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Behaviour of Lateritic Soils – A Characterisation Study

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ABSTRACT: Lateritic soils, also called as red soils, are residual soils found in the tropical and sub-tropical regions. They are widely used in construction especially in pavement construction as sub-grade, sub-base or base-course, in earthen embankments or in the form of laterite blocks for building construction purpose. The properties of such soils are highly variant in nature and depend on various factors such as properties of parent rock material, climate and rainfall, topography, age of the deposits, vegetation etc. Alternate wet and hot seasons are mandatory for their formation and hence such soils are confined to the tropical and sub-tropical regions of the country. For a geotechnical engineer, to ensure the safety on quality of the material used, the properties and the behaviour of such soils under different practical situations must be known. This study is an attempt to review and compile the findings of the various researches carried out across the world regarding the behaviour of lateritic soils, the factors affecting their formation, the classification of lateritic soils, the different engineering and index properties of lateritic soils etc. to get a better understanding of the nature of such soils, which are widely used for engineering construction activities in our country. The characterisation study conducted on two lateritic soil samples collected from two different locations from the Malabar region of Kerala, was carried out to analyse the basic geotechnical characteristics.

KEYWORDS: Laterites, Lateritic Soils, Weathering, Classification, Geotechnical Characteristics.

I. INTRODUCTION

Lateritic soils are residual soils found in tropical and sub-tropical regions of the world, derived by the continuous weathering process from the parent rock material named laterites. The tropical regions are characterised for their typical warm-humid climatic conditions that creates the natural environment for the origin of such deep and wide lateritic profiles which are having 'stable structural form with porous surficial horizon'; which on extensive weathering forms the residual lateritic soils. As the well-defined periodical cyclic wet and dry seasons give birth to latertic soils, their formation and characteristics at a particular region are significantly affected by the prevailing climatic and topographical conditions and hence the lateritic soils formed in different regions of the world vary significantly in their physical, chemical and mineralogical properties.

Need for the sustainable environment has made us think over choosing naturally available construction materials. The use of natural materials in construction work can prevent to some extent the increased pollution, waste generation and other related environmental impacts. Hence wherever there occurs a wide geographical distribution of residual lateritic soils, the same is been widely used as the major construction material in many of the geotechnical engineering applications such as highway and railway embankments, earthen dams, building construction etc. They are widely used as sub-grade, sub-base and base-course for low cost roads that carry low to medium traffic.

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Residual lateritic soils are extensively used as construction materials in geo-environmental engineering applications such as landfills. Good quality lateritic soils can also be used as the fill materials for earthen embankments and embankment dams. Lateritic blocks, commonly used for building construction in tropical regions, are naturally available, strong, durable and fire-resistant with low thermal conductivity. They ensure the sustainable building concept, for being environmentally friendly, energy efficient and economical [3], [5]. Thus lateritic soil can be considered as an ideal material for sustainable engineering applications.

II. OBJECTIVES

To a geotechnical engineer, the lateritic soils are very important, as they are widely used for construction in tropical and sub-tropical regions. But to ensure the safety on quality of the material, the properties and the behaviour of such soils under different practical situations must be well known; as their properties are observed highly variant in nature and are been affected by a number of parameters. The objectives of this research review report can be summarised as:

1. To study the behaviour of lateritic soils by reviewing the various available researches carried out so far on lateritic soils pertaining to their basic geotechnical characteristics and general behaviour and
2. To compare the basic geotechnical characteristics of two lateritic soils and to analyse the data for better understanding of the subject.

III. ABOUT LATERITIC SOILS

Laterite (commonly known as “red soils”) is used to cover all tropically weathered soils having varying proportions of particle size, ranging from clay size to gravel, usually coated with sesquioxide rich concretions [5]. The significant feature of the lateritic soils is their unique spectrum of colours, which can be used as their true visual indicator. The colour can vary from whitish pink to yellowish orange, saffron red, rusty red or even deep liver brown. Lateritic soils are rich in secondary oxides of iron, aluminum, and silica. They also contain appreciable amounts of cohesive binding material (commonly kaolinite). The colour is attributed to the presence of ion oxides. Ion oxides can exist in both the amorphous and crystalline inorganic forms, which defines the specific vesicular structure of laterites.

From literature study, the optimum conditions required for the formation of laterites include (1) high seasonal rainfall and high temperature causing intense chemical weathering and subsequent severe leaching, (2) strong acidic and oxidising environment, (3) sustained long duration weathering (4) a chemically unstable parent rock, (5) good internal drainage and (6) continuous supply of freshly formed sesquioxides of iron either from the underlying parent material or from an adjacent area of similar petrological environment.

The process of formation of laterites is called ‘laterisation’. This commences with the formation of cracks in the parent rock, as a result of prolonged cyclic processes of heating and cooling by rain and sun. The cracked parent rock will gradually undergo upper facial decomposition under the fundamental conditions that are requisite for the chemical and mineralogical alterations to happen, which ultimately results in laterisation. The formation of lateritic profiles is either from removal in solution through leaching of combined silica and bases along with the relative accumulation of sesquioxides. The upward movement of the accumulated sesquioxides leads to form ‘high-level laterites’ and the lateral movement of the sesquioxides leads to form ‘low-level laterites’. The choice between upward or downward movement of the sesquioxides depends on the local topography and drainage conditions.

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A. Factors Affecting the Formation of Lateritic Soils

Origin of laterites and thereafter the formation lateritic soils through the process of weathering is a complex phenomenon as it is dependent upon a number of environmental factors. The major factors influencing their formation are: (1) properties of the parent rock material, (2) climate, (3) topography, (4) vegetation, and (5) time. These are briefly explained below.

1. *Properties of the Parent Rock Material:* Adeyemi (1995), Giorgiset al.(2014) studied about the influence of parent rock properties on properties of lateritic soils and found out that the parent rock factor may cause a remarkable difference in the characteristics of the derived lateritic soils structurally as well as mineralogically [5]. The parent rock can be igneous, sedimentary or metamorphic by origin, but should have high amount of iron content, for the formation of lateritic soils to happen.

2. *Climate and Rainfall:* Climate at a region describes the temperature and rainfall pattern existing there. A tropical region which is having a deeply wet humid climate, with a mean annual rainfall of greater than 1500 mm, and also having alternately hot climate with mean annual temperature of between 20-30 °C, is expected to be having the highest rate of chemical weathering, which implies the significance of climate on latertic soil formation. The minimum annual rainfall required for laterite formation is suggested as 750 mm. The higher the rainfall above this value, the greater is the leaching effect and therefore increases the degree of laterization [5].

3. *Topography:* Topography controls the horizontal and vertical drainage conditions, as it controls the drainage conditions and hence the proportion of rainwater that infiltrates and leaches the weathered zone. Topography has a direct influence on the rate of surface erosion which again defines the quantity of soil deposited/accumulated. A gently sloping terrain with good drainage conditions always favours ample leaching and laterisation[5].

4. *Vegetation:* Laterites usually develop under conditions of high precipitation and thick vegetation. Vegetation works in two ways: (1) It prevents the surface run off and erosion, assisting in soil deposition and (2) It influences the rate of dehydration to a great extent, as the dehydration of the soil's colloidal hydrated oxides is an important step in the development of lateritic profile. It reduces thermal amplitude reaching the soil surface thus reducing the effect of soil heating and immediate dehydration

5. *Age:* The role of time in the formation of soils is very important. Since the geological ages of the parent materials vary greatly, ageing or the time of exposure of the parent material to soil forming processes will also have a major effect on soil development [6].

B. Occurrence of Lateritic Soils in India

As laterites and lateritic soils are formed in tropical countries, they are widely distributed in peninsular India over the places with warm-humid climate, covering a total area of around 2,48,000 sq. kilometres. The Deccan Plateau region, the Eastern Ghat region of Odisha, the Western Ghat region of Malabar, Karnataka, Kerala, Tamil Nadu, Madhya Pradesh, Maharashtra, and some parts of Assam contain lateritic soil.

In Kerala, both high level and low level laterites are available; the high level laterites being found in the hilly regions of Western Ghat in the Northern Kerala and the low level laterites at the mid-land areas of Southern Kerala. The Coorg region and Mysore regions in Karnataka and the Ratnagiri region in Maharashtra are also found with lateritic soils. In West Bengal, the area between the Damodar and the Bhagirathi is found with basaltic and granitic hills, with a laterite capping. The contents of potash, phosphorus and nitrogen are also low in such soils. In Bihar also, laterites occur principally as a capping [2].

IV. METHODOLOGY

Two lateritic soils (named as sample L1 and L2 respectively) have been selected for the comparative study, collected from two different locations from the Malabar region of Kerala. The geotechnical characterisation study for the basic index properties have been carried out for both the soil samples at the Central Soil and Materials Research Station, New Delhi.

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The basic index properties tested are: Particle size distribution by mechanical analysis, liquid limit and plastic limit (Atterberg Limits) determination, Specific gravity test (using density bottle method), Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) determination from the Standard Proctor compaction test. The tests have been conducted as per Indian Standard codalprocedures for all the above mentioned tests and the results obtained for both the samples are analysed.

V. RESULTS AND DISCUSSION

A. Mechanical Analysis Test (as per IS 2720: Part IV)

As both the soil samples were passing 4.75 mm sieve, the pipette analysis was carried out for the silt and clay fractions and wet sieve analysis for the sand portions (i.e. fine sand, medium sand and coarse sand) respectively. The test set up for mechanical analysis test is shown in figure1 below and the results obtained for both the lateritic soil samples tested are presented in the table I below respectively.



Fig 1. Test Set-up for mechanical analysis by pipette method

Table I. Results of mechanical analysis test

Details	\leq 0.002 mm (%)	0.002 to 0.075mm (%)	0.075 to 0.425 mm (%)	0.425mm to 2.00mm (%)	2.00mm to 4.75 mm (%)	≥ 4.75 mm (%)
Sample L1	41.4	9.6	20.6	25.2	3.2	Nil
Sample L2	60.1	18.1	13.1	8.50	0.20	Nil

Lateritic soils generally have a good representation of both the cohesive (i.e. fine-grained) and cohesionless (i.e. coarse-grained) portions of its particle sizes. Fine-grained portion comprises of silt and clay size particle with varying degrees of plasticity as indicated using the Atterberg Limits. Coarse-grained portion is characteristically non-plastic and comprises of sand size and larger particles and are segregated by mechanical sieving. The colluvial lateritic soils found in the immediate vicinity of the parent rock generally comprises of larger portion of gravel size particles.

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B. Atterberg Limit Test (as per IS 2720: Part V)

The liquid limit of both the soil samples were found out using the Casagrande's apparatus. The plastic limit was also found out by making them in to a thread of 3 mm dia. and 10 mm long. The results obtained are presented in table II below:

Table II. Atterberg limit test results

Details	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
Sample L1	52.7	35.5	17.2
Sample L2	56.5	34.8	21.7

As per the IS Classification System, both the lateritic soil samples L1 and L2, fell under the 'MH' classification, with plasticity index values below A-Line in the Plasticity Chart.

The clay mineralogy of different types of lateritic soils can be interpreted in the light of their genesis and pedogenic factors, degree of weathering, clay-size content and clay mineralogy. Liquid limit of both the lateritic soils tested got above 50 %. As per literature studied, the lateritic soils may fall above or below A-Line in the plasticity chart. Most of the fine grained lateritic soils usually fall in CH, MH or OH category.

The clay content (i.e. the percentage of clay fraction) of lateritic soils also is a very important factor as it determines the stability and compressibility of the soil, especially when used in engineering applications like in embankments or embankment dams. As pointed out by Gidigasu (1976), the lateritic soils which fall below the 'A' line category, i.e. the fine-grained lateritic soils, which contain clay or silt fractions, need to be well taken care of regarding their engineering properties when the soils are used for any construction purposes [5].

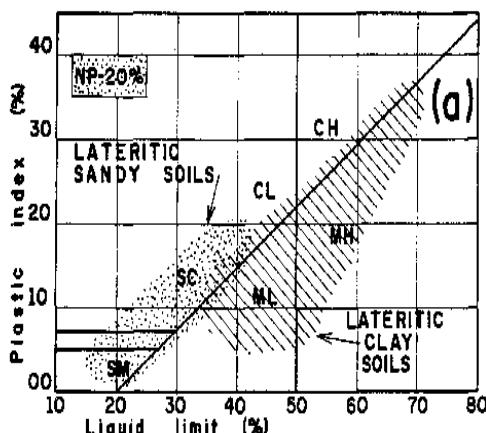


Fig 2. General position of lateritic fine-grained and coarse grained soils in the plasticity chart (after Nogami and Villibor, 1991)

C. Specific Gravity Test (as per IS 2720: Part II)

The specific gravity was determined in the laboratory by the Density Bottle method, using 50ml density bottle. The value obtained was 2.60 for both the samples. The specific gravity of lateritic soils falls within a wide range of about 2.40 to 3.50, as found from various literatures. High specific gravity test value is attributed to its high iron content. Again, it is observed that the iron content of high specific gravity minerals increases with age of formation and hence the specific gravity of lateritic soils should increase with increasing degree of weathering.

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In a well graded lateritic soil, the coarser particles will be having a higher value of specific gravity than the finer particles. Specific gravity depends significantly on the factors which are size of samples, position of samples in soil profiles, grading characteristics, mineralogical composition of parent rock materials, amount of iron content and accumulation of ferrous materials.

D. Compaction Test (as per IS 2720: Part VII)

The proctor density was found out in the laboratory using the Standard Proctor Compaction Test. The standard mould having 100 mm diameter and 127.3 mm height and of 1000 ml capacity was used . The soil was compacted in three layers with 25 numbers of blows to each of the layers, using a hammer of weight 2.6 kg by dropping from a height of 310 mm. The test set-up for Standard Proctor Compaction in the laboratory is shown in figure 3 below.



Fig3. Standard Proctor compaction test set-up and determination of moisture content

The maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for the samples obtained were: MDD of 1.68 g/cc for the sample L1 and 1.61g/cc for the sample L2 respectively. The OMC for L1 was 19.90% and for L2 was 20.80% respectively. The compaction curves showing the variation of dry density with variation in moisture content for both the samples are presented in figure 4 below.

The moisture density relationship in lateritic soils is affected by factors like degree of weathering, crushing strength of the gravelly materials formed, grading pattern, the amount and type of the prevailing clay mineral formed, placement condition of the material formed nature of the soil, particle size gradation, mineralogical composition, specific gravity, plasticity and amount of clay size content present. From the available literature reviewed, it is observed that the optimum moisture content of lateritic soils varies between 9% - 20% whereas maximum dry density vary between 1.3 g/cc - 2.4 g/cc.

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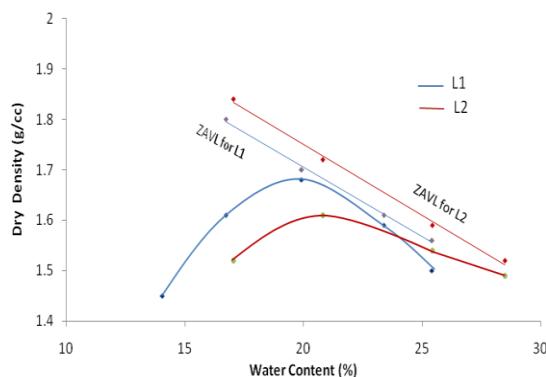


Fig 4. Variation of dry density with moisture content for the two soils

VI. CONCLUSIONS

From the literature review and the characterisation study carried out, the most important inferences regarding the geotechnical characteristics and general behaviour of lateritic soils can be drawn as below:

- Lateritic soils are residual red coloured soils, formed as a result of prolonged weathering of parent rocks of different origins, under sustained conditions of alternate warm and humid climates, prevailing in tropical and sub-tropical regions.
- Their formation depends upon so many factors like nature of the parent material, climate, rainfall, topography, vegetation, age of the deposit etc; each factor having its own impact on the soil formation.
- From the literature review study, the specific gravity of lateritic soils can vary within a wide range of about 2.40 to 3.50. Higher specific gravity value is attributed to its high iron content. For the two samples tested, the value of specific gravity obtained was 2.6.
- As per literature, the plasticity index of lateritic soils may fall above or below A-Line in the plasticity chart. Most of the fine-grained lateritic soils fall in CH, MH or OH category generally. Coarse-grained lateritic soils, may be of SW or GW type generally. In the present study both the samples tested were of MH category.
- The maximum Dry Density (MDD) obtained in Standard Proctor Compaction test for the two different samples tested were 1.68 g/cc and 1.61 g/cc respectively and the Optimum Moisture Content (OMC) obtained were 19.90% and 20.80% respectively. From the available literature reviewed, the optimum moisture content (OMC) of lateritic soils generally varies between 9% to 20% whereas the maximum dry density (MDD) varies between 1.3 g/cc to 2.4 g/cc.

The present study on basic characterization regarding the index properties of lateritic soils thus gives the general behaviour of the two selected lateritic soil samples, which can further be empirically connected to the important engineering properties like shear strength, permeability and compressibility characteristics. The values of index properties obtained in this study were well confirming to the range suggested by the earlier researchers. The study can be further extended to find out the engineering properties of lateritic soils, which define their suitability to various practical situations and also to find out their correlation with the index properties, by selecting a large domain of lateritic soil samples.

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