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Evaluation of dispersive nature of soil in the piping affected regions of Kerala

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Abstract — The soil piping erosion has been closely related to the soil composition and its dispersive nature. The phenomenon of dispersivity is explained by the property by virtue of which the soil breaks down into their component particles upon exposure to water. Dispersive soils are highly prone to erosion. If the soil at top is hard and soft dispersive clays present at bottom, in presence of seepage water, there are chances for piping erosion to occur. These kinds of process are very common in lateritic terrains. In appearance the normal erosion resistant clays are similar to dispersive clays, they are, in fact, prone to significant erosion and are susceptible to severe damage. Exchangeable sodium present in the soil is the primary cause of dispersivity. Special methods are required to distinguish between dispersive and non-dispersive soils, common soil classification tests are not sufficient. The recommended tests to identify the dispersive clay soils are Crumb test, Double hydrometer test, Pin hole erosion test, and some chemical tests.

This paper reports the problems associated with dispersive soils and discuss the results of double hydrometer tests carried out in various piping regions of Kerala along with the stabilization of dispersive soils with lime. Double hydrometer test as per British standards have been used in the present study. Comparative study of the dispersion ratios obtained for various samples shows that the Idukki samples are having more dispersion ratio than other regions. And as the piping was present in those areas the dispersion ratio was expected to be higher than 30%, the lower values obtained can be due to the erosion of dispersive clays in those regions. Effectiveness of stabilization with lime is checked and it was found that the ideal proportion of lime for minimizing dispersion potential is 1%.

Keywords— Soil Piping Erosion, Dispersive Clays, Double hydrometer test, crumb test& lime stabilization.

I. INTRODUCTION

The Various cases of failures of structures and sub grades by the land subsidence problems resulted from the soil piping erosion has been reported recently from various regions of Kerala by NCESS Trivandrum, India [1-3]. According to Boucher, Soil piping erosion is defined as the extraction of subsurface soil, leading to the creation of subterranean channels and voids [4]. There are various countries such as Australia, Victoria, Nigeria, and Tasmania where failures due to piping erosion is very common. The problems due to piping erosion in Kerala have been reported recently. It became a major concern in highland regions of Western Ghats, Kerala. Failures of structures were found mainly due to the land subsidence resulted from soil piping erosion, almost 9 highland districts of Kerala are under danger by this phenomenon as per the reports of NCESS Trivandrum. Kasaragod and Kannur are the two widely affected districts among them. Soil piping erosion is closely related to the composition of soil and its dispersive nature. If at a location the hard soil is present at top and weak dispersive soils present at bottom and water seeps to the bottom through any cracks or hole at surface there are chances for the piping erosion to occur, A typical case of piping failure from Kasaragod district is depicted in Figure 1. It is a silent trigger if the inlets or outlets are not identified on time, because of the unpredictability in collapse of roofs of soils.

Fig. 1 Piping erosion observed in Kasaragod, Nelliyadukkam

In appearance the normal erosion resistant clays and dispersive clays are same. Special methods are required for the identification of dispersive clays. Dispersive clays are distinguished by the presence of highly exchangeable sodium ions.

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1.1 Process of Piping Erosion

Soil piping erosion is a strange phenomenon. The process of piping erosion is first described by Downes [5]. Later a number of authors refined the process including Floyd [6], Crouch [7], Laffan and Cuttler [8], Boucher [9], and Vacher et al. [10]. The studies show that piping erosion occurs on a variety of soils ranging from duplex, loess and uniform clayey soils, but the necessary condition required is it to be dispersive in nature. Climate is found to be not having any role in piping process because it is observed on climates exhibiting significant fluctuations in temperature, precipitation, and seasonal rainfall patterns. The initiation of piping erosion according to various researchers are, initiated by loss or disturbance of vegetation which results in the developments of cracks and generation of subsurface runoff [5,7,8], formation of gully erosion which provides the water to flow outlet [4,9] poor consolidation and disturbance of dispersive clays [11-13], or increased infiltration due to ponding [10,14].

When two particles of dispersive clays having high concentration of adsorbed sodium ions sit close to one another, the double electron layers of these ions overlap or interact. The osmotic pressure developed by the above process draws water between the particles and causing them to hydrate and swell. If the water involved in this process is of low electrolyte nature, then the clay platelets will swell to a point that the clay platelets detach from each other. This process is termed as spontaneous dispersion by Australian Academy Science,1999. Rainfall and excess runoff further initiate the piping erosion by entraining more dispersed clay particles, resulting in propagation of cavities until a continuous pipe is formed [8,15]. And at the final stage piping may reach to an extend where complete roof collapses and gullies forms [8].

1.2 Dispersion Phenomena

Dispersivity is the property by virtues of which the soil breaks down into their component particles when comes in contact with water. In the presence of water, the clay fraction in the dispersive soils behaves like single grained particles with low electrochemical attraction. According to Bhuwaneswari and Soundra [16], presence of exchangeable sodium ions is the main reason to make soils dispersive. The fluid flow will induce shearing stress on the surface of soil, through which it passes, and when this shearing stress is large enough to cause particle removal then erosion will occur. The resistance to erosion in cohesionless soils is attributed to the submerged weight of sediments. In the case of cohesive soils, soil erosion involves the interplay between soil structure and the interaction of pores with eroding fluids at the surface. Several factors, such as clay type, pH, organic matter, temperature, thixotropy, water content, and the type and concentration of ions in pore fluids, impact the shearing stress that triggers piping erosion [17-22].

The erosion by dispersion is accelerated by a process known as slaking of clay. Slaking is more pronounced in soils with high flocculation and low plasticity [23]. Soil compaction (dry density, moisture content), pore water, mineral composition and concentration, as well as fabric cracks, are identified as internal factors influencing dispersion phenomena [24].

II. METHODOLOGY

2.1 Sample Collection Details

Samples were gathered from three principal piping regions in Kerala, encompassing Idukki, Kannur, and Wayanad.The land subsidence sites discovered in Kannur district are Kottathalachimala near Chattivayal and Thirumeni localities (2006), Niranganpara locality in Ayyankunnu Panchayat, Thalassery Taluk (2014).

In Wayanad district subsidence reported in a place located a few kilometers downstream of Banasurasagar dam, Vythiri taluk and which arises panic of dam safety. Idukki is a district where a greater number of landslides and land subsidence due to piping has been reported. The four main places of Idukki district where piping observed are Kulamavu, Peringassery, Udaygiri and Thattekkanni.

An incident of land subsidence is reported at 2011 from Peringassery where it was observed to be affected the Cheruthoni-Udumbanoor road. And a case reported in 2010 was subsidence at Neriyamankalam- Cheruthoni road side. This article utilized samples obtained from various locations, namely Thirumeni and Kottathalachimala in Kannur district, Vythiri taluk in Wayanad district, and Peringassery, Thattekanni, and Neendapara in Idukki district, for the current study.

2.2 Experimental Programme

Multiple investigations suggest that Atterberg's limits, visual classification and particle size analysis do not provide a basis for differentiating between dispersive clays and typical erosion-resistant clays [25]. Therefore, special test methods are required to identify the dispersive soils. In India and the United States of America, the identification of dispersive soils commonly relies on four main laboratory tests: the Crumb test, Sherard's pin hole erosion test, Double hydrometer test, and Chemical analysis of pore water.

In the current study, the assessment of soil sample dispersion potential is performed through double hydrometer analysis. Acknowledged as one of the most appropriate tests for classifying dispersive soils, this analysis is conducted at the soil's natural water content. It gauges soil dispersibility by measuring the clay fraction's tendency to suspend in the presence of water.

As the experimental procedure Standard hydrometer analysis is conducted in the soil specimen with strong mechanical agitation and chemical dispersant and find out the particle size distribution. Subsequently, a parallel hydrometer test is conducted on a duplicated soil sample, excluding chemical dispersant and mechanical agitation. The dispersion ratio is determined by the quantity of particles finer than 0.005 mm in the parallel test compared to the standard test [26]. Soils exhibiting a dispersion ratio exceeding 50% are classified as highly dispersive, those within the range of 30% to 50% are deemed moderately dispersive, those falling between 15% and 30% are categorized as slightly dispersive, and soils with a dispersion ratio less than 15% are classified as non-dispersive [27]. There are similar systems with different ranges utilized by Gerber and Hames [28] and Walker [26].

The test methods employed for double hydrometer analysis at present adhere to American standards (ASTM International, 2007), British standards (BSI, 1990), and South African Technical Methods for Highways-TNH1 (NITRR, 1986).

Fig. 2 Testing using double hydrometer analysis

Figure 2 shows a snap shot of the testing using double hydrometer analysis. In the present investigation British standards have been used. Dispersing agent used was 100 ml Sodium hexa metaphosphate solution comprising 33g Na-hexa. + 7g Na- carbonate in distilled water to make 1 litre of solution. Soil sample is soaked in solution overnight for the standard hydrometer test. Hydrometer reading was taken at 8 min, 30 min, 2 h, 8 h and 24 h.

$$D = \frac{finer < 5\mu m(Nodispersant)}{finer < 5\mu m(S\tan dard)} \quad \text{--------} \quad \text{Eq. (1)}$$

III. Results and Discussion

The dispersion ratios for samples from different locations are summarized in Table 1 and shown in graphical representation in Figure 3.

From the samples gathered in Idukki, samples 1, 2, 3, and 6 originated from the pipe wall, while samples 4 and 5 were taken from the soil profile outside the pipe wall. In Kannur, all samples were collected from the wall of pipe erosion, each from different depths. Sample 11 from Wayanad district was obtained from the pipe wall, whereas sample 12 was collected from the surface of the piping region.

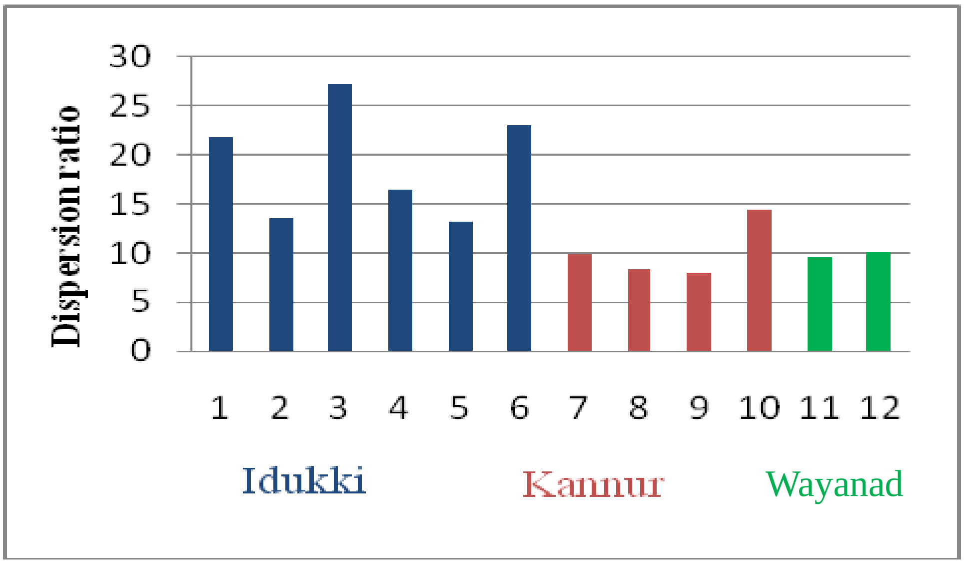

Fig. 3: Dispersion ratios of different samples

Table 1: Dispersion ratio for different samples

Sample No.	Location	Coordinates	Dispersion Ratio (%)
1	Idukki-Peringassery	9°52'2.9"N 76°51'28.4"E	21.8
2	Idukki-Thattekanni	9°59'55.6"N 76°53'15.2"E	13.6
3	Idukki-Thattekanni	9°59'55.6"N 76°53'15.2"E	27.21
4	Idukki-Neendapara	10°01'19.0"N 76°50'09.6"E	16.42
5	Idukki-Neendapara	10°01'19.0"N 76°50'09.6"E	13.11
6	Idukki-Naalam mile	9°39'34"N 76°59'29.2"E	23.04
7	Kannur-Thirumeni	12°15'36.0"N 75°26'45.7"E	9.96
8	Kannur-Kottathalachimala	12°16'16.3"N 75°25'48.8"E	8.33
9	Kannur-Kottathalachimala	12°16'16.3"N 75°25'48.8"E	7.97
10	Kannur-Kottathalachimala	12°16'16.3"N 75°25'48.8"E	14.43
11	Wayanad-Kappundikkal	11°40'26.0"N 75°58'04.0"E	9.55
12	Wayanad-Kappundikkal	11°40'25.5"N 75°58'03.8"E	10.12

Several approaches have been proposed to mitigate soil sensitivity to dispersion or prevent internal erosion, including the use of lime, fly ash, cement, gypsum, and various polymers. Lime stabilization, in particular, is a commonly employed method due to its effectiveness and economic feasibility.

The introduction of hydrated lime raises the overall concentration of calcium cations while reducing sodium content, effectively managing dispersivity. Pozzolanic reactions between lime and clay particles, leading to the formation of calcium silicate hydrates, have the potential to strengthen the soil and mitigate soil erosion.

Bell identified the optimal lime addition for soil stabilization to be between 1% and 3%, while other researchers recommended a range of 2% to 8% lime by weight. In a study on stabilization using lime, conducted on a sample from Idukki with high dispersion potential, various percentages (1%, 2%, 5%, and 8%) were tested.

The dispersion potential was assessed after adding each percentage through double hydrometer analysis. The various results (dispersion potential obtained for different lime percentage) of stabilization on Idukki sample are shown in Table 2.

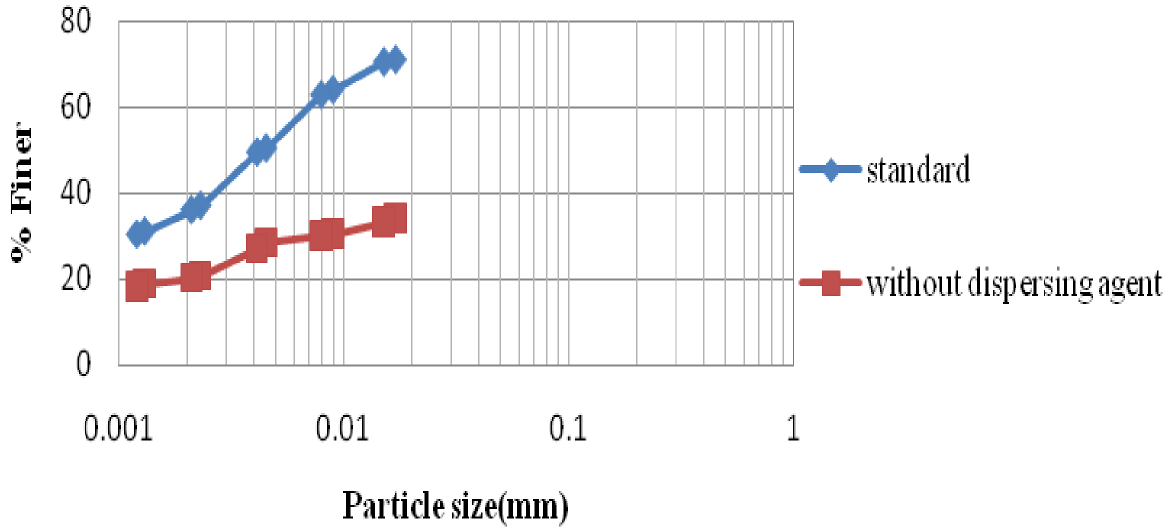

Fig. 4 Typical Double hydrometer test for sample with 2% lime

One typical Double hydrometer result obtained for 2% addition of lime is depicted in Figure 4. While comparing the outcomes of the double hydrometer test across various samples, it was observed that the Idukki samples exhibited a higher dispersion ratio within the range of 13.11% to 27.21%. Samples collected from the pipe wall demonstrated greater dispersive characteristics compared to those obtained from the soil profile outside the piping region. The anticipated range of dispersion ratio on the pipe wall exceeded 30%. The lower values recorded are presumed to be due to the loss of dispersive clay caused by pipe erosion in those areas, as the samples were collected from the eroded pipe region.

In the case of samples from Kannur district, the dispersion ratio ranged from 8.33% to 14.43%. Analysis of all samples from this district, collected from the pipe wall, suggests that the lower values may be attributed to the loss of dispersive clays. A comparison of results from samples

8, 9, and 10collected at different depths from the same region revealed that as the depth increased, dispersion also increased, while top dispersion remained low. This is attributed to the surface dispersive soil being eroded in the presence of water.

From Wayanad district, samples were obtained from both the pipe wall and the hard surface portion of the piping region, which had recently experienced a high rate of piping erosion. High dispersive soils from Idukki samples were subjected to testing for effectiveness in reducing dispersion potential by adding lime at concentrations of 1%, 2%, 5%, and 8%. Dispersion potential obtained for different lime percentages are shown in Figure 5.

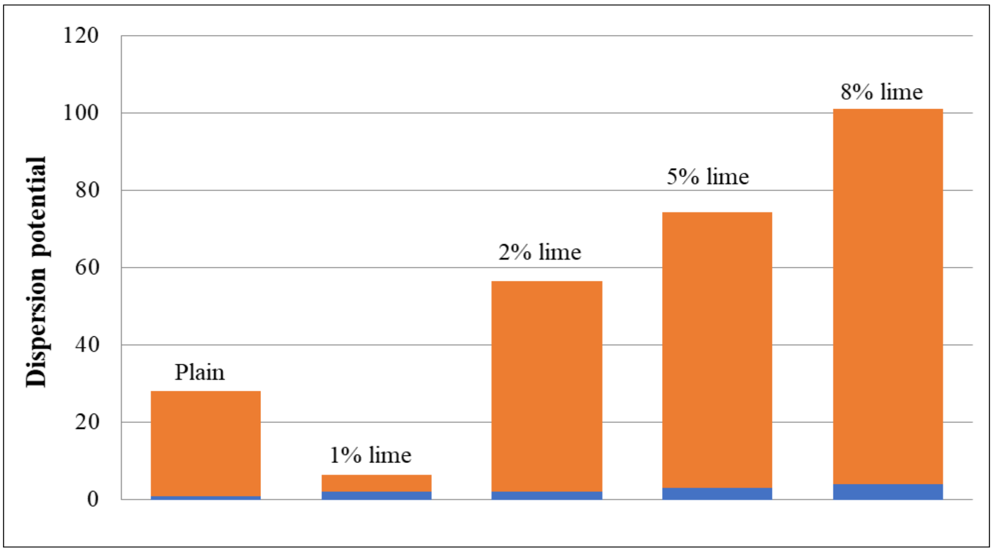

Fig. 5 Dispersion with various lime percentage

Table 2 shows that the optimum percentage of lime to be added is 1%. Above which results shows an increasing trend. It indicates that if we are adding lime in such areas to improve the soil properties there can be increase of dispersion potential also. Application of lime in dispersible soils is limited to only 1% from the study conducted here.

Table 2: Dispersion potential obtained for different lime percentage

Percentage of Lime	Dispersion potential
Plain	27.2%
1% lime	4.38 %
2 % lime	54.62%
5% lime	71.42%
8% lime	97%

IV. Conclusion

The ongoing investigation, assessing the dispersive characteristics of soil through the double hydrometer test, reveals that the soils in Idukki exhibit a higher degree of dispersive nature when compared to samples from other locations. The samples chosen for this study are found to be dispersive in nature. Stabilization by addition of lime has found to be negative effects on the dispersive characteristics after a certain lime percentage, it was found to be 1% in this study.

Particle size analysis indicates that the percentage of sand content is high for the sample having high dispersion potential. This is due to the reason that the binding property is very low in such case. Stabilization results tells that addition of 1% lime decreases dispersion potential from a value of 27.21% of plain sample to 4.38%. It was a noticeable decrease. But after that addition of lime increases the dispersion potential. It can even reach to a percentage of 97% at 8% lime addition, which was strongly recommended to be avoided.

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