to addition of salt.

The effect of curing time on the compressive strength of the samples can be seen from Table 3.

Permeability

Aitchison and Wood (1965) showed that piping occured when the permeability was 10^{-4} cm/sec or more and therefore a basic requirement is that the maximum permeability should not exceed 10^{-5} cm/sec for stabilization of the soil and to prevent deflocculation.

The coefficient of permeability value obtained by using a standard constant head permeability test on Khon Kaen old type of soil with different chemical additives are shown in Table 4. From the results of these tests it is observed that lime is most effective in reducing the coefficient of permeability out of the three chemicals tried. Gypsum can also reduce the coefficient of permeability but it is less efficient than lime. Aluminium sulphate is not much effective in reducing the coefficient of permeability as it showed only a marginal change in the permeability of the soil for the dose tested. Similar observations were made earlier and it is reported that the permeability of compacted soil-lime mixture is much less than that of compaction alone. The reason is the early physico-chemical reactions of lime that produce the amelioration effects on soil clays and the nature of the cementing compounds that produce the final cemented product and reduction in such parameters as swell pressure, volume change on drying and permeability.

TABLE 4

Permeability of Soil with and without Additives

Test No.	Additives	Percent of Additives	Rate of Flow g (ml/min)	Permeability K (cm/sec)	Saturated w (%)	pH
p1	Lime	2	5.33×10^{-3}	3.84×10^{-6}	13.77	12.4
p2	Gypsum	2	5.60×10^{-3}	3.03×10^{-6}	12.77	5.3
p3	Aluminium sulphate	1	6.20×10^{-3}	4.47×10^{-6}	12.11	3.4
p4	---	0	6.40×10^{-3}	4.61×10^{-6}	12.23	7.5

Clay Mineralogy

Holmgren (1977) observed from the test results that montmorillonite, kaolinite and illite all could become the dominant clay minerals in dispersive soils. Montmorillonite is particularly dispersive due to special structure and very small edge/face surface ratio. Kaolinite cannot form tactoid structures and with a high edge/face surface the dispersion ratio, only occurs at a relatively high sodium absorption ratio.

From the *X*-ray diffraction analysis carried out, the mineralogy of the soils in this study can be seen in Table 5. Lam Sum Lai dam soil, consists of kaolinite, illite and small amount of montmorillonite and vermiculite with traces of interstratified clay minerals between 10 to 14 A and with traces of quartz. Khon Kaen old type sample consists of mostly kaolinite, traces of montmorillonite and probably illite and traces of quartz. Khon Kaeon young type soil consists of mostly kaolinite, traces of quartz and small amount of 14 A group of clay minerals. Lam Sum Lai dam soil has the highest montmorillonite content (65%) and so it can be expected that this soil will exhibit highly dispersive characteristics among the soils tested.

The results of the tests on treated soils by adding gypsum 1, 2, 3 percent, flyash 5.7 percent, aluminium sulphate 0.5, 2p ercent and hydrated lime 2 percent of weight of dry soil, indicate that :

(*i*) When 1 to 3 percent of gypsum or hydrated lime is added to the soil, the *X*-ray patterns are more or less same.

(*ii*) When flyash is added there is a marked effect on *X*-ray intensity, 7% flyash tremendously decreases the kaolinitic peak and interferes the illitic and 14 *A* group peaks.

(*iii*) When aluminium sulfate is added, there is slight decrease in kaolinitic peak when 2% aluminium sulphate was added whereas there was no significant effect when the aluminium sulphate added was only 0.5%.

From *X*-ray diffraction analysis, it can be concluded that the mineralogy of the soil does not get affected by adding chemical additives. X-ray pattern obtained for treated soils shows that the spacing of peaks are not affected by the additives. However, there is an increase or decrease in the intensity of the peaks.

Identification Test Results

The results of crumb test showed that the Lam Sum Lai Dam soil is Grade 3 to 4 and Khon Kaen old and young type of soils are Grade 2 soils as per Sherard et al (1976). Based on the results of this test only L.S.L. soil can be classified as dispersive soil and the other two soils are not dispersive soils. Sherard et al (1976) studied the relationship between percentage of sodium in saturation extract for dispersive and nondispersive soils and the total dissolved salts. He divided the region in three zones to classify the soils as dispersive, nondispersive and in transition state (see Fig. 1).

The results for all the three samples are plotted in Fig. 1. All the three soils fall in zone A which corresponds to dispersive soils as per Sherard's observations.

The results of Pinhole test on three different types of soils and Khon Kaen old types of soil mixed with different chemical additives are shown in Table 6. From this table it can be seen that Khon Kaen young type soil is classified as *D*1 whereas the Khon Kaen old soil and Lam Sum Lai dam soil classify as *D*2 grade. All the three types of soil are dispersive type of soil as per the results of this test. This further confirms the results of the

TABLE 5

Test Results of Mineralogy of Clay Fraction Before and After Treatment

Site	Additives	Kaolinite	Montmorillonite	Quartz	Interstratified	Illite	Vermiculite	14A
L.S.L.	nil	moderate	small	trace	trace	moderate	small	trace
K.Y.	nil	predominant	0	trace	0	0	0	small
K.O.	nil	predominant	trace	trace	0	probable	0	,,
K.O.	gypsum 1%	,,	,,	,,	0	,,	0	,,
K.O.	gypsum 2%	,,	,,	,,	0	,,	0	,,
K.O.	gypsum 3%	,,	,,	,,	0	,,	0	,,
K.O.	flyash 5 %	moderate	,,	,,	0	,,	0	,,
K.O.	flyash 7%	,,	,,	,,	0	,,	0	,,
K.O.	lime 2%	predominant	,,	,,	0	,,	0	,,
K.O.	aluminium sulphate 0.5%	predominant	,,	,,	0	,,	0	,,
K.O.	aluminium sulphate 2%	moderate	,,	,,	0	,,	0	,,

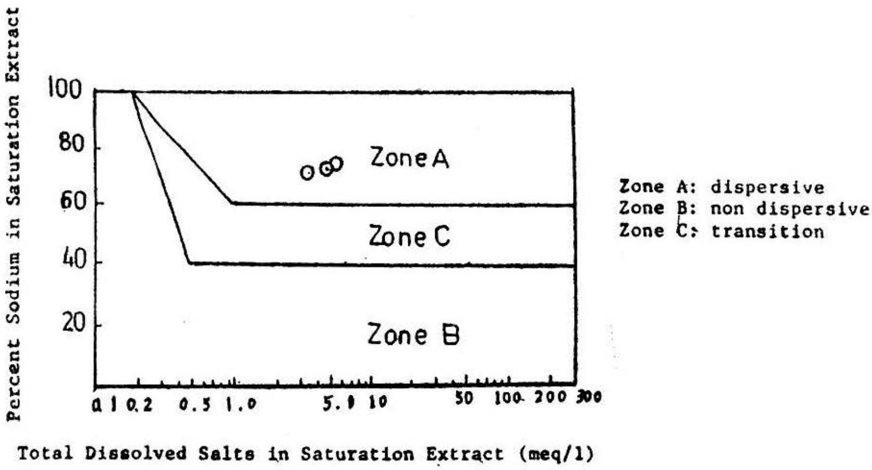

FIGURE 1 Results of Chemical Analysis

chemical analysis in which all the three soils were also classified as dispersive soils as per Sherard et al (1976).

The results of pinhole test on Khon Kaen old type of soil mixed with different chemical additives, indicate that the mixing of lime improves the properties of the soil against dispersion. All the tests carried out on specimens mixed with lime showed a grade ND1 and classify as nondispersive soils by this test. The soil samples mixed with 2% aluminium sulphate also indicated similar behaviour. Adding of gypsum improves the nondispersivity of the soil and the grade improves from ND4 to ND1 when the content of gypsum is increased from 1 to 3%. Contrary to this, addition of salt shows a reverse trend and the grade changes from ND1 to ND4 when the salt content is increased from 1 to 3%. Addition of flyash does not indicate any significant improvement on the grade of the soils, as per the results of this test. It is needed to study further pinhole test on soil with chemical additives before any conclusive inferences can be drawn from the results of this test.

Conclusions

1. Crumb test can not be used as a very reliable test to identify dispersive soils. The test failed in two out of three cases in this study.

2. The results of chemical analysis test used for classifying soils as dispersive soils as suggested by Sherard et al (1976) is found to be a reliable test for the identification of dispersive soils.

3. The results of pinhole test and chemical analysis test for all the three specimens are found to be in agreement to each other. Pinhole test may be treated as a reliable method of identifying dispersive soils.

TABLE 6

Results of Pinhole Tests

Additives	Percentage	Discharge (ml/s) under a hydraulic head of in. 2 in. head velocity cm/sec	7 in. head velocity cm/sec	15 in. head velocity cm/sec	40 in. head velocity cm/sec	Hole size after test	Specification
K.O.	0	2.22	2.14	3.33	4.55	2X	D2
K.Y.	0	5.00	8.33	—	—	15X	D1
L.S.L.	0	2.22	2.50	2.94	4.55	2X	D2
Lime	1	0.83	1.67	3.13	4.55	X	ND1
Lime	2	0.37	2.00	2.78	4.55	X	ND1
Lime	3	0.10	0.29	0.72	0.81	X	ND1
Salt	1	0.19	0.71	1.06	1.67	X	ND1
Salt	2	1.33	1.67	2.08	3.57	1.5X	ND4
Salt	3	1.43	2.00	2.50	3.33	1.5X	ND4
Aluminium Sulphate	2	1.25	1.33	1.67	2.50	X	ND1
Gypsum	1	1.82	2.00	2.63	3.33	1.5X	ND4
Gypsum	2	1.64	2.22	2.50	3.85	X	ND2
Gypsum	3	0.27	0.32	0.53	0.56	X	ND1
Flyash	3	1.43	1.82	2.17	3.33	1.5X	ND4
Flyash	5	1.67	2.00	2.50	3.85	2X	D2

4. Clay containing high percentage of montmorillonite shows high dispersivity. However, soils containing kaolinite and illite may also show dispersivity.

5. Lime is found to be more effective in reducing the permeability of the soil than aluminium sulphate and gypsum.

6. The strength of the soil improves when a chemical additive is added. Gyspum and flyash mixtures are found to be the most efficient additives. Flyash, gypsum and lime can be used in diminishing order of their utility as chemical additives.

7. The strength of treated sample is maximum after 21 days of curing in the tests conducted and the recommended curing time is 21 days. For flyash, there is not much gain of strength after 14 days and the curing time may be limited to this value.

8. For the lime soil mixture, strength increases and pH value decreases with increase in the curing time.

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