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Feasibility Study on Dispersivity of Lignosulphonate Treated Clay using Pinhole Test

Sowmya V Krishnankutty[1[0000-1111-2222-3333]] and Keerthi Sabu[2[1111-2222-3333-4444]]

[1] Assistant Professor, Department of Civil Engineering, Federal Institute of Science and Technology, Angamaly -683577
[2] Assistant Professor, Department of Civil Engineering, Federal Institute of Science and Technology, Angamaly -683577
sowmya.krishnankutty@gmail.com
Keerthisabu.1990@gmail.com

Abstract. Natural clay is highly erodible by flowing water. Clay particles present in soil are likely to disperse and deflocculate when water is added. Dispersive soil is characterised by unstable structure and tends to crumble and erode even at a low flow rate. This leads to stability problems in earthwork construction such as dam embankment, roadway embankment, etc. Dispersive soil is characterised by a higher exchangeable sodium percentage. To study dispersion characteristics, soil collected was mixed with 50% sodium bentonite. The results of the double hydrometer and crumb test confirmed the dispersivity of bentonite mixed clay. To control the dispersivity of the soil, sodium lignosulfonate was added. The selected Lignosulfonate contents were 0.5%, 1%, 1.5% and 2% of dry soil mass. The Optimum percentage of Lignosulfonate was 1.5% which was determined by the pinhole test. The results of the double hydrometer test on soil treated with Sodium Lignosulfonate confirmed the non- dispersivity of soil. The dispersivity of soil was found to reduce from 64% to 30% at the optimum percentage of lignosulfonate.

Keywords: Dispersivity, Bentonite, Lignosulfonate, Double Hydrometer, Pinhole test.

1 Introduction

Dispersive soils are easily eroded by water even under a very low flow rate due to its unstable structure. Most of the failures in embankments, earth dams, and slopes were composed of clays with low to medium plasticity that contains montmorillonite. Exchangeable sodium ions present in the clay are a major cause of the dispersivity of Soil. This enables the particle to separate and move freely. This type of soils is known as sodic soil. If the presence of exchangeable sodium percentage is greater than 15%, the soil is classified as sodic which means the sodium occupies more than 15 % of the soil’s cation exchange capacity. Such soils exhibit low permeability and infiltration due to swelling and dispersion of clay[8].

To assess the extent of the injury and also to plan for a suitable remedy, it is necessary to characterize soils. This cannot be identified by the conventional laboratory index tests such as visual classification, gradation, specific gravity, or Atterberg's limits and compaction characteristics. The conventional method of improving dispersive clay is by chemical additives such as using lime, cement, and pozzolanic materials. Using the lignosulfonate additive which is environmentally friendly, it can be considered advantageous in overcoming the limitations associated with treatment with traditional additives. In comparison with the untreated dispersive clay, the one treated with the lignosulfonate achieved higher resistance when subjected to the erosion test. The Pinhole test, double hydrometer test, and crumb test are popular in India for assessing dispersive characteristics.

T.S Umesh et. Al (2011) conducted studies on the characterization of suddha soils of southern parts of Karnataka. This study explores the possibility of using standard tests like shrinkage limit and unconfined compressive strength tests to check the dispersivity of the soils. It has been concluded in their study that dispersivity ascertained from strength tests is more reliable [11]. S.L Gupta et.al (2011) conducted studies on the identification of dispersive soils. The four tests most commonly used to identify these soils are described here such as crumb test, pinhole test, chemical test, and double hydrometer test [10]. Abhirami Suresh et.al (2013) conducted studies on the dispersive nature of the soil. This article reports the results of crumb and pinhole tests administered on laterite soils and marine clay collected from various locations in Kerala [1]. Maharaj A (2013) gives the standard test procedure for the identification of dispersive soil. The standard testing procedures are the soil Conservation Service (SCS) Double Hydrometer test, the Pinhole Test, Crumb test, and chemical analysis test [6].

Mohammed Yousif Fattah (2014) conducted studies on the modification of pinhole apparatus, which works on the idea that water is passed horizontally under the influence of hydraulic head in the soil sample [7]. Amir HosseinVakili (2017) conducted studies on a highly dispersive clay and it was treated with various proportions of lignosulphonate, an environmentally friendly stabilizer. The electroosmosis technique is understood as an efficient and modern soil improvement method. In the subsequent stage of the study, the consequences of electroosmosis treatment on the dispersive clay were investigated by using different potentials [2]. ASTM D4647-93 (2006) gives the standard test method for identification and classification of dispersive clay soils by the pinhole test [3] and ASTM standard D4221 gives the standard test method for identification and classification of dispersive clay soils by the double hydrometer test [4].

In the past dispersive clay soils weren't recognized, and failure of several structures occurred before dispersive action was identified. Now, it's documented about the presence, properties, and tests for the identification of dispersive clays and its use in engineering structures. To conduct a study on the dispersivity nature of soils, apart from the basic tests, a pinhole test apparatus was developed. In the present study, sodium lignosulphonate was used as a chemical additive for controlling the dispersivity of soil. For studying the effectiveness of lignosulphonate, the performance of soil with its various percentage of the addition was evaluated from the dispersivity test results.

2 Materials Used for the Study

Various tests have been conducted in Kuttanad clay, bentonite -mix clay sample, and clay treated with sodium lignosulphonate. These tests were conducted to determine the engineering properties and to check the dispersive characteristics of the samples.

2.1 Kuttanad clay

The soil sample used in the study was collected from Kuttanad. The sample was collected at a depth of 1 m from the ground surface. Undisturbed soil samples were collected using a cylindrical mould. Samples were then stored in airtight plastic bags at its natural moisture content.

2.2 Bentonite

Bentonite is mainly composed of montmorillonite, a plate or leaflet shaped mineral that gives bentonite its unique properties such as the ability to swell. Bentonite is highly dispersive in nature [9]. The soil collected from Kuttanad was intermediate dispersive. To make it more dispersive, bentonite was added to the soil. Thus, in this study bentonite is used for artificially preparing a dispersive soil sample.

2.3 Sodium Lignosulphonate

Sodium Lignosulfonate is a non-toxic and non-corrosive waste material coming from the wood and paper processing industry. In the industrial process, the lignin is separated from the cellulose and since lignin does not have good solubility in water, it is converted into lignosulphonate in a chemical process called sulfonation. This by-product is available in both solid and liquid forms, which contain carbon (C), oxygen (O), sulfur (S), and sodium (Na). The lignosulfonate is considered to be an economical material, easy to use, and can rapidly become effective. Sodium Lignosulphonate is used to reduce the dispersivity of soil. It is a brown coloured powder with pH 4. The optimum percentage of lignosulphonate to be added was found out from a pin-hole test.

3 Major Tests Conducted

Consistency of fine-grained soil is used to denote the degree of firmness of the soil. Consistency limits or Atterberg's limits were determined using Casagrande's apparatus (IS 2720 Part V). The specific gravity of solid particles can be determined in a laboratory using a density bottle fitted with a stopper having a hole. The density bottle with 50 ml capacity is generally used (IS: 2720-Part II -1980). Since the soil contains a substantial quantity (say more than 5%) of fine particles, wet sieve analysis and hydrometer tests were done to obtain the particle size distribution curve (IS 2720 Part IV). In all the tests for checking the dispersivity of soil, the sample was maintained at optimum moisture content. To determine the optimum moisture content and maximum dry density Standard Proctor test was done (IS 2720-part VIII-1980). For conducting dispersivity tests on bentonite - clay mix, it was compacted to maximum dry density in the proctor mould and was then extruded from the mould. The various engineering properties of Kuttanad clay were determined. The dispersivity of the soil was determined using the Crumb test. A double hydrometer was also conducted to determine the dispersivity of soil. Dispersive clay was artificially prepared by the addition of bentonite into intermediate dispersive Kuttanad clay. The Physical Properties of bentonite clay mix was determined.

3.1 Bentonite – Clay mix preparation and tests conducted

Soils available in Kerala are less dispersive. So for studying the effectiveness of lignosulphonate in controlling the dispersion, dispersive clay was artificially prepared by the addition of bentonite into intermediate dispersive Kuttanad clay. Highly dispersive sodium bentonite was used for this study. To find the optimum percentage of bentonite-clay mix, 10%, 20%, 40%, 50%, and 60% bentonite of dry soil mass were added. After determining the optimum percentage, the physical properties of the optimum bentonite-clay mix was found. The dispersivity of the optimum bentonite-clay mix was determined from the double hydrometer test. A pinhole test was also conducted on the bentonite-clay mix to determine the dispersivity grade.

After confirming the dispersivity characteristics of an artificially prepared bentonite-clay mix, it was treated with sodium lignosulphonate to check its effect on control of dispersivity. The selected lignosulphonate contents were 0.5%, 1%, 1.5% and 2% of dry soil mass. Then it was added with an amount of water equal to Optimum moisture content. The solution thus obtained is then thoroughly mixed with 3 kg Bentonite-clay mix and stored in airtight plastic bags. It was stored for a curing period of 7 days. This was for ensuring the complete reaction of lignosulphonate with soil. Cured clay mix was then compacted and filled into the proctor mould and the sample was taken from it using the sampling tube for conducting pinhole tests. The double hydrometer test was also conducted for the selected lignosulphonate treated bentonite clay mix whose results showed better control on dispersivity.

3.2 Crumb test

This test is employed to work out the dispersivity nature of soil qualitatively. The crumb test is the simplest of the test used for detecting dispersive clays. The test is performed by placing a crumb of soil about 15mm in diameter into a transparent plastic glass partly filled with diluted 0.001M Sodium Hydroxide solution. The crumb is usually prepared at natural water content unless the soil is extremely wet. The crumb is dropped at the edge of the glass bottom and left in the glass undisturbed for a minimum of 1 hour. At the end of the waiting period, the clod and water are observed and the presence of any colloidal cloud in the water is evaluated. A second observation is suggested after leaving the clod within the glass overnight. Some soils haven't any reaction after 1 hour, but have a big reaction after the long waiting time. As per ASTM D6572-20, soil grade is assigned to the test result using the criteria as shown in table 1[5]. This test was used to determine the dispersivity of Kuttanad clay

Table 1. Guide for observation of crumb test.

Grade	Reaction	Categories
Grade 1	G1- no reaction Crumbs may slake or run out to form out from a shallow heap on the bottom of the beaker, but there is no sign of cloudiness caused by colloidal in suspension	Non-Dispersive
Grade 2	G2- slight reaction Very slight cloudiness can be seen in the water at the surface of the crumb	Non-Dispersive
Grade 3	G3- moderate reaction There is an easily recognizable cloud of colloidal in suspension, usually spreading out in thin streaks at the bottom of the beaker	Dispersive
Grade 4	G4- strong reaction A colloidal cloud covers most of the bottom of the beaker, usually as thin skin. In extreme cases, all the water becomes cloudy.	Dispersive

3.3 Pinhole Test

Pinhole test is conducted for direct measurement of the dispersivity (colloidal erodibility) of compacted fine-grained soils. In this study pinhole test apparatus was designed regarding the specifications given in a study conducted by Mohammed Yousif Fattah et.al.[7]. The inlet of the pinhole apparatus is connected to a hydraulic head (50 mm, 180mm, 380mm, and 1020mm) and a graduated cylinder is placed at the outlet to collect the water passing through the clay sample. The dispersivity of the soil sample is determined from the turbidity of effluent, final flow rate, and diameter of the hole according to the specification as shown in table 2.

Table 2. Dispersive classification of clayey soils.

Dispersive Classification	Head (mm)	Test time for given head(min)	Final flow rate through specimen(ml/s)	Cloudiness of flow at end of the test		Hole size after the test (mm)
				From side	From top	
D1	50	5	1.0 to 1.4	Dark	Very dark	2.0

D2	50	10	1.0 to 1.4	Moderately dark	Dark	>1.5
ND4	50	10	0.8 to 1.0	Slightly dark	Moderately dark	≤1.5
ND3	180 380	5 5	1.4 to 2.7 1.8 to 3.2	Barely visible	Slightly dark	≥1.5
ND2	1020	5	>3.0	Clear	Barely visible	<1.5
ND1	1020	5	≤3.0	Perfectly clear	Perfectly clear	1.0

A glass tube of diameter 33mm and length 100mm is used. It consists of an inlet and outlet as shown in figure 1. The flow of water through the inlet is controlled by a valve. The glass tube was detachable between the inlet and outlet for convenience in cleaning.

Fig. 1. The glass tube of pinhole apparatus.

Fig. 2. Sample extracted using sampling tube

A sampling tube of diameter 33mm and length 150mm was used for cutting the soil sample from the proctor mould. The sample was extracted from the sampling tube carefully as shown in figure 2. Then it was cut to the desired length (38 mm) as per the specification of the pinhole test apparatus. A layer of fine gravel (6-10 mm size) with a thickness of 50mm was placed at the bottom of the pinhole apparatus and above that, a circular wire mesh of 2.36mm square opening as shown in figure 3(a) is placed. The clay extracted from the sampling tube was inserted into the glass tube and was carefully made to rest on the mesh. The conical ring as shown in figure 3(b) was then inserted into the center of the top of the sample. A needle of diameter 1 mm was inserted inside the conical ring that works as a guide that maintains the needle in the middle of the entry form, then the needle is pressed into the soil slowly to penetrate the needle to the fine gravel layer. The needle was then withdrawn cautiously.

(a)

(b)

Fig. 3. (a)Circular wire mesh (b)Conical ring

Then the second circular wire mesh was accurately placed on the form and the remaining space at the top of the model layer was filled with 10 mm thick gravel. The glass tube was held horizontal using a clamp stand. The Inlet of the glass tube was connected to the hydraulic head and at the outlet, a graduated cylinder was placed.

Under varying hydraulic head water flow through the soil specimen, water coming through the outlet was collected in the cylinder. The schematic diagram of the pinhole test apparatus is shown in figure 4.

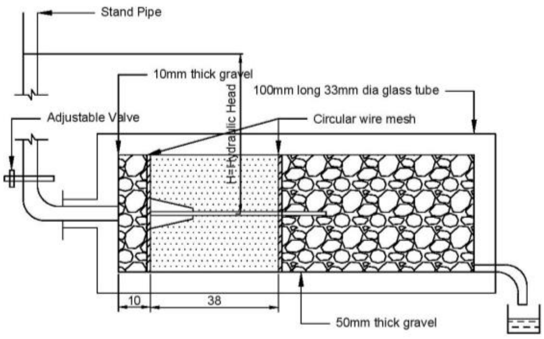

Fig. 4. Schematic diagram of the pinhole test set up

4 Result and Discussion

The preliminary tests were conducted to determine the engineering properties of un-treated air-dried Kuttanad clay such as moisture content, specific gravity, Atterberg limits, grain size analysis, and maximum dry density. The results of the preliminary tests conducted are shown in table 3. Chemical tests were conducted on air-dried soil at Sophisticated Test and Instrumentation Centre (STIC), CUSAT to determine the various chemical contents of soil and are shown in table 4

Table 3. Physical properties of Kuttanad clay

Sl. No.	Physical Properties	Value
1	Natural Moisture Content (%)	99%
2	Specific Gravity	1.95
3	pH	7.9
4	Liquid Limit (%)	130%
5	Plastic Limit (%)	46%
6	Shrinkage Limit (%)	33%
7	Gravel (%)	0
8	Sand (%)	20%
9	Silt (%)	51%
10	Clay (%)	19.2%
11	Dry Density (g/cc)	1.97

Table 4. Chemical properties of Kuttanad clay

Sl. No.	Element	Oxide (%)
1	C	33.61
2	Na	0.74
3	Mg	3.11
4	Al	14.62
5	Si	34.56
6	S	2.74
7	K	1.35
8	Ca	0.99
9	Ti	0.084
10	Fe	7.45

4.1 Dispersivity of untreated kuttanad clay

By conducting the Crumb test on Kuttanad clay soil at its natural moisture content, it was found that the soil is intermediate dispersive. The Kuttanad clay is categorized under Grade 3 since the samples gave a cloudy appearance at the bottom of the beaker. A double hydrometer test was also conducted to identify the percentage dispersivity of soil. From this test, it was found that Kuttanad clay has 35% dispersivity which shows that it is intermediate dispersive.

4.2 Bentonite – Clay mix

For different 10%, 20%, 40%, 50%, and 60% bentonite added clay mix, the soil crumb did not show any change after an observation period of 1 hour. Hence it was left undisturbed for another 24 hours and observation was made. For 50% bentonite-clay mix colloidal cloud covers most of the bottom of the beaker as shown in figure 5. The soil crumb obtained resembled the grade which is highly dispersive and hence was categorized under grade 4.

Fig. 5. Crumb of 50 % Bentonite-clay mix before and after 24 hours of observation

Physical properties of Bentonite - Clay mix Various tests were conducted on the optimum bentonite-clay mix to determine various properties of the soil mix and are given in table 5.

Table 5. Physical Properties of Bentonite-Clay Mix

Sl. No.	Physical Properties	Value
1	Specific Gravity	2
2	pH	9
3	Liquid Limit (%)	202.9
4	Plastic Limit (%)	86.7
5	Shrinkage Limit (%)	31.2
6	OMC	44.8

Dispersivity of Bentonite-Clay mix From the results of the double hydrometer test, the bentonite-clay mix was found to have a dispersivity of 64% which shows the mix is highly dispersive**.** From crumb, pinhole, and hydrometer tests, it can be concluded that bentonite-clay mix is highly dispersive with percentage dispersivity of 64% and grade D2.

4.3 Treatment of Bentonite – Cay mix with Sodium Lignosulphonate

While examining the turbidity of the effluent collected from the pinhole test apparatus, it was found that bentonite-clay mix treated with 1.5 % lignosulphonate is highly dispersive. Table 6 shows the observations of the Pinhole test.

Table 6. Observations of pinhole test

Lignosulphonate content (%)	Head (mm)	Time (Sec)	Flow Rate (ml/s)	Colour	Hole size (mm)	Grade
0	50	10	1	Moderately dark	1.6	D2
0.5	50	10	1	Slightly dark	1.4	ND4
1	380	5	2.5	Barely Visible	1.5	ND3
1.5*	1020	5	3.3	Perfectly clear	1	ND1
2	1020	5	5	Clear	1	ND2

*Percentage Lignosulphonate to be added for good control on dispersivity

From the double hydrometer test, the dispersivity for the 1.5 % treated sample was found to be 30%. It indicates that the sample is non-dispersive. The Dispersivity of the untreated sample was 63.5%. This indicates that lignosulphonate has a significant effect on the control of the dispersivity of soil. The efficiency of lignosulphonate in reducing dispersivity is about 52.75%.

5 Conclusions

As the clayey soils available in Kerala are less dispersive, hence highly dispersive sample was artificially made for study by adding bentonite. The optimum percentage of bentonite was found out from the crumb test. Cloudy formation observed from the crumb test showed that 50% bentonite-clay mix is highly dispersive and percentage dispersivity was 64% from the double hydrometer test. To study the effect of chemical additives on the dispersivity of soil, a pinhole test was conducted. Sodium lignosulphonate was selected as the additive and its varying percentage was added to the bentonite-clay mix. After analyzing the results of the pinhole test it was found 1.5% of lignosulphonate added clay mix had clear water effluent, hence it was highly non-dispersive. To check the feasibility of the pinhole test, a Double hydrometer test was also conducted for 1.5% lignosulphonate added clay mix and the percentage dispersivity was 30%. This again confirmed the sample is non-dispersive. From the results, it can be concluded that the lignosulphonate has a significant effect on control of dispersivity, and from the current study it was able to achieve about 52.75% reduction in dispersivity.

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