Behaviour of Cochin Marine Clay in the Presence of Sulphate

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***Abstract*—Marine clays are normally weak and expansive. Sulphate content in marine clay is due to the presence of sulphate compounds. Improving the engineering behavior of soft clays using lime has been used for several decades. Even though chemical stabilization of clays has proved to improve the engineering properties, problems arise when calcium – based stabilizers are used in soils rich in sulphate bearing minerals. Therefore lime stabilization technique should be cautiously applied in sulphate enriched environment or in marine clays containing sodium sulphate. Sulphate content is thus clearly the most important property to consider when evaluating such soils as foundation medium or for construction purposes and also determined its effects on engineering properties .The samples of Cochin marine clay are collected and sulphate content is determined. Strength, compressibility and plasticity characteristics are studied with varying sulphate content. The work plan includes collection of sample from Ernakulum and nearby areas, evaluation of sulphate content with appropriate method and various tests were conducted on the same and results were well concluded. This study also focuses on the effect of sulphate attack in lime stabilzed marine clays and the formation of ettringite and how the ettringite formation affects the engineering behaviour of marine clay and modifications made in the foundation.**

Keywords—Sulphate content, ettringite, lime stabilisation, shear strength

I. Introduction

The growth of Indian port cities over the last few decades has been phenomenal and Cochin is no exception. With the increase in population, housing and construction of various facilities have been a problem with urbanization. Thus studies on the nature and engineering behaviour of soft clays covering long stretches of coastal line and methods to improve their geotechnical properties have been of great relevance. Marine clays are normally weak and expansive. Sulphate content in marine clay is due to the presence of sulphate compounds. Improving the engineering behavior of soft clays using lime has been used for several decades. Even though chemical stabilization of clays has proved to improve the engineering properties, problems arise when calcium – based stabilizers are used in soils rich in sulphate bearing minerals. Therefore lime stabilization technique should be cautiously applied in sulphate enriched environment or in marine clays containing sodium sulphate. Sulphate content is thus clearly the most important property to consider when evaluating such soils as foundation medium or for construction purposes and also determined its effects on engineering properties. This study also focuses on the effect of sulphate attack in lime stabilized marine clays and the formation of ettringite and how the ettringite formation affects the engineering behaviour of marine clay and modifications made in the foundation.

II. MATERIALS AND METHODOLOGY

A. Materials

*1) Soil:*The soil used in this study is marine clay collected from Maradu, Munambam and Eloor in Cochin City, which is situated on the western coast of India. Representative soil samples were collected from the same depths, but from different boreholes at various locations were mixed thoroughly into a uniform mass and preserved in polyethylene bags so as to retain its natural water content.The properties of marine clay used for this study were determined and are given in the Table 1.

TABLE 1 PROPERTIES OF MARINE CLAY

Properties of marine clay	Sample I	SampleII	Sample III
Specific gravity	2.66	2.65	2.62
Grain size distribution			
Sand (%)	20	24	18
Silt (%)	50	47	49
Clay (%)	30	29	33
Liquid limit (%)	100	110	125
Plastic limit (%)	45	52	56
Shrinkage limit	20.5	21.8	22.5
Plasticity Index (%)	55	58	69
Natural Water content(%)	52	60	67.5
IS classification	CH	CH	CH

*2) Sulphate rich Chemicals:*Sulphate rich chemicals used for this study were purchased from a local fertilizer agent near Alappuzha.The chemicals used are ammonium sulphate and sodium sulphate.

B. Methodology

The key issue in deciding how the sulphate content in marine clay affects the geotechnical properties of soil is to efficiently determine the sulphate content of soils and to determine the threshold quantity of sulphate likely to cause damage.The experimental program consists of three phases, namely, sample collection, determination of plasticity characteristics, determination of engineering properties. The samples have been collected from different locations in the region to obtain soils withdifferent sulphate content and immediately, their natural water content and sulphate content weredetermined. Thesoluble sulphates present in water are measured in parts per million (ppm) and often expressed either in ppm or percent.10,000ppm are equivalent to 1.0%.Therefore 3,000ppm are equivalent to 0.3% and 5,000ppm to 0.5%. The soluble sulphate content should be reported on a dry soil basis to ensure consistency of test results. IS 2720 Part XXVII lays down the procedure for determining the total soluble sulphate content of soils by: Precipitation method or Standard Method, volumetric method or Subsidiary Method and Calorimetric or Turbid metric method.

For this study volumetric method or Subsidiary Method is used. The volumetric method depends upon insoluble barium sulphate forming and settling rapidly when barium chloride solution is added to the sulphate solution. The barium chloride reagent is added in excess and the excess is determined by the standard solution of barium chromate. With the formation of potassium chromate, the slight excess of chromate reagent becomes evident from the resultant yellow color of the supernatant solution. The end point can be further tested (confirmed) by silver nitrate solution used as an external indicator. A brick red colouration is obtained when a drop of silver nitrate is added to a drop of the chromate solution.

III. RESULTS AND DISCUSSIONS

The sulphate content of three samples was determined by using volumetric method and results were tabulated in table 2.

TABLE 2: RESULTS OF VOLUMETRIC METHOD

Sample	Water content (%)	Total soluble sulphate (%)	Inference (IS 2720 Part XXVII)
1	52	0.45(4500 ppm)	Does not cause harmful disruptions
2	60	0.70(7000 ppm)	Moderate to high risk
3	67.5	0.82(8200 ppm)	High risk to stabilize with lime

If the total level of soluble sulphates is below 0.3%, or 3,000 parts per million (ppm), by weight of soil, then lime stabilization should not be of significant concern and the potential for a harmful reaction is low. Total soluble sulphate levels of between 0.3% (3,000 ppm) and 0.5% (5,000 ppm) are of moderate concern. Generally, these sulphate levels do not result in harmful disruption, but on occasions have caused localized distress. Total soluble sulphate levels between 0.5% (5,000 ppm) and 0.8% (8,000 ppm) present are moderate to high risk. Total soluble sulphate levels of greater than 0.8% (8,000 ppm) are generally of high risk to stabilize with lime. Soils with total soluble sulphate contents greater than 1.0% (10,000 ppm) generally are not suitable for lime stabilization because of the high risk of sulphate-induced disruption and failure.

A. Plasticity Characteristics

A series of Atterberg limit tests were carried out in the laboratory on different samples of marine clay at natural water content. The liquid limit and plastic limit of the soil samples in the natural state were in the range of 100% - 125% and 45% - 56% respectively. Table 3 shows the values of atterberg limits of marine clay used.

TABLE 3: VALUES OF ATTERBERG LIMITS

Samples	Sulphate ontent	Liquid limit	Plastic limit	Shrinkage limit	Plasticity Index
I	45	100	45	20.5	55
II	70	110	52	21.8	58
III	82	125	56	22.5	69

Fig.1 shows the variation of liquid limit with sulphate content. Both liquid limit and plastic limit were found to be linearly increasing with increase in sulphate content.

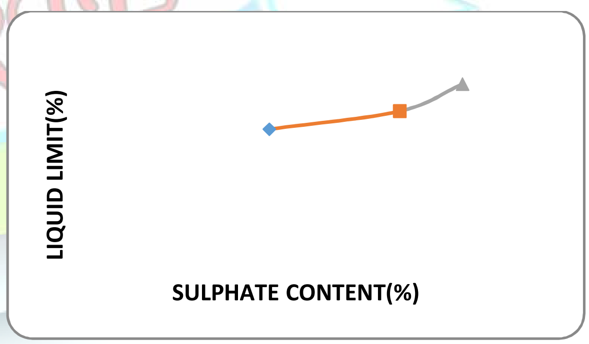

Fig.1 Liquid limit variation

It can be seen that as the sulphate content of the soil increases, water holding capacity of the soil was found to increase and it varies linearly.

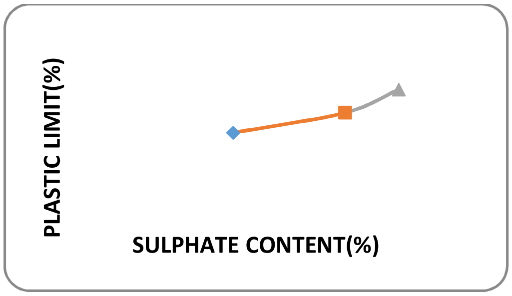

Fig.2 Plastic limit variation

Figure 3 shows the variation of shrinkage limit with sulphate content. As the sulphate content increases, the shrinkage limit also increases. It can be seen that the water content at which shrinkage ceases will be high for clays having more sulphate content.

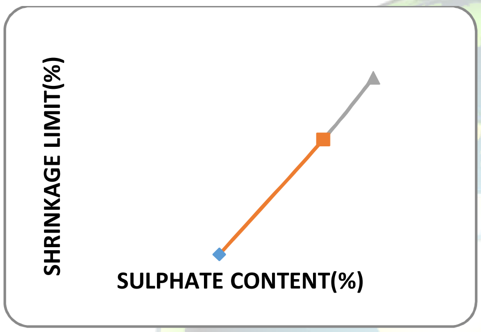

Fig.3 Shrinkage limit variation

As the particle size decreases, both the liquid limit and plastic limit increases but the former increases at a faster rate. Therefore the plasticity index also increases at a rapid rate. Plasticity index is a measure of the fineness of the particle.

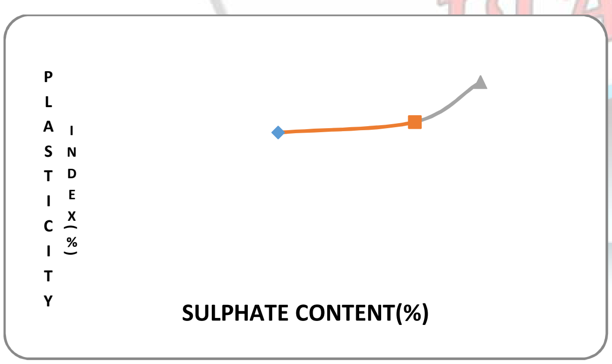

Fig.4 Variation of plasticity index

From the values of shrinkage limit, specific gravity of clay was determined. It can be seen that shrinkage limit is the smallest water content at which the soil is saturated. As the sulphate content of the soil gets increased, more water is needed for the saturation.

B. Shear Strength Characteristics

The tests were conducted at natural water content and found that strength of marine clay is approximately equal to zero. Therefore UCC test were conducted after keeping the sample for a period of 24 hours. The undrained shear strength of soil was found to be decreasing with increase in sulphate content. Sodium sulphate present in clay adversely affects the strength characteristics of marine clay. Soils with total soluble sulphate content greater than 1.0% (10,000 ppm) are generally weak and results in sulphate-induced disruption and failure. Table 4 shows the UCC values of marine clay used.

TABLE 4: UCC RESULTS

Samples	Sulphate content (%)	UCC value (kN/m^2)
I	45	5.3
II	70	3.6
III	82	2.3

Figure 5 shows the results of unconfined compression tests on marine clay with various sulphate content. It can be infer that, the dry strength of the clay was found to be decreasing with increase in sulphate content. This is due to the fact that, the concentration of sulphate in soil leads to the disruption of the structural bonds developing between the particles. Since no confinement is provided in this case, the shear strength of clay was found to be decreased.

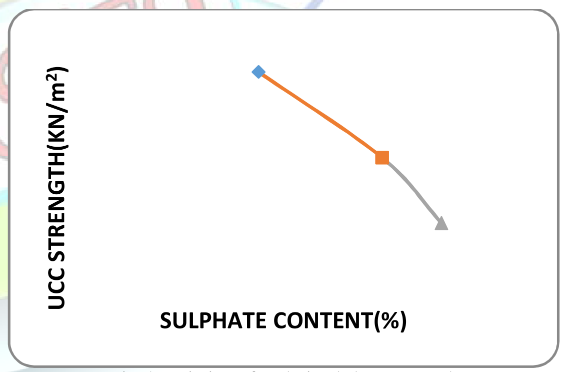

Fig.5 Variation of undrained shear strength

C. Consolidation Characteristics

Fig.6 depicts the relationship between sulphate content and settlement obtained from one dimensional consolidation tests. It can be seen that, with the increase in sulphate content settlement of the soil increases. This is due to the fact that as the concentration of sulphate in the soil is more, the load bearing capacity decreases. Settlement value depends on thickness of the sample, rate of load applied and time period of consolidation.

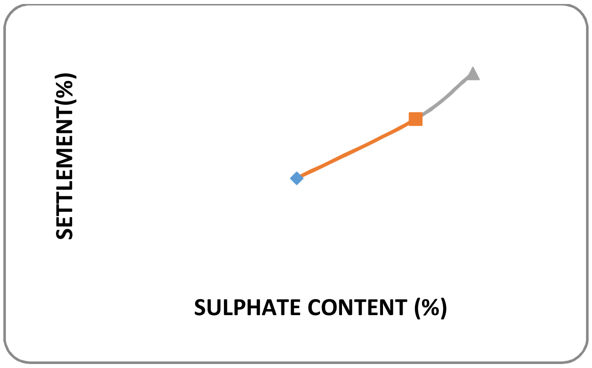

Fig.6 Variation of settlement with sulphate content

The coefficient of primary consolidation (Cv) was decreased with increase in sulphate content as seen from the figure 7. The Cv values were calculated for each applied stress for different samples and their average were taken in the figure.

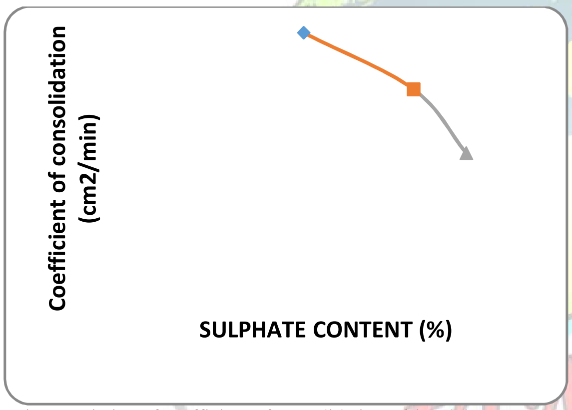

Fig.7 Variation of coefficient of consolidation with sulphate content

IV. CONCLUSIONS

The effect of sulphate content on the plasticity, shear strength and compressibility characteristics of Cochin marine clay has been studied. The test results indicate that the sulphate content significantly affect the geotechnical properties of this clay. The plasticity characteristics were found to increase linearly with increase in sulphate content. It can be seen that as the sulphate content of the soil increases, water holding capacity of the soil was found to increase.The shear strength of the clay was considerably decreased with increase in sulphate content. Sodium sulphate present in clay adversely affects the strength characteristics of marine clay.The coefficient of primary consolidation was found to decrease and percentage of settlement was found to increase with increase in sulphate content. This is due to the fact that as the concentration of sulphate in the soil is more, the load bearing capacity decreases. Sulphate content is thus clearly the most important property to consider when evaluating such soils as foundation medium or for construction purposes and also determined its effects on engineering properties.

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