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AN INVESTIGATION INTO THE GEOTECHNICAL ENGINEERING PROPERTIES OF LATERITE SOILS IN NILAI, MALAYSIA

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BEng (Hons) in Civil Engineering

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Abstract

An increase in construction and material use in tropical environments has made way for engineering knowledge of related basic properties of soils within those areas. One such soil found abundantly are the laterite soils. This study is based on determining the engineering geotechnical properties of laterite soils which are observed to occur in the town of Nilai, Malaysia. These basic properties were generally determined for non-problematic laterite soils. Experimental analysis of earlier research as well as related journals on the same subject were reviewed. Five sites were randomly chosen throughout Nilai from which disturbed and undisturbed laterite soil samples at a depth of 1m were collected. The objectives of this study were satisfied by a series of standardized tests done on the soil using laboratory equipment. Comparison of the determined engineering properties were compared with properties of similar studies done on laterite soils found in parts of the world.

The findings show particle distribution of laterite soils found throughout Nilai are very similar in nature. While less than 10% of aggregates were present, the predominant material consisted of sands of either medium or fine grains. Fines ranging from 4% to 21% were encountered while the overall classification could be said as Sandy Clay (SC) or Sandy Silt (SM) material. Natural moisture content range between 18 to 34% and mean value was observed at 26%. Maximum dry unit weight (MDD) and optimum moisture content (OMC) were found to be 16.4 KN/m^3 and 16.4% respectively. The specific gravity ranges between 2.66 and 3.02 with an average of 2.78. Plastic limits range between 18 to 28%, liquid limits 22 to 43% and plasticity index 4 to 16%. Almost all samples lie above the A-Line meaning they are mostly inorganic clays of either low or medium plasticity. Average cohesion and angle of internal friction are 16.2 KN and 25.2°. The unsoaked CBR ranges from 5.8 to 24%. Unconfined compression strength (UCS) and undrained shear strength cohesion parameter (Cu) were found to be within the range of 38 to 134 kPa and 19 to 67 kPa respectively.

Calculations of experimental data and its analysis with the use of spreadsheets have been summarized in chapters 3, results published in chapter 4 and in depth workings shown in the appendix.

Keywords: (Keywords: Laterite, Lateritic soil, particle size analysis test, Atterberg limit test, British standard light compaction test, specific gravity, California bearing ratio, soil classification, geotechnical engineering properties).

Declaration

I declare that the study performed and consequent report of those studies are my own work under the guidance of my supervisor Dr. Eric Loh. To my best of knowledge, this study nor any of its findings and conclusions have been presented as part of final year project in Inti International University, Nilai. All sources used for this study have been cited and duly acknowledged.

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Acknowledgement

First and foremost, I would like to thank my creator, Almighty Allah for granting me the strength and wisdom to undertake this task. Secondly, I thank my parents for being constantly by my side providing uplifting moral support in any endeavor I take.

Final year project (FYP) is the ultimate evaluation module and criteria for students in determining their level of comprehension of the knowledge acquired throughout the course of the degree program. During the said course, numerous lecturers with varying disciplines of engineering aspects guided students in their respective appointed teaching classes. In appreciation, I would like to acknowledge those lecturers who took the time and effort to provide innumerable knowledge and guided the students in the required direction, ultimately contributing in making this project a successful one.

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List of Symbols & Abbreviations

Designation		Units
LL	Liquid limit	%
PL	Plastic limit	%
PI	Plasticity Index	%
G_s	Specific gravity of soil	
w	Moisture content	%
NMC	Natural moisture content	%
AD	Air drying with natural humidity	
OD	Oven drying at a temperature of 105 °C	
UCS	Unconfined compression strength	KPa
γ	Moist unit weight	KN/m^3
OMC	Optimum moisture content for compaction test	%
γd	Dry unit weight	KN/m^3
γd max	Maximum dry unit weight (in compaction test)	KN/m^3
MDD	Maximum dry unit weight (in compaction test)	KN/m^3
CBR	California Bearing Ratio	%
qu	Unconfined Compression Strength	KN/m^3
AASHTO	American Association of State Highway and Transportation Officials.	
ASTM	American Society for Testing and Materials.	
USCS	Unified Soil Classification System	
BS	British Standard	

CHAPTER 1

1.0 INTRODUCTION

1.1 Preamble

Laterite soils are a highly leached type of soil usually the product of intensive weathering of variety of rocks. These soils are rich in iron oxide and aluminium. It is this iron oxide that gives the soil its reddish colour. Laterite soils are commonly attributed to tropical areas with hilly terrains, uniform temperature, high humidity and abundant rainfall.

Nilai is a town *in* the state of Negeri Sembilan, east of Malaysia and is considered a tropical area with rather predictable wet climate throughout the year (MET.GOV.MY, 2014). Annually it has been recoded to have an average temperature of 27.2 degrees Celsius and approximately 2223mm of precipitation annually (EN-CLIMATE-DATA.ORG, 2014). Upon first glance, it is visibly covered in some areas with a reddish soil similar to the soils found throughout Malaysia.

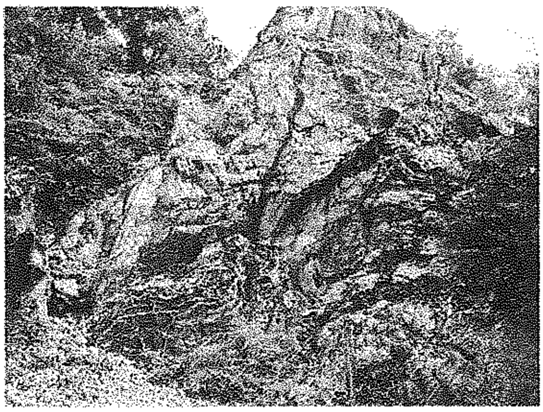

Plate 1.1: Weathering rocks, Nilai

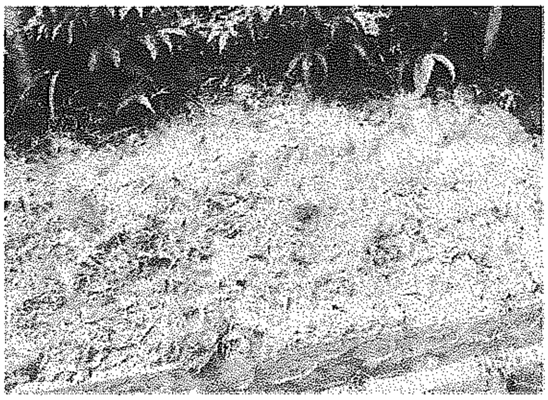

Plate 1.2: Weathered laterite soil composite, Nilai

Hence by default, the soils of that particular nature found in Nilai are assumed to be lateritic due to appearance being in a tropical environment. These lateritic soils can be found throughout the town. This soil does show similar characteristics associated with lateritic soils such as colour, small particle size, absence of siliceous material and leaching of soluble materials from the weathering sources of rock. (BELL, 2007).

Research on history of lateritic soil shows that it has been used for many generations as building material especially if it is in a tropical area where it is found in abundance. This is frequently evident from the structures still surviving from past generations made possible only due to the favorable combination of characteristics and properties of this soil (LUTGENS & TARBUCK, 2012).

Lateritic soils and its properties have to be determined for it to be either used as a construction material or to understand its limitations and impacts. For this reason, numerous tests and studies have been conducted and published over the years. However in Nilai, for the most part, its lateritic soils and properties have been assumed to have typical characteristics as those found in other areas. Hence, little is known of laterite soil types and its engineering properties from Nilai. To one's best of knowledge, no research has been done on laterite soils found in Nilai, nor studies similar to it has been done as part of a final year project in Inti International University.

This study tackles the task of providing the relevant data on properties of laterite soil in Nilai. Initial tests prior to determination of the said properties reveal that the soil under consideration is indeed laterite soil.

As clearly stated in the topic, only laterite soil and its engineering properties and characteristics are indulged upon in this study. Any deeper studies could not be made given the time limitation.

1.2 Problem Statement

Laterite soils in Nilai, its conditions, characteristics and properties are all too important in determining the feasibility of its use in construction and also its behavior and impacts in surrounding areas. Laterite soils has been attributed to being a construction material and also in some cases, the failure of soil slopes which is a result of reduction in strength due to water seepage (ALAYAKI, 2012). A soil study is needed to measure and record such data for immediate or future use in planning where it is found in abundance.

Hence, this study is such an undertaking to review the nature of the laterite soil in Nilai and its various aspects with regard to the particular engineering properties it has.

1.3 Aim and Objectives

This project aims to study the geotechnical engineering properties of five (5) lateritic soils encompassing the town of Nilai.

The consequent objectives of this study are as stated below:

1. To critically review published literature to source the types and characteristics of lateritic soils.
2. To determine various geotechnical engineering properties of laterite soils found in Nilai.
3. To analyze and compare the findings in this study to those found in the literature review.

1.4 Scope

The scope of the study is purely on the type of laterite soils collected in Nilai and its engineering properties. Methods of determining the properties are ten standard soil tests done in the laboratory based on guidelines stated in the British Standards 1377 (BS:1377-PART-2, 1990; BS:1377-PART-4, 1990; BS:1377-PART-7, 1990).

The governing guideline used to obtain soil classification, moisture content, plastic limit, liquid limit and specific gravity is BS1377-part 2:1990.

The governing guideline used to obtain maximum dry unit weight, CBR and optimum moisture content is BS1377-part 4:1990.

The governing guideline used to obtain direct shear and unconfined compressive strength is BS1377-part 7:1990.

Any other additional studies are not part of the study as it would require further research and comparisons for which time does not permit.

1.5 Thesis Organization

This study has been organized into six chapters with subdivisions within the chapters.

The introductory chapter gives a brief description of the location of interest, background information on the topic and the objectives of the study. Aims and scope along with a brief summary of the study are stated here.

The second chapter is a full literature review of the subject at hand, describing the type of soil being tested. Its origins, process of formation, classification and referenced to prior studies is presented here. Considerations of using laterite soils as construction material are clearly discussed as well. Soil sample collection areas and a brief description of overall geographical, geological, climate and soil conditions are given. Photographic records have also been included within.

The third chapter provides a step by step methodology of how the project is to be handled and progressed in light of the objectives of the study. Testing procedures are clearly defined here. The methodology is a tentative one with consideration to other studies done on the subject.

The fourth chapter deal with the practical aspects of the study where sample collection, laboratory tests, data collection, analysis of the results and discussions are made. Photographic records are also incorporated into the results as evidence. Comparisons of the results to that of previous studies on laterite soil have been presented as well.

Chapter five concludes the project study. Recommendations have also been suggested for the overall project and its phases of study.

In addition to these chapters, references and appendices relevant to the study have been included.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Laterite Historical Literature

Laterite is a term derived from the Latin word 'latere' which means 'brick'. The term was first coined by an English surgeon Francis Buchanan in his manifold published journals and observations during his travels along the western coast of southern India in 1807. He linked the name to the highly ferruginous clay material which was used in the process of making earth bricks. He described the soil content as being vastly distributed without the immediate appearance of layers, having numerous cavities and pores, high iron content and so soft that it could be cut with iron tools to the shape desired but later hardened like bricks once exposed (RAYCHAUDHURI, 1980). The very first application of the word thereby was for the use of laterite material in brick making in India and Cambodia (LUTGENS & TARBUCK, 2012).

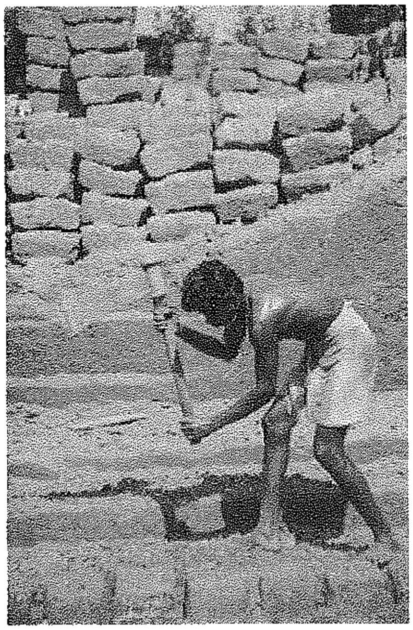

Figure 2.1: Laterite brick making, India

In Asia, laterite has been well-known source of construction material as far back as a thousand years. Basic methods of making laterite soil bricks remains the same, in which the excavated soils are dug up, shaped and left to harden under the sun. In the tropics, buildings constructed using laterite remain to this day in fairly good condition since chemical weathering had removed the soluble materials during the formation of the laterite soil originally. (LUTGENS & TARBUCK, 2012).

Figure 2.2: Leached lateritic soil, Amazon forest (LUTGENS & TARBUCK, 2012)

Latosol is a term used to define all tropical and equatorial zone soils having its dominant characteristic as low silica-sesquioxide ratio, low base exchange, low primary mineral content, low soluble constituents and some red colour. Hence this term is a collective term for lateritic soils (RAYCHAUDHURI, 1980).

Since Buchanan's first expression of laterite as a term to describe the type of soil, numerous studies have been conducted on other soil types. A common practice since then has been to apply the term laterite to any kind of red soil and rock in the tropics that bares similarity. Alternatively, over the years, laterite soils are known by many names such as Brickstone, Iron clay, Ironstone, Murram and Ferricrete, to mention a few.

Although a few differences in interpretation of the subject exists, laterite soils and its studies have yielded great increase in undivided understanding in knowledge of its origins, contents, formation, use and impacts (RAYCHAUDHURI, 1980). Consequent studies and resulting discussions resulted in agreement among researchers that laterite soil are like fine grained sands in varying sizes and classified as one which has undergone weathering and has a ratio of silica to iron oxide and aluminium.

This conclusion although agreed upon, is not in its full capacity, accepted and practiced, leading to frequent misuse of the term and assumptions made that any type of red soils are laterites. The use of the term laterite to describe a broad group of tropical soils with similar properties is simply misleading and untrue due to the fact that research shows differences in properties vary with location, climate, topography and soil conditions. For this reason, any such type of soils that show characteristics of laterites need to be investigated in detail for that particular area of interest.

2.2 Formation, Profiles & Occurrence

2.2.1 Formation

Laterite soils are the consequent product of intense and long periods of weathering of rocks that are usually associated with tropical and subtropical climatic conditions such as the Malaysian peninsula with hilly terrains, uniform temperature, high humidity and rainfall. The original soluble minerals are removed due to chemical weathering. The ultimate resulting product is a highly leached soil type (due to water passing through soil) which has an accumulation of hydrated iron and aluminium oxides. These laterite soils are hence insoluble and very stable (UGBE, 2011).

Research suggests that an average annual temperature of 25°C is required for formation to occur given the fact that tropical areas show warm and wet periods with consistence. Any deviation from these observed requirements hinder formation such as in the case of excessively high rainfall where laterites do not develop freely (CIRIA, 1995).

Observations made on rainfall suggests a minimum of 750mm precipitation annually is required for formation of laterite soils. Precipitation levels above this mark results in greater leaching of silica and reduces silica/sesquioxide ratio which in turn increases the degree of laterizations (CIRIA, 1995). Sesquioxide rich clay is described as a 'plinthite' which either is the hardened product of soft red mottles or the irreversible hard pans formed by the repeated wetting and drying due to weather (RAYCHAUDHURI, 1980; PEARRING, 1968).

Figure 2.3: Outcrop of laterite, Northern Ireland

The process of conversion of the weathered clay material to what is defined as laterite is due to the removal of siliceous material which is brought on by the action of carbonated water present in the soil. Also during the wet season, the soluble minerals are leached off by chemical weathering. As the water table recedes due to dry season, minerals like iron that are mobilized are oxidized. The dry season allows for the groundwater to be drawn to the surface due to capillary action which precipitates minerals as the water evaporates. The minerals that are being accumulated consist of hydrated peroxides of iron, aluminium and to some degree, manganese, all of which fall under a given horizon of the soil profile. These hydroxide minerals are in fact insoluble and makes way to the formation of impermeable lateritic soil at one point. When this happens, the formation of laterite is hindered since no further leaching takes place. In many laterite formations, as a consequence of these turn of events, lateritic deposits are found to be less than 7m thick (BELL, 2007). In some cases it has been recorded to be 10m thick (PEARRING, 1968).

ALAO (1983) describes the formations to be of three layers.

Laterite crust: Composed of a cellular texture and generally hard to break with a geologists' hammer. Commonly found as boulders on slope surfaces, on top of flat-topped hills and beneath the ground.

Laterite gravel: Found below laterite crust layer. At some locations, the gravel deposit is only covered by a thin layer of soil.

Lateritic clay: Lateritic clay is often located above the weathered basement and below the gravel or the crust and is comprised of very rich reddish-brown color. This material is often is used in the construction of earth dams (ALAO, 1983).

MAKASA (1998) (ZELALEM, 2005), classifies soil formation as the three processes stated below:

Decomposition: Physical and chemical breakdown of minerals with the exposure of constituent elements (Fe_2O_3, Al_2O_3, SiO_2, CaO, Na_2O, MgO, K_2O, etc) in ionic form.

Leaching: The combined effect of removing soluble mineral bases and silica and accumulation of hydroxide and oxides of sesquioxides (oxide containing three atoms of oxygen with two atoms of another element). This is called laterization. The extent to which this process takes place depends on the rate and amount of chemical weathering of primary minerals. Low level of chemical soil formation does not yield laterites but rather clays with mineral kaolinite and sometimes hydrated oxides of iron and aluminium.

Dehydration/Desiccation: Dehydration of the sesquioxide constituent materials, its composition and distribution is altered which is generally a fixed form and irreversible upon re-wetting. The soluble minerals had long been leached and insoluble minerals are left in place which is considered impermeable and more stable. Clay formation processes are also influenced by dehydration. In the case of complete dehydration, granular soils with cementation may be formed (BLIGHT, 1997). Dehydration occurs generally due to climatic changes such as dry weather. Other reasons include upheaval of land and human intervention.

The weathering of rock and resulting residual clay itself is the culmination of three types which are physical, chemical and biological processes. The first stage involves the weathering of parent rock and minerals. This releases internal energy and breaks them down to smaller particles which has lower internal energy and hence formation of more stable soils. This physical weathering increases the surface area which makes way for chemical weathering to take place. Both physical and chemical weathering can be a direct outcome of biological weathering processes such as tree roots making way into the rock joints and cracks and eventually prying the rocks apart (BLIGHT, 1997). The weathering can be affected by at least five factors which directly influence the end product. These are parent material, living organisms (mostly vegetation), topography, climate and time (PEARRING, 1968).

The importance of relating weathering process to mean rainfall and temperature is shown in Figure 2.4 below. According to Malaysian mean rainfall and temperature recordings, its weathering mechanism is strong in chemical weathering, shown marked as 'x' (FOOKES, et al., 1971).

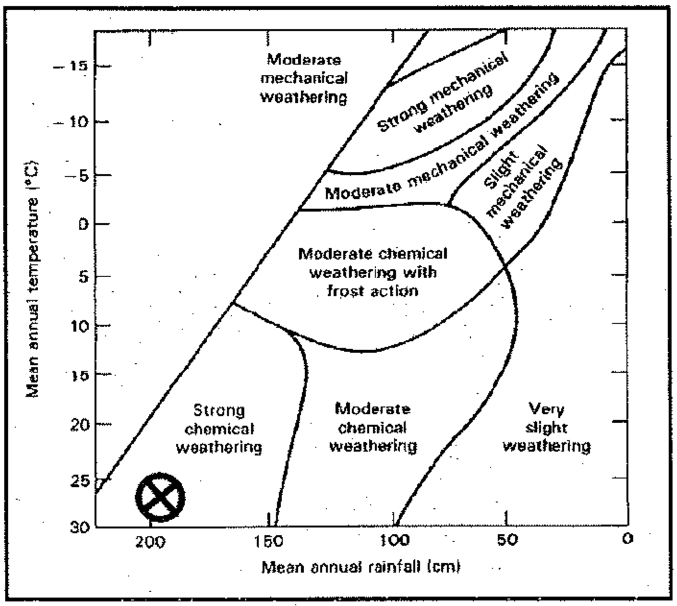

Figure 2.4: Climate to weathering relationship (FOOKES, et al., 1971)

Topography and climatic conditions have a direct influence on the rate of weathering. Topography is linked to the rate of weathering partly by factors such as amount of water available and the rate at which it moves through the weathering zone. Topography also is found to control the profile of soil by controlling the rate of erosion of surface weathered material. Evidence of this is the deeper profiles found in valleys and gentle slopes in contrast to higher ground and steep slopes. In places where humidity and moisture is in abundance, chemical weathering rate is found to be more compared to that of dry climate areas where physical wreathing is predominant. (BLIGHT, 1997).

The angle of slope determines the water content moving through the weathering zones. Generally, steeper slopes do not favor of deep weathering as seepage rate is higher. Deep soil profiles are produced in significantly flat slopes due to uninterrupted periods of weathering. Level grounds are subject to other types of soil dominate the grounds since water seepage is impeded. According to RAYCHACDHURI and CHAKRAVORTY (1940), negative correlation with the SiO_2/Al_2O_3 ratios are associated with annual rainfall and altitude of the clay fractions of Indian lateritic soils (RAYCHAUDHURI, 1980).

2.2.2 Laterite soil profile & horizons

Throughout the tropics, weathered residual soils occur in numerous forms, among which the most common residual soil profile is the weathering profile of laterite. These profiles are deemed as those having lateritic horizons (layers) or those capable of developing lateritic horizons under favorable conditions. (MUSTAPHA & ALHASSAN, 2012).

Below the humus stained top soil, lateritic weathering profile can be distinguished into three major horizons (MUSTAPHA & ALHASSAN, 2012).

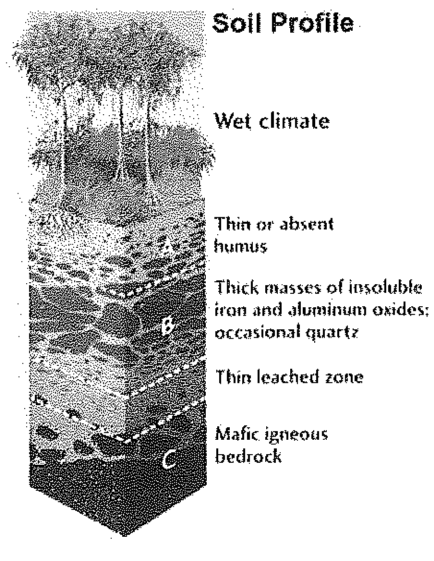

Figure 2.5: Typical laterite Soil profile

i. **Lateritic horizons with rich sesquioxides**: They are either gravelly or hardened in-situ forms. The so called ground water laterites with low permeability and rainfall are indurated/hardened with iron compounds. These profiles are thick and formed from any parent rock material under typical drainage conditions of a tropical high temperature climate.

ii. **Mottled zone with hints of sesquioxide enrichment**. Deep reddish soil profiles with rich iron and aluminium oxide due to basic weathering of igneous rock under moderately good drainage in seasonally high rainfall regions. These profiles contain small pea-sized concretions. Below this is a mottled red layer which may be soft in nature but dries out to hard lumps when exposed to atmosphere. Such hardened types of laterite soils are quarried for use in road construction.

iii. **Horizon that overlies parent rock**, referred as leached or pallid zone. This zone contains rocks which has mineralogical and chemical changes although physical appearance remains the same.

It is generally considered that the weathered residue is uniform with depth, i.e. constituents and properties are assumed to be same. Although much work has been done on laterite soils, little is study has been made on the weathering horizons and the characteristic change with depth. These studies suggest weathering laterite products vary in geotechnical properties, chemically and physic-chemically in horizontal and vertical directions (MUSTAPHA & ALHASSAN, 2012).

BELLO & ADEGOKE (2010) described the profiles of laterite soils are of three types in general:

(1) **Overlaying soil**, direction of transport downwards

(2) **Underlying weathered rock**, direction of transport upwards

(3) **Laterites in which crust material is detrital** (deposited, precipitated and transported)

Laterites may occur as unhardened clayey deposits, gravels, or as hard pans on the surface. Thus the geotechnical properties and characteristics have direct relationships to the pedological factors (topography, weathering period, climate, vegetation and parent material), degree of weathering, depth of soil in profile and position on the topographic site (BELLO & ADEGOKE, 2010).

The compact B horizon in Figure 2.5 hinders root penetration. The water or moisture levels in this profile is considered low since retention is relatively low (RAYCHAUDHURI, 1980).

2.2.3 Occurrence

Laterite and lateritic soils are largely predominant to tropical areas with moist climate. Coverage of laterites around the world mainly pertain to Africa, India, Australia, South-east Asia, Central America and South America. Residual soil and especially recent lateritic soils are present dominantly in major parts of south-east Asia, Laos, Vietnam and Malaysia (CIRIA, 1995). These locations generally fall between latitudes 35°S and 35°N (BELLO & ADEGOKE, 2010). A collective laterite world occurrence and distribution map is shown in Figure 2.6.

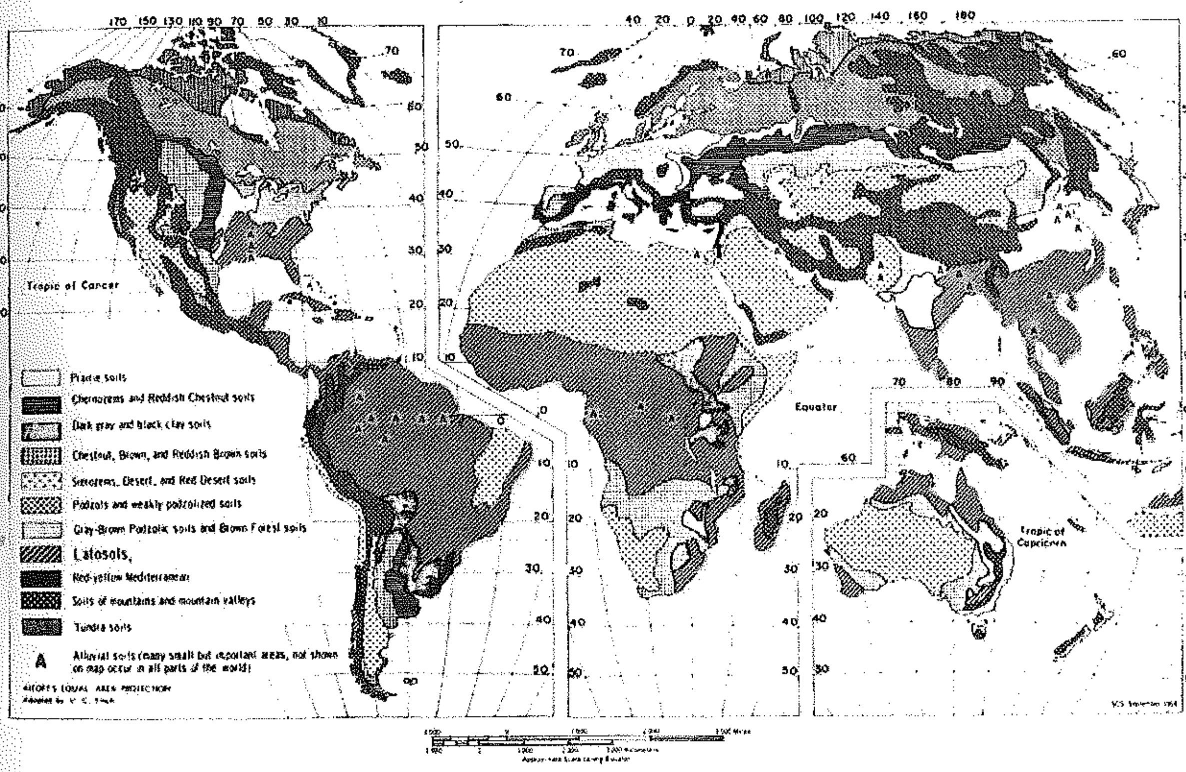

Figure 2.6: Latosol soil (collective laterite) world distribution (http://www.nzdl.org)

Geological plate movement and shifting has continuously distributed laterites outside the tropical zones. In India for example, it has been roughly suggested to cover 248,000 sq. kilometers, largely on the summits of hills. All laterite soils in occurrence are have a poor lime and magnesia content while nitrogen is absent altogether (CIRIA, 1995).

High level and low level laterite classification pertains to the altitude of occurrence in which high level laterites are found 2000 ft. above sea level and low level laterites below that mark. In Tamil Nadu, India, high level laterites soils are found to be more acidic while rich in plant nutrients. Low level laterites are found to have poor organic nutrient content. This occurrence is just one of many varieties of situations found throughout the world in terms of soil constituents (RAYCHAUDHURI, 1980).

Basaltic and granitic hills in India have been observed to have laterite soil capping. Plateaus in this region occasionally are found to have considerable thickness of laterite soil.

2.3 Characteristics of Laterite

2.3.1 Composition and form

The residual clays formed from weathering are basically enriched with insoluble deposits of hydroxides of ferric iron and aluminium. This coupled with the removal or leaching of silica due the humid conditions of the region results in a hydrated form of iron and aluminium oxides (BELL, 2007). It is important to note that the constituents of the soil is taken as a criterion of laterite. Laterites that are poor in iron oxides and rich in aluminum oxides are called bauxites. The iron oxide content accumulation gives the soil its distinctive reddish colour ranging from light red through bright red and also brown shades (BELL, 2007).

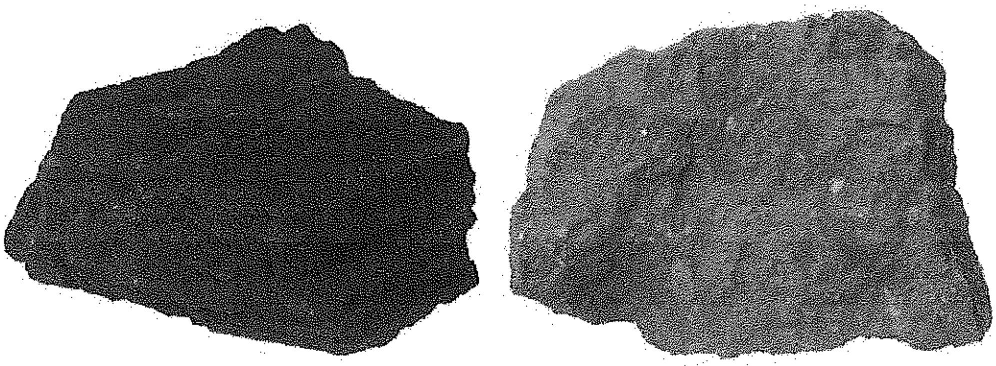

Figure 2.7: Laterite samples approx. 8cm (http://www.sandatlas.org)

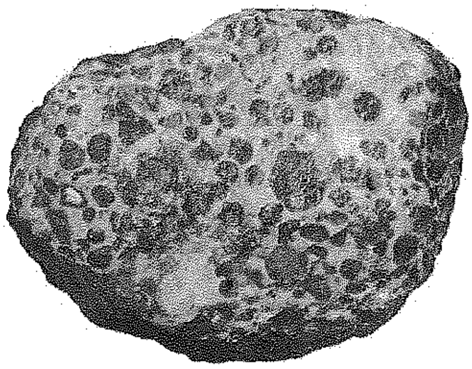

Figure 2.8: Aluminium rich Bauxite approx. 8cm (http://www.sandatlas.org)

The word laterite is defined by geologists as a varying proportion of mixtures of hydroxides of iron and aluminium with other quantities of substances mixed together. It is also described as plastic, mostly fine grained, volumetrically inactive, high iron content with red colour. This term has been used broadly by Civil Engineers to describe all red colored soils of the tropics.

Although the red colour is due to the high iron oxides, the early stages of formation and development may limit the quantities of oxides which makes the soil inadequate to impart on colour (PEARRING, 1968).

Apart from being enriched with iron and aluminium oxides, laterite soils are also rich in sesquioxides which are secondary oxides of iron and aluminium while being low in bases and primary silicates. Identifiable amounts of quarts and kaolinite may also be found.

The degree of laterization is expressed as the silica to sesquioxides ratio. The ratios SiO_2/ Fe_2O_3 and Al_2O_3 are (BELL, 2007; PEARRING, 1968):

Ratio < 1.33	= Laterite soils
$1.33 <$ Ratio < 2	= Indication of laterite soils
Ratio > 2	= Non lateritic soils

Under the right conditions, lateritic soils become impermeable in nature and are found in cemented continuous or honeycombed mass and also as gravels. Honeycombed masses are crumbly in nature and confined to the surface (RAYCHAUDHURI, 1980).

Laterite sediment areas are particularly hard enough under certain conditions with almost negligible settlement effects (BLIGHT, 1997). It is also this property that makes it ideal in certain parts of the world to use it as a road base (SCOTT, 1980). However one drawback is that the strength of soil may decrease with increase in depth.

2.3.2 Particle size and distribution

Although laterite soil is most commonly associated with clay like fine grained particles, all shapes and sizes ranging from fine to gravel have been observed throughout the world. They are found to occur from loose to massive sizes although most commonly in fine to coarse grained composition. Those larger sizes include pea sized gravel to 3 inch gravels and in rare cases, even larger cemented masses. Figure 2.9 shows typical laterite particle distribution. They may be at times found to contain nodules or concretions especially in areas where high concentrations of oxides occur. Higher oxide concentrations gives rise to laterite formation (BELL, 2007).