STABILIZATION AND MICROSTRUCTURAL MODIFICATION OF DISPERSIVE CLAYEY SOILS

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ABSTRACT: Soils that are dislodged easily and rapidly in flowing water of low salt concentration are called dispersive soils. Structures such as embankments, channels and other areas are susceptible to severe erosion, when such soils are used for construction. The erodability of clayey soil due to flow of rain water is a critical factor in long term performance of earth structures. Hence, for these applications it becomes essential to test the erodability especially during conditions of high surface flow. This kind of erosion manifests itself as the internal erosion which creates a progressive removal of soil particles along the internal pore channels termed as “piping”. The dispersive nature of the soil minerals and its erodability can be assessed by a “pinhole test”. This comprises of measuring the rate of flow through a 1mm diameter hole in the test soil of standard dimension under specified condition. The erodability is decided based on increase in rate of flow and turbidity of the outflow. The dispersive soil can also have a high swell shrink potential and low resistance to erosion and have low permeability in an intact state; hence in this paper an attempt is made to alter this basic characteristic by stabilizing with suitable additives. The effect of these stabilization agents are studied through the, pinhole tests, double hydrometer, crumb test and chemical tests. The strength development takes place through the alteration in the microstructure and mineralogy. Hence the intricate mechanisms through which the stabilizing effects manifest itself in the microstructure level are studied by Scanning Electron Microscope.

Keywords: dispersive clay; erodability; piping; pinhole test; stabilization; mineralogy

1. INTRODUCTION
Many earth dams, hydraulic structures and other structures like road way embankments have suffered serious erosion problems and have failed due to the presence of the dispersive soils. Though the problem has been identified in many parts of the world in recent times, design advances and technical preventive measures are yet to be fully developed and practiced. As the scope and magnitude of the problem which can result from the use of dispersive soil is very high, preventing the failures caused by the dispersibility of the soils has become one of the major concerns of the geotechnical engineers.

In the earlier days clays were considered to be non erosive and highly resistant to water erosion, however recently it was found that highly erosive clay soils do exist in nature. The tendency of the clays to disperse or deflocculate depends upon the mineralogy and soil chemistry and also on the dissolved salts in the pore water and the eroding water [1].

Based on the observed dispersive soil in the world, clays of alluvial origin, some soil derived from Mud rocks laid down in a marine environment can be dispersive. Soil derived from weathering of igneous and metamorphic rocks and soil with high organic content usually are non dispersive. Dispersive soils are usually found in flood plains and lake bed deposits. They are abundant in various parts of Thailand, United States, Australia, Mexico, Brazil, South Africa and Vietnam [2].

2. DISPERSION PHENOMENON
When the dispersive clay comes in contact with water, the clay fraction behaves more like a
single-grained particle with a minimum electrochemical attraction and thereby does not adhere or bond with the other soil particles. The interparticle force of repulsion (Electrical surface forces) exceed those of attraction (Van der Waals attraction) and as such when the water flows, typically as in a crack in an earth dam, the detached clay particles are carried away and piping occurs. These 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. However the attractive forces are independent of these factors [3]. The dispersiveness of the soil is mainly a function of the concentration of sodium ions within the soil structure however chemical and mineralogical analysis conducted at the Asian Institute of Technology have revealed that in the absence of Montmorillonite, dispersion does not occur even at high sodium content in pore water, thus dispersiveness seems to be a result of sodium adhering to Montmorillonite rather than the Na\(^+\) present in the pore water [4].

when a crack or opening occurs the clay particles get into suspension and easily carried away by water forming a large opening there by enlarging it[5]. Fig1 shows the typical erosion failure due to dispersive soil at the NTPC plant in Uchhar (UP), India. The problem of dispersive soils is often encountered in both Geotechnical and Geoenvironmental projects. Generally soil replacement is considered as a remedy but most of the cases it becomes expensive or laborious. Therefore alternative solution such as chemical treatment is usually adopted in most projects. The common additives used are lime, gypsum, alum and fly ash, thus the stabilization of the dispersive soil is more of a physio-chemical process [6].

In this paper, an attempt has been made to alter the dispersive characteristics of the soil by suitable additives such as lime, flyash and a combination of both. The change in microstructure and the chemical alterations are also studied. The study of these parameters is relevant to its applicability in earth dams and landfill clay liners.

2.1. Evaluation of Dispersiveness of the Soil

The identification of the dispersive soils should start with the field reconnaissance investigations to determine if there are any surface indications such as unusual erosion patterns with tunnels and deep gullies, concurrent with excessive turbidity in any storage water. Dispersive clays cannot be identified by the standard laboratory index tests such as visual classification, grain size analysis, specific gravity or Atterberg’s limits and therefore, other laboratory tests have been derived for this purpose.

The five laboratory tests generally performed to identify dispersive clays are the crumb test, the double hydrometer test, the pinhole test, the test of dissolved salts in the pore water and the SAR (sodium absorption ratio) based tests. These tests are commonly used in the United States, Australia, and South Africa. [7]

3. MATERIALS AND METHODS

Most failures associated with dispersive soils have occurred in clays that contain Montmorillonite.
Bentonite which contains Montmorillonite as the predominant clay mineral is used in the present study as it is utilized in many geotechnical and geo environmental projects. Table 1 and 2 presents the engineering and chemical properties of the bentonite soil used.

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid limit (%)</td>
<td>358</td>
</tr>
<tr>
<td>Plasticity index (%)</td>
<td>323</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>2.79</td>
</tr>
<tr>
<td>Optimum Moisture content (%)</td>
<td>22</td>
</tr>
<tr>
<td>Maximum dry density (kN/m³)</td>
<td>15.5</td>
</tr>
</tbody>
</table>

Table-2 Chemical analyses of Soil

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>EXCHANGEABLE CATIONS (meq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca++</td>
<td>11.97</td>
</tr>
<tr>
<td>Na+</td>
<td>50.01</td>
</tr>
<tr>
<td>Mg++</td>
<td>20.03</td>
</tr>
<tr>
<td>K+</td>
<td>0.17</td>
</tr>
</tbody>
</table>

The additives used are lime and flyash. Laboratory reagent grade calcium hydroxide (hydrated lime) was used in the experiments. The flyash used was of class F type with no self-cementing calcium carbonate compounds, fly ash is the byproduct of the coal industry and obtained from the combustion of the bituminous coal.

4. EXPERIMENTAL STUDY

The bentonite soil which is used for the present study basically contains Sodium Montmorillonite which makes the soil highly dispersive in a hostile environment. The soil is treated with different percentages of additives. The additives used are lime, fly ash and their mixture. The various percentages of the additives are added to the soil and the free swell test is carried out, the probable decrease in the dispersion of the soil upon addition of the various additives is calculated. The dispersion varies with the amount of lime, flyash and their mixture. The optimum percentage of the additive is found and used for the further analysis to study the process of control of dispersion. The dispersion of the soil and the decrease in the dispersion with the addition of additives is also verified through the double hydrometer tests, pinhole test and the crumb test.

The chemical analysis is carried out for the different percentage of the additives. Finally, the change in the structure of the soil because of the physio-chemical processes due to the addition of the additives is studied through the scanning electron microscope.

5. RESULTS AND DISCUSSION

The results of free swell, double hydrometer, pinhole, chemical analysis and SEM are discussed separately in the following section.

5.1. Free Swell Tests

The soil sample of 10gms was mixed with 1, 3, 5, 7, and 9% of lime by weight of soil. The mixture was diluted with water and made up to 100 ml and kept in a measuring jar. The mixture was left over for 24 hrs and the % dispersion was calculated. The dispersion was nearly 1000% for 0% of lime and there was no change for 1%, but significant decrease was observed for higher concentration of lime with the optimum content being 5% and the % dispersion being 400. This would have been due to availability of higher concentration of lime for flocculation of the particles, ion exchange reactions and thus increasing the force of attraction but for 9% there is not much decrease due to the saturation level of lime. As the higher percentage only helps in formation of cementatious compounds which are time dependent. Fig.2 presents the variation of dispersiveness with lime addition.

![Fig.2 Treatment of Soil with Different Percentages of Lime.](image-url)
The addition of only flyash to control the dispersion did not cause any predominant changes and the % of dispersion remained at 1000. The flyash was the type of class F which has no self cementing properties due to the absence of calcium compounds so the process of flocculation and aggregation was not developed. But with the addition of activators like lime, cementing characteristics was imparted to flyash. 2% of lime was maintained constant and the amount of flyash was varied as 5, 7, 9, 11, and 15%. The lime induces the flocculation process and the flyash acts as a binding agent. The combined action of aggregation and mechanical binding reduces the dispersion. The percentage of dispersion reduces to nearly 420% for flyash content of 15% which was equivalent to the one with optimum lime content of 5% as can be seen from the Fig 3, So the use of lime can be reduced to a very less quantity as it is very expensive and the amount of flyash can be increased. As flyash is a byproduct from the coal industry and present in abundance, this can be a suitable and economical way for its disposal.

5.2. Double Hydrometer Tests

The double hydrometer test also known as soil conservation service laboratory dispersion test was performed to identify the dispersiveness of soil. The particle size distribution of the soil is first determined using the standard hydrometer test where the soil is dispersed in distilled water with strong mechanical agitation and chemical dispersant. A parallel hydrometer test is then made on a duplicate soil specimen but without mechanical agitation and without a chemical dispersant [8].

The percent dispersion is the ratio of the dry mass of particles smaller than 0.005mm diameter of the second test to the first expressed as a percentage. The value of greater than 50 is highly dispersive.
The percentage of dispersion was calculated for different percentage of additives, the soil sample is highly dispersive with a dispersive percentage of 71. Smaller percentage of lime was not sufficient to reduce dispersiveness, the addition of 5% lime decreased the ratio to 9.5 and the combination of 2% lime and 9% flyash, 2% lime +11% flyash, 2% lime +15% fly ash, the ratio was nearly 1 and 0 indicating non dispersiveness. The results are presented through the figures 4-6.

5.3. Pin Hole Tests

The pinhole test was carried out for these soil samples. In this experiment, water is allowed to flow through a small hole in the soil sample, where the water flow through the pinhole simulates water flow through a crack or leakage channel in the impervious core of the dam or other structure. For dispersive soils, the flow emerging from the soil samples is cloudy and the hole rapidly enlarges. For non dispersive soils, the flow is clear and the hole does not enlarge.

In this study method of pinhole testing adopted was as per ASTM4647-93 and the method A was adopted the test was carried out for selected samples which were compacted to optimum moisture content and cured for a period of 7 days. The test carried out on soil alone was slightly dispersive and there was a slight color in the solution and so it was classified as ND4 (intermediate) [9]. This may be due to the swelling nature of bentonite soil, which is actually dispersive but with time the swelling of the soil clogs the hole but in actual field conditions the hole or crack may be large enough to cause greater dispersion of the soil.

The test was repeated for soil samples with 5% Lime content and for samples with 2% Lime and 9, 11, 15 of flyash, samples for which double hydrometer was performed. The samples with fly ash did not disperse and the outflow was a clear solution and it was classified as the ND1.

5.4. Crumb Tests

The crumb test was carried out as it gives a good quick indication of the dispersiveness of the soil. This test is used in conjunction with the pinhole test, and the double hydrometer test [10].

Based on the tendency for clay particles to go into colloidal suspension that is observed after 5-10 minutes of immersion, soils are classified as nondispersive or dispersive based on the reaction observed. The specimen of 1.5cm cube is placed in about 250ml of distilled water. The soil sample showed strong reaction getting into colloidal form in 5 to 10 minutes, where as the other samples with additives took a longer time for dispersion.

Thus from these tests it was clearly shown that the addition of lime, flyash improves the properties of the dispersive soil. The degree of dispersion decreases for increasing percentage of additives.

5.5. Chemical Tests

The chemical test of the soil pore water is carried out to find the concentration of different ions. This is important as there is a relationship between electrolyte concentration of the soil pore water and the exchangeable ions present and also to check the equilibrium of the soil with the environment. The presence of high sodium concentration makes the soil more dispersive. The two parameters which are often used to check the chemical compatibility are Sodium Absorption Ratio (SAR) and Percent Sodium (PS) [11, 12].

The soil samples, diluted to 1:10 ratio were acid digested for one day and the extracts were used to conduct chemical analysis. The concentration of Ca++ and Mg++ was found by titration methods and Na+ and K+ were determined by atomic absorption spectroscopy method. The values of SAR and PS were compared with Sherard Curve [5, 13].

From the comparison, it was observed that the sample 1 is highly dispersive, for the other samples the sodium ion concentration was replaced by the calcium ions supplied by addition of lime. And hence the values of SAR and PS were very less and classified as non dispersive. The results of the chemical analysis are given in the Table 3.
Table-3 Exchangeable cations in soil samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ca^++</th>
<th>Mg^++</th>
<th>Na^+</th>
<th>K^-</th>
<th>SAR</th>
<th>PS</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.97</td>
<td>20.03</td>
<td>50.01</td>
<td>0.17</td>
<td>12.5</td>
<td>60.85</td>
<td>Dispersive</td>
</tr>
<tr>
<td>2</td>
<td>59.88</td>
<td>22.33</td>
<td>16.57</td>
<td>0.45</td>
<td>2.58</td>
<td>16.70</td>
<td>Non-Dispersive</td>
</tr>
<tr>
<td>3</td>
<td>68.86</td>
<td>19.25</td>
<td>16.41</td>
<td>0.32</td>
<td>2.47</td>
<td>15.65</td>
<td>Non-Dispersive</td>
</tr>
<tr>
<td>4</td>
<td>44.71</td>
<td>20.80</td>
<td>16.82</td>
<td>0.38</td>
<td>2.94</td>
<td>20.34</td>
<td>Non-Dispersive</td>
</tr>
<tr>
<td>5</td>
<td>66.67</td>
<td>25.80</td>
<td>16.80</td>
<td>0.45</td>
<td>2.47</td>
<td>15.31</td>
<td>Non-Dispersive</td>
</tr>
<tr>
<td>6</td>
<td>40.32</td>
<td>30.04</td>
<td>16.33</td>
<td>0.64</td>
<td>2.75</td>
<td>18.70</td>
<td>Non-Dispersive</td>
</tr>
</tbody>
</table>

1- Soil alone   2-Soil+2%Lime   3-Soil+5%Lime   4-Soil+2%Lime+9%Flyash   5- Soil+2%Lime+11%Flyash   6- Soil+2%Lime+15%Flyash

6. MICROSTRUCTURE AND MINERALOGICAL CHANGES

The mechanism in which the dispersive property is controlled by the addition of the lime and flyash is by the process of chemical reactions. The beneficial changes are attributed to the ion exchange and cementation reactions.

6.1. SEM Analysis

The scanning electron microscope is one of the ideal tools available for the measurement of fabric of clays because of its higher resolution capacity together with large depth of focus and also it is possible to get the three dimensional view of the arrangement of the particles. The lime treatment manifests itself as change in the microstructure of the clay particle arrangement. The scanning electron microscope is operated at 20kV and is of the type FEI Quanta 200. First the entire area of the fractured surface is scanned under low magnification and then, the chosen representative areas are magnified to get the clear picture of the micro fabric arrangement.

Seven days cured compacted samples were taken for this study so that there is sufficient time for the development of the cementatious bonds. The samples were split apart in the direction opposite to that of the compaction, and a cube of 10mmx10mmx10mm is obtained in the undisturbed state as the fractured surface provides the details of the crystals present.

In this study the samples of soil alone, Soil+5%Lime, Soil+2%Lime+9%Flyash, Soil+2%Lime+11%Flyash were studied under the microscope to get the detailed microstructure. The soil sample shows a dispersed type of fabric arrangement, with layered structure with more open arrangement. Figures 7-9 show the micrograph of the soil samples.

On treatment with lime it shows clay aggregates formed as a more coherent mass due to the pozzolanic reactions and ion exchange reactions. On further treatment with flyash along with lime, the cementatious compounds are formed and the flyash 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.
7. CONCLUSIONS

The soil chosen for the study was highly dispersive. The addition of lime and lime+flyash mixture caused significant decrease in the dispersive characteristics of the soil. This is substantiated by the following observations.

1. The amount of dispersion by free swell test for the soil decreased from 1000% to 400% on addition of 5% lime and 2% Lime+15% Flyash. But there was no significant change when flyash alone was added. Hence the optimum percentage of lime and lime, flyash mixture was found to be 5 and 2, 15.

2. The percentage of dispersion by the double hydrometer test for soil alone was 71% which decreased to 9.5 when optimum lime was added and to nearly 1% when optimum flyash and lime mixture was used.

3. The soil was classified as ND4 by the pinhole test, the addition of optimum percentage of additives changed it to ND1. The crumb test and chemical tests were also in conjunction with the above result.

4. The mineralogical and micro structural changes studied by SEM analyses clearly show the alteration in the fabric and pore spaces due to the chemical reactions initiated by the additives.

REFERENCES


9. ASTM D4647-93 – Standard Test Method for the identification and classification of Dispersive Clay Soils by the Pinhole Test


