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A Study of the Engineering Properties of Bhubaneswar Laterite Soils

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Abstract. Laterite soils are one of the predominant soils found in the eastern and southern region of Odisha. These soils are known to display a wide range in their engineering characteristics like plasticity, permeability, shear strength etc. Bhubaneswar is one of the fastest developing cities in eastern India and large parts of the city are underlain by a lateritic soil. In this study, laterite soils sample were collected from four different parts of the city and their index properties and engineering properties like plasticity, percentage of fines, shear strength parameters (under dry and wet conditions), compaction characteristics and permeability were studied. These were accomplished using methods like the standard proctor test, direct shear testing and falling head permeability testing. From the study it was found that the soils had high values of maximum dry density, moderate permeability and low to medium shear strength characteristics. It was observed that while the engineering parameters varied in a fairly narrow range, they were mainly affected by the fines content of the soil. Investigations like this can be used for a general understanding of soil properties in the Bhubaneswar region for future infrastructural projects.

Keywords: Laterite soil; shear strength; permeability, compaction

1 Introduction

Laterite soils and rock are found in several parts of eastern, western and southern India. The city of Bhubaneswar, which is situated in the eastern part of Odisha has a large amount of laterite soil. These soils have a significant amount of Iron and Aluminum oxides in the hydrated form, which give them their characteristic reddish to reddish-brown colour. In addition to iron and aluminium oxides, lateritic soils also contain some fraction of clay (especially kaolinite) and silica (Varma et al., 2020) [1]. In general Laterite soils are found in several tropical regions of Asia, Africa and South America where there is a lot of heat and precipitation. The environmental conditions lead to severe weathering of parent rocks, generally rich in iron, alumina, manganese etc resulting in laterite soil formation (Oluermi et al., 2017) [2] (Oluremi et al., 2020) [3].

Laterite soils have diverse physical and mineralogical properties. Among this, higher permeability, poor nutrient concentration and acidic nature have been known to be some of the characteristics of the lateritic soils of Odisha. Due to the deficiency in nutrients like nitrogen, phosphorus etc, these soils are often considered to have low fertility. The particle size is known to vary from sandy loamy to clayey (Soils of Orissa and its management, 2005) [4]. Several researchers investigated the properties of laterite soils and suggested means to stabilize these soils or improve their specific engineering properties. Hegde and Daware (2010)[5] explored the effect of alternate wetting and drying cycles on the bearing capacity and plasticity of laterite soils found in the Konkan region of India. Ademila (2017)[6], studied the failure of several highways in Nigeria and found that subgrade soils with high fines content, high water absorption and low shear strength parameters were causing damages in the pavements. Latifi et al. (2017)[7], found that the addition of chemical stabilizers like TX-85 and SH-85 to a clayey laterite soil can increase its strength within a short time, making them a viable option for engineering projects. Saing et al. (2018) [8] showed that, laterite soils subjected to 10% lime treatment and 28 days of curing lead to a significant improvement in their bearing capacity.

The objective of this study was to study the geotechnical properties of laterite soils found in the Bhubaneswar region, to get a general appraisal of the characteristics of laterite soils in this region. For this purpose, laterite soils samples were collected from four different parts of Bhubaneswar city properties such as plasticity, grain size distribution, shear strength, compaction characteristics and permeability were investigated. Any variations in the engineering properties with respect to basic features like grain size, plasticity etc were studied.

Fig 1. A sample of laterite soil used for the study

2 Experimental Program and Materials

For this study laterite soil samples were collected from four different locations in Bhubaneswar, namely i) Kharavela Nagar ii) Bapuji Nagar iii) Kalinga Nagar iv) Mahura. These soils samples were designated as Soil1, Soil 2, Soil 3 and Soil 4 respectively. The samples were collected in bags of approximately 10-15 kgs and brought to the lab for study. As most of the samples were collected during the Monsoon month of September, they had small amount moisture. The samples were spread out in large trays and oven dried before carrying out subsequent testing.

After oven drying, all the oven-dried soil samples were initially passed through the 4.75 mm sieve, to take out any stone sized materials. Wet sieve analysis was done on the samples to determine the percentage of fines. The grain size analysis revealed the soils to be predominantly coarse grained. The wet sieve analysis was followed by specific gravity tests and Atterberg limits tests. Shrinkage limit tests were not performed as the soils were not very clayey in nature. Literature suggests that laterite soils are generally not expansive in nature (Netterberg, 2014) [9], (Latifi et al., 2017). Kaolinite is the main clay mineral present in lateritic soil. All these basic soil properties determined are listed in table 1.

These tests were followed by engineering tests. Standard proctor tests were performed to determine maximum dry density and optimum water content for the soils. As the samples were found to be more on the coarser side, the compaction tests were started with around 8% initial moisture content and the water content was increased by intervals of 2.5%. The test was performed using the IS light compaction mold and hammer.

Direct shear tests were performed on all four samples to measure the shear strength parameters (friction angle and cohesion). The tests were conducted at loads of 0.5 kg/cm^2, 1.0 kg/cm^2 and 1.5 kg/cm^2. The first set of tests was conducted on dry samples. The next set of tests was conducted on moist samples, with a water content of 4% above OMC. This water content was chosen arbitrarily, to see the effect of wetting of soil on its shear strength. Shearing was performed under drained conditions.

Lastly permeability tests were conducted on the samples to determine their coefficient of permeability (k). The falling head permeability apparatus was used because of the presence of around 35% fines content on an average. The samples were compacted in three layers inside the standard permeameter using a tamping device. Fig 2 shows the reservoir and the permeameter used for the test. In the following section, the results from all the tests are discussed.

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Fig 2. Compaction test and permeability test being conducted on the soil samples

3 Results and interpretation

The results from the basic characterization tests performed are shown in table 1. The results show that all the four soils have coarse fraction of more than 50%, classifying them as coarse-grained soils. The Atterberg limits showed that the samples had a low to intermediate plasticity. The liquid limit varied from 28.7 to 39.2, whereas the plastic limit varied from 15.0 to 25.6.

Table 1. Basic properties of the four laterite soil samples

Soil sample	**Coarse fraction (%)**	**Specific gravity**	**Liquid limit (%)**	**Plastic Limit (%)**
Soil 1	62.4%	2.58	35.2	25.1
Soil 2	74.1 %	2.55	26.5	15.0
Soil 3	56.0 %	2.54	28.7	21.2
Soil 4	66.5 %	2.61	39.2	25.6

The results from the standard proctor compaction tests revealed that the maximum dry density of the samples was between 1.7 g/cc to 2.05 g/cc. The plots of dry density versus moisture content are shown in figure 3.The corresponding optimum moisture contents varied from 8% to 15%, a range typical for soils with lower clayey fraction. These results point towards the fact that the soil has a potential to attain high densities through compaction. Although CBR tests were not conducted on these soils, literature suggests that CBR tests conducted on laterite soils in different countries in Africa showed very high CBR values for samples prepared at OMC and MDD. Empirical correlations were proposed to determine CBR values from OMC, MDD and plasticity index of soils (Netterberg, 2014).

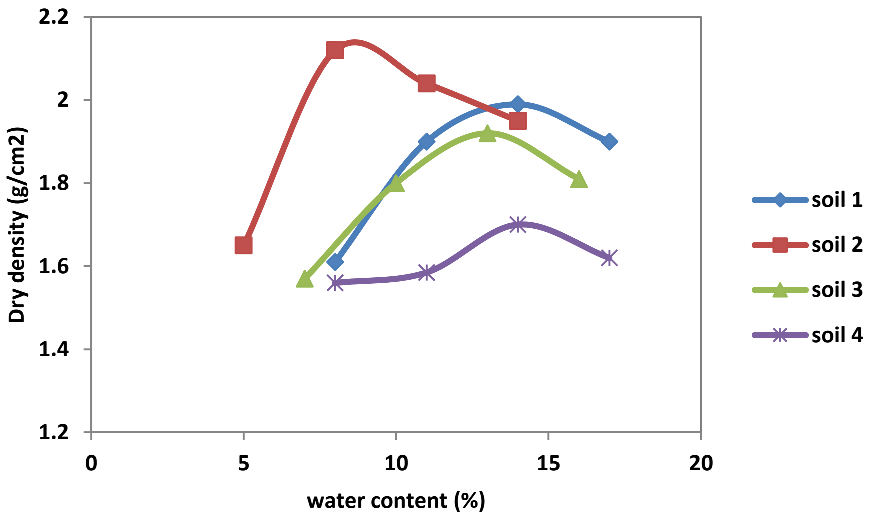

Fig 3. Compaction curves for the four soil samples

Fig 4 shows the results of direct shear testing on the four soil samples. The results from direct shear testing showed that the friction angles (φ') of the soils were generally low and varied from 18.8° to 25.9° (shown in Table2). Sample 1 had the lowest φ value of 18.8° and sample 2 had the highest φ' value of 25.9°. Figure 5 shows the results from direct shear tests conducted on the samples in wet condition. For the wet samples it was observed that the drained friction angle was reduced. The φ' values varied from 8.6° to 14.1° in this case.

For both the dry and wet soils, the direct shear testing showed the presence of a small amount of cohesion between 0.12 kg/cm^2 to 0.27 kg/cm^2

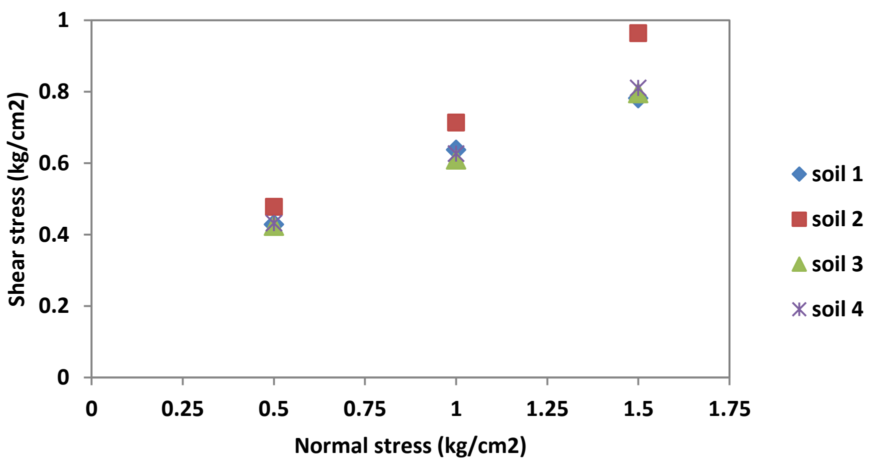

Fig 4. Results of direct shear testing for the dry soil samples

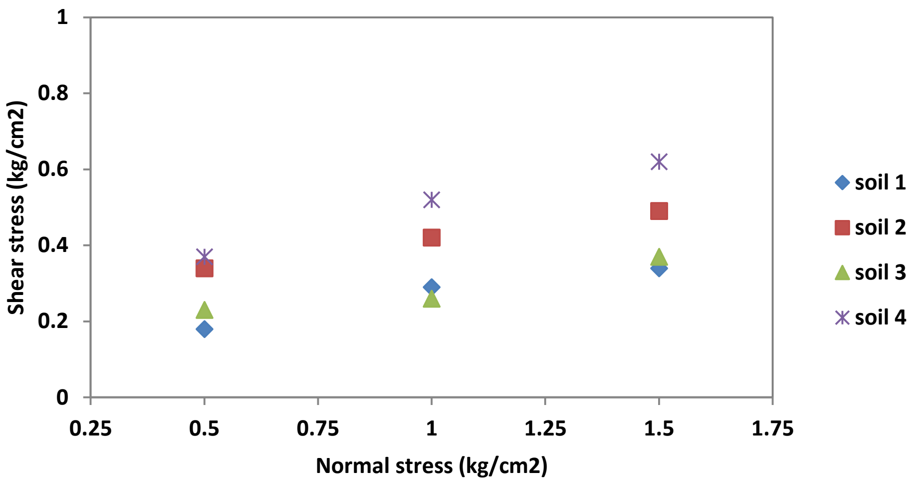

Fig 5. Results of direct shear testing for the wet soil samples

Lastly, the permeability of the soils was examined. The falling head test setup was deemed suitable for the soils, considering the amount of fines content the soils were having. The results from the test are shown in Fig 6. It is seen that the permeability of the soils was of the order of 10^{-4} cm/s to 10^{-3} cm/s. Soil 1 had the highest permeability of 2.9 x 10-3 cm/s and soil 3, which had a higher amount of fines fraction, had the lowest permeability of 5.8 x 10-4 cm/s.

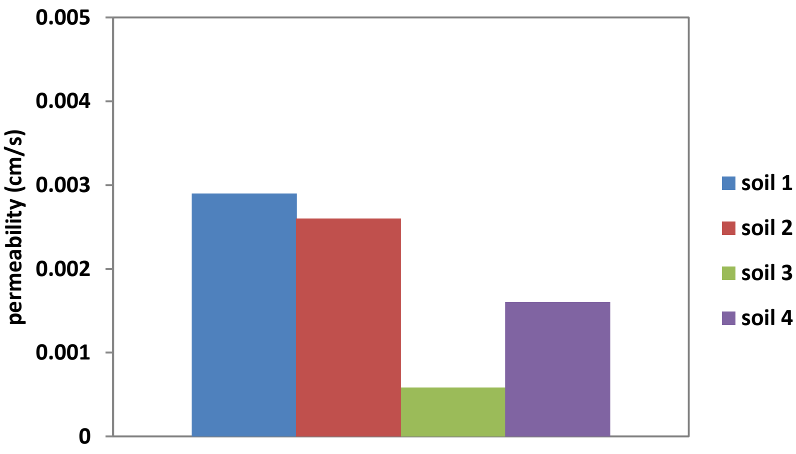

Fig 6. Results of falling head permeability test of the samples.

The results from all the engineering tests are summarized in the table below. It was found that the laterite soils tested had a medium-high range of max dry density indicating that the soils have a tendency to be compacted to high densities on application of mechanical effort. The soils have a low value of cohesion and a generally low friction angle. The results show that the soils could be categorized as low to medium shear strength soils.

Among the basic soil properties, coarse fraction appeared to be a major factor influencing the engineering behavior of the soils. Both the permeability and friction angle (for dry soil) showed an increase with coarse content. These finding appears reasonable as coarse soils are generally known to have a higher permeability and friction angle. MDD increased and OMC decreased with coarse fraction but only at a higher value. Again, this aspect reflects the behavior typical to coarse grained soils. These relationships are shown in Fig 7.

Table 2. Engineering properties of the four laterite soil samples

Soil sample	**OMC (%)**	**MDD (g/cm^3)**	**Φ' (dry) (degrees)**	**Φ' (wet) (degrees)**	**c (dry) (kg/cm^2)**	**c (wet) (kg/cm^2)**	**Permeability (cm/s)**
Soil 1	14.0	1.99	18.8	8.7	0.27	0.12	2.9×10^{-3}
Soil 2	9.1	2.12	25.9	8.6	0.22	0.26	2.6×10^{-3}
Soil 3	12.8	1.91	20.5	7.6	0.21	0.15	5.8×10^{-4}
Soil 4	14.2	1.70	21.2	14.1	0.22	0.25	1.6×10^{-3}

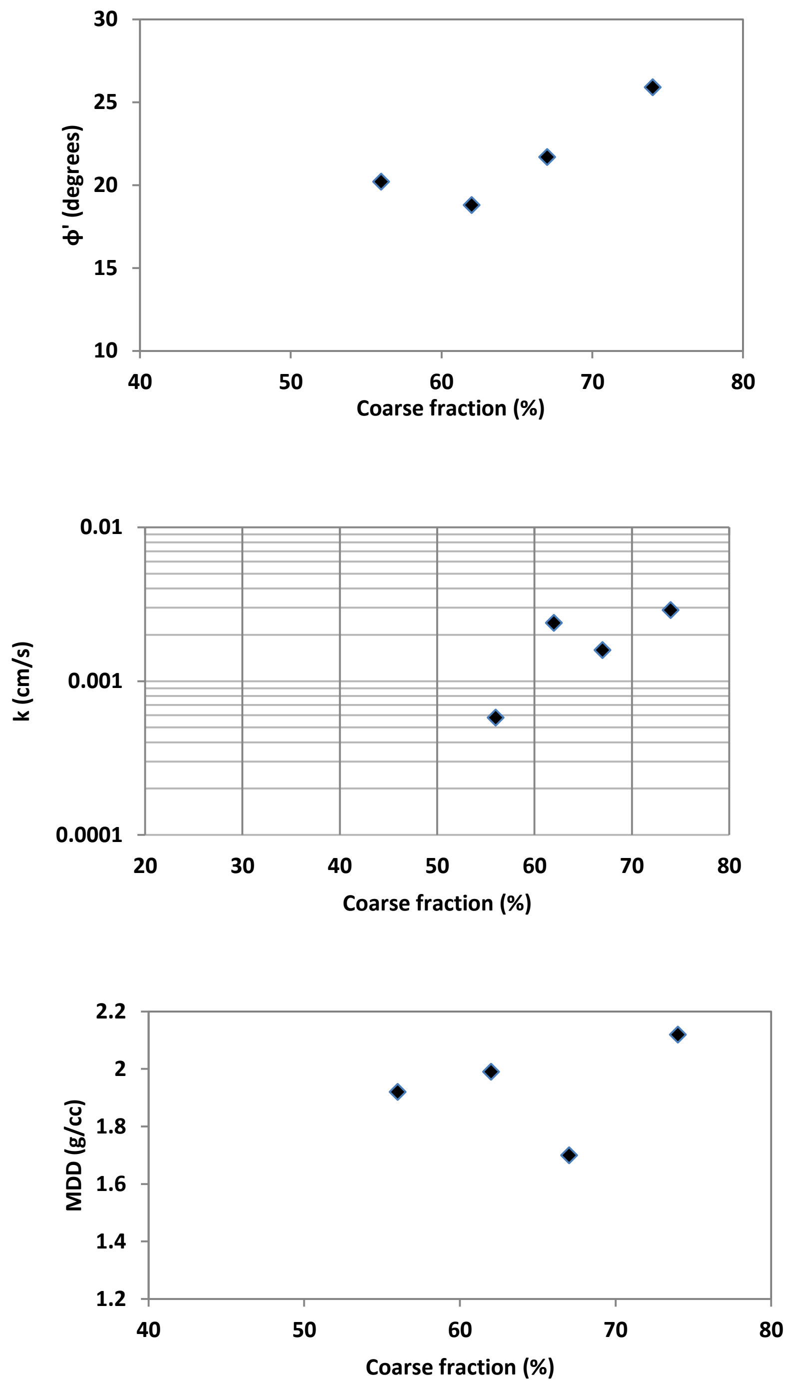

Fig 7. Variation of a) friction angle b) permeability c) MDD with coarse content

4 Conclusion

From the study it was observed that the four laterite samples collected from Bhubaneswar city had a predominant coarse-grained fraction. They had a low to intermediate plasticity. The high values of maximum dry density observed point towards the fact these soils make good highway subgrade and fill material. However, these soils do not possess a high shear strength and the strength is further lost upon wetting. Care must be taken while constructing on these soils, especially where there is a risk of frequent water inundation. The soils have a moderate to high permeability, which might make them consolidate faster than high plasticity clayey soils.

Overall, the laterite soils of Bhubaneswar region appear to make moderately good material for foundation and highway construction. However, engineering properties can be enhanced by mechanical or chemical stabilization Further studies must be conducted to investigate other properties of Bhubaneswar laterite soils such as CBR values, Triaxial shear strength tests (CU and CD), and consolidation. The results can be compared and correlated with any available field data such as SPT or CPT. These kinds of investigations could be useful for future infrastructural projects or research work in eastern India.

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