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Control of Dispersivity of Soil using Lime and Silica Fume

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***Abstract:* Soils which collapse or disperse to form dissolved slurry when in contact with water are termed dispersive clay. Extend of dispersivity depend on the exchangeable sodium present in the structure. Dispersion of clay occur when it is wetted and the clay particles are forced apart. Thus even under a small seepage velocity it is seen dispersive soils erode and can affect the stability of earth and earth retaining structures. In these soils the attractive forces are less than the repulsive force under saturated conditions and this will help the particles to segregate and to move in suspension. Many structures are built on clay because of its low permeability. In the past dispersive clay soils were not recognized and failure occurs before dispersive action was identified.**

This paper mainly deals with dispersion study in sodium bentonite by performing crumb test and double hydrometer test, which proved that the soil is indeed highly dispersive. Hydrated lime ($Ca(OH)_2$) and silica fume were chosen as stabilizing agents for making the soil non-dispersive. From the modified free swell and double hydrometer tests, it was found that the optimum amount of lime required was 5%, whereas the optimum amount of lime and silica fume was 2% and 12%. Using the optimum amount of lime and lime and silica fume, percentage dispersion was reduced to 18.75% and 13.45% respectively thereby making the soil non-dispersive.

Keywords: crumb, dispersivity, silica fume, lime, double hydrometer

I. INTRODUCTION

Many earth dams, hydraulic structures and other structures such as road embankments are constructed using clayey soil because of the very low permeability characteristics of the clayey soil. Later on it was observed that they suffered serious erosion problems and has failed due to the presence of the dispersive soils. Though the problems have been identified in the various parts of the world, design advances and technical preventive measures are yet to be fully developed and practiced. The magnitude of problem dispersive soil bring about is very high and therefore this has become the major concern of geotechnical engineers these days.

In the earlier days it was said clayey soils are non erodible. But recently it was found some clayey soils have the tendency to erode. The dispersive nature of the clayey soil is mainly due to mineral structure, soil chemistry and also on the dissolved salts in the pore water and the eroding water. Dispersive soils contribute to the failure of many conservative practices. These problems include complete breaching of the embankment to severe erosion of earth fills and excavation. These may be placed into two broad categories. First one is erosion of external slope in which Rainfall and runoff may cause erosion of the exposed slopes made of dispersive clays. As a result this can cause severe rilling and gullying of the slopes. Second one is the internal erosion in which in which earth fills constructed of dispersive clay may fail because of the internal erosion through cracks or other openings in the fill. Water which flows through the cracks causes the enlargement of the crack creating an irregularly shaped tunnel through the fill.

When the dispersive clay come in contact with water there is a tendency for the soil to get eroded because the Van der Waals attraction is less than inter-particle force of repulsion. This repulsive force is mainly depending on the thickness of the double layer which is increased by decreasing the concentration of the adsorbed ions or by increasing the dielectric constant. In this paper an attempt has been made to alter the dispersive characteristics of the soil by suitable additives such as lime, silica fume and a combination of both.

II. MATERIALS AND METHODOLOGY

A. Soil

Bentonite which contains Montmorillonite as the predominant clay minerals have been used in the study since it is used widely in the geotechnical field these days. The soil used for the study was collected from Associated Chemicals, Cochin. Table I shows the

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engineering properties of the soil used.

TABLE I
PROPERTIES OF BENTONITE

Soil Properties	Values Obtained
Liquid limit (%)	336
Plastic limit (%)	40.1
Shrinkage limit (%)	15.6
UCC strength (kPa)	112.7
Free Swell (ml/2g)	24
OMC (%)	40
MDD (g/cc)	1.256
Specific Gravity	2.51
% Clay	77
% Silt	15
% Sand	8

B. Additives

Additives used were lime and silica fume. Laboratory reagent grade calcium hydroxide (hydrated lime) was used in the experiment. Silica fume used in the study was actually a by-product of production of silicon metal or ferrosilicon alloys. It is widely used these in geotechnical engineering field because of its high pozzolanic property. Silica fume is actually a very reactive pozzolan.

C. Crumb Test (ASTM D 6572-12)

Place the sample fully immersed in a non-porous container in a horizontal work space which is completely free of vibrations for about 6 hours. At 1 hour and 6 hour determine and record the soil dispersion grade in accordance with the following criteria:

1) *Grade 1 (Non-Dispersive):* No reaction, the soil may crumble, slake, diffuse and spread out but there is no turbid water created by colloids suspended in water. All particles settle during the first hour.
2) *Grade 2 (Intermediate):* slight reaction, this is the transition grade. A faint bearly visible colloidal suspension causes turbid water near the portions of the soil crumb surface. If the cloud is easily visible assign grade 3. If the cloud is faintly seen over small area assign grade 1.
3) *Grade 3 (Dispersive):* Moderate reaction, an easily visible cloud of suspended clay colloids is seen around the outside of the soil crumb surface. The cloud may extend up to 10 mm away from the soil crumb mass along the bottom of the dish.
4) *Grade 4 (Highly Dispersive):* Strong reaction, a dense profuse cloud of suspended clay colloids is seen around the entire bottom of the dish.

D. Double Hydrometer Test (ASTM D 4221-99)

This test is used to identify the dispersiveness of the soil. Particle size distribution of the soil is first determined using standard hydrometer test where the soil is dispersed in distilled water with strong mechanical agitation and chemical dispersant. A parallel hydrometer test is then magde on a duplicate soil specimen but without mechanical agitation and without a dispersing agent.

The percent dispersion is the ratio of the dry mass of the particles smaller than 0.005 mm diameter of the second of the second test to the first expressed as percentage. Following guidelines have been followed for interpreting the results:

% dispersion > 60 – soil is dispersive
% dispersion< 30 – non- dispersive
between 30% and 60% - intermediate

E. Modified Free Swell Test

Modified free swell index was developed in 1987 by Sivapullaiah et al. it follows same procedure as that of free swell index but employs a different formula to classify the swelling potential of the soil. In the original free swell index test, problems arose due to difficulties in soil measurements as well as occasionally producing a negative index value. Modified equation eliminates these errors and correlates more closely to a soil's engineering properties (Sivapullaiah et al., 1987).

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To perform the test 10 grams of an oven dried sample is measured and transferred into a 100 mL graduated cylinder of water. The sample is thoroughly agitated and stoppered for 24 hours. This allows the clay particles to disperse and then settle in the cylinder. After 24 hours, the swollen volume is measured according to the graduations on the side of the cylinder. Free swell index is calculated using the equation

Modified Free Swell Index = $(V - V_s) / V_s$

where V is the volume after swelling

V_s is the volume of soil solids calculated from the formula

$$V_s = W_s / G_s \times \gamma_w$$

Where, W_s is the weight of dry soil

G_s is the specific gravity of the soil solids.

TABLEI III

SWELLING POTENTIAL BASED ON MODIFIED FREE SWELL INDEX (SIVAPULLAIAH, 1987)

MODIFIED FREE SWELL INDEX	**SWELLING POTENTIAL**
< 2.5	Negligible
2.5 to 10	Moderate
10 to 20	High
>20	Very High

III. RESULTS AND DISCUSSIONS

Results of crumb, free swell and double hydrometer test are discussed separately in this section.

A. Crumb Test

Fig 1 shows the soil crumb obtained after an observation period of 1 hour. Since it did not show any change, the crumb was kept undisturbed for 24 hours and a second observation was made to confirm the soil nature.

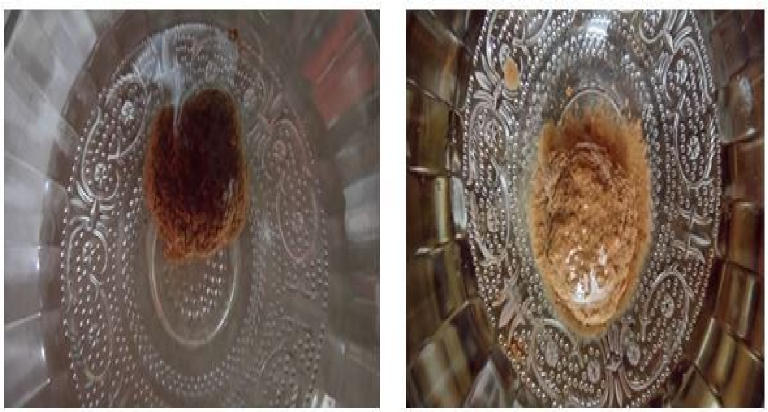

Fig. 1 Soil crumb observed after 1 hour (left) and soil crumb observed after 6 hours (right)

The soil crumb obtained after an observation of 6 hour resembled the grade 3 which indicated that the soil is highly dispersive in nature. With the addition of additives the soil crumb took longer time for getting into colloid form. Thus from the test it was clear that addition of lime, silica fume improves the properties of the dispersive soil.

B. Modified Free Swell Test

The soil samples of 10 grams were mixed with 1,3,5,7 and 9 percentage of lime by weight of soil. The mixture was diluted with water and made up to 100 mL. The sample was thoroughly agitated and stoppered for 24 hours. The optimum amount of lime was found to be 5%. At higher concentration, more lime was available for flocculation of particles, ion exchange reactions and thus increasing the force of attraction. But for 9% there was not much decrease due to saturation level of lime as higher percentages only help in the formation of cementitious compounds which are time dependent. Table III shows the variation in modified free swell

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index with percentage addition of lime.

TABLEI IIII
VARIATION IN MODIFIED FREE SWELL INDEX WITH ADDITION OF LIME

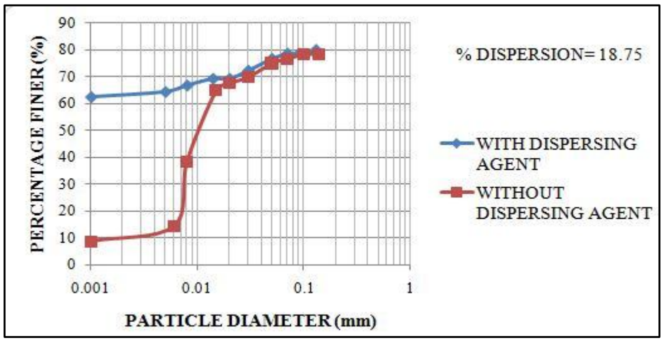

Fig. 2 Double hydrometer test result for soil alone

% ADDITION OF LIME	MODIFIED FREE SWELL INDEX	CLASSIFICATION
0	10.2	Highly Dispersive
1	9.8	Highly Dispersive
3	5.2	Moderately dispersive
5	2.4	Non-dispersive
7	2.2	Non-dispersive

Modified free swell index was also conducted to find out the optimum amount of lime and silica fume mixture. The addition of silica fume alone did not cause any predominant change in the dispersion and percentage dispersion remained as 96.89%. Therefore lime content was maintained at 2% and silica fume content was varied as 5%, 8%, 10%, 12% and 15% for conducting the modified free swell test.

TABLEI IVI
VARIATION IN MODIFIED FREE SWELL INDEX WITH ADDITION OF LIME AND SILICA FUME

% ADDITION OF LIME AND SILICA FUME	MODIFIED FREE SWELL INDEX	CLASSIFICIATION
2% lime + 0% silica fume	9.6	Highly Dispersive
2% lime + 5% silica fume	9.2	Highly Dispersive
2% lime + 8% silica fume	8.3	Moderately dispersive
2% lime + 10% silica fume	5.3	Moderately dispersive
2% lime + 12% silica fume	2.4	Non-Dispersive
2% lime + 15% silica fume	7.9	Moderately dispersive

Silica fume does not have any cementing properties but the addition of activator like lime imparted cementing characteristics to silica fume. Lime induces the flocculation process and silica fume acts as a binding agent. The least percentage dispersion was obtained for the optimum amount of lime and silica fume mixture of 2% and 12%. Thus the amount of lime can be reduced and silica fume can be increased due to pozzolanic property of silica fume.

C. Double Hydrometer Test Results

Double hydrometer test result for soil alone is shown in figure 2.

From the double hydrometer test, it was found that percentage dispersion for Sodium Bentonite is 96.89. Since the value of dispersion is greater than 60%, the soil can be termed as highly dispersive.

Double hydrometer test result for soil mixed with 5% lime is shown in fig 3.

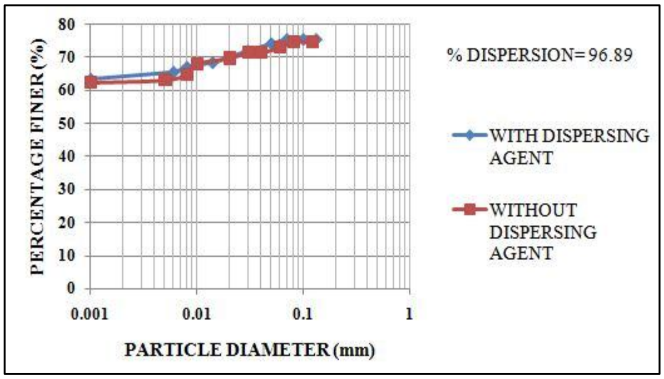

Fig. 3 Double hydrometer test result for soil+ 5% lime

With the addition of 5% lime the percentage dispersion reduced to 18.75%. Double hydrometer test results for soil mixed with 2% lime and 12% silica fume is shown in fig 4.

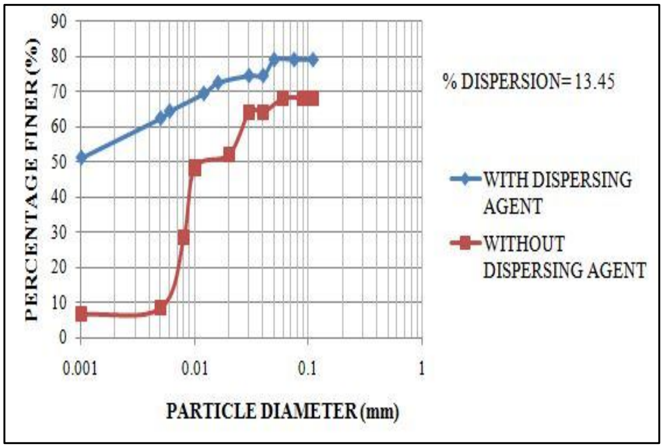

Fig. 4 Hydrometer test result for soil + 2% lime + 12% silica fume

Variation in dispersivity with addition of different percentage of silica fume and 2% lime is shown in fig 5.

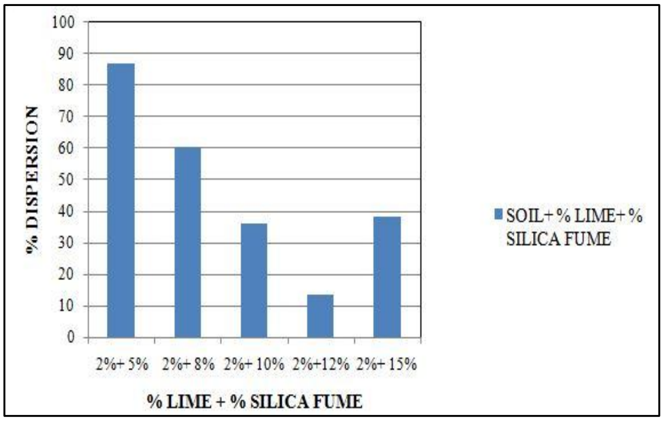

Fig. 5 Variation in dispersivity with addition of various percentage of lime and silica fume

The percentage of dispersion was calculated for different percentage of additive. Smaller percentage of lime was not sufficient to reduce dispersiveness. Addition of 5% lime reduced dispersiveness to 18.75% and the combination of 2% lime and 12% silica fume reduced dispersiveness to 13.45%.

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IV. CONCLUSION

The soil chosen for the study was highly dispersive in nature. The addition of suitable additive such as lime and lime+ silica fume caused significant decrease in the dispersive characteristics of the soil. From the modified free swell test, crumb test and double hydrometer test it was observed that 5% lime and 2% lime+ 12% silica fume decreased the dispersive characteristics of the soil soil.On treatment with lime, clays aggregate to form a more coherent mass due to pozzolanic reaction and cation exchange reactions. Further treatment with silica fume along with lime, the cementatious compounds are formed and the silica fume imparts a mechanical bonding which forms well developed floccules and shows a more porous nature. Thus this type of aggregation and improvement in porosity brings the desired improvement in the engineering properties of the soil.

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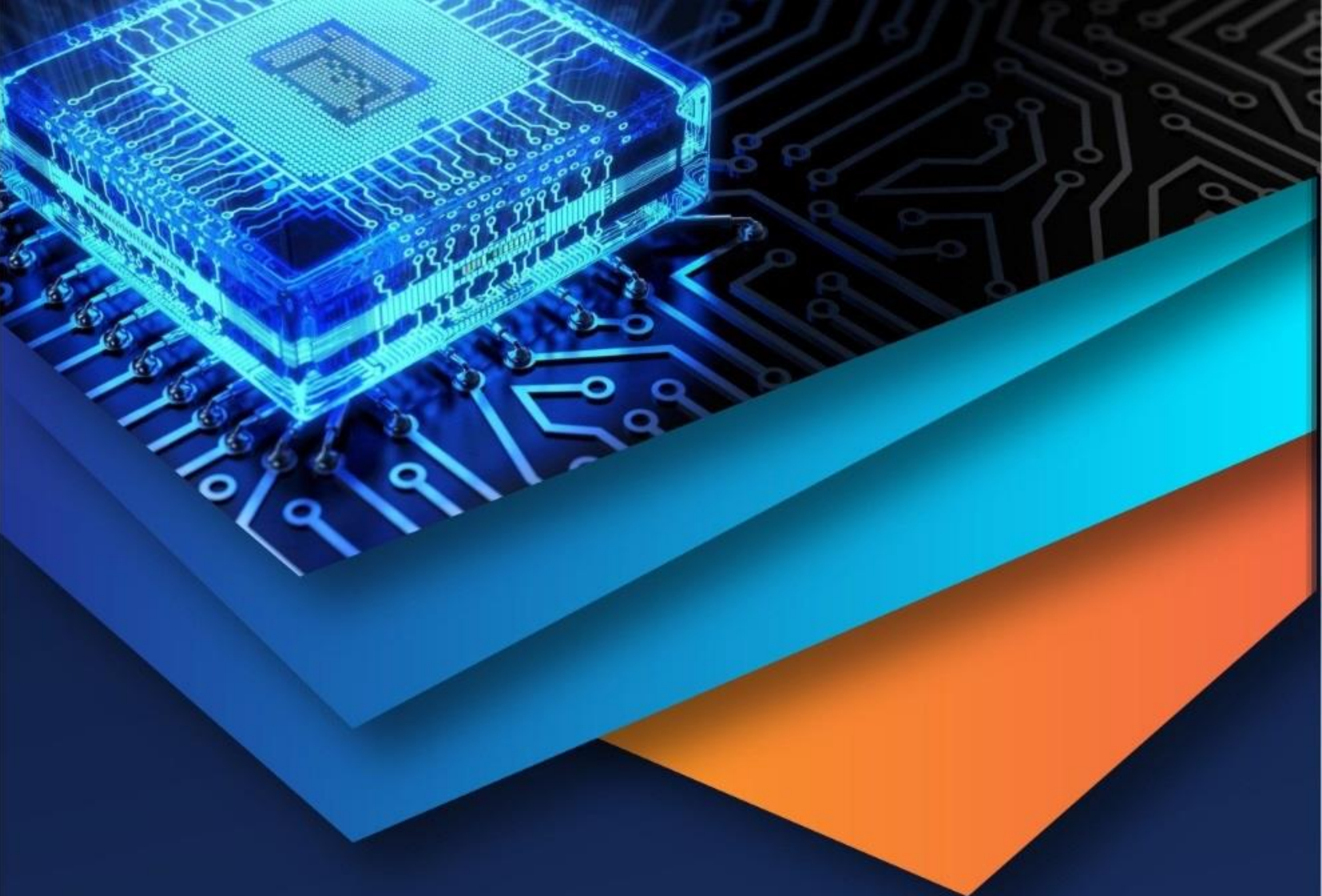

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