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Technical Note

Role of Iron Oxide on the Shear Strength Behaviour of Lateritic Soils

by

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Introduction

Lateritic soils are extensively encountered in India and in many parts of the world. In India, they occur widely in the Western region and along the coastal zone of Kerala and Goa. In Kerala lateritic soils are wide spread in the central zone with hills and valleys gradually rising to Western Ghats. High temperature and tropical monsoons observed in this state are ideally suited for the formation of lateritic soils. According to Alexander and Cady (1962) lateritic soil is a highly weathered material rich in secondary oxides of iron, aluminium or both. It is nearly devoid of bases and primary silicates but it may contain large amounts of quartz and kaolinite. Attempts have been made by various investigators to formulate criteria for identification and evaluation of lateritic soils for engineering purposes (Gidigasu, 1975), Townsend, 1985). Adoption of standard classification system based on particle size and plasticity tests has proved to be misleading for these soils, because of the following reasons :

(1) These classification systems may not yield reproduceable results, since their behaviour is highly influenced by degree of drying, time of mixing, testing procedures etc. (Terzaghi, 1958, Gidigasu and Yeboa, 1972, Townsend, 1985 etc.) and

(2) They exist in various stages of weathering. The index property tests carried out on these soils do not give adequate indications of their engineering properties without including, degree of decomposition and laterization (Lohnes *et al*, 1971, Gidigasu 1974).

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The iron oxide present in these soils is considered to play a key role in cementation and aggregate formation and affects their engineering behaviour significantly (Townsend *et al* 1969, Townsend *et al* (1971), Townsend 1985, Rao *et al* 1988). Moh and Mazhar (1969) have shown that, increasing the degree of laterization results in an increase in the thickness of free iron oxide coating of soil particles. These particles later get coagulated into particles of larger specific surface. However the information regarding the influence of iron oxide on the engineering properties of Kerala laterites are scanty. In this paper an attempt is made to highlight the role of iron oxide on the engineering behaviour of lateritic soils. Soils for this study have been collected from a location in Calicut district, Kerala State. Based on the various experimental results obtained from the present study the influence of iron oxide on the physical, physico-chemical and shear strength behaviour of lateritic soils are examined in detail.

Experimental Work

Lateritic Soils of Kerala

Lateritic soil is found in various parts of Kerala. The eastern border of Kerala is well marked by the mountain ranges, of the Western ghats, varying in height between 600 m and 1800 m with a few peaks rising still higher. This strip between mountain range and Arabian sea is only 20 km to 80 km wide. This is longitudinally divided into three regions. The coastal region is low lying and sandy with a few peaks of laterites at some places. The central zone is an undulating region of lateritic hills and narrow valleys, gradually rising to Western ghats. In the elevated region of the east, gneiss and charnokites form irregular mountain ranges, covered most of the places by lateritic coping. Gneiss of various types forms the important rock type in this region and the main constituents of these rocks are quartz, feldspar, hornblende, mica, magnetite and haematite. The lateritic soils occur in the continuously cemented vesicular type to the concretionary form with a little or no cohesion. Based on the available data on the engineering properties it is observed that the liquid limit of these soils varies from 38 percent to 54 percent with most of the values lying in the range of 45 percent to 50 percent. Plasticity index is in the range of 10 percent to 13 percent with extreme values varying from 6 percent to 18 percent. Plastic limit usually lies between 30 percent to 40 percent.

Soil for the Present Study

In the present investigation, soils which have undergone different degrees of weathering have been obtained by collecting samples at different depths from a laterite quarry. This quarry was located 20 km North of Calicut city, nearer to Regional Engineering College, Calicut campus. Disturbed and undisturbed samples were collected at depths of 0.2m, 0.6m and thereafter at every 0.6 m up to 4.8 m below ground level. The soil profile at various locations are shown in Fig. 1. Also shown in this figure are

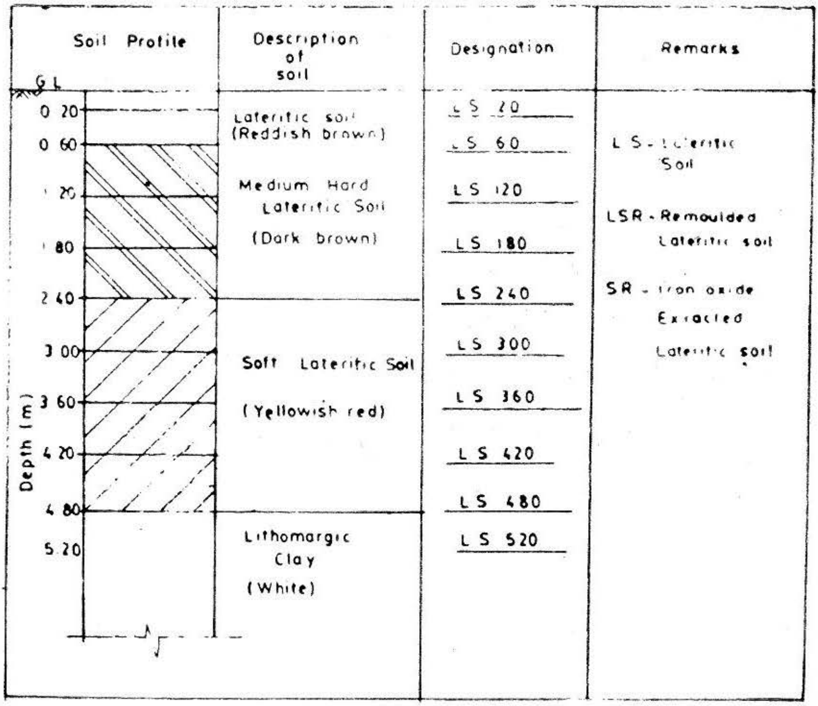

FIGURE 1 Soil Profile Studied

the designations of the various samples used in the investigation. Both undisturbed and disturbed samples collected from the field were sealed properly to avoid moisture loss during transportation and storing period.

From the profile shown in Fig. 1 it is seen that from the ground level up to a depth of 0.6m lateritic soil, dominant in gravel exists. From 0.6m to a depth of 2.4m medium hard laterite was observed. From 2.4 to 4.8m soft laterite was seen. From 4.8m onwards, lithomargic clay is observed.

Tests for Physical and Physico-Chemical Properties

Physico-chemical properties were determined by carrying out X-ray diffraction pattern, determining soil pH, organic matter and iron oxide content.

X-ray diffraction patterns were obtained using Phillips diffraction unit, by Cuk-L radiation. Clay fractions collected after dispersion were magnesium saturated, glycol solvated and oven dried before taking the X-ray diffraction pattern.

pH of the soil sample was measured in a soil slurry (soil : water = 1 : 1) using standard pH meter. Organic matter was removed from the soil using the standard hydrogen peroxide method. The organic content was determined by obtaining the loss of weight after removal of organic matter. Iron oxide was extracted from the samples by dithionite-citrate-bicarbonate method (Mehra and Jackson, 1960). Soil obtained after three extractions was found to be completely free from iron oxide, which was used in various tests for identifying the influence of iron oxide.

Tests for Atterberg limits, grain size analysis etc. were carried out as per IS standards. The results presented in this paper are the average of the two tests carried out.

Tests for Shear Strength Behaviour

Shear strength behaviour was studied by conducting consolidated drained direct shear tests. Effective shear strength parameters were determined by conducting strain controlled consolidated drained strength tests in a box shear apparatus. Shearing was done after the consolidation under normal stress was complete. The speed of the test (0.001mm/min) adopted was such that no pore pressure was developed during the test.

Results and Discussion

Fig. 2 presents a typical X-ray diffraction obtained for the soil sample collected at 4.2 m (LSR 420) depth. Soil specimens collected from other depths also show the same pattern. Clear prominant peak at 7.24° showed that kaolinite is dominant in this soil. Presence of gibbsite, geothite and quartz was also seen in the silt fraction of this soil.

Physical and Physico-Chemical Properties

The variation of natural moisture content, in-situ bulk density, *pH*, organic matter and iron oxide with depth is presented in Table 1. From this table it can be seen that the natural moisture content varies from 16 percent to 26 percent. Natural moisture content was found to be increasing with depth. Not much conclusion can be drawn from this variation in natural moisture content, since soil collection was done in a rainy season which leads to high natural moisture contents. The rain water might have percolated down showing high natural moisture content at greater depths. Presence of clay fractions in large quantities in these layers also would have contributed for this change. Bulk density of the specimen was found to increase slightly with depth (From 1.74 gm/cc to 1.9 gm/cc). Soil samples were found to be acidic throughout the depth and *pH* was found to vary from 5.0 to 5.9. Soil nearer to ground layer (Top 1.5m to 2.0m) was found to be rich in organic matter. Percentage Organic matter in this layer was found to vary from 12 percent to 14 percent. This high organic content was attributed to the presence of decayed vegetation seen in the site. The soil was rich in iron oxide throughout the depth. Iron oxide was found to vary from 10 percent to 21 percent.

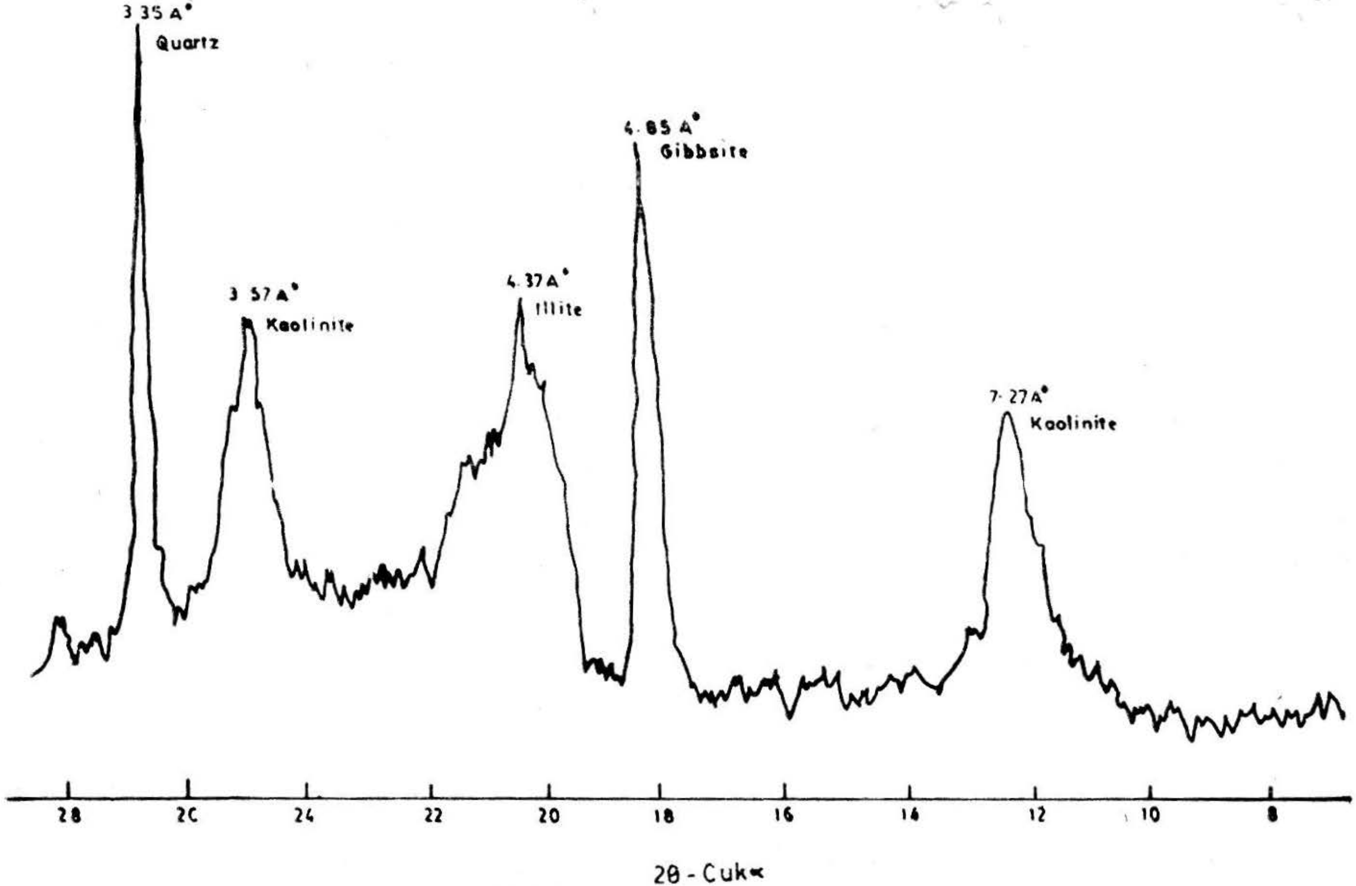

FIGURE 2 Typical X-ray Diffraction Pattern-Depth of Sampling 4.2 m

TABLE 1

Variation of Natural Moisture Content, Bulk Density and Physico Chemical Properties with Depth

Depth of sampling 'm'	Designation	Natural moisture content (%)	Bulk density (gm/cc)	pH	% Organic matter	% Fe_2O_3
0.2	LS 20	16.0	1.8	5.1	14.0	21.0
0.6	LS 60	16.3	1.9	5.2	12.0	20.8
1.2	LS 120	18.4	1.78	5.9	10.0	18.4
1.8	LS 180	16.0	1.76	5.9	4.0	17.3
2.4	LS 240	16.8	1.74	5.5	—	15.3
3.0	LS 300	18.1	1.80	5.7	—	12.2
3.6	LS 360	21.3	1.77	5.0	—	11.4
4.2	LS 420	26.4	1.75	5.3	—	10.1

Table 2 presents the results of the tests carried out for physical properties. Results from the tests for particle size analysis showed that gravel and sand particles are dominant in comparison to silt and clay fractions. Clay content was less for the samples from top layer and is found to increase with depth. A comparison of grain size distribution of original samples with those obtained after iron oxide removal showed that in all cases, iron oxide removal increases the clay content. The increase in the clay content can be attributed to the breaking of the bonds on iron oxide removal. Similar observation have also been obtained by previous investigators (Seshagiri Rao and Raymahashay, 1981, and Rao *et al* 1988).

Table 2 shows that both liquid and plastic limits decrease with depth. Liquid limits vary from 43 percent to 71 percent and plastic limits from 22 percent to 30 percent. It can also be seen from the table that both liquid and plastic limits decrease on iron oxide removal inspite of its increase in clay content. This may probably be due to the fact that on removal of iron oxide soil becomes less flocculated, which in turn reduces liquid and plastic limits (Townsend, 1985, and Rao *et al* 1988).

Fig 3 is the plasticity chart showing the position of the soil samples studied in the natural state and after iron oxide removal. It can be seen that most of the soil samples studied lie above A-line in medium to high compressibility zone. It is interesting to note that even after removal of iron oxide soil remains above A line, but the position changes from high

TABLE 2

Variation of Physical Properties with Depth

Depth of sampling (m)	Designation	Grain size analysis (%)				Liquid Limit (%)	Plastic limit (%)	Plasticity index (%)
		Clay	Silt	Sand	Gravel			
0.2	LS 20	8	15	45	32	53.5	30.0	23.5
0.6	LS 60	3	9	48	40	57.5	28.0	29.5
1.2	LS 120	2	8	46	44	52.6	22.5	30.1
1.8	LS 180	3	14	53	30	43.0	39.0	14.0
2.4	LS 240	4	19	53	24	45.5	26.0	19.5
3.0	LS 300	5	18	47	30	51.0	26.0	25.0
3.6	LS 360	8	15	56	21	47.5	24.0	23.5
4.2	LS 420	19	24	41	16	69.5	28.0	41.5
4.8	LS 480					71.0	30.0	41.0
0.6	SR	66	14	20		18.0	11.4	6.6
4.2	SR	31	18	51		38.0	18.0	20.0

compressibility zone to low compressibility. The decrease in the plasticity characteristics inspite of increase in the clay content can be attributed to the decrease in the degree of flocculation on iron oxide removal.

Effective Shear Strength Parameters

Stress-strain-volume change behaviour was studied from a series of strain controlled drained shear tests. Typical stress-strain curves obtained for the LSR 420 samples are shown in Fig 4. Similar curves are obtained for other samples also. It can be seen from this figure that no clear peak exists in the stress strain curve and the behaviour is similar to normally consolidated clays (Table 3). Initial tangent modulus of the stress strain curves are found to increase with the normal stress for all the samples studied. Samples collected from bottom layers fail at smaller strains which are typical behaviour of cemented soils. The above observation corroborates the results obtained in the previous sections that, in the top layer iron oxide exists in the form of inert material where as in the bottom layers it exists as a cementing material. Table 3 presents the shear strength parameters obtained for samples collected from different depths. It can be seen from this table that the shear strength parameters of undisturbed and remoulded samples varied only marginally in the samples collected from the top layers whereas

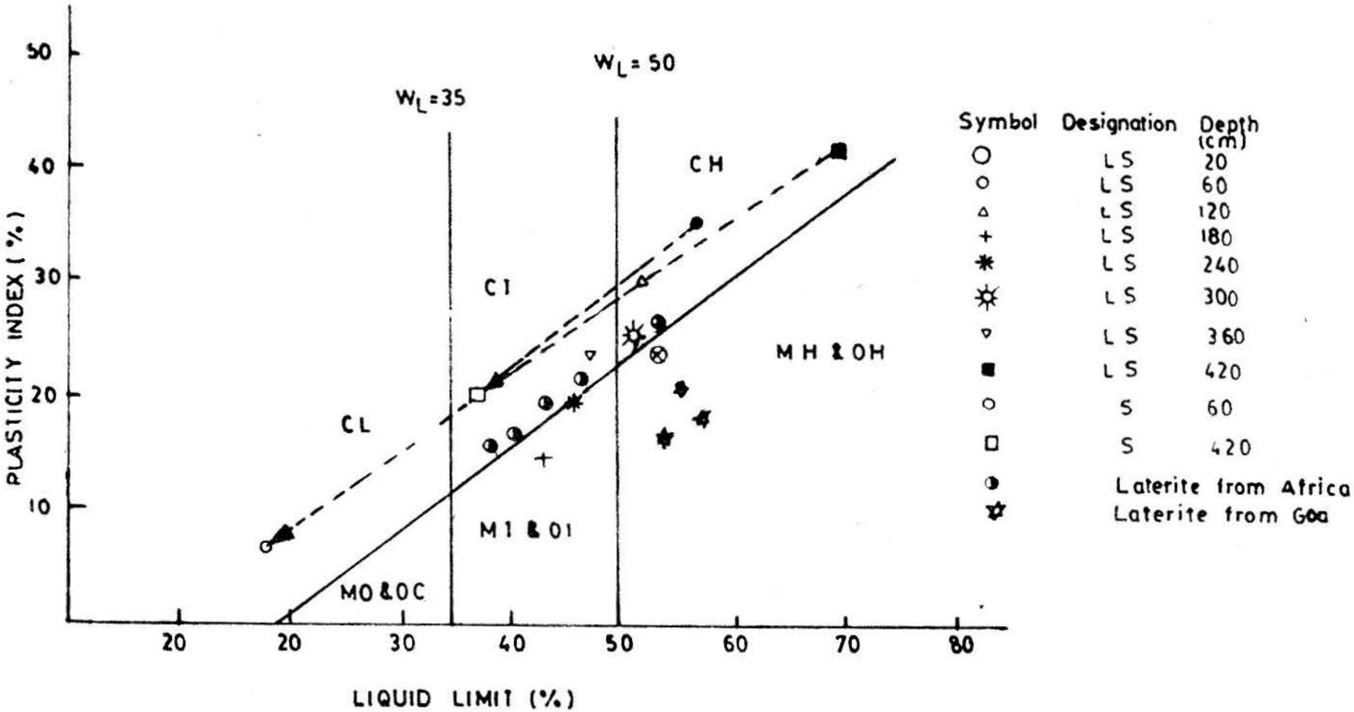

FIGURE 3 Plasticity Chart showing Representative and Iron Oxide Removed Samples

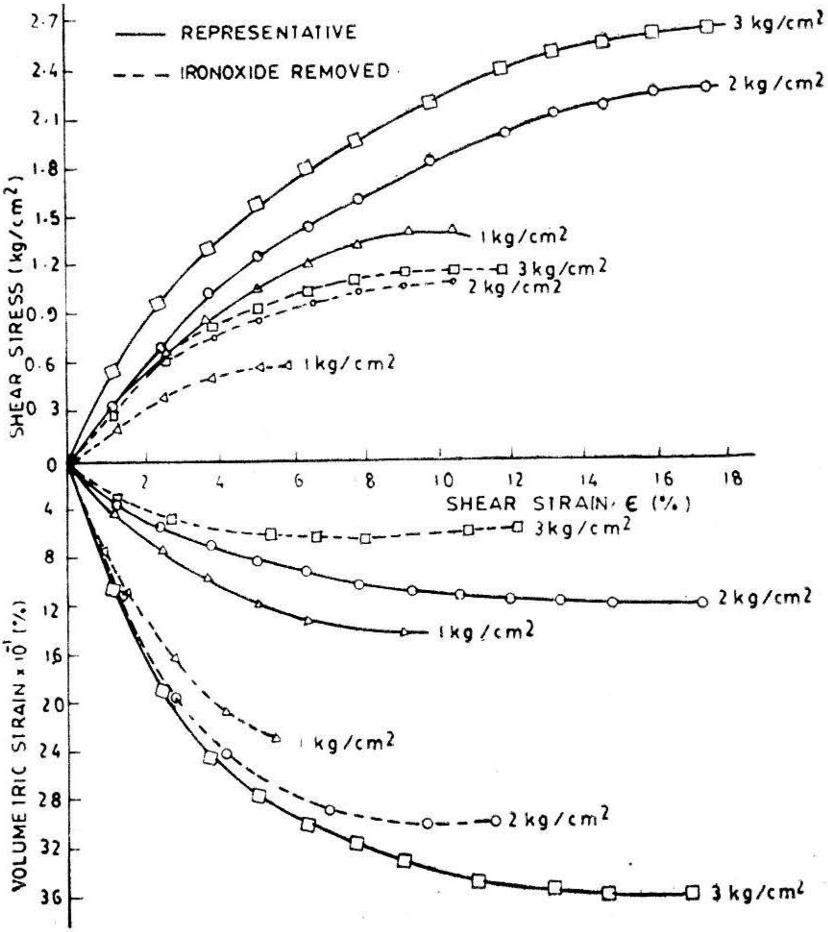

FIGURE 4 Stress-Strain Volume Change Behaviour of Soil Samples Before and After Iron Oxide Removal—Depth of Sampling 4.2 m

significant difference in shear strength parameters was observed in the samples obtained at greater depths. This may be due to the reason that in samples from greater depths the natural bond might have broken on remoulding.

A comparison of shear strength parameters obtained from tests conducted on remoulded samples, obtained after iron oxide removal showed that the angle of shearing resistance decreases significantly after iron oxide removal. It may be noted that density and moisture content were maintained constant for both the samples during remoulding. The higher shear strength of natural samples can be attributed to the presence of iron oxide. Iron oxide present in the natural samples (which varied from 10 percent to 20 percent) gives a more flocculated and rigid structure to the soil which in turn increases the shear strength of the soil. It can also be

TABLE 3

Results of consolidated Drained direct shear test On Soils obtained at depths of 0.6 m and 4.2 m

Depth of sampling (m)	Designation	Condition	Normal stress (Kg/cm^2)	Maximum shear stress (Kg/cm^2)	Shear strain at failure (%)	Volume strain at failure (%)	Cohesion C (kg/cm^2)	Angle of shearing resistance ($\phi°$)
0.6	LS 60	Undisturbed	1	0.90	15.0	2.1		
			2	1.53	15.3	1.8	0.25	32.5
			3	2.66	18.6	1.9		
0.6	LSR 60	Remoulded	1	1.10	8.0	—		
			2	1.70	6.6	0.6	0.40	31.0
			3	2.50	7.8	0.7		
0.6	SR 60	Iron oxide extracted	1	0.5	11.0	4.4	0.30	9.6
			3	0.8	8.0	0.7		
4.2	LS 420	Undisturbed	1	1.16	5.3	—		
			2	1.40	8.0	—	0.6	26.3
			3	1.70	4.0	—		
4.2	LSR 420	Remoulded	1	0.5	10.0	4.3		
			2	1.0	11.3	4.2	0.1	26.5
			3	1.6	12.0	0.7		
4.2	SR 420	Iron oxide extracted	1	0.6	5.3	2.3		
			2	1.6	10.3	3.1	0.2	15.8

noted that even though the soil collected from the top layer has larger iron oxide content than in the soils collected from the bottom layer, its shear strength is low in comparison to the samples collected from the bottom layer. The iron oxide present in the form of large granules in the top layer exist as inert material and/or as an incrustation of gravel size particles whereas in the bottom layer iron is present in small quantities in the form of cementing material and develops higher shear strength. From these it can be inferred that it is the form of existance of iron oxide and not the total iron oxide content in the soil present that influences the shear strength behaviour of lateritic soil.

Conclusions

From the investigations carried out for studying the influence of iron oxide on the physico-chemical aspects and shear strength behaviour of lateritic soils, the following conclusions may be drawn.

1. Kaolinite forms the major mineral constituent of the lateritic soils. The other minerals present are gibbsite, geothite and quartz. Alumina is present as gibbsite, iron as geothite and silica as quartz.

2. The stress-strain characteristics of lateritic soils in the top layer are similar to those of normally consolidated clays and in the bottom layers, to those of cemented soils.

3. The lateritic soil used in the present investigation is rich in iron oxide (10 percent to 21 percent). Its percentage is more in the top layer and less in the bottom layer. The iron oxide is present in the top layer, as an inert material and in the bottom layer it exists as a cementing material. The iron oxide present in the bottom layer acts as a cementing material and increases the shear strength.

4. It is the form and existance of iron oxide and not the total iron oxide present in the soil that influences the engineering behaviour of lateritic soil.

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