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Physical Properties of Cochin Marine Clays

by

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Introduction

THE city of Cochin, the queen of the Arabian Sea, has been witnessing hectic construction activity during the last few decades. Most of the industries of the state are situated in and around Cochin making it the commercial capital of Kerala. Heavy industrial structures and high rise buildings have sprung up during the last two decades. Most of the area in Greater Cochin consists of marine clays which has with its poor shear strength and high compressibility, posed insurmountable problems to foundation engineers Added to this, is the lack of detailed investigations regarding the geotechnical properties of the clays encountered in this region. The many failures of embankments and foundations resting on these clays, in the recent past, stress the dire need for a detailed investigation of these clays. In view of the above, the geotechnical engineering division of Cochin University of Science and Technology, has taken up a comprehensive study of Cochin Marine Clays. In this paper the physical properties of Cochin Marine Clays have been presented. Attempts also have been made to bring out the variations in the properties brought about by air and overdrying of the moist natural clay. The results and conclusions drawn will help in better understanding of these clays in geotechnical engineering practice.

Locations and Sampling

Samples from three sites viz., Munambam, Nettoor and Cheranelloor spread over the northern half of the Greater Cochin Area were taken up for the present study. Figure 1 shows these three locations. Their respective distances from Ernakulam South Railway Station are 30 km., 6 km., and 10 km. respectively. From Nettoor site, undisturbed and representative samples were collected from a depth of 1.0 to 2.0 m by accessible exploration

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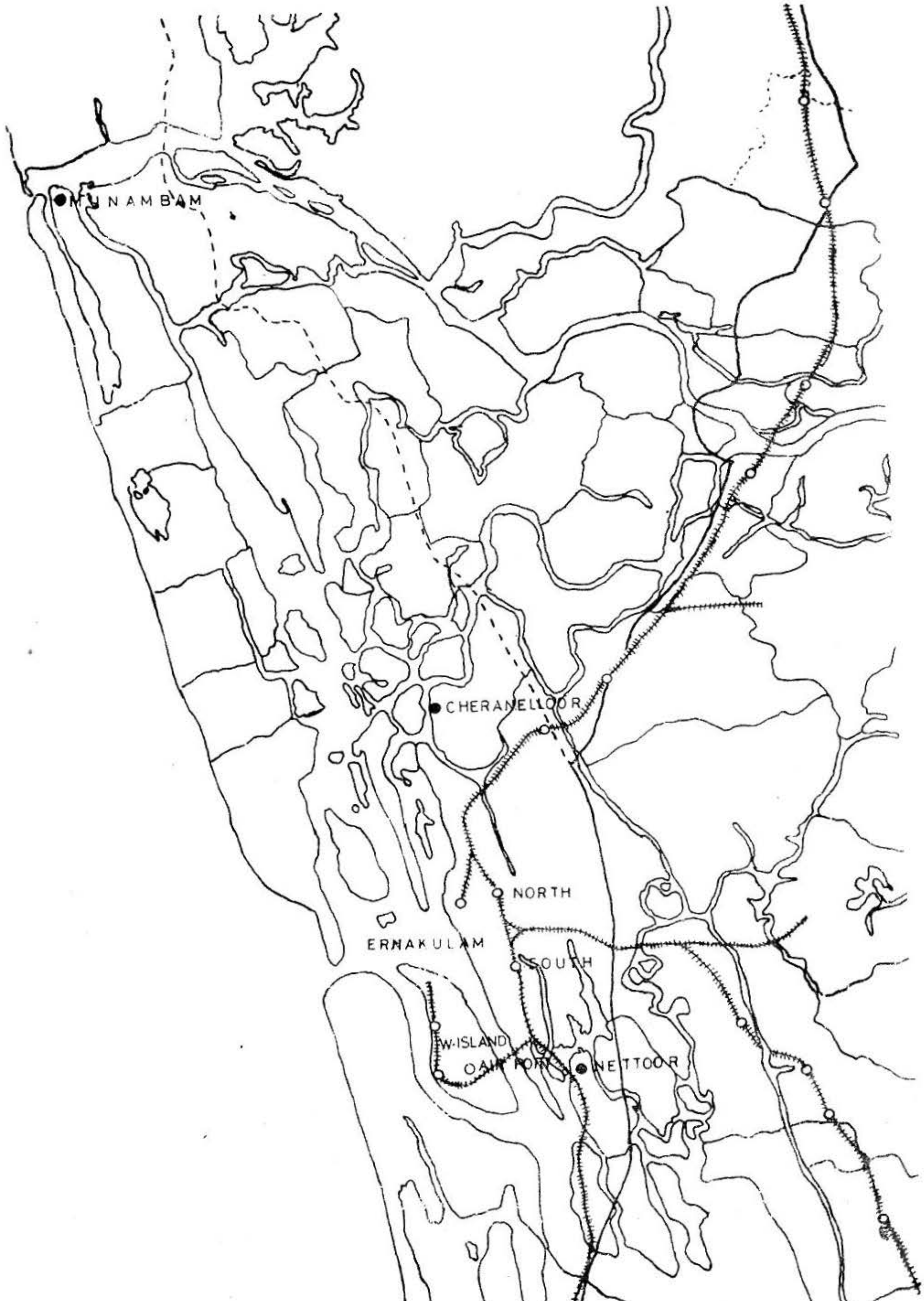

FIGURE 1 Sampling Locations

as thick layers of marine clay were available at shallow depths. In the other two locations, sampling was done at depths varying from 5 to 16 m., as the top layers consisted of sand or clayey sand. Boring was carried out using the shell and auger method with the sides protected by casing pipes. Typical bore hole logs from Munambam and Cheranelloor are given in Fig 2.

Preparation of Samples

Preliminary tests for physical properties showed significant differences depending on the method of preparation of samples for respective tests. In order to find the effect of initial condition/method of preparation of soil samples, they were prepared in a systematic way and tested as detailed below.

Various tests for physical properties were conducted on samples in four different conditions, viz., moist, washed, air dried and oven dried. Representative samples which were collected in polythene bags and sealed to avoid loss of pore fluid are designated here as "moist" samples. Many of the Characteristics of the marine clays can be attributed to the presence of salts in the pore water. In order to study the properties of this clay without the marine pore water and excess salts, representative samples were repeatedly washed with large quantities of distilled water taking extreme care not to loose any fines. Such samples are termed "washed" samples.

Moist representative soils were spread in trays and allowed to dry under room temperature and humidity. These samples which reach equilibrium in about 15 days are called "air dried" samples. "Oven dried" samples are prepared by drying the air dried samples in trays kept in an oven and dried at 105°C for 2 days. Two days are sufficient to reach equilibrium condition.

Physical Properties

The physical properties of the samples from the three sites are presented in Table 1. In the case of Munambam and Nettoor, typical results from samples obtained at three depths are presented. The representative samples have been obtained at depths of 9 to 15 m., for Munambam and 1.0 to 2.0 m. for Nettoor. Results of samples for Cheranelloor obtained at a depth of 5.5m are also reported in Table 1. At this location, the clay layer is very thin. It can be seen from Table 1 that the results obtained from the three locations, eventhough separated by 15 to 20 km apart, are quite comparable. For all the samples, it is seen that the natural water contents are very near to the liquid limit, eventhough some of the samples from Munambam area are from a depth of 15m. These clays are essentially normally consolidated.

Preliminary investigation showed that all these clays are finer than 425 micron sieve (on wet sieving) and hence they were directly used for testing for consistency limits.

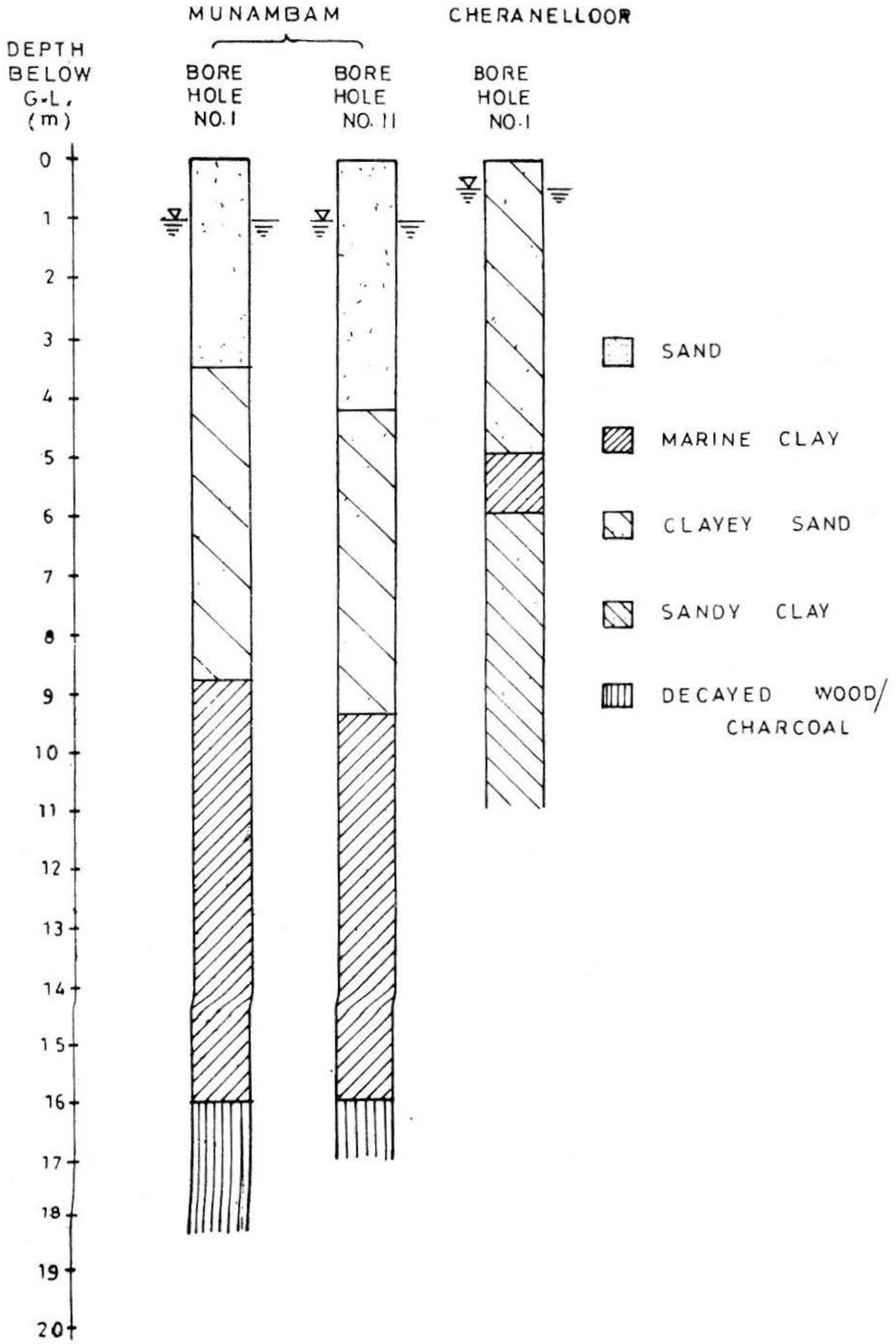

FIGURE 2 Typical Borehole Logs

TABLE 1

Physical Properties

Sl. No.	Site	Munambam			Nettoor			Cheranelloor
	Depth of Sampling (m)	9.40	10.40	12.10	1.0	1.50	2.0	5.50
1.	Specific Gravity	2.66	2.60	2.63	2.64	2.65	2.72	2.66
2.	Bulk Density (gm/cc)	1.50	1.52	1.68	1.42	1.40	1.42	1.42
3.	Natural Moisture content (%)	92.0	96.5	76.4	124.0	120.5	128.8	87
4.	Liquid Limit (%)							
	(*a*) moist soil	116.5	139.0	83.5	135.5	131.5	175.0	118.5
	(*b*) air dried	—	—	—	87.5	102.0	120.0	96.5
	(*c*) oven dried	57.0	64.0	48.5	44.8	58.5	59.5	57.0
5.	Plastic Limit (%)							
	(*a*) moist soil	45.5	52.0	33.8	47.5	48.0	60.6	45.3
	(*b*) air dried	—	—	—	38.7	44.7	57.6	41.5
	(*c*) oven dried	38.0	37.4	30.6	33.6	39.5	42.3	34.5
6.	Plasticity Index (%)	71.0	8					
	(*a*) moistsoil	71.0	87.0	49.7	90.0	83.5	114.4	73.2
	(*b*) air dried	—	—	—	48.8	57.3	62.4	55.0
	(*c*) overn dried	19.0	26.6	17.9	11.2	19.0	17.2	22.5
7.	Liquidity Index	0.65	0.51	0.86	0.84	0.87	0.60	0.57
8.	Shrinkage Limit (%)							
	(*a*) moist soil	22.5	23.1	23.2	17.8	17.0	18.1	19.3
	(*b*) air dried	—	—	—	19.5	17.8	17.9	18.5
	(*c*) oven dried	27.0	26.3	28.6	19.5	25	21.4	20·3
9.	Grain size Distribution							
	(*a*) moist soil							
	(*i*) Clay size (%)	42	54	35	48	47	45	36
	(*ii*) Silt Size (%)	40	40	55	31	33	42	43
	(*iii*) Sand size (%)	18	6	10	21	20	13	21
	(*b*) air dried							
	(*i*) clay size (%)	—	—	—	32	43	37	33
	(*ii*) Slit size (%)	—	—	—	43	35	48	46
	(*iii*) Sand size (%)	—	—	—	25	22	15	32
	(*c*) Oven dried							
	(*i*) clay size (%)	23	26	20	25	29	27	23
	(*ii*) slit size (%)	59	65	70	48	58	58	56
	(*iiii*) sand size (%)	18	10	10	27	23	15	21

Sl. No.	Site	Munambam			Nettoor			Cherane loor
	Depth of Sampling (m)	9.40	10.40	12.10	1.0	1.50	2.0	5.50
10.	Activity							
	(*a*) moist soil	1.69	1.61	1.43	1.88	1.77	2.47	2.03
	(*b*) air dried	—	—	—	1.53	1.36	1.68	1.67
	(*c*) oven dried	0.83	1.04	0.90	0.44	0.69	0.63	1.0
11.	Free swell Index (cc/gm)							
	(*a*) moist soil	4.30	3.0	3.40	5.20	4.20	5.90	4.50
	(*b*) air dried	—	—	—	1.70	1.80	2.20	2.42
	(*c*) oven dried	1.40	1.57	1.50	1.20	1.60	1.50	1.66
12.	Organic Matter (%)	6.30	7.05	6.85	7.64	7.07	8.27	7.61
13.	pH value	7.72	7.67	8.0	7.83	7.40	7.10	7.60
14.	Calcium Carbonate (%)	—	—	—	—	14.0	19.36	23.50
15.	Cation Exchange Capacity (m.eq/100gm)	—	37.7	—	26.0	—	36.0	—

Moist Samples

For the moist samples, the liquid limit varies from 83.5 to 175.0 and the plastic limit from 33.8 to 60 for all the clays tested. They clay size fraction varies within a range of 35 to 54% and the soil could be generally classified as CH. For these clays both silt and clay fractions are of the same order and the sand content is quite low, maximum obtained in the tests being 21%. The activity of the moist samples range over 1.37 to 2.47 which could be classified as active clays (Sekmpton, 1953). The shrinkage limit is quite high for moist sample when compared to their liquid limit and plastic limit from which one can infer that the moist clay consists of flocs. It has been reported (Lambe, 1958) that higher shrinkage limit indicates flocculant fabric. The liquidity index for these clays varies over a range of 0.51 to 0.87 which indicates that these clays could be taken as medium to very sensitive as per Bjerrum's classification (Bjerrum, 1954).

Table 1 also reports the free swell index as defined by Sridharan *et al* (1985). The conventional free swell tests could not be carried out on these marine clay samples, since drying affects the free swell characteristics of the soil significantly. The free swell index of the moist samples were obtained by measuring the swollen volume of the soil without any restraints with distilled water in a measuring jar, per unit weight of dry soil. The equilibrium was reached in about 7 days and the dry weight was determined thereafter. The free swell index was then expressed in terms of cm^3/gm.

This value was found to vary from 3.0 to 5.9 for Cochin Marine Clays. Similar tests carried out for Kaolinite and bentonite sand mixtures (Sridharan *et al*, 1985) resulted in free swell index values of 1.45 and 6.7 cm^3/gm respectively. As per their classification (Sridharan *et al*, 1985) Cochin Marine Clays could be termed as moderately swelling.

The organix content of the Cochin Marine Clay is not very high, but significant enough to influence its physical properties. The value varies from 6.05 to 8.59% for the samples investigated. The *p*H value of soil samples give an idea about the alkalinity of the pore fluid. The *p*H value ranges from 7.40 to 10.0 for these clays. The calcium carbonate percentage varie from 14.0% to 23.5% for these clays which is considerably lower than the values in case of fine grained carbonate soils off west coast (Nambiar *et al*, 1985). The cation exchange capacity ranges from 26.0 to 37.7 meq/-100gm.

Effect of Air Drying and Oven Drying

From Table I, it can be seen that both air drying and oven drying significantly reduces the liquid limit and free swell index of these clays. The oven dried samples have liquid limits in the range of 40%-60% of the natural moist sample and air drying reduces liquid limit by 20%-30%. The main reason attributed to this striking behaviour is the aggregation of particles on air drying and oven drying. A similar reduction can be seen in the case of plastic limit as well as free swell index. Nambiar et al (1985 aso have reported reduction in liquid limit of fine grained carbonate soil from off the west coast though not significantly. Jagdish Narain and Iyer (1967) reports significant reduction in the liquid limit of Kuttanand clays on air drying.

For most of the cases, the shrinkage limit got increased for oven dried samples. It is as sought to be since coarser particles formed by aggregation resulted in higher shrinkage limit. As one would expect, the activity of the air dried and oven dried samples got reduced (Table 1).

Fig. 3 presents the liquid limit vs plasticity index for the various clays tested in this investigation. All the points are very close to the A-line whether they are moist on air dried or oven dried. A statistical fit to the points results in the equation.

$$PI = 0.836\ (LL - 30.50)$$

with correlation coefficient of 0.977.

Bjerrum (1954) reports the liquid limits and plasticity index of Norwegian marine clays. The liquid limit of these clays varies over a range of 59.4% to 21%. A statistical fit of liquid limit vs plasticity index gives a relation of

$$PI = 0.795\ (LL - 17.2)$$

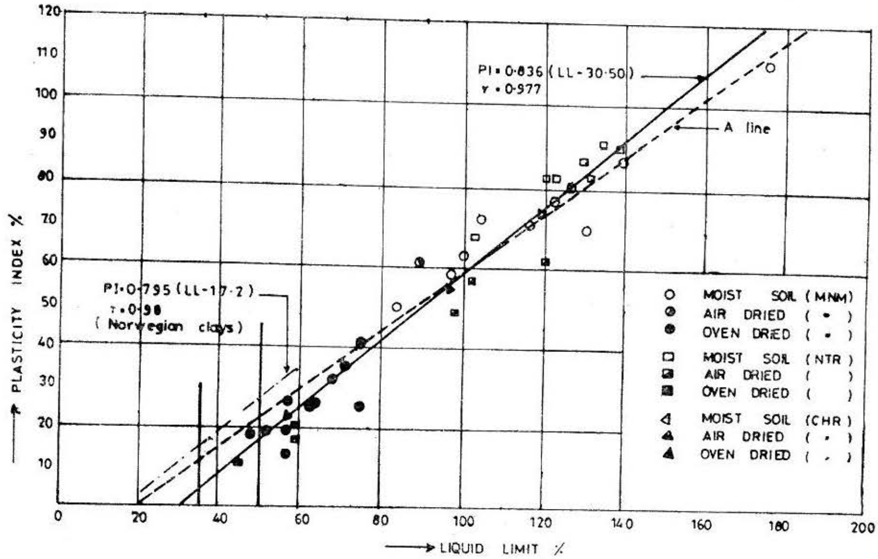

FIGURE 3 Plasticity Index *vs* Liquid limit Plot for Various Clays

It can be taken that the slopes for both Cochin Marine Clay and that of Norwegian marine clay is of the same order. Contrary to above, the analysis on 520 samples of inorganic soils, the liquid limit varying upto about 120% shows a statistical correlation (Nagaraj and Jayadeva, 1983).

$$PI = 0.74\ (LL{-}8)$$

In other words, for inorganic soils the relationship on the Casagrande plasticity chart lies above that of the relationship obtained for Cochin Marine Clays and that of Norwegian clays. This behaviour may possibly be due to the presence of organic matter in these clays.

Figure 4 presents the liquid limit vs percent of clay size fraction which can be represented linearly with an equation

$$LL = 2.39\ (C{-}3.1)$$

where C = % of clay.

This relation has correlation coefficient of 0.775. Once again it is seen that irrespective of air drying or oven drying of the clays, a common line could be drawn. The fact that both the relationships PI vs LL and LL vs C could be correlated for all the three conditions of the clay *viz.*, moist, air dried and oven dried, supports the reason that the effect of air or oven drying results in aggregation.

Figure 5 presents the relationship between plasticity index and percent clay for moist, air dried and oven dried clays. It also shows the Skempton's

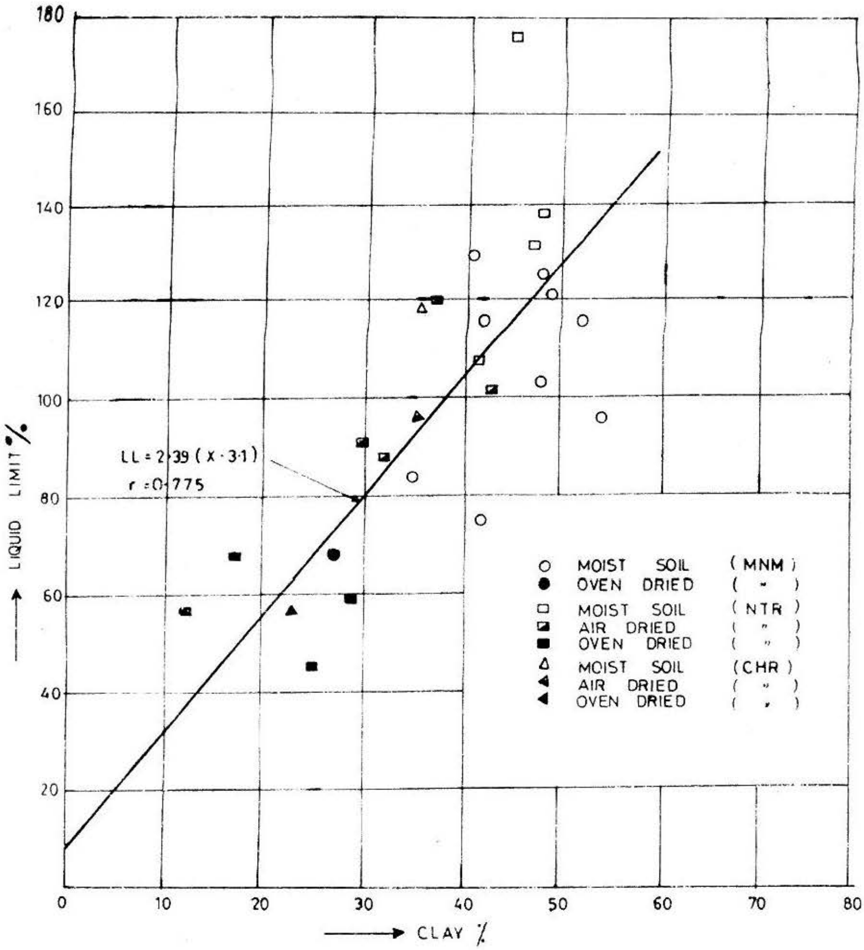

FIGURE 4 Liquid Limit vs Percent Clay Plot for Various Clays

(1953) classification demarkating active, normal and inactive clays. While the moist soil clearly falls under active clays the oven dried falls in between normal and inactive clays. The air dried clays fall in between active and normal clays. It is needless to state that the colloidal activity gets diminished on oven drying.

Figure 6*a* and 6*b* present grain size distribution curves for soils obtained from Munambam and Nettoor. The effect of air drying and oven drying on clay aggregation is very much evident from these results. It may be seen that aggregation takes place at all size levels. It may be mentioned here that while carrying out the hydrometer analysis dispersing agents were used as per IS 2720 (Part IV) 1975. In spite of using the dispersing agent and mixing the soil slurry with stirrer, the aggregation resulted from air drying and oven drying could not be broken to finer particles.

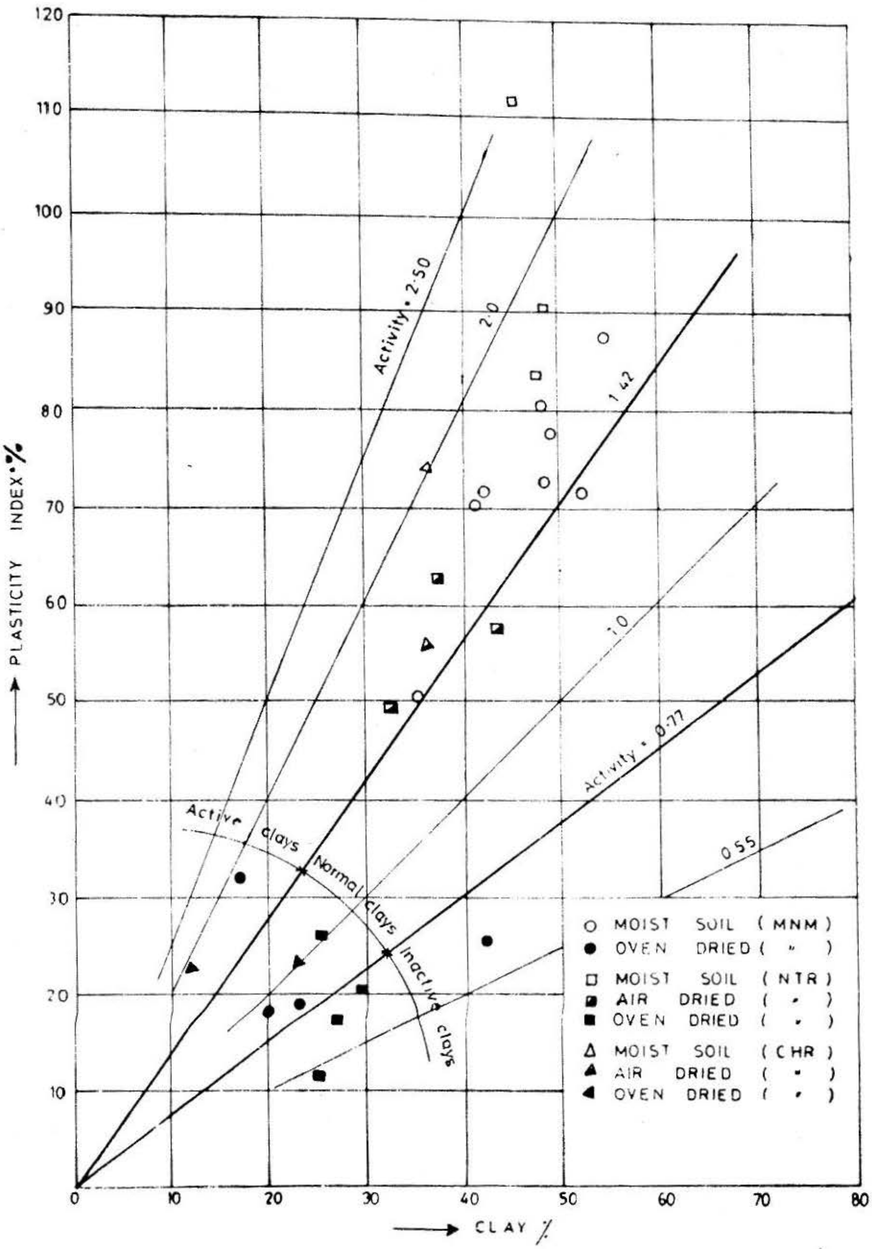

FIGURE 5 Relationship between Plasticity Index and Percent Clay under Different Pretest Conditions

In order to study the grain size distribution of the clays without the dispersing agent, series of tests were conducted with and without standard dispersing agent, for both Munambam and Nettoor samples. Figure 7*a* and 7*b* present the results. It can be seen from both these figures that the

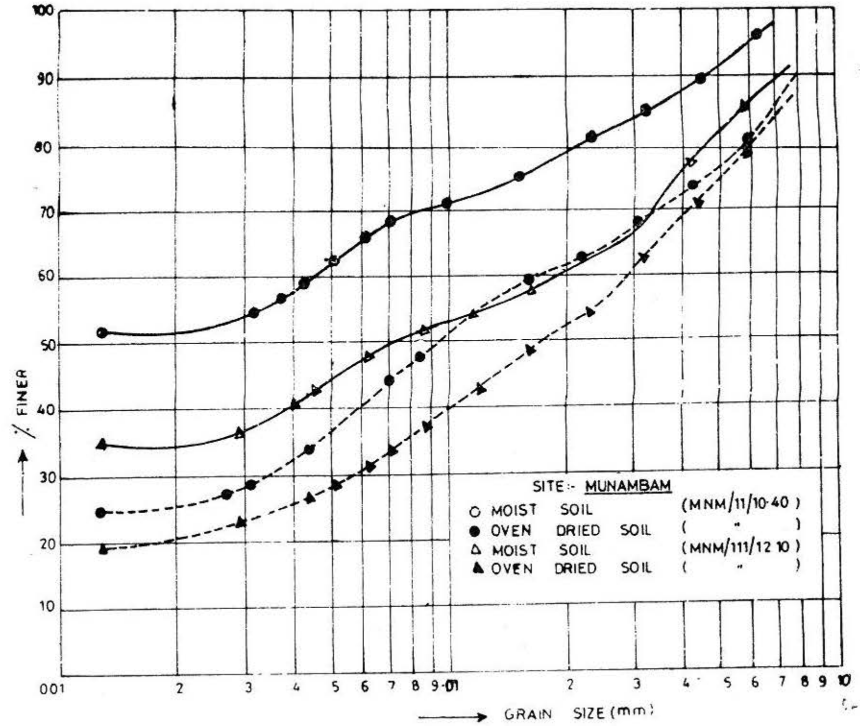

FIGURE 6(a) Grain Size Distribution Curves for Munambam Soil

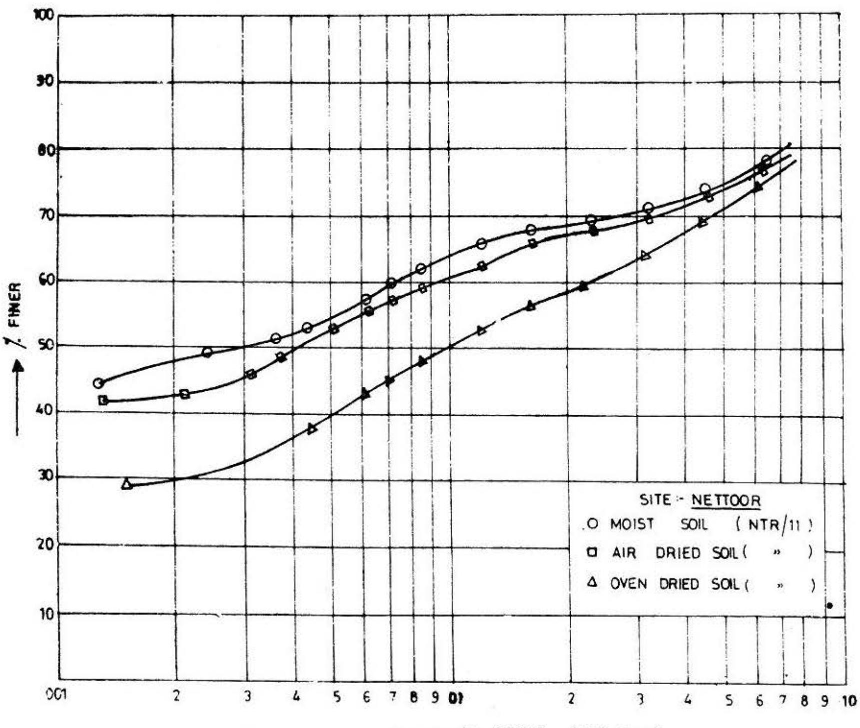

FIGURE 6(b) Grain Size Distribution Curves for Nettoor Soil

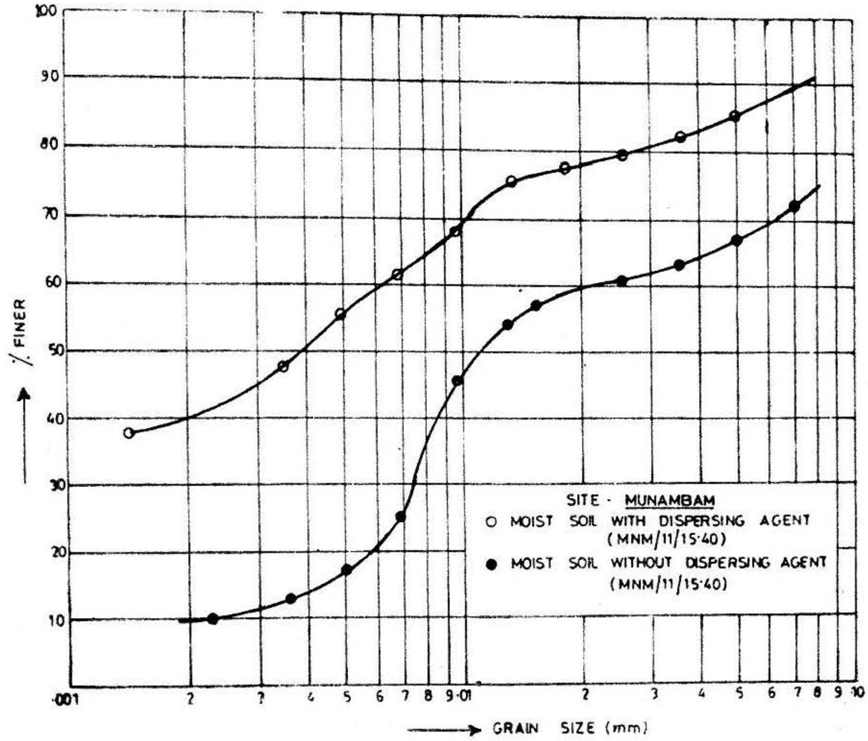

FIGURE 7(a) Grainsize Distribution Curves for Munambam Soil with and without Dispersing Agent

percentage of clay size fraction increases considerably with the use of dispersing agents. In case of Munambam soil, the clay size percentage increased from 9% to 42% and for Nettoor sample, the value increased from 27% to 50%. Similar results have been obtained for other samples. These results clearly point to the fact that under natural conditions, a major part of the clay content is in the form of flocs whose size is larger than the clay size. This means that —78% of clay content of Munambam soils and —46% in the case of Nettoor soils are in the form of flocs in its natural state. These flocs cannot be disturbed by the conventional use of the stirrers. Thus the dispersing agents have a greater role to play in the grainsize analysis by hydrometer method in case of marine clays. A matter of interest is that in the experiments that are carried out without the dispersing agent, beyond a certain point of grain size, the hydrometer reading showed a constant value (e.g. oven dried Nettoor soil without dispersing agent, Fig. 7*b*).

Effect of Washing

In order to study the effect of salt content already present in the natural moist soil, series of tests were carried out on repeatedly washed moist soil. For this purpose, large quantities of moist soil were taken in a bucket of 20 litre capacity and mixed thoroughly with large quantities of distilled water

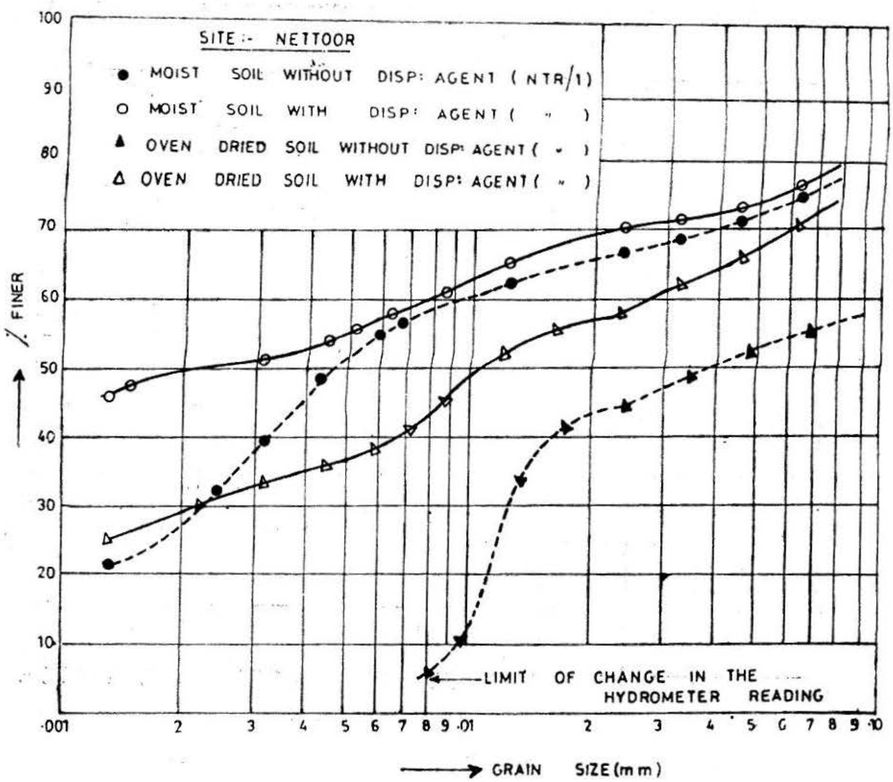

FIGURE 7(b) Grainsize Distribution Curves for Nettoor Soil with and without Dispersing Agent

with a mechanical stirrer. After thorough mixing, the samples were allowed to settle down for number of days. The clear supernatant liquid is carefully siphoned out taking extreme care not to permit any loss of fines. In the initial few washings, the water at the top was clear without the presence of any colloids. As the salt content got reduced by washing, more and more colloids were released by deflocculation, increasing the time for sedimentation. The washing was repeated till the supernatant water is free of salts. The process took more than 3 months. Series of tests for physical properties on such prepared clays was carried out.

Table 2 presents the test results of washed clay of Nettoor. It is seen that washing results in reduction in liquid limit though not significantly. The plastic and shrinkage limits are also get reduced marginally.

While discussing the mechanism controlling the liquid limit of soils, Sridharan and Rao (1975) and Sridharan *et al* (1986) have brought out that for montmorillonitic soils, the liquid limit is recognised to be a function of diffuse double layer thickness. For kaolinitic soils, the fabric of clays controls the behaviour (Sridharan and Rao, 1975, Sridharan, *et al* 1988).

TABLE 2

Effect of Washing—Nettoor Soil

Sl. No.	Depth of sampling (m)	Type of soil	Sp. Gr.	Liquid limit %	Plastic limit %	Plasticity index %	Shrinkage limit %	Grain size distribution: Clay size %	Silt size %	Sand size %	Free swell index (cc/gm)
1	1.0	(*a*) Natural soil-moist	2.62	137.5	47.5	90.0	17.80	48	31	21	5.20
		(*b*) Washed soil-moist	2.73	120.0	37.3	82.7	14.80	—	—	—	—
2	2.0	(*a*) Natural soil									
		(*i*) moist	2.70	175.0	60.6	114.4	18.1	45	42	13	5.90
		(*ii*) air dried	2.59	120.0	57.6	62.4	17.9	37	45	18	
		(*iii*) Oven dried	2.63	59.5	42.3	17.2	21.4	27	58	15	1.50
		(*b*) Washed soil									
		(*i*) moist	2.74	162.0	50.0	112.0	18.0	38	36	26	3.75
		(*ii*) air dried	2.59	87.5	39.5	48.0	17.0	—	—	—	—
		(*iii*) oven dried	2.59	69.0	42.0	27.0	20.0	22	53	25	1.48

Washing of soils, deflocculates the fabric and because of this, the liquid limit will decrease since water held by flocs gets lost. At the same time, washing also results in more and more formation of colloids. Because of this, the effective diffuse double layer thickness increases and the liquid limit is likely to increase. It is well known that decrease of concentration of ions increases the diffuse double layer thickness. Hence it is seen that effect of washing results in two opposing phenomena. Thus 'washing' can result in either decrease or increase in liquid limit values depending on the dominating mechanism. The results presented in Table 2 shows a reduction in liquid limit, thought not significantly, indicating that the decrease is due to change in fabric from flocculant to relatively less flocculant fabric.

It is to be noted from Table 2 that inspite of repeated washing, the reduction in liquid limit of air dried and oven dried samples are of the same order, thus revealing that, presence of excess salts is not the primary reason for aggregation formation. The grain size distribution of both natural moist and washed moist clay shows that there is a reduction in percent of clay size fraction. No reasons are offered for this behaviour at this stage.

Effect of Soaking on Oven Dried Clays

It is possible that the reduction in index properties due to oven drying could be regained by soaking the sample for sufficient time. Series of experiments were carried out by soaking the oven dried soil for different periods viz., two weeks, one month and two months. Table 3 presents the experimental results on index properties. It is seen that oven drying has reduced the liquid limit by about 67%. By soaking the oven dried soil, the liquid limit showed consistent increase from 45% to 67.5%. Similar behaviour is also seen in plastic limit. The shrinkage limit decreased on soaking and tend to approach towards the shrinkage limit of moist soil.

TABLE 3

Effect of Soaking on Oven Dried Soil Nettoor Soil

Sl. No.	Test	Moist soil	Oven dried soil			
			Unsoaked	Soaked for two weeks	Soaked for 1 months	Soaked for 2 months
1.	Specific gravity	2.62	2.55	2.61	2.62	2.60
2.	Liquid limit %	137.5	44.8	63.0	64.50	67.5
3.	Plastic limit %	47.5	33.6	38.0	37.40	38.0
4.	Plasticity index %	90.0	11.2	25.0	27.10	30.0
5.	Shrinkage limit %	17.80	19.5	19.5	18.1	18.4
6.	Liquid limit ratio		0.33	0.46	0.47	0.49

TABLE 4

Effect of Salts on Physical Properties—Nettoor Soil

Sl. No.	Description of the test	Specific gravity	Liquid limit %	Plastic limit %	Palsticity index %	Shrinkage limit %	Grain size distribution: Clay size %	Silt size %	Sand size %	Free swell index (cc/gm)
1.	Moist soil	2.72	137.5	47.5	90.0	17.80	48	31	21	5.20
2.	Moist soil+Sod. Chloride									
	(1) 5% Nacl	2.70	134.0	43.4	90.0	18.5	44	32	24	4.55
	(2) 10% Nacl	2.80	129.0	42.0	87.0	25.4	—	—	—	4.35
	(3) 20% Nacl	2.82	122.5	39.0	83.5	30.1	—	—	—	2.70
3.	Moist soil+Calcium chloride									
	(1) 5% Ca cl_2	2.55	131.0	47.0	84.0	14.4	36	34	19	4.16
	(2) 10% Ca cl_2	2.63	122.0	40.0	82.0	14.0	—	—	—	3.12
	(3) 20% Ca cl_2	2.46	102.0	34.0	68.0	12.6	—	—	—	2.80

Effect of salts

It is possible that addition of salts like sodium chloride and calcium chloride can have marked change on the physical properties of these marine clays. In order to get preliminary information on this, index and other properties were determined with different percentages of sodium chloride and calcium chloride salts. For these, the moist soil was mixed thoroughly with 5 to 20% by dry weight of sodium chloride and calcium chloride salts and the physical properties were determined. It is seen from Table 4 that addition of salts reduces the liquid and plastic limits. While the reduction in liquid limit is marginal (138% to 122%) for the addition of 20% sodium chloride, to reduction is quite considerable (138% to 102%) for the addition of 20% calcium chloride. The effect of salt concentration has been explained by depression of electrical double layer (Olsen and Mesri, 1970 and Mesri and Olsen, 1971 and Sridharan and Jayadeva, 1982). In this case also the reduction in liquid limit could be attributed to the depression of double layer because of increase in salt concentration (Sridharan and Rao, 1975).

Table 4 also presents data on shrinkage limit and free swell index. The shrinkage limit with sodium chloride as additive has shown significant increase, while calcium chloride as additive, not much variation. Further there is a marked reduction in free swell index with the increase in salt content. The authors attribute this to deflocculation and aggregation of particles. The slight increase in silt size and sand size content support the marginal formation of aggregation due to addition of salts.

Conclusions

A detailed study of some natural Cochin Marine Clays has shown that these clays have properties which are peculiar to them. The following conclusions which are believed to be of general interest may be drawn for the above study.

(1) In spite of testing samples from varying depths and from different locations which are far apart, their physical properties are quite comparable. Most of these clays have the natural water content very near to their liquid limits, eventhough they are normally consolidated.

(2) The grain size distribution of these clays show that they have low sand content and almost equal amount of silt and clays.

(3) The activity of these clays ranges from 1.37 to 2.47 which could be classified as active clays.

(4) The liquidity index for these clays varies over a range of 0.51 to 0.87 suggesting that these clays are medium to very sensitive.

(5) The shrinkage limit is quite high when compared to the liquid and plastic limits, suggesting the presence of flocculant fabric.

(6) The free swell index of these clays is quite high and could be classified as moderately swelling.

(7) The calsium carbonate percentage varies from 14.0% to 23.5%. The organic content is not high (less than 9%).

(8) The physical properties get significantly affected by air or oven drying. Both the liquid limit and free swell index decreases drastically. While there is a marginal decrease in plastic limit, the shrinkage limit increases by reasonably high percentage. The changes in the physical properties have been attributed to aggregation of finer particles. These aggregation cannot be easily broken by soaking the soil, even upto about two months.

(9) Irrespective of the condition of the soil—naturally moist, air dried or oven dried, there seems to be a unique relation between liquid limit and plasticity index which is close to Casagrande's "A" line.

(10) The results of grain size distribution reveals that silt size fraction increase significantly due to air or oven drying. The dispersing agent plays a decisive role in obtaining the grain size distribution curve. With the addition of dispersing agent, "flocs" of clay particles get broken resulting in higher percent of clays. The clay flocs are not easily broken by stirring the clay slurry.

(11) The natural moist active clays become normal—inactive clays on air or oven drying.

(12) Removal of salts by washing reduces the plasticity characteristics, although marginally.

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