Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

On Reversing the Effects of Drying on Cochin Marine Clay

Amal Azad Sahib [1][0000-0002-1408-3471] and Retnamony G. Robinson [2][0000-0001-6114-7637]

[1] Associate Professor, Department of Civil Engineering, TKM College of Engineering, Kollam-691005
E-mail: azad52@yahoo.com
[2] Professor and Head, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai-600036
robinson@iitm.ac.in

Abstract. The marine clays of Cochin and Kuttanad are highly popular for changes in plasticity characteristics and engineering behavior thereof, on drying. Since the 1960s, research on this behavior has been ongoing and well documented. The irreversible nature of these properties acquired on drying was another distinguishing fact about these clays. Kuttanad and Cochin marine clays are highly compressible and exhibit soft clay behavior. Drying of these clays resulted in a marked decrease in its liquid limit. This invariably changes the strength and compressibility characteristics of the clays as well. Literature suggests that these changes are irreversible and various attempts to reverse the properties did not find success. The reasons attributed were many, including presence of halloysite mineral, hydrated sesquioxides, organic matter, presence of divalent and trivalent ions and high pore water salinity.

This paper suggests a high energy dispersion technique that is capable of reversing the properties of Cochin marine clays. This method could be applied to capture the properties of the clays in the natural form even if the samples were subjected to drying.

Keywords: Cochin marine clay, Atterberg limits, drying, liquid limit

1 Introduction

The engineering performance of clayey soils is inherently rooted to their plasticity characteristics. These are essentially liquid limit and plasticity index. Generally, an idea of these properties is utilized to predict characteristics such as compressibility and settlement, while designing structures on these clays. The plasticity characteristics are usually determined by procuring field samples in the laboratory and subjecting them to the standard Atterberg limits (or consistency limits) test. However, this procedure, posed significant problems in marine clays.

Ayyar (1966) was one of the first researchers to investigate on Kuttanad clay and report that samples subjected to drying, exhibited an irreversible change in plasticity characteristics from field condition, even after subjecting to wetting cycles. Many standard sample preparation procedures insist that the soils be dried for the sake of uniformity and sieving through 425 micron sieve, before performing Atterberg limits tests. Consequently, the predictions of engineering behavior of the dried soils would drastically vary from field behavior.

A subsidy housing project on clay soil in Botshabelo, South Africa, revealed large number of failures due to the variation in the predicted heave from the observed values. The heave prediction methods were based on the commercial laboratory values of liquid limit and plasticity index of dried soil (Stott and Theron, 2015). Compared to natural condition of soil, the plasticity characterisitics in the dried form were reduced and hence the heave predicted for natural soils were underestimated.

Clays that exhibit an irreversible change in physical and mechanical properties on drying are found in many parts of the world. Central America, Japan, India, Indonesia, New Guinea, New Zealand, Kenya and Java are a few regions where this behaviour is reported (Pandian, Nagaraj, and Sivakumar Babu 1993). In India, Kuttanad clay and Cochin Marine Clay belong to this category (Ayyar 1966; Rao, Sridharan, and Chandrakaran 1989; Suganya and Sivapullaiah 2015). The compressibility and shear strength behaviour of these soils also undergo significant change on drying (Pandian, Nagaraj, and Sivakumar Babu 1991). The postulated causes of irreversible change in properties on drying are many. Alteration of clay mineralogy on dehydration, particle aggregation, presence of gibbsite and allophane, presence of cementing agents such as iron oxides, carbonates and organic matter, prevalence of high pore water salinity, presence of divalent and trivalent cations in the pore fluid are some of the reasons attributed to this behaviour (Townsend 1985; Rao, Sridharan, and Chandrakaran 1989).

This paper focuses on the method of rewetting and utilization of dried Cochin marine clay samples, to closely represent the field condition. A high-energy mechanized dispersion technique is employed to disintegrate the aggregated structure and reverse the plasticity of Cochin marine clay (which is known for change in properties on drying)

2 Some past discussions

Rao, Sridharan, and Chandrakaran (1989) investigated the factors responsible for change in the liquid limit behaviour of Cochin Marine Clay. The dried specimens were soaked for a period of 15 days before testing for Atterberg limits. They concluded that the presence of divalent/trivalent ions and a high pore salt concentration facilitates strong inter-particle attraction and small particle separation, whereas monovalent Na ions promote strong interparticle repulsion. Cochin marine clay consists of divalent and trivalent ions that permit an intimate contact of particles during drying, thereby reducing the available surface area for interaction with water and hence reduction in liquid limit. In the discussion of this work, Ayyar et al. (1990) emphasized the similarity between CMC and Kuttanad clay; reiterating the role of salts and organic matter in the formation of cementitious compounds that prevent the reversal of the plasticity characteristics after air drying. It was also suggested that the finding by Rao et al. (1989) requires further validation to confirm that aggregation is due to the bonding hydration energy of higher valency ions on air drying. This could be achieved by converting the Cochin marine clay into Na+ form without air drying, and then comparing the liquid limits in the undried and air-dried states.

Pandian, Nagaraj, and Sivakumar Babu (1991) also indicated the change in the index and engineering properties of Cochin Marine Clay (from Cochin, Kerala State, India) on air drying and that the test results of standard procedures which recommend air drying could be misleading. They had soaked the dried specimens in distilled water for different time periods up to 12 months and reported that the plasticity values were still not reversed back to the natural state. They also compared with other soils showing similar trend on air drying and concluded that liquid limit state can be used as a good reference for identifying the change in engineering behaviour with drying (Pandian, Nagaraj, and Sivakumar Babu 1993)

3 Present study

This study closely looks into the further scope of the work previously done on Cochin marine clays. This includes investigating the soaking and wetting procedures on dried Cochin marine clays, the use of existing mixing tools to disintegrate the aggregated structure, the role of suction during the drying stages and finally the use of a high energy dispersion mixer to reverse the properties of dried clays.

The CMC samples used in this study were procured from Vallarpadam, Cochin. The samples taken from a depth of 8 to 10 m with a natural moisture content of 116%, brought from the field, were stored air tight, in sealed bags and laid in water-filled desiccators to avoid loss of moisture. The results of the basic tests conducted on the samples are shown in Table 1. The liquid limit and plastic limit values were determined using Casagrande’s method as per Indian Standard Specifications (IS: 2720-Part 5 1985). Tests were conducted in three conditions such as in natural state, air-dried state and oven-dried state. In order to determine the liquid limit in the natural state, water was added to the soil in its natural state and mixed thoroughly using a spatula. The specimen was spread in a glass plate and allowed for moisture loss. At intermittent times, the soil was thoroughly mixed again and liquid limit test was carried out. For air drying, the sample was spread uniformly on a glass plate and exposed to room temperature of 35–40°C for several days. Oven drying of the samples was carried out at 110°C in a temperature-controlled hot-air oven. After drying, the specimens were soaked in distilled water to sufficiently rewet and further thoroughly hand mixed to determine the liquid limit and grain size distribution.

Table 1 Properties of Cochin marine clay

Soil property	**Value**
Age	Normally consolidated young clay
Depth of sample location	8 to 10 m
Natural moisture content	116%
pH	8.5
Electrical conductivity	1.11 mS/cm
Organic matter	6%
Clay minerals (XRD)	Illite, Montmorillonite and Kaolinite

Plasticity characteristics	Liquid limit	Plastic limit	Shrinkage limit	% silt size	% clay size
Natural state	103	34	19	37	63
After air drying	77	33	19	43	57
After oven drying	66	35	20	43	57

As can be seen from the table, the liquid limit values, after air drying and oven drying for CMC are 77% and 66%, which are 25% and 36% lower than those of soils in natural condition. The reduction in plastic limits is marginal. The shrinkage limits are practically the same for all the conditions.

It was necessary to find out at which stage of drying, the irreversible change sets in. Different specimens of CMC were dried at room temperature to various water contents from slurry state (Sahib and Robinson, 2020). As the specimens attained different water contents after drying, they were subsequently tested for liquid limits.

The liquid limit, plastic limit and shrinkage limit of the soil in their field condition without drying) are also indicated on the plot. The liquid limit values after drying to various initial moisture contents get reduced. This can be observed in Fig. 1. The reduction in liquid limit is predominant in the region where the specimens were dried at water contents below plastic limit. In other words, when the natural clay gets dried to water content below plastic limit, the liquid limit gets reduced. Beyond shrinkage limit, the change is most predominant. One of the reasons why this happens may be aggregation due to shrinkage stresses.

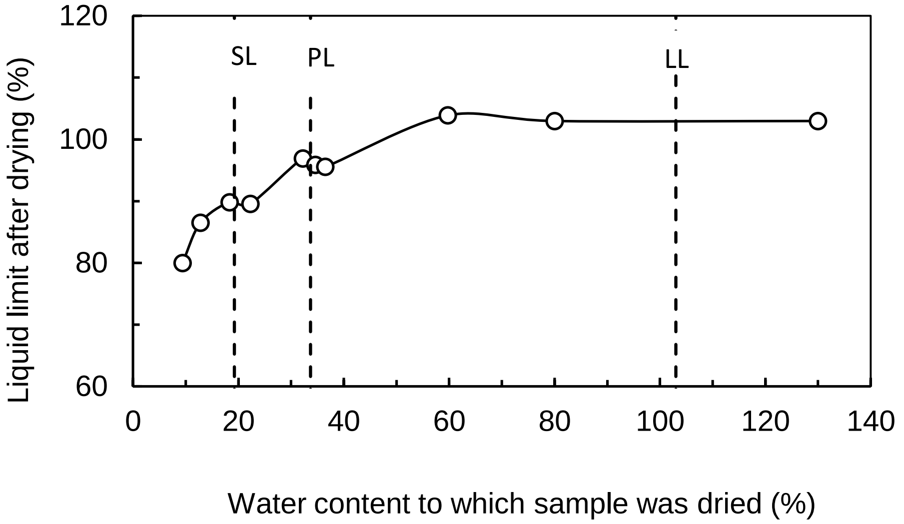


Fig. 1 Liquid limit variation for Cochin marine clay with change in initial moisture content of the sample

To verify the role of shrinkage stresses upon drying, suction values were measured in Cochin marine clay specimens using Dew point Potentiameter (WP4) that employs the chilled mirror hygrometer (Sahib and Robinson, 2020). The suction measurements of Cochin marine clay are plotted in Figure 2. The total suction is the sum of osmotic and matric suction. At initial water contents, the total suction is about 0.2 MPa or 200 kPa. Considering the matric suction in the initial stages to be zero, as the soil is saturated, this value refers to the osmotic pressure. This high initial value is indicative of the high salinity of the soils. Osmotic suction is negligible in the absence of salts (Thakur and Singh, 2005). It can also be observed that below the water contents corresponding to plastic limit, the suction values increase rapidly which has led to the strong aggregation of colloidal fraction. Assisted by the attractions generated by the osmotic ions, this aggregation may be strong enough not to be disintegrated on further rewetting. Osmotic suction is also known to increase with reduction in water content (Krahn and Fredlund 1972). This could be a reason for the consistent reduction in the liquid limit values of the soils, dried below plastic limits as observed from the previous section.

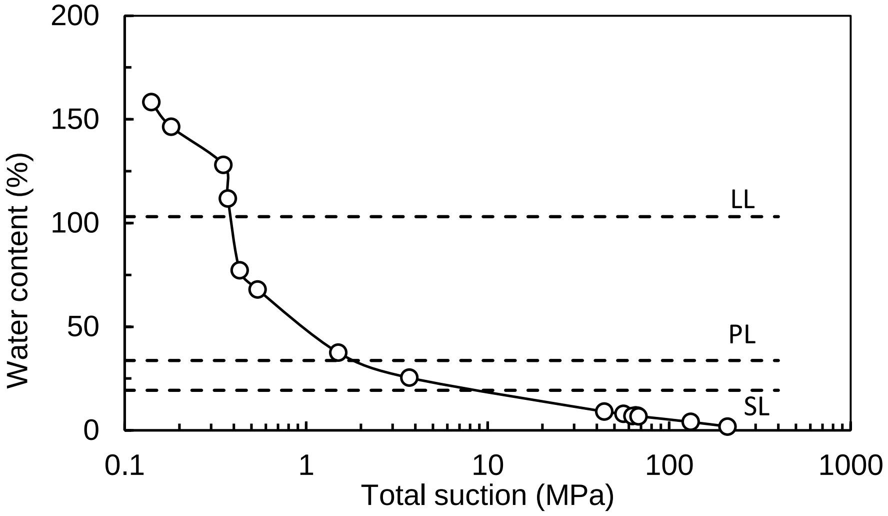
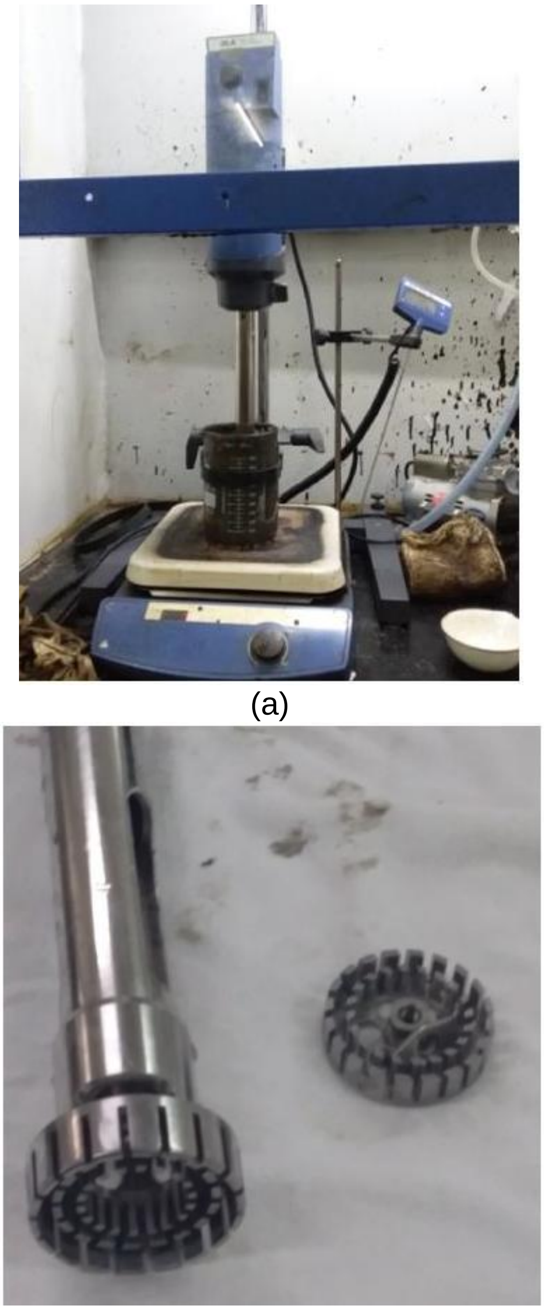


Fig. 2 Gravimetric water content versus total suction for Cochin marine clay

4 Reversing the Atterberg limits of the dried samples

In this study, a heavy duty dispersion tool (IKA-T 50 Digital Ultra Turrax Disperser with S50N-G45F dispersing element of 45 mm stator diameter and 40 mm rotor diameter), as shown in Figure 3, was used to successfully disperse the dried soil. The dispersion is effected by a forced vortex action that allows an inward-out motion of the particles in suspension. Soil suspensions constituting 200 g of soil solids in 800 ml suspension were used for every dispersion trial. Some initial trials were conducted to fix the speed and time of mixing. Subsequently, a speed of 9000 rpm and dispersion time of 30 min was fixed. The dispersed specimens were subjected to liquid limit determinations as per standard procedures.



(a)

(b)

Fig. 3 (a) IKA- T 50 Digital UltraTurrax Disperser and (b) dispersing element

4.1 Results and Discussions

Figure 4 shows the flow curves obtained for soils in various conditions in the Casagrande's liquid limit test. The results obtained for the dispersed air-dried and oven-dried specimens are compared with the natural, air-dried and oven-dried specimens not subjected to the dispersion technique. These results indicate that the dispersion technique has effectively dispersed the clay particles aggregated on drying and increased the liquid limit values closer to the original values in natural state. Table 2 gives the results of liquid limit tests on the dispersed soil specimens along with that of the undispersed soil specimens. Cochin marine clay has a liquid limit of 103% in its natural state, 77% in air-dried condition and 66% in oven-dried condition. Dispersion has increased the values to 96% and 98% for air-dried and oven-dried specimens, which is 93% to 95% close to the liquid limits in natural condition. This technique has reversed the properties attained on drying close to that in its natural state. From the values of plasticity indices, it is clear that the natural plasticity is restored well.

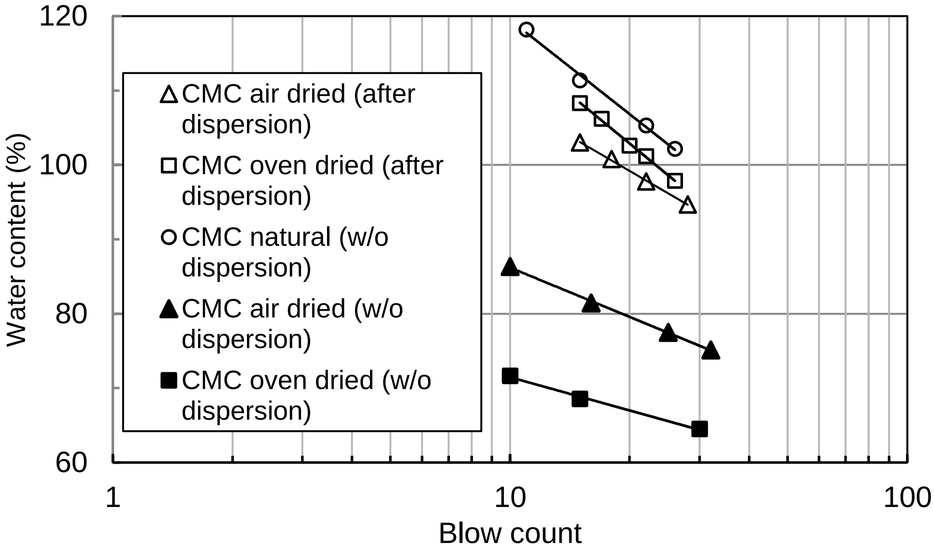
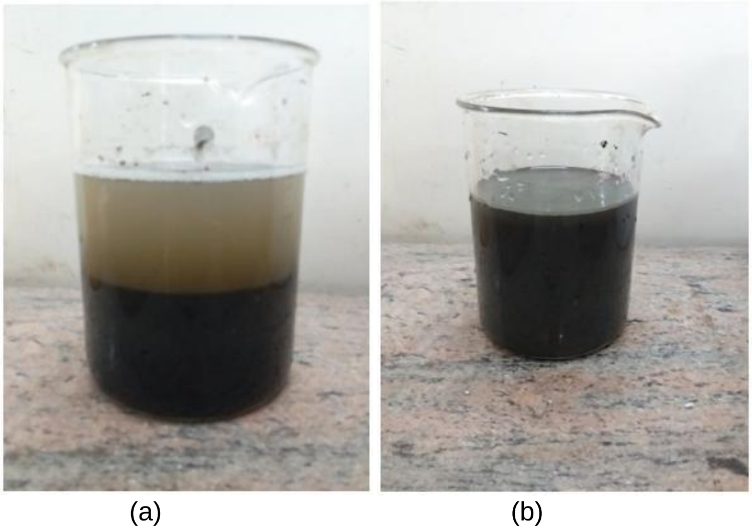


Fig. 4 Comparison of flow curves for Cochin marine clay

Table 2 Comparison of liquid limit and plastic limit for Cochin marine clay

	Without Dispersion			With dispersion		
	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)	Liquid limit (%)	Plastic limit (%)	Plasticity Index
Air dried	77	33	44	96	33	63
Oven dried	66	35	31	98	38	60



(a) (b)

Fig. 5 Images of oven dried specimen in suspension (a) before dispersion (b) after dispersion

The change can be observed physically in Figure 5(a,b) wherein before dispersion, the dried soil particles in solution settle due to floc formation. After dispersion, the clay particles are deflocculated and hence remain in suspended form. In order to check whether the grain size of the dispersed soils is different from the natural conditions, hydrometer analysis was carried out and the results are compared in Figure 6. The primary observation of clay aggregation that leads to an increase in the silt size fraction and reduction of clay fraction was seen in the grain size distribution of air-dried and oven-dried soils (which were not subjected to dispersion). Reduction of surface area and consequent loss in water holding capacity led to the reduction in plasticity and hence lower liquid limit values. On dispersion, the grain size distributions indicate that the agglomerated clay particles were efficiently separated and the clay fractions returned to the values close to the natural state. The percentage clay fraction of Cochin marine clay is 63% in natural state; 57% in the undispersed air-dried condition and undispersed oven-dried condition. Dispersion increased the clay fraction to 63% for air-dried and 62% for oven-dried specimens, respectively; these values being the same as that of natural soil (Table 3). However, some amount of grinding of the sand and silt-size fraction could not be ruled out in this technique, but nevertheless, the clay fraction obtained is representative of the natural soil. From the above results, it can be summarized that the dispersion technique is capable of reversing the properties acquired on drying.

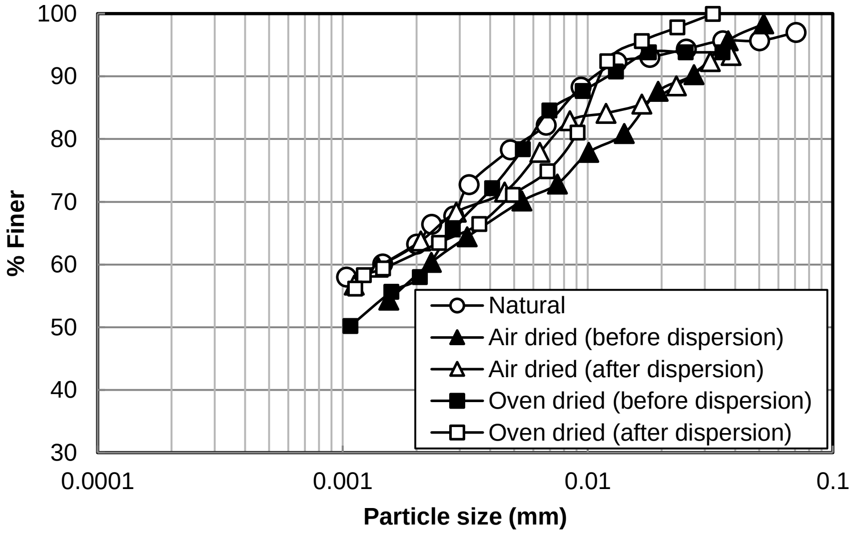


Fig. 6 Grain size distribution by hydrometer analysis for Cochin marine clay in different conditions

Table 3 Comparison of grain size distribution by hydrometer analysis for Cochin marine clay

	Without Dispersion		With dispersion	
	Silt size (%)	Clay size (%)	Silt size (%)	Clay size (%)
Air dried	43	57	37	63
Oven dried	43	57	38	62

4 Conclusion

Cochin marine clays are highly popular for drastic changes in plasticity behavior on drying. Researchers have tried to reverse these changes by repeated wetting processes and concluded that they undergo irreversible changes on drying. This work has introduced a high energy dispersion technique as a means to reverse the changes. The dispersion technique has significantly reversed the properties of Cochin marine clays, acquired on air drying and oven drying. This method can be employed to soils that get dried up when transported from field to laboratory, before conducting the standard testing procedures. Not only do the original values of plasticity be captured but these can used to predict the engineering behavior of these clays more accurately.

References

1. Ayyar, T. S. R. 1966. Strength Characteristics of Kuttanad Clays. Ph.D. thesis, University of Roorkee, Roorkee.
2. Ayyar, T. S. R., N. Balasubramanian, V. Raman, and S. Esakku. 1990. “Discussion: Influence of Drying on the Liquid Limit Behaviour of a Marine Clay.” Geotechnique 40 (4): 673–676. doi:10.1680/geot.1990.40.4.673
3. Krahn, J., and D. G. Fredlund. 1972. “On Total, Matric and Osmotic Suction.” Soil Science 114 (5): 339–348. doi:10.1097/00010694- 197211000-00003.
4. Pandian, N. S., T. S. Nagaraj, and G. L. Sivakumar Babu. 1991. “Effects of Drying on the Engineering Behaviour of Cochin Marine Clays.” Geotechnique 41 (1): 143–147. doi:10.1680/geot.1991.41.1.143.
5. Pandian, N. S., T. S. Nagaraj, and G. L. Sivakumar Babu. 1993. “Tropical Clays. I: Index Properties and Microstructural Aspects.” Journal of Geotechnical Engineering 119 (5, May): 826–839. doi:10.1061/(ASCE) 0733-9410(1993)119:5(826).
6. Rao, S. M., A. Sridharan, and S. Chandrakaran. 1989. “Influence of Drying on the Liquid Limit Behaviour of a Marine Clay.” Geotechnique 39 (4): 715–719. doi:10.1680/geot.1989.39.4.715
7. Sahib, A.A and Robinson, R.G. (2020) “Drying and Atterberg limits of Cochin marine clay”, International Journal of Geotechnical Engineering, doi: 10.1080/19386362.2020.1711554
8. Stott, P. R., and E. Theron. 2015. “Some Shortcomings in the Standard South African Testing Procedures for Assessing Heaving Clay.” Journal of the South African Institution of Civil Engineering 57 (2): 36–44. doi:10.17159/2309-8775/2015/v57n2a5.
9. Suganya, K., and P. V. Sivapullaiah. 2015. “Effect of Changing Water Content on the Properties of Kuttanad Soil.” Geotechnical and Geological Engineering 33: 913–921. doi:10.1007/s10706-015-9873- 9
10. Townsend, F. 1985. “Geotechnical Characteristics of Residual Soils.” Journal of Geotechnical Engineering 111: 77–94. doi:10.1061/(ASCE) 0733-9410(1985)111:1(77).
11. Vikas, K. S. T., and D. N. Singh. 2005.“Rapid Determination of Swelling Pressure of Clay Minerals.” Journal of Testing and Evaluation 33 (4): 239–245.