DISTRIBUTION OF ENGINEERING PROPERTIES OF SOILS USED IN HIGHWAY CONSTRUCTION IN NIGERIA

By

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DECLARATION

I hereby declare that this thesis is my research work at Ahmadu Bello University, Samaru, Zaria. It has not been accepted in any previous application for a higher degree. All sources of information have been fully acknowledged in the references.

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APPROVALS

This Thesis entitled "Distribution of Engineering Properties of Soils used in Highway Construction in Nigeria" by Osim Adebisi meets the regulation governing the award of the degree of Master of Science of Ahmadu Bello University and approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work to Almighty God for His privilege and grace given to me to be alive today. I give Him glory for making it possible for me to complete the work in good health.

ACKNOWLEDGEMENTS

I wish to acknowledge the contribution of my able supervisor Engr. Dr. K. J. Osinubi. Also to be acknowledged is my head of unit in the office Engr. G. N. Okeke, for his understanding, not to be left out is Engr M.I. Chukwuma for his contribution towards my Thesis. May the Almighty God grant you all your heart's desire (amen).

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ABSTRACT

Areas with alluvium (Qa) soil from the Quartenary Era, have A-2-4, A-2-6, and A-2-7 classifications according to the AASHTO Soil Classifications, while areas with sands and clays (Qp) from coastal plain sands are mainly classified as A-7-5, and A-7-6 with few locations having A-2-4, A-2-6, and A-2-7 classifications. Also, sands and clays (Qc) from Chad formation of Quaternary Era have A-2-4, A-4 and A-6 classifications. Sands, clays, and shales (Ti) of Illaro formation from the Tertiary era are of A-7-5 classification. Shales and roundstone (Kro) of Nkporo shale group formed from cretaceous era have A-7-5, A-2-7 and A-6 classification; Shales, and limestone (Kwn) of Agwu-Ndeaboh shale group formed from cretaceous era are classified as A-6, A-2-7, and A-7-5; while black shale and siltstone (Kea) of Eze Aku shale group formed from cretaceous era have A-2-6, and A-7-6 classifications.

Granitoids (Pcg) of older granites series in basement complex formed from Pan Africa era are mainly A-7-6, A-7-5 with few A-6, and A-2-6 classifications; Gneiss migmatate complex (Pcb) of Migmatate Gneiss schist complex formed from Basement complex of Precambrian era have A-2-4, A-2-6, A-2-7, A-7-5, and A-7-6 classifications; Meta-sediments/Volcanics Gneiss formed from Migmatate Gneiss schist complex of Basement era have A-4, A-6, A-7-5 and A-7-6.

Generally, it is observed that the lower the Atterberg limits, the better the materials. The sub grade materials in the North central zone have the percentage passing BS No 200 sieve from 7 to 94, while the liquid limit value ranged from non plastic (NP) to 72 % and

plasticity index ranged from non plastic (NP) to 46 %. The soils used for sub-grade are suitable except in few locations where the specification was not met.

The sub grade materials in the North east zone have the percentage passing BS No 200 sieve from 10 to 93, while the liquid limit value ranged from NP to 61 % and plasticity index ranged from NP to 33 %. Suitable materials were met except in few locations where the specifications were not met.

The sub grade materials in the North west zone have the percentage passing BS No 200 sieve from 2 to 89, while the liquid limit value ranged from NP to 77 and plasticity index ranged from NP to 45. The soils are of good qualities in most locations except in few areas with very fine soil where percentage passing BS No 200 sieve is greater than 35, with high value of liquid limit These make the soils to be susceptible to high volume changes upon contact or withdrawal of moisture.

The sub grade materials in the South west zone have the percentage passing BS No 200 sieve from 9 to 56, while the liquid limit value ranged from NP to 65 % and plasticity index ranged from NP to 28 %.

The percentage passing BS No 200 sieve for sub grade materials in the South east zone have ranged from 7 to 94, while the liquid limit ranged from NP to 72 % and plasticity index ranged from NP to 46 %. The material was very fine and this region had stone base and soil-cement in their base course.

The percentage passing BS No 200 sieve for sub grade materials in the South south zone ranged from 15 to 60, while the liquid limit value ranged from NP to 70 % and

plasticity index ranged from NP to 44 %. The material is very fine. This region has stone base and soil cement in their base course

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CHAPTER ONE

INTRODUCTION

1.1 **Preamble**

For any highway to perform its traditional function of carrying vehicles and passengers safely from one location to another it must be properly designed, properly constructed, regularly maintained and at a later age, properly rehabilitated to improve on its residual life. Highway construction and rehabilitation involves accurate survey works, use of heavy and complex machinery and provision as well as placing in accepted manner, all highway construction materials.

However, no matter how beautifully the highway is designed; no matter how accurately the components are set out and no matter how efficiently the operator manipulate the machines, if the construction materials are of poor quality, the highway will not outlive its useful life. The situation is even more pronounced in highway pavement and drainage structures.

With the large network of federal highways constructed in the 1970s and the budgetary allocations to the Federal Ministry of Works, which are geared towards rehabilitation of a significant proportion of this network, it has now become even more necessary that the highway engineer must have a sound knowledge of highway construction materials. It is necessary to know the important engineering properties of construction material and how to control their quality at site in order to construct very durable roads and rehabilitate the existing ones, thus saving the huge investment in the highway sector of the economy.

Nature has endowed different parts of the country with soils suitable for highway construction. However, the soils are not evenly distributed and their basic properties differ.

Soils suitable for use in highway construction must be required to meet certain criteria for use. For soils to be suitable for use they must have limited maximum values of percentage passing BS No. 200 sieve; limited maximum values of plasticity index, limited maximum values of liquid limit and they must meet certain strength criteria, the most popular in Nigeria being the California Bearing Ratio (CBR).

Suitable soils for highway construction appear not to be evenly distributed throughout the country. Certain areas are known to lack these materials in significant proportions. These depend on geological formation of the rock bed and their geographical formations. This study is presenting the AASHTO soil classification of common highway soils encountered in Nigeria on a map.

1.2 **Aim**

The aim of this study is to present in a simplified format the distribution of conventionally suitable soils in the country, to enable the engineer-planner in making decisions concerning haulage and rates in the Bill of Engineering Measurements and Evaluation (BEME).

1.3 **Objectives**

To enable the researchers and engineer-planner to have impression of the availability of soils as construction materials in any area through which a highway is being proposed.

It will help in making decision concerning haulage and rates in the BEME.

1.4 Significance of the study

Not all soils are suitable for use in highway construction and rehabilitation. The conventionally suitable ones are not evenly distributed in all parts of the country. This study is therefore meant to highlight the properties and distribution of suitable soils in Nigeria. This result of study is presented in the form of a map for easy reference by the engineer-planner, contractors and other stakeholders in the delivery of endurable highways in Nigeria. It is also hoped that it would form a basis for further research by highway engineers in future.

1.5 Limitations

This study was limited to existing carriageways. Existing data were collected where possible. Materials sampling and classification tests were also carried out. The data collected were limited to Materials sampling and classification tests and no California Bearing Ratio (CBR).

CHAPTER TWO

LITERATURE REVIEW

2.1 **Natures, Origin and Formation of Soil**

The highway engineer defines soil as all loose deposit of the earth's crust. It is an assemblage of solid particles forming a porous structure. These pores may contain water, air or both. It can also be defined as a mass of mineral particles, variable in size, shape and degree of compaction between which there exists an intricacy of pores each connected with others by channels of different sizes (Okeke 2001).

The engineering definition of soil is very broad. Soil might be defined as all the earth material, both organic and inorganic, that blankets the rocks crust of the earth (Paul and Radnor 1979). Soils are practically formed from the disintegration of the rocks of the earth's crust. This disintegration or weathering is brought about by the action of chemical and mechanical forces, which have been exerted upon the parent rock formation for countless ages. These forces include those of wind, running water, freezing and thawing, chemical decomposition glacial action and many others.

It is commonly accepted today that soils do not occur haphazardly but are formed by logical natural process. A similar set of natural processes, acting on a similar parent material will produce a similar profile (Kanthy and Morse 1961).

Soils may be described based on the principal agencies responsible for their formation and position. Thus, we have the residual, transported, aeolian, and sedimentary to mention but a few.

Residual Soils: These are soils that live directly above the parent materials from which they were derived. They are characterized by varying degrees of concentration of the soil

mass with depth, their generally unstable or "weathered" nature, and a gradual transition from the soil layer into bedrock.

Transported Soils: They are those carried to their present position by some transporting agent such as wind, glacier or water. They are mostly alluvial and prove to be rather variable.

Aeolian Soils: They are typical examples of wind blown soil deposit. This is soil formed by the action of wind.

Sedimentary Soils: They are soil formed through the action of water. They are of extreme importance to the engineer as many of the soil with which he deals are of this type. Typical sedimentary soils are formed by the settling of soil particles (or groups of particles) from a suspension existing in a river, lake or ocean. They may range in type from beach or river sands to highly flocculent clays of marine origin.

Soils may also be described based on the amount of organic material contained in them; soil in which the mineral portion (soil particles) predominates is properly called inorganic soils. While, organic soils are soils in which large amount of organic matter is contained. Soils vary greatly in their physical and chemical composition at different locations over the surface of the earth because they lack homogeneity. Generally speaking, soils derived from the same parent material under similar factors of geographical location, climate and topography will be similar wherever they are found (Okeke 2001). Several soil types may exist within a comparatively small area. Soil deposits are also characteristically varied with depth. Sedimentary soils are stratified when their deposits have layers of varying fineness during the process of formation.

2.2 **Constituents of Soil**

2.2.1 **Solid material in soils**

Soil particles are a mixture of matter derived from physical and chemical weathering of rocks. Inorganic matter and organic matter more or less consist of decomposed remains of plants and animals organisms.

2.2.1.1 **Organic matter**

They are derived from either plants or animals. They are added to soil when the organism die and are decomposed. The fraction from animals is not much because it decomposes rapidly and products are utilized as nutrients by living plants. The fraction from plants is large and persists in soil for a longer period due to the resistance of some plant material from decomposition. It is concentrated generally in the top 50-300 mm of soil, except due to action of earthworm and leaching that extend the depth to which organic admixture can occur (Glanville 1952).

Organic deposits such as peat or coal may extend too much greater depths due to geological factors. From engineering point of view, an organic matter has open spongy structure and is mechanically weak. It undergoes considerable volume changes when loaded in the presence or absence of water. It is acidic in nature and thus tends to attack materials buried in the soil. This acidic nature of the constituents gives an acidic reaction to the water in the soil, which may have a corrosive effect on material buried in the soil. Soils containing appreciable amounts of organic matter are generally removed from site prior to construction.

2.2.1.2 **Inorganic matter – mineral matter**

They form the main bulk of soil; they originate from various types of rocks occurring on earth's crust by physical and chemical soil forming processes. The nature of the mineral matter is influenced by: climate, topography, associated vegetation, the nature of the parent rock, and geological time.

Size and shape are to some extent a function of the mineralogical constitution; example is micaceous soils where the particles have laminar structure of the mineral bulk. A very hard mineral such as quartz gives rise to particles that are less rounded than those derived from softer minerals under similar weathering conditions. The alumino- silicate clay minerals, kaolinite and montmorillonite occur only in the finer range of particle sizes, probably owing to their mode of formation (Glanville 1952).

2.2.2 The air in soil

The air in soil is of importance from the agricultural point of view since it supports vegetation but of no significance to the highway engineer as it contributes anything to the strength of the soil. It should be removed as much as possible through compaction.

2.2.3 **Water in soil**

The water in soil plays an important role in determining the physical properties of a soil such as in cohesion, shrinkage, swelling, etc.

2.2.3.1 **Cohesion**

In fine-grained soils (clays, and silt) individual particles are bound together by films of water. This is possible when water molecules are associated with the surfaces of particles. Cohesion decreases rapidly as the moisture content increases.

2.2.3.2 **Suction**

Water molecules can be associated with the surface of soil particles and it is generally considered that the former are in adsorbed state, that is, the particles surfaces are hydrated. The forces causing the hydration plus the surface tension at the water/air interface combine to produce a state of reduced pressure of suction in the water.

Suction is continuous for all soils and increases as the moisture content decreases (Kanthy and Morse 1961). In clays (saturated at moisture content (MC) > 15%) suction is due to particles hydration while in granular soils it is due to surface tension.

2.2.3.3.1 Swelling

It is common in clay and is associated with hydration. Due to short distance between each clay laminar particles the absorbing forces acting on water molecules are very strong. As the absorbed layers grow, the effective solid volume of each particles increases, and this is reflected in an increase in the total volume of the solid structure. In practice, the absorbed water in clays continues to grow in thickness until the pressure generated thus comes in a state of equilibrium with the overburden pressure due to the soil's self weight or externally applied load. In this state of equilibrium, if loading is

increased, the absorbed water films are reduced in thickness and settlement occurs. This is called consolidation.

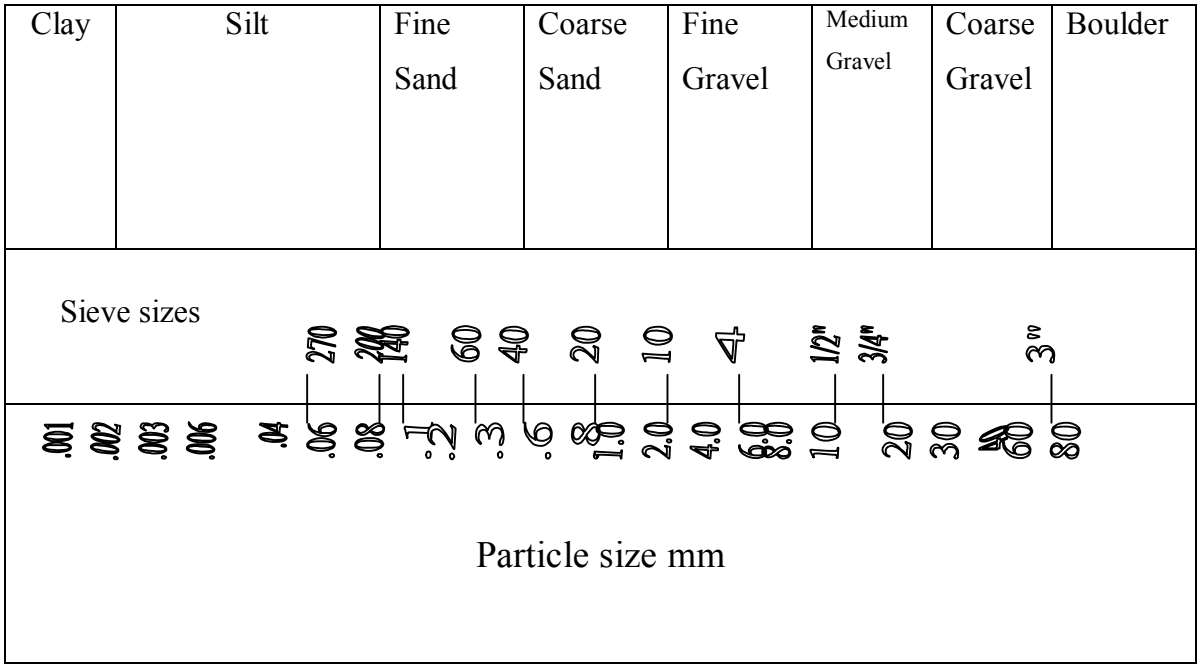
2.3 General Soil Types

Certain general soil types are important to the highway engineer. They are classified by their grain size (grain size is the average dimension or diameter of a soil particle contained within a soil mass) into several principal groups and many subgroups.

The principal divisions of any classification system based on grain size are usually gravel, sand, silt and clay. Several different classification systems have been proposed and the one in general usage among highway engineers is shown in Fig. 2.1 (Grain size classification AASHTO Materials, Part I: Specification 1978).

There is need to emphasize that although in many cases a knowledge of the distribution of grain size in a soil is valuable to an understanding of soil action, this knowledge alone is not enough to give an accurate picture of the properties of a soil and its behaviour under various conditions. For example a fine silt or a rock flour may have a large percentage of particles that fall within the range of clay sizes and yet have entirely different properties from those exhibited by an inorganic clay having about the same range of particle sizes. Similarly, two sands composed of particles of about the same size may be radically different in such a property as shearing resistance if one is beach sand composed of smooth, rounded grains and the other is composed of grains that are sharp and angular. The term “clay” and “silt” carry meanings that go beyond mere reference to particle size. Additional information must be given if the description is to prove adequate from an engineering viewpoint.

Many soil deposits will contain particles that fall into two or more of the groups described above. Thus, a soil might contain percentages of sand, silt and clay as defined by the chart in Fig. 2.1. In these cases terms such as “sandy clay”, “silty clay”, silty sand” and many others are used in describing the soils. Also the particle size distribution of a soil sample is a function of the degree of weathering, the parent rock and the position of the sample in the soil profile (Madu 1975).



Materials smaller than 0.001 mm are called colloids

Figure 2.1: Grain Size Classification (AASHTO Specification) (After Paul Radnor 1979)

2.4 **Common Soil Types**

Sand and gravel: They are coarse-grained soil types possessing little or no cohesion. They can be identified by visual inspection and are distinguished, by their relative stability under wheel loads when confined by their high permeability and failure to shrink or expand in

detrimental amounts with change in moisture content. Gravel is usually applied to natural pit, river or bank gravels consisting largely of rounded particles; crushed gravel or crushed stone is the term applied to the product of crushing larger rocks into gravel sizes.

Silts: Is the term applied to fine-grained soils of low to medium plasticity, intermediate in size between sand and clay. This has little cohesion, undergo considerable shrinkage and expansion with change in moisture content and possess a variable amount of stability under wheel loads. Silt that contains large percentage of mica flakes is likely to be highly compressible and somewhat elastic in nature. Organic silts contain appreciable amounts of decomposed organic matter and are generally highly compressible and unstable.

Clays: They are distinguished by the occurrence of very fine particles, since many types of clay are principally composed of particles that are colloidal in size. Clays generally possess medium to high plasticity, have considerable strength when dry, undergo extreme changes in volume with change in moisture content and are practically impervious to the flow of water.

Silty clays or clayey silts are referred to as lean clay. Fine colloidal clays of high plasticity are called fat clays. Clays possess' considerable strength in their natural state, this strength is sharply reduced and sometimes completely destroyed when their natural structure is disturbed, that is, when they are remoulded.

Peats: are soils composed principally of partially decomposed vegetable matter. Peat has high water content, and woody nature (fibrous to amorphous texture). It is dark-brown to black in colour with an organic odour. It is soft silt or clay, very high in organic content, which is usually found in swampy areas and river or lake bottoms. Its high compressibility makes it an extremely undesirable foundation material.

2.5 Some Basic Soil Properties

In understanding soil action, an engineer must be familiar with certain basic soil properties. A soil engineer must have similar knowledge relative to soils. Soil engineer are faced with complicated jobs because many soils are quite complex in nature, both physically and chemically and the soil deposits are likely to be extremely heterogeneous in character.

2.5.1 Moisture content

The moisture content is defined as the weight of water contained in a given soil mass compared with the oven dry weight of the soil, it is expressed as a percentage (BS 1377:1990):

$$W = \frac{m_2 - m_1}{m_3 - m_1} x100\% \quad \text{.....(2.1)}$$

Where m_1= mass of container (g),

m_2 =mass of container and wet sample (g)

m_3= mass of container and dry sample (g)

Water in soils may be present in its normal liquid form as when filling or partly filling the voids of a sand mass, or it may be present in the form of absorbed water existing as films surrounding the separate soil particles or groups of particles, as in the case of the water remaining in partially dried clay mass.

The water films existing in the dried clay mass may have properties sharply differing from those exhibited by water in its normal form. The properties of fine-grained soils are greatly dependent upon the properties and behaviour of the absorbed water films.

2.5.2 **Specific Gravity**

This is the ratio of the unit weight of soil particles to the unit weight of water at some known temperature (usually 4^{o}c), and range numerically from 2.60 to 2.80. Within the range the lower values for the specific gravity are typical of the coarser soils, while higher values are typical of the fine-grained soil types. Values of the specific gravity outside the range of values given may occasionally be encountered in soils derived from parent materials that contained either unusually light or unusually heavy minerals (Paul and Radnor 1979).

2.5.3 Unit Weight

The unit weight of a soil is the weight of the soil mass per unit of volume and is expressed in gram per cubic millimeter.

Wet Unit Weight: Is the unit weight of a soil mass having moisture content, which is anything different from zero.

Dry Unit Weight: Is the unit weight of the soil mass in an oven-dry condition. It can be determine using the expression (BS 1377:1990):

$$\gamma_d = \frac{\gamma_w}{\{(100 + w\%)/100\}} \quad \text{.....(2.2)}$$

Where, γ_d=Dry unit weight

$\gamma_{w=}$ Wet unit weight

2.5.4 **Void Ratio**

It is used in describing the weight – volume relationship of soils. It is defined as the ratio the volume of voids contained in a soil mass to the volume of solids.

$$e = \frac{\rho_s}{\rho_d} - 1 \quad \text{.....(2.3)}$$

Where, $\rho_{s=}$ The particle density (Mg/m^3)

$\rho_{d=}$ Dry density of soil (Mg/m^3)

2.5.5 **Porosity**

It is the ratio of the volume of voids to the total volume of solids expressed as a percentage:

$$n = \frac{e}{1+e} x100\% \quad \text{.....(2.4)}$$

where n =Porosity ,

e =the void ratio.

2.5.6 **Degree of saturation**

Is defined as the ratio of the volume of water contained in the voids to the volume of voids. It is expressed as a percentage:

$$S_r = \frac{w\rho_s}{e}(\%) \quad \text{.....(2.5)}$$

Where w = the moisture content as a percentage of the mass dry soil.

2.5.7 **Permeability**

It is the property of a soil mass that permits water to flow through it under the action of gravity or some other applied forces. Permeability is expressed as coefficient of permeability (k). It is defined as the velocity of flow of water through a soil mass under the action of a unit hydraulic gradient. The coefficient of permeability of a soil is dependent upon its void ratio, grain size, structure, density and viscosity of the water flowing through the soil.

Coarse-grained soil, such as sand and gravel, has high coefficients of permeability and are said to be pervious. Clays and other fine-grained soils have much lower coefficients of permeability and are said to be relatively impervious.

2.5.8 **Capillarity**

The property which permits water to be drawn into the soil from a free water surface through the action of surface tension and independent of the force of gravity. Capillary flow in soils is generally associated with an upward movement of water from the water table, although in reality this type of flow can occur in any direction.

This flow of water in soils is a complex phenomenon. However, the height of water in the soil by capillary action is known to be primarily dependent upon the size of the void spaces and upon the size of the soil particles (Paul and Radnor 1979). This is greater in clay soils than in silts. Water saturation in clay mass will require a much longer time than that silty soil. Coarse gravel and sand are not normally subjected to detrimental effect of capillary action.

2.5.9 **Shrinkage and Expansion**

Soil undergoes shrinkage as their moisture content is reduced from that existing when they are partially saturated or saturated. Shrinkage is greatest in clays and other fine grained soils. The same soils may show considerable expansion or swelling if they have been dried and their moisture content is later increased. Sand and gravel show little or no change in volume with change in moisture content.

The shrinkage of the clay mass is due to forces attributed to the surface tension existing in the water films created during the drying process. As evaporation continues, these forces become greater until the soil attains certain limiting volume or else cracking occurs.

The presence of water in a problem soil will destroy the internal forces in the soil and cause a confined clay mass to expand or swell. Excessive shrinkage or swelling is a matter of great concern to the highway engineer especially as related to the behaviour of a sub grade soil used as a support for a flexible or rigid base or pavement.

2.5.10 **Compressibility**

This is the property of a soil that permits it to consolidate under the action of an applied compressive load. “Consolidation is applied to the compression of a saturated clay mass under a vertical load. The amount of compression occurring in a given soil under a given set of conditions depends upon a variety of factors, including the magnitude and the method of application of the load, the void ratio, structure and history of the soil mass concerned. The rate of compression in a saturated soil is evidently a function of the permeability (Paul and Radnor 1979).

2.5.11 **Elasticity**

This is the property of a soil that will permit it to return to its original dimension (or nearly so) after the removal of an applied load. No soil is perfectly elastic, but some soil possess elasticity to a degree which may be detrimental when they are used in sub grade or base construction. Examples are silts and clays with sizable amount of mica and high percentage of organic colloids like peat (Paul and Radnor 1979).

2.5.12 **Shearing Resistance**

This is the failure that occurs in soil masses as a result of the action of highway loads. Shearing resistance is attributed to the existence of internal "friction" and "cohesion". In a cohesionless sand the force required to overcome shearing resistance on any plane is assumed to be given by the expression:

$$\tau_r = \sigma \tan \Phi \qquad (2.6)$$

Where σ = the normal force (stress) on the plane being considered

Φ = the angle of internal friction.

For dry sand, Φ is primarily dependent upon density (void ratio); the lower the void ratio the higher the value of Φ. The angle of internal friction Φ is zero for saturated clay.

2.5.13 **Compaction**

During compaction, particles of soil are made to pack closely together by reduction in its air-void content. This is achieved by mechanical means. When soil is compacted with a given compacting effort in moulds with increasing moisture content (MC) it is observed that the dry density rises to a maximum, before it starts to decrease giving a curve when plotted against the MC. This is so because:

(i). When soil is dry, inter granular friction prevents the particles from sliding over each other. Thus it does pack more closely during compaction.

(ii). With the addition of moisture, the points of contact with the particles are lubricated. This enables the soil particles to be forced to move closer to a denser state.

(iii). In the limit, the voids become filled with moisture.

(iv). Further additions of moisture displace the particles, making them to stay farther apart- thus increasing the total volume and thereby lowering the dry density.

2.6 **Sieve Analysis, (Particle Size Distribution)**

This involves the separation of soils into its fractions and is done by shaking the dry loose material through a set of sieves of increasing fineness, that is, successively smaller openings. The sieve analysis may be performed directly upon soil that contains little or no finer such as clean sand or soil in which the fines may be readily separated from coarser particles. Soils that can easily be crushed between the fingers are pre-washed and fine materials removed.

The material that is retained on BS No. 200 sieve during washing process is dried and subjected to sieving. In many soil laboratories a combined sieve and hydrometer analysis are used. See Fig. 2.2 for typical grading size distribution curve.

Particles size has the most significant influence on the physical characteristics of a predominant inorganic soil. This is evaluated by the distribution of sizes among the particles. It is not practicable to determine the sizes of every particle. Determinations are therefore made of the quantities of particles with sizes lying between sets of arbitrary defined size limits. These size limits are expressed in terms of **equivalent particles diameter,** assuming that sizes are spherical. It should be noted that the size range defined by two limits is referred to as a "fraction" of soil. The various fractions are named to correspond to the type of soil which they resemble e.g. sand, silt, clay.

For engineering purposes, the following system of size limits is adopted (Paul and Radnor 1979).

Gravel Fraction – 60 mm-2.0 mm equivalent particles

(a) Sand Fraction – 2.0 mm-0.06 mm

(b) Silt Fraction – 0.06 mm – 0.002 mm

(c) Clay Fraction - < 0.002 mm

Table 2.1a shows sieve numbers and their dimensions:

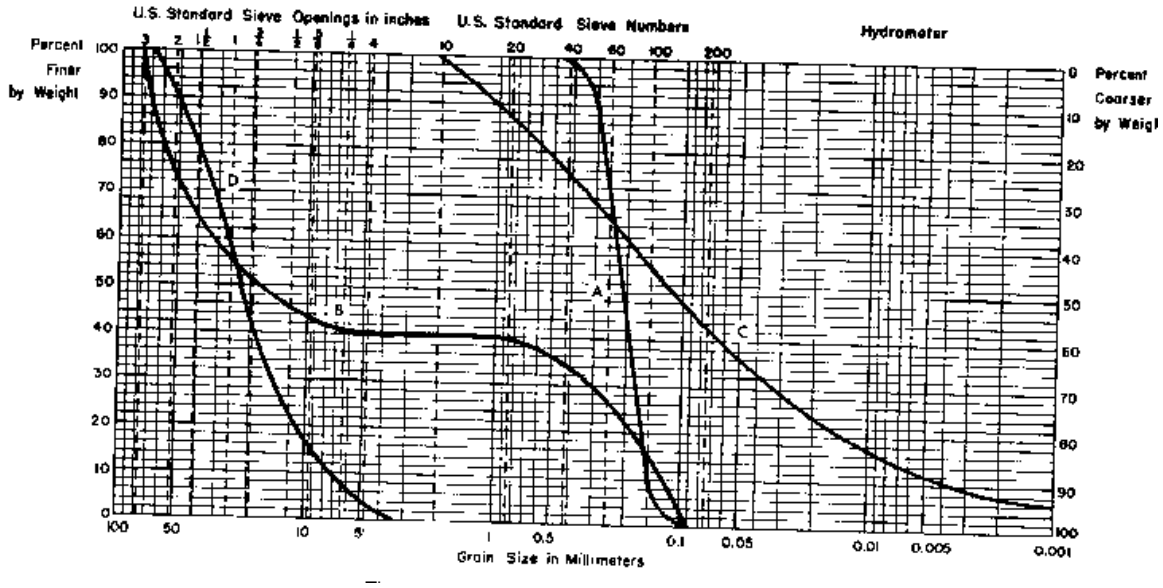


Figure 2.2: Typical Particle Size Distribution Curves (After Paul and Radnor 1979).

Table2.1a Typical BS Sieves Number and sizes for Stone Base and soil Classification (after PEU FMW)

STONE BASE		SOIL	
Sieve No	Dimension	Sieve No	Dimension
INCH In	mm	INCH In	mm
2	50	3⁄4	17.00
11⁄2	38	⅜	9.50
1	25	3⁄6	4.75
3⁄4	19.00	BS No7	2.36
3⁄8	9.50	BS No14	1.18
3⁄16	4.75	BS No25	0.600

BS No 7	2.36	BS No 36 or No 40	0.425
BS No 14	1.18	BS No 52	0.300
BS No 25	0.600	BS No 100	0.150
BS No 36 or No 40	0.425	BS No 200	0.075
BS No 52	0.300	PAN	0.0
BS No 100	0.150		
BS No 200	0.075		
PAN	0		

Table2.1b The Sieves sizes in American (A.S.T.M) and the British equivalents.(After Public Road Administration (P.R) System 1945)

United State (A.S.T.M) E.11/26	Great Britain (B.S.410)
10	8
40	36
200	200

Hydrometer Analysis

A representative sample of air-dried soil is selected and separated into two parts by passing it over an ASTM No. 10 sieve. The coarse material retained on the ASTM No. 10 sieve is subjected to sieving. The sample that is retained is dispersed and put into suspension in water, usually in the presence of a deflocculating agent. The changes of the specific gravity of the suspension with the passage of time are then noted by means of a hydrometer. Calculations based upon Stoke's law can then be employed to determine the percentages of grains of various average diameters remaining in suspension. In other words, for each of the time intervals specified in the test procedure, there may be determined by the percentage of the dispersed sample finer than (or coarser than) a certain

grain size. After the completion of hydrometer analysis, which may require 24 hours or more if the percentage of particles of colloidal size is to be determined by washing over BS No. 200 sieve material retained on the sieve is oven dried and sieve analysis is carried out. The results of sieve analysis and hydrometer analysis are combined to give complete grain-size distribution curve for soil being tested (BS 1377:1990).

2.6.1 **Liquid limit**

This is defined as the minimum moisture content at which the soil will flow under the application of very small shearing force. At this moisture content the soil behaves practically as a liquid. It is determined in the laboratory by a mechanical device.

2.6.2 Plastic limit

This is defined as the moisture content at which the soil remains in plastic condition. It can further be described as the lowest moisture content at which the soil can be rolled into a thread $^{1}/_{8}$ in diameter without crumbling.

2.6.3 **Plasticity index (P.I)**

It is defined as the numerical difference between the liquid limit and the plastic limit of the soil. It indicates the range of moisture content over which the soil is in a plastic condition. Sandy soils and silts have characteristically low plasticity index, while clay soils show high value of plasticity index.

Generally speaking, soils, which are highly plastic, are also highly compressible. Plasticity index is also a measure of cohesiveness. High value of plasticity index indicates a high degree of cohesion. Soils without plastic limit such as cohesionless sand are reported as being non plastic (NP).

2.6.4 **Shrinkage limit**

This is the most important of the shrinkage factors and is defined as the maximum calculated water content at which, upon continued drying the soil will continue to lose weight but will decrease in volume (BS 1377:1990).

2.7 **Soil Classification for Highway Purposes**

The objective of the use of soil classification system for highway purpose is to be able to predict the sub grade performance of a given soil on the basis of a few simple tests performed upon the soil in a distributed condition. The other objective is for engineers to always speak in one voice on matters concerning properties of soils. On the basis of these test results and their correlation with field experience, the soil may then be correctly identified and placed into a group of soils, all of which have similar characteristics and properties.

The principal soil classification system in use in this country by highway engineers is the American Association of State Highway and Transportation Officials (AASHTO classification system). There is also the Unified Soil Classification System (USCS). The principal tests utilized by AASHTO and other classification systems are the mechanical analysis and various routine laboratory tests. The sieve analysis is performed upon the

entire sample and has as its objective the determination of the proportion of particles of various sizes in the given soils.

The routine tests are performed upon the "soil binder" or fraction passing ASTM No. 40 sieve. The most important of the routine tests or "soil constants" are the Atterberg Limits and the field moisture equivalent.

2.7.1 **Unified Soil Classification System**

This system is based upon the Airfield classification system developed by Professor A. Casagrande of Harvard University during World War 11. The system was modified slightly and became the Department of the Army Uniform soil classification system. It was slightly modified and adopted by the Corps of Engineers and the Bureau of Reclamation in January 1952. The unified system is based primarily upon characteristics that determine how a soil will behave when used as a construction material. Table 2.2 shows the unified system charts. Soils may be classified into one of the 15 major soil groups in the unified system by using either laboratory or field identification methods. In this method, soils are classified based on:

(1) Percentage of gravel, sand and fine (fraction passing the No. 200 sieve)

(2) Shape of the grain size distribution curve

(3) Plasticity and compressibility characteristics.

The coefficients of uniformity (Cu) and gradation (Cg) are used to judge the shape of the grain size distribution curve of a coarse-grained soil. The symbol ''D_{10}'' shown on Table 2.2 means the grain size (diameter) that corresponds to 10 percent on a grain-size distribution curve shown in Fig. 2.2 D_{30} and D_{60} have similar meanings.

The influence of the relationship between liquid limit and plasticity index are shown on plasticity chart of Fig. 2.5. Clays (C) and silts (M) are further divided on the basis of low (L) or high (H) liquid limit. Table 2.3 gives more information on the engineering characteristics of various soil groups, as they pertain to roads and airfield.

Table 2.2 Unified Soil Classification System (After Paul and Radnor 1979) .

Major Division			Group Symbols	Typical Name	Field Identification Procedures (Excluding Particles Larger Than 3 Inches and Basing Fractions on Estimated Weight)		
1	2		3	4	5		
Coarse-grained Soils: More than half of material is larger than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.	Gravels: More than half of coarse fraction is larger than No. 4 sieve size. (For visual classification, the 1/4-inch size may be used as equivalent to the No. 4 sieve size).	Clean gravels (little or no fines)	GW	Well-graded gravels, gravel-sand mixture, little or no fines.	Wide range grain sizes and substantial amounts of all intermediate particles sizes.		
			GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		Gravels with fines (appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).		
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).		
	Sands: More than half of coarse fraction is smaller than No. 4 sieve size.	Clean sands (little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain size and substantial amounts of all intermediate particle sizes.		
			SP	Poorly-graded sands, gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		Sands with fines (appreciable amount of fines)	SM	Silty sands, sand-silt mixtures	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).		
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).		
Fine-grained Soils: More than half of material is smaller than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.	Silts and Clays: Liquid limit less than 50				Identification procedures on fraction smaller than No. 40 sieve size		
					Dry strength (crushing characteristics	Dilatancy (reaction to shaking)	Toughness (consistency near PL)
			ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, with slight plasticity	None of slight	Quick to slow	None
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, learn clays	Medium to high	None of very slow	Medium
			OL	Organic silts and organic silty clays of low plasticity	Slight to medium	Slow	Slight
	Silts and Clays: Liquid limit greater than 50		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Slight to medium	Slow to none	Slight to medium
			CH	Inorganic clays of high plasticity, fat clays	High to very high	None	High
			OH	Organic clays of medium to high plasticity, organic silts	Medium to high	None of very slow	Slight to medium
Highly organic soils			Pt	Peat and other highly organic soils	Readily identified by color, odor, spongy feel and frequently by fibrous texture		

(1) Boundary classifications: Soils possessing characteristics of two groups are designated by combinations of group symbols. For example Adopted by Corps of Engineers and Bureau of Reclamation, January 1952.

Information Required for Describing Soils	Laboratory Classification Criteria			
6	7			
For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics Give typical name; indicate approximate Percentages of sand and gravel, max. size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses Example: Silty sand, gravelly; about 20 percent hard, angular gravel particles1/2-in. maximum size; rounded and subangular sand grains coarse to fine; about 15 percent nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM)	Use grain-size curve in identifying the fractions as given under field identification.	Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows: Less than 5 percent GW, GP, SW, SP; More than 12 percent GM, GC, SM, SC. 5 percent to 12 percent	$Cu = \frac{D_{60}}{D_{10}}$ greater than 4 $Cg = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			Not meeting all gradation requirements for GW	
			Atterberg limits below A line or PI less than 4	Above A line with P1 between 4 and 7 are borderline cases requiring use of dual symbols
			Atterberg limits above A line with PI greater than 7	
			$Cu = \frac{D_{60}}{D_{10}}$ greater than 6 $Cu = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			Not meeting all gradation requirements for SW	
			Atterberg limits below A line or PI less than 4	Limits plotting in hatched zone with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Atterberg limits above A line with PI greater than 7	
Give typical name, indicate degree and Character of plasticity, amount and maximum size of coarse grains, color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information; and symbol in parenthesis For undisturbed soils add information On structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions Example: Clayey silt, brown, slightly plastic, small percentage of fine sand, numerous vertical root holes, firm and dry in place, loess, (ML)				

Table 2.3 Classification and Characteristic of Soil for Roads and Airfield (Based on Cassangrade Classification) (After CP2001:1957)

	1 Major division	2 Description and identification	3 Sub-groups	4 Casa-grande group-symbol	5 Applicable classification tests (carried out on disturbed samples)
COARSE-GRAINED SOILS	Boulder and cobbles	Soils consisting chiefly of boulders larger than 8 inch in diameter or cobbles between 8 inch and 3 inch Identifiable by visual inspection.	Boulder gravels	_	Mechanical analysis.
	Gravel and gravelly soils	Soils with an appreciable fraction between the 3 inch and No. 7 sieves. Generally easily identifi-able by visual inspection. A medium to high dry strength indicates that some clay is present. A negligible dry strength indicates the absence of clays.	Well-graded gravel-sand mixtures, little or no fines.	GW	Mechanical analysis.
			Well-graded gravel-sands with small clay Contents.	GC	Mechanical analysis, liquid and plastic limits on binder.
			Uniform gravel with little or no fines.	GU	Mechanical analysis.
			Poorly-graded gravel-sand mixtures, little or no fines.	GP	Mechanical analysis.
			Gravel-sand mixtures with excess of lines.	GF	Mechanical analysis, liquid and plastic limits on binder if applicable.
	Sands and sandy soils	Soils with an appreciable fraction between the No. 7 sieve and the No. 200 sieve. Majority of the particles can be distinguished by eye. Feel gritty when rubbed between the fingers. A medium to high dry strength indicates that some clay is present. A negligible dry strength indicates absence of clay.	Well-graded sands and gravelly sands, little or no fines.	SW	Mechanical analysis.
			Well-graded sand with small clay content.	SC	Mechanical analysis, liquid and plastic limits on binder.
			Uniform sands, with little or no fines.	SU	Mechanical analysis.
			Poorly-graded sands, little or no fines.	SP	Mechanical analysis.
			Sands with excess of fines.	SF	Mechanical analysis, liquid and plastic limits on binder if applicable.
FINE-GRAINED SOILS Containing little or no coarse-grained material	Fines grained soils having low plasticity (silts)	Soils with liquid limits less than 35 percent and generally with less than 20 percent of clay. Not gritty between the fingers. Cannot be readily rolled into threads when moist. Exhibit dilatancy (see Appendix C).	Silts (inorganic), rock flour, silty fine sands with slight plasticity.	ML	Mechanical analysis, liquid and plastic limits if applicable.
			Clayey silts (inorganic).	CL	Liquid and plastic limits.
			Organic silts of low plasticity.	OL	Liquid and plastic limits from natural conditions after oven drying.
	Fines grained soils having medium plasticity	Soils with liquid limits between 35 and 50 percent and generally containing between 20 and 40 percent clay. Can be readily rolled into threads when moist. Do not exhibit dilatancy. Show some shrinkage on drying.	Silty clays (inorganic) and sandy clays.	MI	Mechanical analysis, liquid and plastic limits if applicable.
			Clays (inorganic) of medium plasticity.	CI	Liquid and plastic limits.
			Organic clays of medium plasticity.	OI	Liquid and plastic limits from natural conditions and after oven drying.
	Fines grained soils having high plasticity	Soils with liquid limits grater than 50 percent and generally with a clay content greater than 40 percent. Can be readily rolled into threads when moist. Greasy to the touch. Show considerable shrinkage on drying. All highly compressible soils.	Highly compressible micaceous or diatomaceous soils.	MH	Mechanical analysis, liquid and plastic limits if applicable.
			Clay (inorganic) of high plasticity.	CH	Liquid and plastic limits.
			Organic clays of high plasticity	OH	Liquid and plastic limits from natural conditions and after oven drying.
	Fibrous organic Soils with very high compressibility	Usually brown or black in colour. Very compressible. Easily identifiable visually.	Peat and other highly organic swamp soils.	Pt	Moisture content and

6	7	8	9	10	11
Applicable observations and tests relating to the material in place (or carried out on undisturbed samples)	Value as a road foundation when not subject to frost action	Potential frost action	Shrinkage or swelling properties	Drainage characteristics	Bulk dry density at optimum compaction, lb./cu. ft. and voids ratio, e
	Good to excellent.	None to very slight.	Almost none.	Good.	—
	Excellent.	None to very slight.	Almost none.	Excellent.	> 125 e < 0.30
Dry density and relative compaction. Moisture content and voids ratios.	Excellent.	Medium.	Very slight	Practically impervious	> 130 e < 0.30
Cementation durability of grains.	Good	None.	Almost none.	Excellent.	> 110 e < 0.50
Stratification and drainage characteristics.	Good to Excellent.	None to very slight.	Almost none.	Excellent.	> 115 e < 0.45
Ground-water conditions. Large scale loading tests.	Good to Excellent.	Slight to medium.	Almost none to slight.	Fair to practically impervious	> 120 e < 0.40
California Bearing Ratio tests. Shear tests and other strength tests.	Excellent to good.	None to very slight.	Almost none.	Excellent.	> 120 e < 0.40
	Excellent to good	Medium.	Very slight.	Practically impervious	> 125 e < 0.35
	Fair.	None to very slight.	Almost none.	Excellent.	> 100 e < 0.70
	Fair to good.	None to very slight.	Almost none.	Excellent.	> 100 e < 0.70
	Fair to good.	Slight to high	Almost none to medium.	Fair to practically impervious	> 105 e < 0.60
	Fair to poor.	Medium to high.	Slight to medium	Fair to poor	> 100 e < 0.70
	Fair to poor.	Medium to high.	Medium.	Practically impervious	> 100 e < 0.70
	Poor.	Medium to high.	Medium to high.	Poor.	> 90 e < 0.90
Dry density and relative compaction. Moisture content and voids ratio. Stratification fissures, etc.	Fair to poor.	Medium.	Medium to high.	Fair to poor.	> 100 e < 0.70
Drainage and ground-water Consolidation tests. Loading tests.	Fair to poor.	Slight.	High.	Fair to practically impervious	> 95 e < 0.80
California Bearing Ratio tests. Shear tests and other strength tests.	Poor.	Slight.	High.	Fair to practically impervious	> 95 e < 0.80
	Poor.	Medium to high.	High.	Poor.	> 100 e < 0.70
	Poor to very poor.	Very Slight.	High.	Practically impervious	> 90 e < 0.90
	Very Poor	Very Slight.	High.	Practically impervious	> 100 e < 0.70
Consolidation tests.	Extremely poor.	Slight.	Very high.	Fair to poor.	-

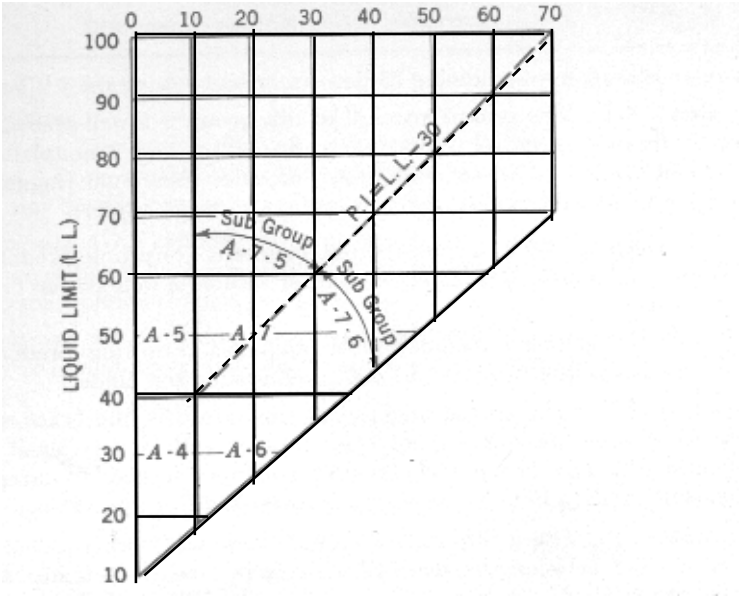


Figure 2.3 Liquid limit and Plasticity index ranges for A-4, A-5, A-6, A-7 (After Paul and Radnor 1979).

2.7.2 **AASHTO Soil Classification System**

This system was originally developed by Hogertogler and Terzaghi in 1929 as the Public Roads Classification system. The Bureau of Public Roads in their research magazine first presented the AASHTO Classification System in 1931 by Bureau of Public Roads in their research magazine. The subgrade soils were grouped by this method into eight principal groups designated by symbols A-1 through A-8 (Paul and Radnor 1979).

The AASHTO classification system describes a procedure of classifying soils into seven groups based on laboratory determination of particle-size distribution, liquid limit and plasticity index. Evaluation of soils within each group is then calculated from an empirical formula or with the use of a chart. The group classification is used in

determining the relative quality of the soil material for use in earthwork structures, particularly embankments, subgrades, subbases and bases.

2.8 Application of Geology in Engineering

Since the foundation is of paramount importance in all engineering works, including the highway, knowledge of the nature and behavior of geological deposits is a primary factor in the planning of these works.

2.8.1 **Geological deposits**

They are 'products of nature'. For practical purposes, engineers classify all geological deposits into 'soils' (or earth') and 'rock'. Soils embrace soft and loose deposits while rocks are hard and rigid deposits (CP 2001: 1957).

Geological classification is based on age and mode of formation. Soils and rocks in engineering sense may be included on any of the groups. Geological classification is as follows:

(a) Drift and superficial deposits e.g glacial and recent river laid, sea or aeolian deposits which are almost entirely soil (from the engineer's definition) and overlie the solid formations.

(b) Solid deposits .e.g sedimentary or stratified deposits (like limestones and sandy or clayed deposits); metamorphic formations and igneous rocks. These are discussed in concise form as follows:

2.8.1.1 **Drift or superficial deposits**

They are the main accumulations of rock debris, derived by weathering from pre-existing formations that have been arrested during transport by natural agencies to the sea. They include gravels, sand, silts and clays. Peats and tuffs are also superficial deposits though of vegetable origin (CP 2001: 1957).

All drifts are soils in engineering sense, the more sandy deposits being classed as non- cohesive and the more clayey as cohesive soils. Their engineering properties differ significantly. The points that should be stressed are: Their mode of occurrence as spreads and patches of varying thickness masking the solid formation. Peats, or organic deposits are characterized by a high degree of compressibility, irregularity in the base of all types of drift (CP 2001: 1957).

2.8.1.2 **Solid deposits**

Sedimentary or stratified deposits:

These consist of materials derived from pre-existing formation by mechanical disintegration and chemical decomposition (i.e., weathering), the loosened fragments and particles being carried away, chiefly by water, and deposited on lake or sea- floors as flat beds which eventually consolidate, the sands and gravels forming sandstones and muds forming clays and shales. Shell debris and calcerous mud accumulate in flat beds, which hardens to form limestones.

Owing to differences in hardness and resistance to abrasion of different minerals, the process of disintegration of the pre-existing strata result ultimately in the formation of different grain sizes amongst the particles of disintegrated material; the harder and tougher

minerals are not so finely divided as the softer. During transport in water, the grain sizes become naturally segregated, the coarser particles settling in water-currents, which are too slow to move them, but still able to transport finer material, which remains in suspension until the currents are further, reduced. Thus sandy deposits are mainly siliceous or quartzose, while muds are mainly aluminous (CP 2001: 1957).

Series of flat beds are built up and eventually the deeper ones, subjected to pressure by the weight of overlying strata, lose their contained water and become consolidated. Sedimentary deposits may be recognized by their bedded structure or stratification, the individual beds, lying one above another, often being distinguishable by differences in colour, texture or composition. Examples of sedimentary deposits are:

i. Sands and Sandstones

Engineering properties: Uncemented sands and gravels constitute the principal non-cohesive soils. All their particles are sufficiently large to be seen with the naked eye, and no forces of cohesion exist between them. The strength of a soil of this type depends entirely on internal friction, and the strength at any section is therefore dependent upon the effective normal pressure acting on that section. The ratio of the shear strength to effective normal pressure is defined as tan Φ where Φ is the angle of internal friction of the sand or gravel. The value of Φ, for a given sand, is almost independent of the normal pressure, but varies with the degree of packing of the particle, i.e, with the density of the sand. If the pressure acting between the particles is reduced as, for example, by water flowing through the soil, the strength is correspondingly reduced; and this is one of the causes of a quicksand or piping condition (CP 2001: 1957).

Sand in a loose state is very sensitive to vibration resulting from earth tremors, pile driving or other causes, which cause it to fall into more dense packing. This will obviously lead to settlement, and, if the sand is saturated, the particle in trying to achieve closer packing will force the pore water upwards and out at the surface. This upward flow reduces the strength of the soil and may cause a quicksand condition. The permeability of non-cohesive soils is high. In problem of bearing capacity the non-cohesive soils are not usually very troublesome since they are only moderately compressible.

Seepage and piping are clearly problems of great importance in non-cohesive soils. These soils are satisfactory for constructing embankments. On all important embankments it is desirable to ascertain by compaction tests the densities of the soil that should be obtained in construction. The materials most suitable for this use, the sieve (mechanical) analysis is generally important and other tests are available to ascertain the suitability of a given material for any particular process. Dense compaction is also required.

Sandy formations frequently contain ground water and are amongst the most prolific water-bearing strata from the point of view of water supplies; ground water near surface, however, may involve the construction of special drainage works on sites requiring deep excavations.

ii. Clay and Shales

Engineering properties: Clays, shales and silts are classed as cohesive soils. They contain an important proportion of very fine particles between which exist forces of cohesion. The particles in many cohesive soils are arranged in an open or honeycomb structure and any disturbance, such as augering or pile driving, breaks down this structure

with a consequent loss of strength. Cohesive soils tend to absorb water and expand, with a resulting softening and loss of strength (CP 2001: 1957).

Owing to the important proportion of fine particles, the void spaces are also of very small dimension and the permeability of cohesive soils is extremely low. The compressibility of most clays and silts under applied pressure is appreciable and, since a volume reduction can take place only by the extrusion of some of the pore water and air in partly saturated soil, the rate at which the compression occurs is very low owing to the low permeability of these soils. This process of slow volume reduction under pressure is referred to as consolidation. When exposed to the atmosphere, cohesive soils dry out in the summer, with the formation of surface cracks, which may extend 0.76 m to 1.22 m deep in Britain (CP 2001: 1957).

The bearing capacity of cohesive soils is usually not very great and it clearly depends on the shear strength. Owing to the shrinkage of clays in the summer, foundations of both roads and structures on these soils should be given special consideration. The seasonal shrinkage and expansion of clays of high liquid limit may be very detrimental to roads and pavements of all types, causing repeated vertical displacements reported to exceed 0.51 m in period of not more than three months (CP 2001: 1957).

Cohesive soils may be treacherous when used as a material of construction. Sandy clays can be used for embankments, earth dams and with the addition of a suitable stabilizer, in earth roads, but it may sometimes be necessary to improve the grading by the addition of sand.

iii. Limestone

Engineering properties: Limestones are among water bearing formations and are extensively tapped as sources of underground water supply.

Metamorphic Formations:

These include any sedimentary deposit or igneous rock, which after consolidation, has become altered by heat or pressure. Sands and sandstone may be hardened or so intensely altered that the individual sand grain is not distinguishable, the rock being an almost glassy quartzite. Limestone may become completely re-crystallized into marble. Clayey rock may be compacted to hard shales of slate-like appearance. However they are still distinguishable as shales by their fissility along bedding planes, or so altered by pressure applied in a direction parallel with the bedding plane, that these become crumpled and finally obliterated, and a cleavage develops oblique to the original bedding resulting in the formation of true slates (CP 2001: 1957).

Igneous rocks**:**

These are formed by solidification of molten material, which has ascended towards surface from the hot lower levels of the earth's crust.

Engineering properties of Igneous rocks:

Basic rocks are generally dark, while acid rocks are pale in colour. Lava-flows, owing to their mode of formation, may present differences in texture and composition, in both intrusive and deep-seated igneous rocks. They were formed by the solidification of a liquid; fairly homogeneous and excavations can be carried out within them without

encountering any considerable change of texture or hardness. If material variation occurs, it will probably be marked by change in colour. All igneous rocks are hard and require explosives to excavate them, while some are extremely tough, especially the fine-grained (not glassy) basic varieties such as basalt and dolerite, which, for this reason, are much in demand as road-surfacing material (CP 2001: 1957).

> As construction materials, igneous rocks are valuable, granites being widely used for masonry, and dolerites and basalts for road metal. Most igneous rocks when crushed and graded are suitable for concrete aggregate, but dolerites and some other basic varieties should not be used indiscriminately, since some samples contain minerals which cause expansion and disruption of the hardened concrete.

2.8.2 **Geological structures**

From the engineering standpoint, geological structures are as important as the physical characters of the rocks and soils themselves. But emphasis must be laid upon the necessity for the engineer to familiarize himself with the different forms of disturbances he is likely to encounter and which are explained in most textbooks on geology.

It must be clear that any mechanical disturbance and dislocation in rocks will destroy their stability and render precautions against failure essential. In most engineering works, the mere dip or tilt of the strata may introduce complications that would be absent were they flat, and the presence of jointing or faulting, even if only on a small scale in the geological sense, may cause trouble if appropriate precautions are not taken. The engineer too, should be alive to the possibilities of geological structures and old topographies hidden beneath superficial deposits which unseen when the ground was geologically surveyed, may not appear on geological maps. When works are to be constructed in valleys special care is called for in preliminary investigations.

2.9 **Formation and Properties of Soils in Nigeria**

2.9.1 **South South**

Soil parent material in Southern Nigerian shown in Fig. 2.4, revealed that the northern part of the region is Pre-Cambrian Basement Complex of predominantly acidic igneous and metamorphic rocks formation while the southern part is Pre-Cambrian rocks, with sedimentary formations of cretaceous, Tertiary and Quaternary era. These sedimentary formations are largely sandstones, and the degree of consolidation increases with age.

The climate of the area has the mean annual rainfall ranging from 1010-1270 mm per annum on the northern part of the region, with over 4140 mm in the south- south deltaic swamps. The natural vegetation of Nigeria has been described as mangrove in the south-south fringe of the delta followed by a narrow belt of fresh water swamp forest (Ackroyd 1967). The main part of the region is under tropical rain forest and this changes into savannah as the boundary with north- central Nigeria is approached.

Benin in South-South Nigerian has a parent material in the area of the southern sedimentary deposit that is generally poorly consolidated sandstone and the end product of kaolinite and free iron oxides (Ackroyd 1964). Under conditions of greater humidity concretions are not formed and the effect of heavy leaching combined with good drainage is to form ferralitic soils with iron oxides evenly dispersed on the kaolinite crystal surfaces.

The immobilized iron on the clay particles facilitates the bonding of clay and silt particles to form stable aggregates of silt and sand sizes. In this case soil practically is reduced and the general stability of the soil increased by the effective coarser grading brought about by the aggregation of the silt and clay fractions.

Non-concretionary Soils: In the South-South sediments, two major groups of non-concretionary acidic sand-clay soils occur, the Benin and Delta sands (Roseveare 1953). In

terms of the Inter African Pedological Service (S.P.I) classification, the Benin sands are red ferralitic soils developed on unconsolidated sediments. The Delta sands are similarly yellowish – brown ferralitic soils and for engineering purposes have been divided into two subgroups, the reddish-yellow Delta sands and the more uniformly graded and silty brownish-grey Delta sand.

The soil in Benin and Delta are sands and clays (Qp), from coastal plain sand of Quaternary era. Auchi has shale and sandstone (Kro), from Kporo shale group and of Cretaceous Era. Agenebode have false-bedded sandstones coal and shales (Kuc) from the False bedded sandstone and upper coal measures of Cretaceous Era. Itu, Ikot-Epkene has clay sandstone, Lignite and shale (TI) from Lignite formation of Tertiary Era.

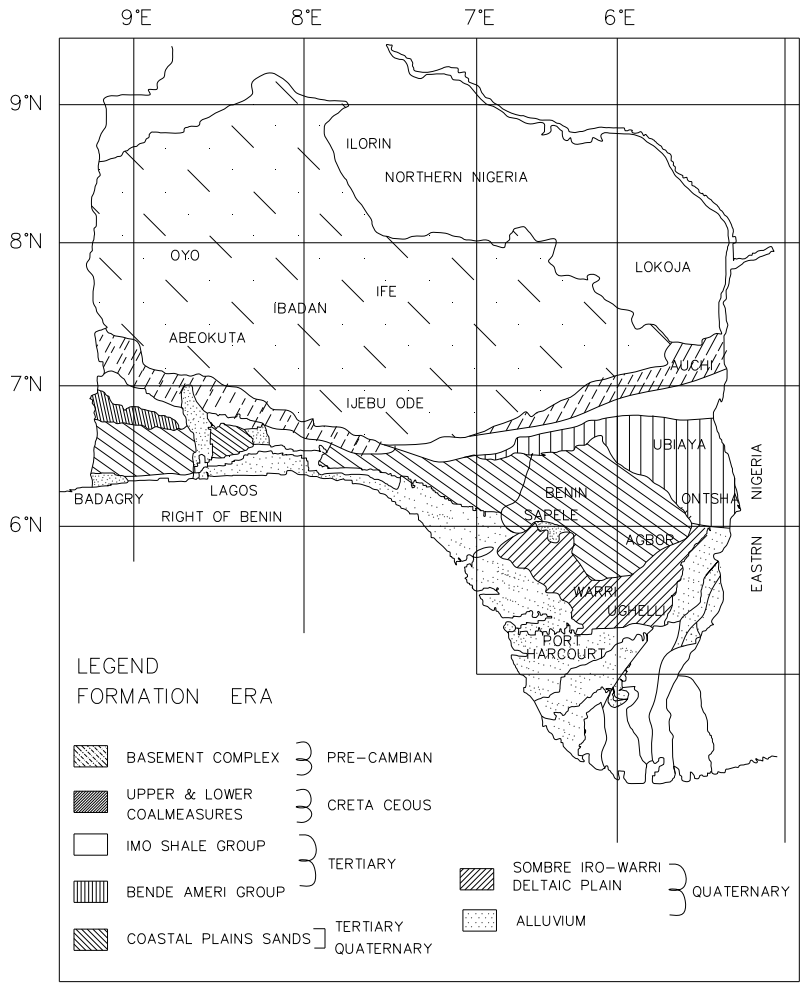


Figure: 2.4 Geological Sketch Map of South-South Nigeria (After Roseveare 1953).

2.9.2 **South-West**

Concretionary Soils: Concretionary gravels occur over the whole area of the Basement Complex rocks, in the South-West sediments' (Ijebu gravels) and along the Northern fringe of the South Eastern sediment clays (Ackroyd 1967).

In order to account for the presence, or absence of ferruginous concretions in soil developed over the South-West Nigerian Sedimentary Formations it is necessary to start with the soil parent material. This is material of secondary origin that is the product of the primary weathering of crystalline rocks. In the hot humid tropics chemical weathering predominates, the net effect on the primary minerals of crystalline rocks being the disappearance of some minerals and the formation of secondary product; that is formation of the weathering complex. These may be summarized as comprising the conversion of feldspars to clay minerals by hydrolysis and the decomposition of ferromagnesian minerals to leave iron oxides in various degrees of hydration. Quartz together with certain other highly resistant minerals is left virtually unaltered. Under condition of strong leaching and good drainage de-silification, a major feature in the process of hydrolysis, is intensified resulting in a clay complex largely composed of kaolinite associated with considerable quantities of free, sesquioxides, i.e. the ferralitic clays (Ackroyd 1967).

The parent material of the soils of the South-West Nigerian sediments from the time of deposition may be considered to be composed of three main constituents: quartz, the kaolinite clay complex and associated iron oxides. South west Ibadan, Ilorin Ogbomosho, have Pcb; while Ifo, Otta, Ikeja have sands and clays (Qp), from coastal plains sands and of Quaternary era; Shagamu has aluvium (Qa), from Quaternary era; Ijebu

Ode, Ipetu, Abeokuta sands, clays, calcareous parts (Kb) formed from Abeokuta formation of the cretaceous era (Ojo 1994).

2.9.3 **South East**

Residual soils occur in different forms in Nigeria and throughout tropical Africa. In Eastern Nigeria, the largest group of residual soils occurs as laterites and coastal sands and the presence of roadside quarries bears testimony to their economic value as road building materials. Among the residual soils occurring in West Africa, are laterites that are assumed by many engineers to be the best materials for such roads (Madu 1975). The region's climate is tropical with rainfall varying from 3600 mm along the coastal to 1550 mm to the north.

The oldest rocks are Pre-Cambrian, but the major part of the region is covered with large deposits of clays, shales, sandstones and siltstones due to extensive transgression and regression of the seas, the sediments being later folded and followed by some igneous activity in some area, See Fig. 2.5

In general, laterite shales have greater quantities of finer materials than sandstone laterites; both sandy-clay and coastal sand have little or no silt or clay (Madu 1975). The particle size distribution of a soil sample is a function of the degree of weathering, the parent rock, and the position of the sample in the soil profile.

In some African countries like Nigeria, Angola, Mali, etc the specifications for soil for the construction of low cost roads include specifications of the index properties.
South East (e.g. Enugu,) have shale and limestone (Kwn) of Awgu – Ndeaboh shale group and formed from Cretaceous Era; shale and roundstone (Kro) of Nkporo shale Group and

formed from Cretaceous Era; Abakaliki has shale and limestone (Kar) of Asu River Group from Cretaceous Era; Nkalagu has black shale and siltstone (Kea) of Eze Aku shale Group and formed in the Cretaceous Era; Okigwe/Nsukka have falsebedded sandstones, coal and shale (Kuc) formed from falsebedded sandstone and upper coal measures they are also of Cretaceous. Umuahia has sands clays and shale (Ti) of Ilaro formation form in the Tertiary era. Also, Adoru has clays and shales with limestone (Tm) of Imo clay-shale Group formed in the Tertiary. Aba has sands and clays (Qp) from coastal plan sands formed in Quaternary era (Ojo 1994).

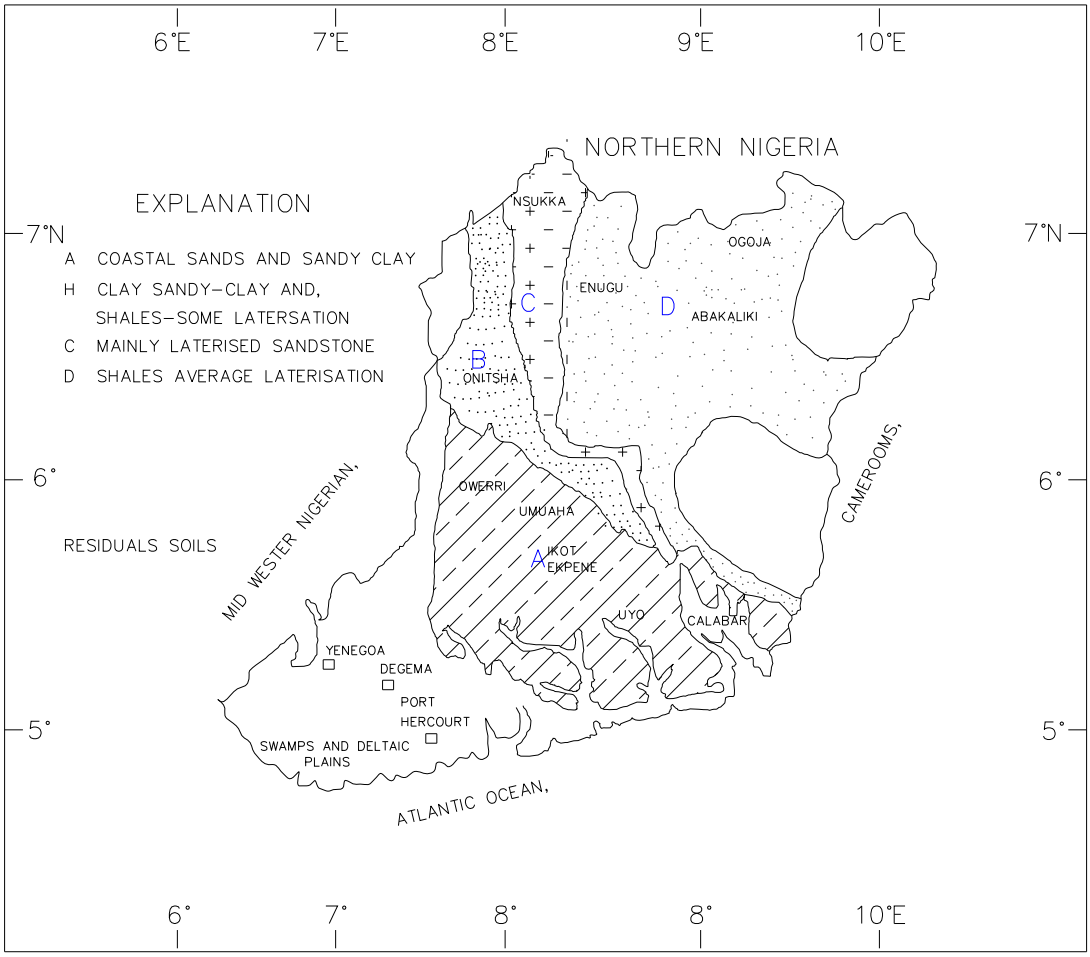


Figure: 2.5 Geological Areas Map of South East Nigeria (After Madu 1975).

2.9.4 **North East**

North-East Nigeria has the black cotton soils, which are dark coloured expansive clays, characterized by the phenomena of swelling on absorption of water and shrinkage on drying. These characteristics make them highly problematic as foundations for both building and road structures. Such soils are common products of tropical weathering and are encountered in several parts of the world.

In general, the black cotton soils derive their origin from basic igneous rocks such as basalts, rich in feldspars and mafic minerals such as montmorillonites. In Nigeria, these soils are found predominantly in the North- Eastern region of the country, lying within the Chad Basin and partly within the Benue trough (See Fig. 2.6). It is believed that these soils derived their origin in Nigeria, from basalts of the upper Benue trough which cover several hundred square kilometers extending North and East of the Jos Plateau, and from quarternary sediments of lacustrine origin from the Chad Basin consisting mainly of shales, clays and sandy sediments.

Black cotton soils generally occur in poorly drained areas, with alternating wet and dry season and with an annual rainfall generally less than 1200 mm. Such physiographical features and climatic conditions are typified in the Chad Basin where sediments were deposited as the lake expanded and shrank during the alternating wet and dry periods. Other conditions conducive to their formation include the cumulative effect of leaching, alkaline environment and retention of calcium and magnesium in the soil.

Bulk of the black cotton soil deposits in Nigeria is found in the North-Eastern States of Bornu, Adamawa, Taraba and Bauchi. These soils generally occur in discontinuous stretches as superficial deposits usually not more than 2 m in thickness, overlain or underlain by sandy sediments.

The far North East i.e. Borno, Yobe are mainly sands and clays (Qc) which is from Chad formation. They are formed from the Quaternary era. North East also has sandstone, siltstone, shale and ironstone (Kg), non marine sand from Gombe formation; Granitoids of

older Granites series in Basement complex (Pcg), formed from Pan Africa era; Gneiss migmatite complex of migmatite Gneiss Schist Complex (Pcb) formed from Basement Complex of Pre-Cambrian era. Yola are mainly felspathic sandstone, sandy clays, shale, calcareous sandstone, and shelly limestone (Kby), formed from Bima sandstone and Yolde formation. There are also shales and limestones (Kp) formed from marine facies all of Cretaceous era (Ojo 1994).

In **N**orth West (Kano, Katsina, Kaduna and. Mainchi) Nigeria are mainly Granitoids of older Granites series in Basement complex (Pcg); Gneiss migmatite complex of migmatite Gneiss Schist Complex (Pcb); with few Meta sediments/Volcanics Gneisis (Pcm) formed from Migmatite Gneisis/Schist Complex of Basement Complex. They are of the Pre-Cambrian. Sokoto is predominatly sandstone and mudstone (Kr); formed from Rima Group of Cretaceous era while Jega is of Pisolitic clays and grits formed from Illo formation of Cretaceous era. (See Fig. 2.6)

North central Nigeria have Aluvium (Qa), (e.g is Abaji, Abaji-loko) formed from Quaternary Era; felspathic sandstone and siltstone (Kn) from Nupe formation and of cretaceous era They also have Pcg, Pcg, Pcm, Pcb (e.g Abuja – Kaduna Rd) (Ojo 1994).

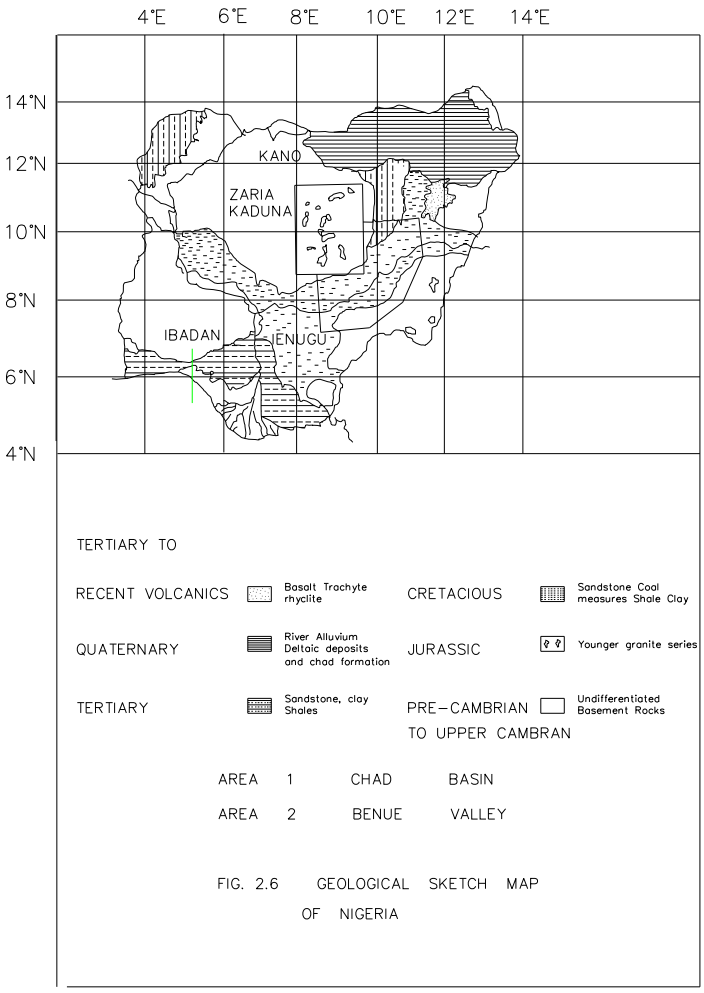


Figure: 2.6 Geological Sketch Map of Nigeria (Roseveare 1953).

CHAPTER THREE

COLLATION OF DATA

3.1 Preamble

Available data were collected and collated from summaries of soils testing results available at the Pavement Evaluation Unit, Federal Highway Department, Federal Ministry of Works and Housing, (PEU/FMW&H) Kaduna and from some consultants in Nigeria.

The data collected include the soil properties for the base, sub-base and sub-grade of existing roads and on-going highway projects in Nigeria. The properties of soils include the particle size distribution, liquid limit, Plasticity index and soils classification.

The principal soil classification system used in this country by highway engineers is the AASHTO (American Association of State Highway and Transportation Officials) classification system. There is also the Unified Soil Classification System.

The principal tests utilized by the AASHTO and other classification systems are the mechanical analysis and various routine laboratory tests. The mechanical analysis is performed upon the entire sample and has its objective as the determination of the proportion of particles of various sizes in the given soils.

The routine tests are performed upon the "soil binder" or fraction passing a ASTM No 40 sieve. The most important of the routine tests are the Atterberg limits and the field moisture content.

The present AASHTO (1978) system is primarily based on the version in 1945. (Roads Administration (P.R) system Classification, 1945). The sub grade soils were grouped by this method into eight principal groups designated by symbols A-1 through A-8.

The AASHTO classification system describes a procedure of classifying soils into seven group based on laboratory determination of particle-size distribution, liquid limit and

plasticity index. Evaluation of soils within each group is made by calculation from an empirical formula or with the use of chart. The group classification is used in determining the relative quality of the soil material for use in earthwork structures, particularly embankments, sub grades, sub bases and bases.

3.2 Soils Groups

Group A-1: The material of this group is a well-graded mixture of stone fragment or gravel, coarse sand, fine sand and non-plastic or feebly plastic soil binder.

Sub-group A-1-a: These materials consist predominantly of stone fragment or gravel, either with or without a well-graded binder of fine material.

Sub-group A-1-b: These include those materials consisting predominantly of coarse sand, either with or without a well-graded soil binder.

Group A-3: The material of this group is fine beach sand or fine desert blown sand, without silty or clay fines or with a very small amount of non-plastic silt. The group includes also stream – deposited mixtures of poorly graded fine sand and limited amounts of coarse sand and gravel.

Group A-2: This group includes a wide variety of granular materials which are border-line cases between the material falling in groups A-1 and A-3 and the silty-clay materials of group A-4, A-5, A-6 and A-7. It includes all materials containing 35 per cent or less passing a BS No. 200 sieve, which cannot be classified as A-1, or A-3, owing to fines content or plasticity.

Sub-groups A-2-4 and A-2-5: These include various granular materials containing 35 per cent or less passing a BS No. 200 sieve having the characteristics of the A-4 and A-

5 groups. They include gravel, and coarse sand with silt content or plasticity index in excess of the limitations of group A-1, and fine sand with non plastic silt content in excess of the limitations of group A-3.

Sub-group A-2-6 and A-2-7: They are materials similar to those described under sub-groups A-2-4 and A-2-5, except that the fine portion contains plastic clay having the characteristics of the A-6, or A-7 group. The combined effects of plasticity indices in excess of 10 per cent and percentage passing a BS No. 200 sieve in excess of 15 are reflected by the group index values of from 0-4.

Silt-clay materials

Group A-4: The material of this group is a non plastic or moderately plastic silty soil usually having 75 per cent or more passing a BS No. 200 sieve. The group also has mixtures of fine silty soil and up to 64 per cent of sand and gravel retained on a BS No. 200 sieve. The group index values range from 1 to 8, with increasing percentages of coarse material being reflected by decreasing group index values.

Group A-5: The material of this group is similar to that of A-4, except that it is usually of diatomaceous or micaceous character and may be highly elastic as indicated by the high liquid limit. The group index values range from 1 to 12, with increasing values showing the combined effect of increasing liquid limits and decreasing percentage of coarse material.

Group A-6: The material of this group is of plastic clay soil usually having 75 per cent or more passing a BS No. 200 sieve. The group includes mixtures of fine clayey soil and up to 64 per cent of sand and gravel retained on a BS No. 200 sieve. These materials are susceptible to high volume change between the wet and the dry season. The group index

values range from 1 to 16, with combined effect of increasing plasticity indices and decreasing percentage of coarse material.

Group A-7: The typical material of this group is similar to that described under A-6, except that it has the high liquid limits characteristic of the A-5 group and may be elastic as well as subject to high volume change. The group index values range from 1 to 20, with increasing value reflecting the combined effect of increasing liquid limits and plasticity indices and decreasing percentage of coarse material.

Sub-group A-7-5: These are materials with moderate plasticity indices in relation to liquid limit, which may be highly elastic as well as subject to considerable volume change.

Sub-group A-7-6: These include those materials, which have high plasticity indices in relation to their liquid limit and are subject to extremely high volume changes.

Classification Procedure

With the required test data available, proceed from left to right in Table 3.1 (AASHTO classification groups and sub group) and the process of elimination finds the correct group. The first group from left into which the test data will fit is the correct classification. All limiting test values are shown as whole numbers.

The plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity of A-7-6 subgroup is greater than LL minus 30 (See Figure 2.3)

The group index values are shown in parenthesis after group symbols as: A-2-6 (3), A-4 (5), A-6 (12), A-7-5 (17) and so forth.

The group index is calculated from the formula below or from a chart used by FMW&H (appendix).

Group Index = (F-35) [(0.2 + 0.005 (LL – 40)] + 0.01 9F-15) (PI –10)

F= Percentage passing 0.075mm (BS No. 200) sieve

LL = liquid Limit

Table 3.1: Classification of Highway Subgrade Materials (with Suggested Subgroups). (AASHTO After F.M.W)

General Classification	Granular Materials (35% or less passing No. 200)							Silt-Clay Materials (More than 35% passing No. 200)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis Percent Passing:											
No. 10 (2.00mm)	60max.										
No. 40 (0.425mm)	30max.	50max.	51min.								
No. 200 (0.075mm)	15 max.	25 max.	10 max.	35max.	35max.	35max.	35max.	36min.	36min.	36max.	36max.
Characteristics of Fraction Passing No. 40											
Liquid Limit				40max.	41min.	40max.	41min.	40max.	41min.	40max.	41min.
Plasticity Index	6max.		N.P.	10max.	10max.	11min.	11min.	10max.	10max.	11min.	11min.
Usual Types of Significant Constituent Materials	Stone Fragments Fine Gravel, and Sand			Silty or Clayey Gravel and Sand				Silty Soils		Clayey Soils	
General Rating as Subgrade	Excellent to Good							Fair to Poor			

Federal Ministry of Works uses the AASHTO classification system as shown in Table 3.1. The material that can be used for sub-grade, sub-base and base course must meet some specification requirements which are shown in Table 3.2

Table 3.2: Summarized F.M.W.&H Specification Requirements (Nigerian General Specification 1997)

CLAUSE(S)	REQUIREMENTS	REMARKS
6201 6122	Material Suitable for **Subgrade/fill** % Passing BS Sieve 200 >35% Liquid limit (LL) >50% Plastic Index (PI) >30%	
6201	Material Suitable for **Sub base** % Passing Sieve 200 >35% Liquid limit (LL) >35% Plastic Index (PI) >12%	Type I Sub-base If % passing BS Sieve 200 is greater than 35 % no need for further tests and material rejected
6201	Material Suitable for **Lateritic Base course** % Passing Sieve 200 >35% Liquid limit (LL) >35% Plastic Index (PI) >12%	If % passing BS Sieve 200 is greater than 35 % no need for further tests and material rejected

.

From the Nigeria General specifications requirements of materials to be used for base course and sub-base that states that: If % passing BS 200 Sieve is greater than 35 %, liquid limit greater than 35 % and plasticity index greater than 12 %, no need for further tests and the material should be rejected. This implies that any soil that does not fall within A-1, A-3, A-2 and all the subgroup of A-2 should not be used for both lateritic base and Sub-base on our highway.

The data collected on some of Nigeria highways are shown in Table 3.3

Table 3.3: Summary of Soil Classification on Nigerian Highways

CHAPTER FOUR

ANALYSIS AND DISCUSSION OF DATA

4.1 Analysis of Data

From the data collected, observations were made on the quality of materials used on Nigerian highways. Table 4.1 shows the extracts of the range of some engineering properties of the base course (BC), sub base (SB), and sub grade (SG) while Figures 4.1 to 4.7 shows the sub grade materials of different zones in a map.

Table 4.1 E**ngineering Properties and Range of Values on Nigerian Highways**

S/N	STATE	RANGES OF ENGINEERING PROPERTIES			
		% PASSING BS NO 200 SIEVE	LIQUID LIMIT, %	PLASTIC LIMIT, %	AASHTO CLASSIFICATION
1	NIGER BC	15-35	12-47	0-20	A-2-4, A-2-6, A-2-7 in most of location stone base is used.
	SB	15-55	12-52	NP-23	A-7-5, A-7-6
	SG	12-58	15-52	0-28	A-2-4, A-2-6, A-2-7
2	NASARAWA BC	34-37	30-55	9-28	Stone base was used in some roads A-2-7, A-4
	SB	15-75	NP-63	NP-41	A-2-4, A-2-5, A-2-6, A-2-7, A-4, A-7-5, A-7-6
	SG	8-94	NP-58	NP-39	A-2-4, A-2-6, A-2-7, A-2-7, A-4, A-6, A-7-6
3	BENUE BC	17-70	20-45	0-20	A-2-4, A-2-6, A-2-7, A-7-6
	SB	17-70	24-57	7-23	A-2-4, A-2-6, A-2-7, A-7-6
	SG	17-69	20-54	5-22	A-2-4, A-2-6, A-2-7, A-7-6, A-6
4	KOGI BC	4-44	26-41	0-21	A-2-4, A-2-6, A-2-7
	SB	1-44	22-41	5-21	A-2-4, A-2-6, A-2-7, A-7-6, A-6
	SG	10-70	2-49	7-20	A-2-4, A-2-6, A-2-7, A-7-6, A-4
5	PLATEAU BC	14-24	20-32	4-9	A-2-4, A-1-a

	SB	10-49	25-60	7-24	A-2-4, A-2-6, A-2-7, A-7-6, A-4, A-7-5
	SG	7-61	19-72	8-46	A-2-4, A-2-6, A-2-7, A-7-6, A-7-5
6	BAUCHI BC	23-30	17-32	0-7	A-2-4, A-2-6,
	SB	15-37	NP-42	NP-17	A-2-4, A-2-6, A-2-7, A4
	SG	13-52	NP-48	NP-26	A-2-4, A-2-6, A-7-5, A4
7	GOMBE SB	23	24	5	A-2-4
	SG	27-60	2	3-9	A-2-4, A-4
8	TARABA SB	12-17	27-46	19-23	A-2-4, A-2-7
	SG	23-24	35-63	19-33	A-2-7, A-4
9	ADAMAWA				
	SB	21-63	17-40	8-14	A-2-4, A-2-6, A-4
	SG	21-55	22-47	6-19	A-2-4, A-6, A-7-6
	YOBE SB	15-54	NP-35	NP-20	A-2-4, A-2-6, A-4, A-6,
10	SG	18-50	NP-13	NP-13	A-2-4, A-4, A-6,
11	BORNO SB	13-84	NP-77	NP-24	A-2-4, A-2-6, A-4, A-7-5
	SG	10-70	NP-61	NP-31	A-2-4, A-2-6, A-2-7, A-4, A-3, A-6 A-7-5
12	JIGAWA SB	11-30	NP-37	NP-19	A-2-4, A-2-6,
	SG	11-66	NP-61	NP-37	A-2-4, A-2-6, A-2-7, A-4, A-6
13	SOKOTOSB	6-64	19-53	4-29	A-2-4, A-2-6, A-2-7,
	SG	2-69	17-77	4-45	A-2-4, A-7-6, A-2-7, A-4, A-7-5
14	KANO BC	7-47	NP-47	NP-27	A-2-4, A-2-6, A-4
	SB	8-45	NP-35	NP-20	A-2-4, A-2-6, A-4
	SG	9-65	19-44	NP-26	A-2-4, A-2-6, A-7-5
15	KADUNA				
	BC	19-42	37-43	5-13	A-2-4,A-2-6, A-4
	SB	22-89	35-53	5-26	A-2-4, A-2-6, A-2-7, A-7-6, A-4, A-7-5
	SG	13-89	19-56	9-26	A-2-4, A-2-6, A-2-7, A-5, A-4, A-7-5
16	KASTINA				
	BC	21-66	NP-42	NP-26	A-2-4, A-2-6, A-2-7, A-4, A-6
	SB	12-66	NP-61	NP-	A-2-4, A-2-6, A-2-7, A-4, A-7-5, A-7-6
	SG	6-67	NP-5	26	A-1-b, A-2-4, A-2-6, A-2-7, A-4, A-6, A-7-5, A-7-6
			4	NP-36	
17	KWARA SG	16-56	28-71	14-37	A-2-6, A-7-5, A-7-6
18	OSUN BC	13-35	10-42	0-11	A-2-4, A-2-6,
	SB	13-59	15-42	2-11	A-2--4, A-2-7, A-2-5, A-4, A-6, A-7-5, A-7-6
	SG	11-59	NP-63	NP-28	
19	ONDO BC	22	15	2	A-2-4
	SB	22	15	2	A-2-4
	SG	20-52	15-65	1-37	A-2--4, A-2-5, A-7-5, A-7-6

20	OYO BC	10-24	14-35	NP-17	A-2-4
	SB	14-43	14-41	NP-17	A-2-4
	SG	9-57	16-56	NP-28	A-2--4, A-6, A-4,
21	OGUN BC	15-22	10-17	33-49	A-2-6, A-2-7
	SB	19-22	33-49	10-17	A-2-6, A-2-7
	SG	20-45	38-62	12-20	A-2-7, A -7-6
22	LAGOS SB	21-44	46-56	9-26	A-5, A-2-7, A-7-6
	SG	38-59	38-63	11-28	A-7-5, A-7-6
23	EDO SB	5-59	NP-56	NP-36	A-2--4, A-2-6, A-7-6
	SG	14-18	NP-70	NP-44	A-2--4, A-2-6, A-2-7, A-7-6, A-6, A-7-5
24	DELTA SB	19-60	NP-61	NP-31	A-2--4, A-2-6, A-2-7, A-7-5, A-6, A-7-6
	SG	15-60	20-67	3-37	A-2--4, A-2-6, A-2-7, A-4, A-7-5, A-6, A-7-6
25	AKWA				
	IBOM SB	17-44	NP-57	NP-23	A-2-4, A-2-7, A-7-5,
	SG	17-38	NP-65	NP-37	A-2-4, A-2-5, A-7-5,
26	IMO SB	15-53	20-56	5-29	A-2--4, A-2-6, A-2-7, A-7-5, A-6, A-7-6
	SG	10-85	21-81	5-36	A-2--4, A-7-5, A-4, A-6, A-7-6
27	ABIA SB	43	51-52	28-31	A-7-5
	SG	36-42	45-58	19-27	A-7-5
28	ENUGU SB	14-85	19-58	4-37	A-2-4, A-2-6, A-4, A-2-7, A-7-5,
	SG	14-85	19-65	4-36	A-2-6, A-2-7, A-6, A-7-5, A-7-6
29	EBOYIN SB	22-24	36-38	10-14	A-2-6
	SG	21-47	27-57	9-31	A-2-6, A-2-7, A-4 A-7-5, A-7-6
30	ANAMBRA				
	SB	3-36	15-67	5-49	A-2-4, A-2-6, A-7-6
	SG	3-48	NP-67	NP-41	A-2-4, A-2-6, A-2-7, A-7-5, A-7-6

4.2 Discussion of Data

Observations were made on important engineering properties in the North Central zone compared with specification requirement in accordance with Federal Ministry of Works and Housing specification (1997), the summary are shown in Tables 4.2a to 4.2c:

Table 4.2a Range of Important Engineering Properties of Base Course in North Central

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	4-44	Specification requirement was not met in 4 out of 28 locations collated
2	Liquid Limit (LL)	12-55	Specification requirement was not met in 4 out of 28 locations collated
3	Plasticity Index (PI)	0-28	Specification requirement was not met in 6 out of 28 locations collated
4	AASHTO Classification	A-1-a, A-2-4, A-2-6 A-4, A-2-7, A-7-6 , A-6	

From Table 4.2a, it can be seen that the percentage passing BS No. 200 sieve and liquid limit was not met in 4 locations while plasticity index requirement was not met in 6 locations out of 28 collated. The soils used for base courses were generally of good quality except in few locations in Abaji-Lokoja/Abuja-Keffi, Otukpa and Yelewa with A-4, A-7-6 and A-6 materials respectively (See Table 3.3). Stone base materials were mostly used in Niger and Abuja-Keffi roads and this resulted in not having base course for them.

Table 4.2b Range of Important Engineering Properties of Sub base in North Central

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	1-75	Specification requirement was not met in 14 out of 93 locations collated
2	Liquid Limit (LL)	NP-63	Specification requirement was not met in 40 out of 93 locations collated
3	Plasticity Index (PI)	NP-41	Specification requirement was not met in 52 out of 93 locations collated
4	AASHTO Classification	A-2-4, A-2-6 A-4, A-2-7, A-7-6 , A-6 A-2-5, A-7-5	

From Table 4.2b, it can be inferred that the percentage passing BS No. 200 sieve was not met in 14 locations, and liquid limit requirement was not met in 40 locations, while plasticity index was met in 41 locations out of 93 collated. The materials used for sub-base were of good quality except in few locations like in Lambata, Pandogari/Suleija/Funimata, Abuja-Keffi/Nasarawa Loko/Otukpa/Minna with A-6, A-7-5 and A-7-6 materials, respectively (See Table 3.3). The sub base materials are clayey, highly plastic in these locations above. These types of materials exhibit high volume changes during wet and dry states which result to cracks due to shrinkage.

Table 4.2c Range of Important Engineering Properties of Sub grade in North Central

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	7-94	Specification requirement was not met in 25 out of 100 locations collated
2	Liquid Limit (LL)	NP-72	Specification requirement was not met in 15 out of 100 locations collated
3	Plasticity Index (PI)	NP-46	Specification requirement was not met in 4 out of 100 locations collated
4	AASHTO Classification	A-2-4, A-2-6, A-4 A-2-7, A-7-6, A-6 A-7-5	

From Table 4.2c, it is observed that the percentage passing BS No. 200 sieve was not met in 25 locations; liquid limit requirement was not met in 15 locations, while plasticity index requirement was not met in 4 locations out of 100 locations collated. The soil materials used for sub-grade were of good quality except in few locations where the specification was not met e.g. Lambata, Suleija, Abuja-Keffi, Nasarawa Loko, Otukpa and Minna.

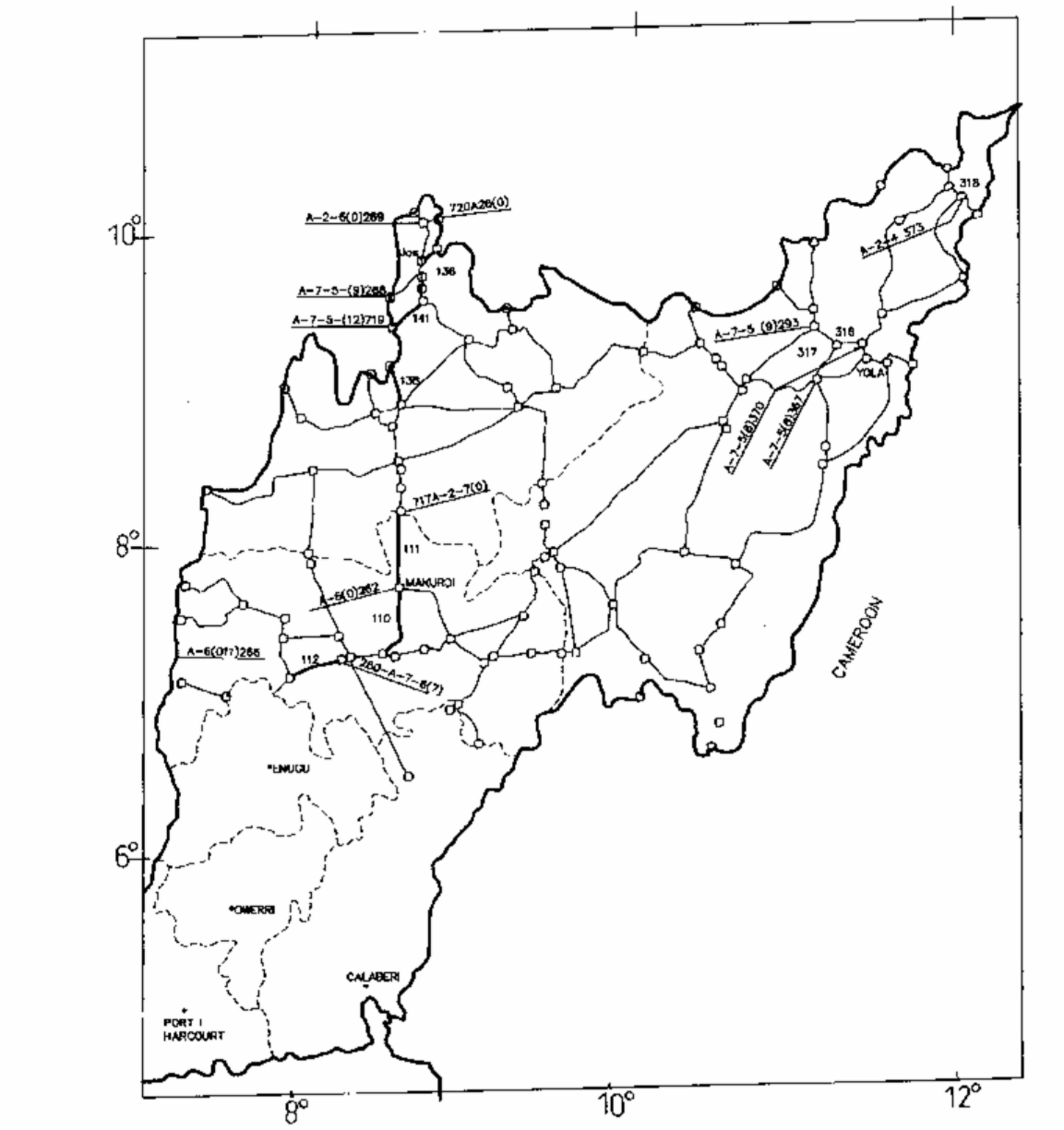


Fig 4.1 Links and Station evaluated in (Region 5) North central zones with their AASHTO Classification

Observation were made on important engineering properties in the North East zone compared with specification requirement; the extract is shown in Table 4.3a to 4.3c:

Table 4.3a Range of Important Engineering Properties of Base Course in North East

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	23-30	Specification requirement was met in 4 locations collated
2	Liquid Limit (LL)	17-32	Specification requirement was met in 4 locations collated
3	Plasticity Index (PI)	0-78	Specification requirement was met in 4 locations collated
4	AASHTO Classification	A-2-4, A-2-6	

From Table 4.3a specification requirement was met in all the four locations collated for base course. The soils material is of good quality.

Table 4.3b Range of Important Engineering Properties of Sub base in North East

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	12-84	Specification requirement was not met in 10 out of 46 locations collated
2	Liquid Limit (LL)	NP-77	Specification requirement was not met in 10 out of 46 locations collated
3	Plasticity Index (PI)	NP-24	Specification requirement was not met in 12 out of 46 locations collated
4	AASHTO Classification	A-2-4, A-2-6, A-4, A-2-7, A-7-5, A-6,	

From Table 4.3b, it is observed that the percentage passing BS No. 200 sieve and liquid limit requirement were not met in 10 locations, while plasticity index requirement was not met in 12 out of 46 locations collated. The soils used for sub-base were of good quality except in few locations where the specification was not met like: Maiduguri/Bauchi/Damaturu/Bama, Potiskum and Dikwa with A-4, A-6, and A-7-5 respectively (See Table 3.3). The soils were moderately plastic i.e high liquid limit. These materials are susceptible to high volume changes upon contact or withdrawal of moisture. They also loose strength in the presence of water.

Table 4.3c Range of Important Engineering Properties of Sub grade in North East

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	10-93	Specification requirement was not met in 20 out of 50 locations collated
2	Liquid Limit (LL)	NP-61	Specification requirement was not met in 4 out of 50 locations collated
3	Plasticity Index (PI)	NP-33	Specification requirement was not met in 4 out of 50 locations collated
4	AASHTO Classification	A-2-4, A-2-6, A-4 A-2-7, A-6 , A-3 A-7-5 A-7-6,	

It is seen from Table 4.3c, that the percentage passing BS No. 200 sieve was not met in 20 locations, while plasticity index and liquid limit requirements were not met in 4 out of 50 locations collated. Good quality materials were used for sub-grade except in few locations where the specification was not met like: Jalingo, Damboa (Borno), and Dikwa with high value of liquid limit and plasticity index. These materials are susceptible to high volume changes upon contact or withdrawal of moisture. They also loose strength in the presence of water.

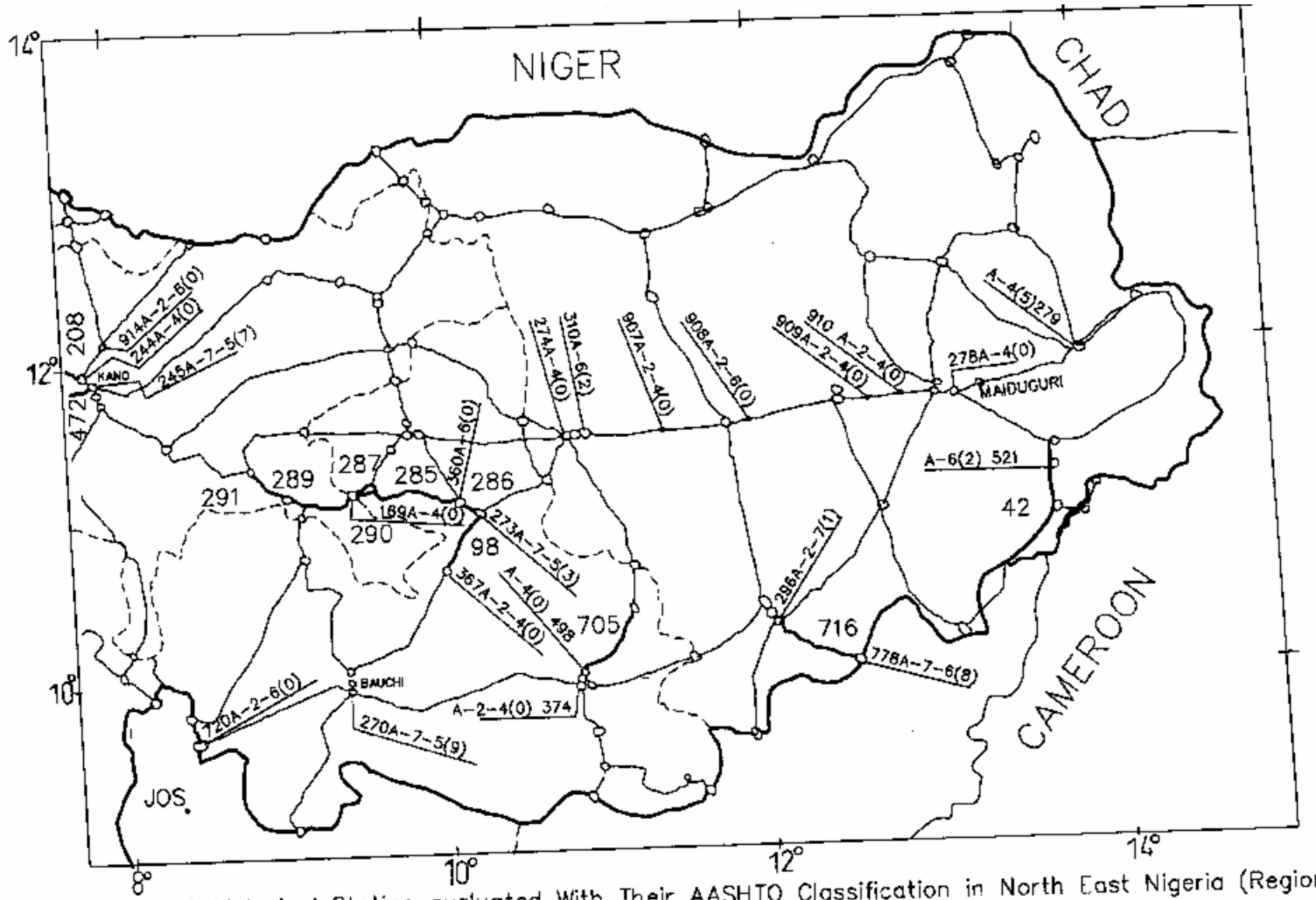


Figure 4.2 Link And Station evaluated With Their AASHTO Classification in North East Nigeria (Regions 1 & 2)

Observations were made on important engineering properties in the North West zone compared with specification requirement; the extract is shown in Tables 4.4a to 4.4c:

Table 4.4a Range of Important Engineering Properties of Base Course in North West

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS NO 200 sieve	7-66	Specification requirement was not met in 16 out of 61 locations collated
2	Liquid Limit (LL)	NP-47	Specification requirement was not met in 20 out of 61 locations collated
3	Plasticity Index (PI)	NP-27	Specification requirement was met in 26 out of 61 locations collated
4	AASHTO Classification	A-2-4, A-2-6, A-4 A-2-7, A-7-6,	

It can be observed from Table 4.4a, that the percentage passing BS NO 200 sieve did not meet specification in 16 locations; liquid limit requirement was not met in 20, while plasticity index requirement was met in 26 out of 61 locations collated. The soils used for base-course are of good qualities except in locations like: Kaduna-Kachia, Funtua-Dayi, Malunfashi-Dabai-Dayi Bakori, Funtua-Zaria with A-4, A-6, and A-7-5 materials were used (See Table 3.3) where the specification was not met.

Table 4.4b Range of Important Engineering Properties of Sub base in North West

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No 200 sieve	8-89	Specification requirement was not met in 45 out of 123 locations collated
2	Liquid Limit (LL)	NP-61	Specification requirement was not met in 43 out of 123 locations collated
3	Plasticity Index (PI)	NP-27	Specification requirement was met in 55 out of 123 locations collated
4	AASHTO Classification	A-2-4, A-2-6, A-4 A-2-7, A-6, A-7-5 A-5	

From Table 4.4b, it can be observed that the percentage passing BS No. 200 sieve and liquid limit requirement was not met in 45 and 43 locations respectively, while plasticity index requirement was not met in 55 out of 123 locations collated. Good quality soils were used for sub-base in most locations except in Kaduna-Suleija, Kaduna-Bukuru, Kachia, Zaria, Katabu, Wasaga where specification was not met, and A-4, A-6, and A-7-5 were used (See Table 3.3). The soils are moderately plastic; thus making them to be susceptible to high volume changes upon contact or withdrawal of moisture.

Table 4.4c Range of Important Engineering Properties of Sub grade in North West

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	2-89	Specification requirement was not met in 40 out of 135 locations collated
2	Liquid Limit (LL)	NP-77	Specification requirement was not met in 8 out of 135 locations collated
3	Plasticity Index (PI)	NP-45	Specification requirement was not met in 5 out of 135 locations collated
4	AASHTO Classification	A-1-b, A-2-4, A-4 A-2-6, A-2-7, A-6 A-7-5 , A-7-6,	

It can be shown from Table 4.4c that the percentage passing BS No. 200 sieve was not met in 40 locations; liquid limit requirement was not met in 8 locations, while the plasticity index requirement was not met in 5 locations out of 135 locations collated. Good quality soils were used for sub-grade in most locations except in Kafancha, Kachia, Kabomo, Kankia, Kunchi, Gamayin, Sokoto. With high values of liquid limit the soils are susceptible to high volume changes upon contact or withdrawal of moisture.

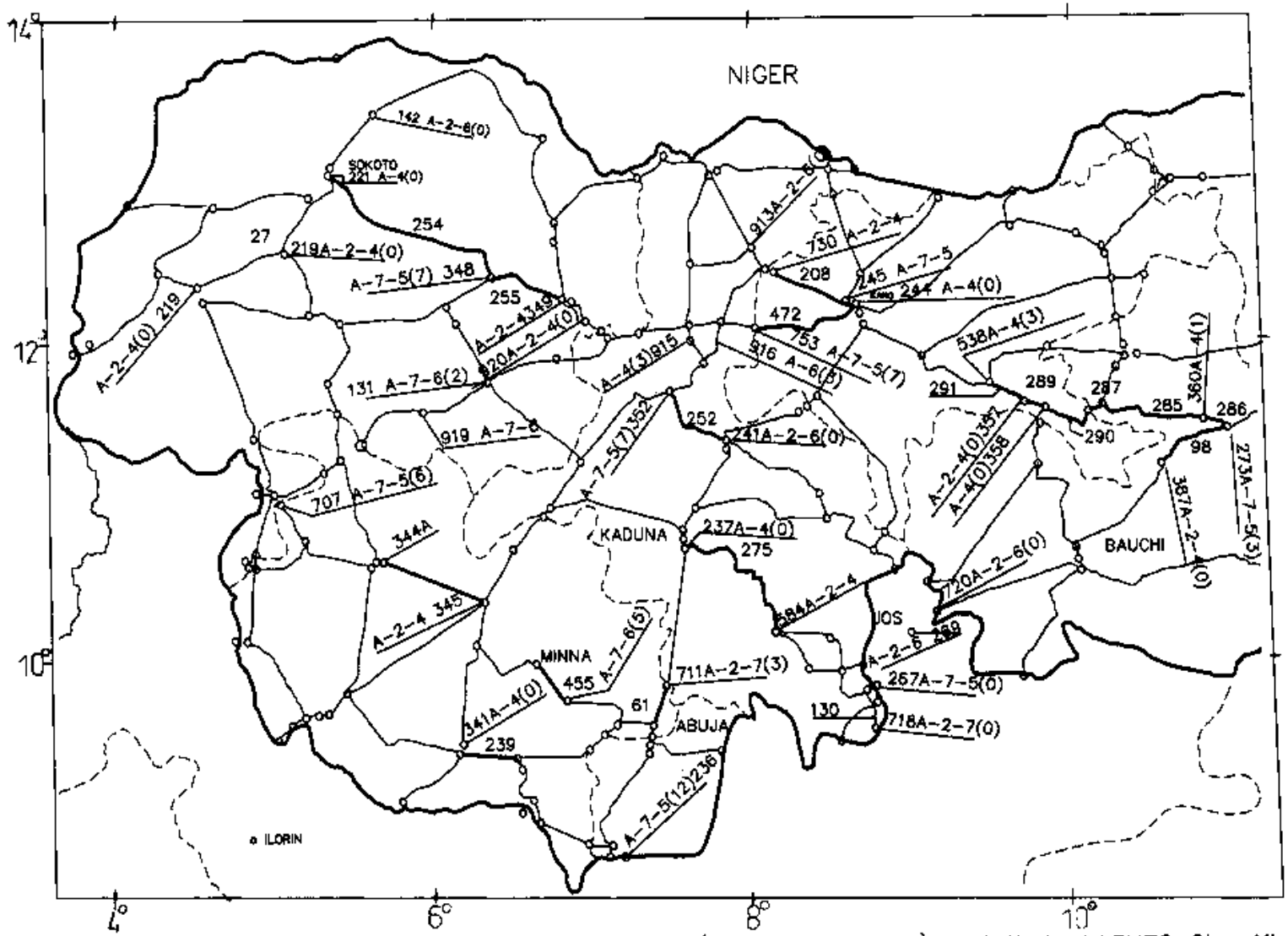


Figure 4.3.Link and stations in North West Nigeria (Regions 1,2 & 4) and their AASHTO Classification

Observations were made on important engineering properties in the South West zone compared with specification requirement; the extract is shown in Tables 4.5a to 4.5c:

Table 4.5a Range of Important Engineering Properties of Base Course in South West

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	10-35	Specification requirement was met in 11 locations collated
2	Liquid Limit (LL)	10-42	Specification requirement was not met in 3 out of 11 locations collated
3	Plasticity Index (PI)	NP-49	Specification requirement was not met in 2 out of 11 locations collated
4	AASHTO Classification	A-2-4, A-2-6, A-2-7, A-2-5	

It is observed from Table 4.5a, that the percentage passing BS No. 200 sieve met specification in 11 locations; liquid limit requirement was not met in 3, while plasticity index requirement was met in 2 out of 11 locations collated. The soils used for base-course were of good quality. Liquid limit was high in Shagamu, Ijebu Ode, Ikirun, and Ilesa.

Table 4.5b Range of Important Engineering Properties of Sub base in South West

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	13-59	Specification requirement was not met in 3 out of 14 locations collated
2	Liquid Limit (LL)	15-56	Specification requirement was not met in 6 out of 14 locations collated
3	Plasticity Index (PI)	11-56	Specification requirement was not met in 5 out of 14 locations collated
4	AASHTO Classification	A-2-4, A-2-5, A-4 A-2-6, A-2-7, A-6, A-7-5, A-7-6	

It can be shown from Table 4.5b that the specification requirement of percentage passing BS No. 200 sieve was not met in 3 locations; liquid limit requirement was not met in 6 locations, while the plasticity index requirement was not met in 5 locations out of 14 locations collated. Good quality soils were used for sub-base in most locations except in Ifon and Ikeja with A-7-6 and A-7-5 respectively. The liquid limit is high in Ikeja, Ikorodu Lagos/Ogun border Ibadan, and Ikirun; thus the soils are susceptible to high volume changes upon contact or withdrawal of moisture.

Table 4.5c Range of Important Engineering Properties of Sub grade in South West

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	9-56	Specification requirement was not met in 19 out of 39 locations collated
2	Liquid Limit (LL)	NP-65	Specification requirement was not met in 9 out of 39 locations collated
3	Plasticity Index (PI)	NP-28	Specification requirement was not met in 4 out of 39 locations collated
4	AASHTO Classification	A-2-4, A-2-6, A-4 A-2-7, A-7-6, A-6 A-7-5	

It can be shown from Table 4.5c that the specification requirement of percentage passing BS No. 200 sieve was not met in 19 locations; liquid limit requirement was not met in 9 locations, while the plasticity index requirement was not met in 4 out of 39 locations collated. Good quality soil materials were used for sub-grade in all locations. The liquid limit is slightly high in Ikeja, Gbagan Ijebu, ILesa, Ibadan, and Ikirun; which make the soils to be susceptible to high volume changes upon contact or withdrawal of moisture.

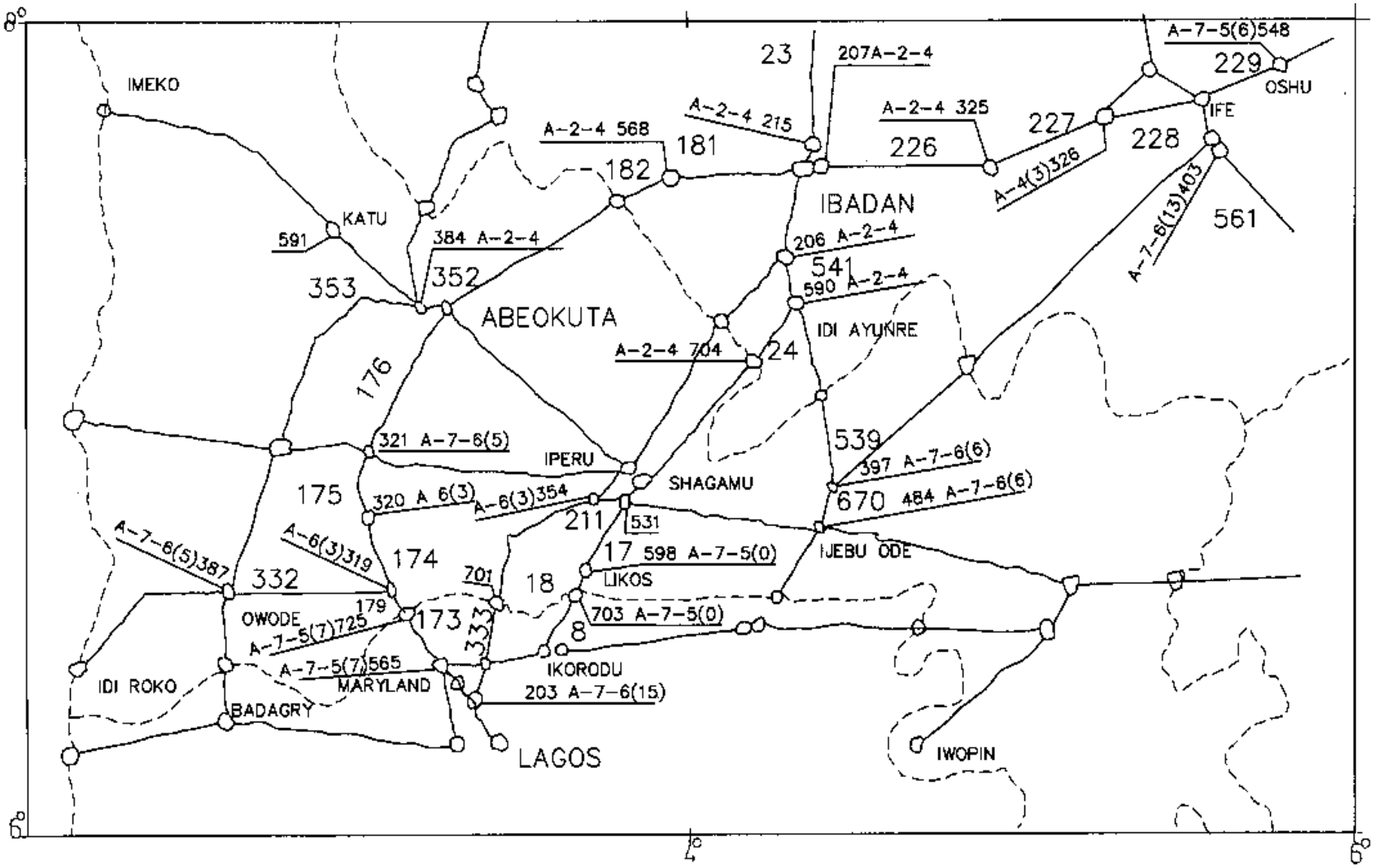


Figure 4.4. Links and Station Evaluated in South-West zones with their AASHTO Classification

Observations were made on important engineering properties in the South East zone compared with specification requirement; the extract is shown in Tables 4.6a and4.6b

Table 4.6a Range of Important Engineering Properties of Sub base in South East

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS NO 200 sieve	3-85	Specification requirement was not met in14 out of 58 locations collated
2	Liquid Limit (LL)	13-67	Specification requirement was not met in 36 out of 58 locations collated
3	Plasticity Index (PI)	4-49	Specification requirement was not met in 38 out of 58 locations collated
4	AASHTO Classification	A-2-4, A-2-5, A-4 A-2-6, A-2-7, A-6, A-7-5, A-7-6	

Table 4.6a shows that the specification requirement of percentage passing BS NO 200 sieve was not met in 14 locations; liquid limit requirement was not met in 36 locations, while the plasticity index requirement was not met in 38 out of 58 locations collated. Good quality soils were used for sub-base in some locations. Akwa-Ekwolobia, Aba, Umuahia, Enugu-Portharcourt have A-7-6 and A-7-5 respectively. The soil samples were highly plastic in most locations with high liquid limit thus making them to be susceptible to high volume changes upon contact or withdrawal of moisture. This region has stone base and soil cement in their base course.

Table 4.6b Range of Important Engineering Properties of Sub grade in South East

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	7-94	Specification requirement was not met in 25 out of 100 locations collated
2	Liquid Limit (LL)	NP-72	Specification requirement was not met in 15 out of 100 locations collated
3	Plasticity Index (PI)	NP-46	Specification requirement was not met in 4 out of 100 locations collated
4	AASHTO Classification	A-2-4, A-2-6, A--4 A-2-7, A-7-6, A-6 A-7-5	

Table 4.6b shows that specification requirement of the percentage passing BS No. 200 sieve was not met in 25 locations; liquid limit requirement was not met in 15 locations, while the plasticity index requirement was not met in 4 out of 100 locations collated. The materials used for sub-grade is good but of high liquid limit in Ekwu-oko-umu-Ibinta, Aba, Abakaliki, Ogikwe, Emene, Enugu-Portharcourt, thus making them to be susceptible to high volume changes upon contact or withdrawal of moisture. This region has stone base and soil cement in their base course.

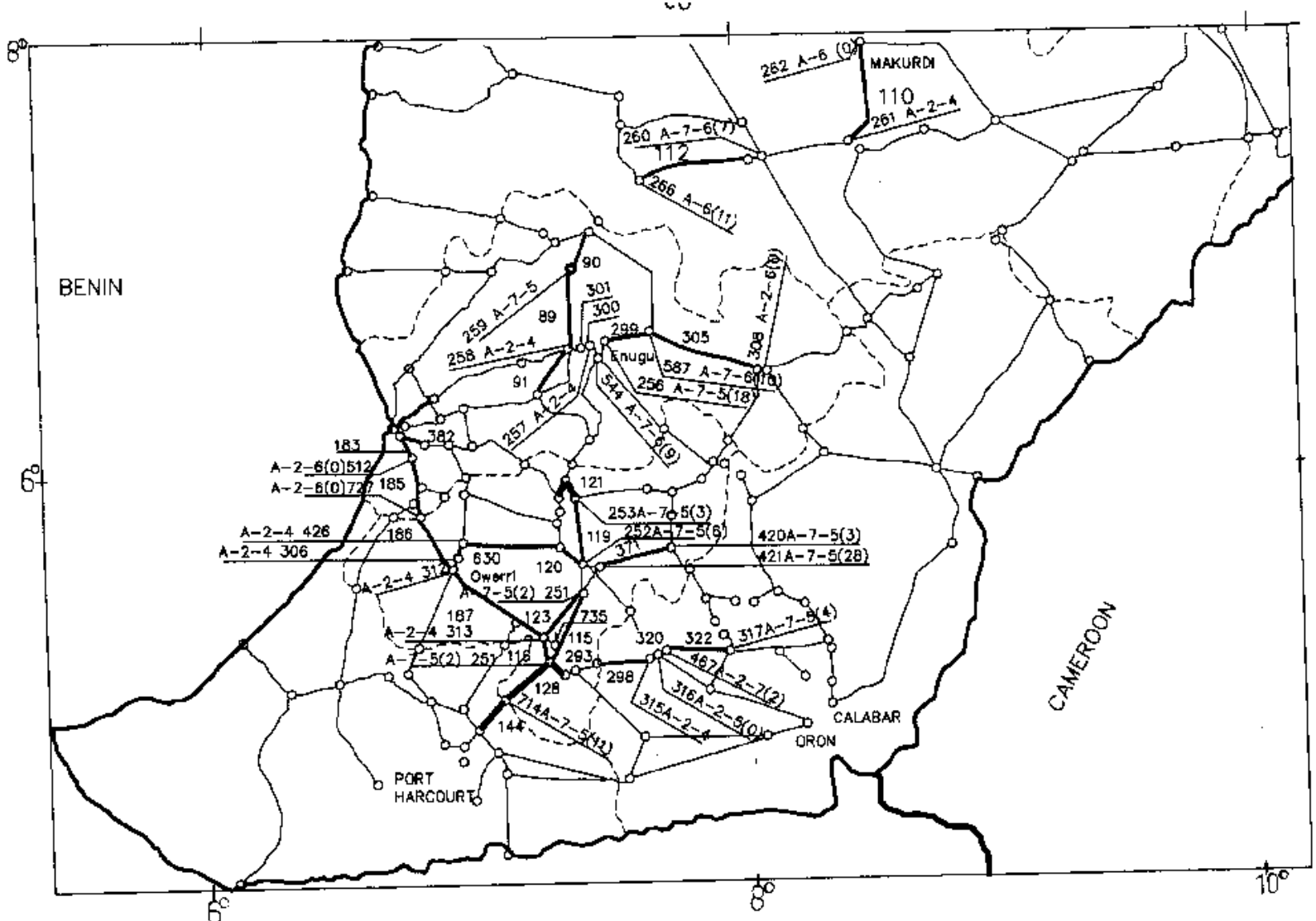


Figure 4.5. Links and Station Evaluated in (Region 5 & 6)South-East Zone with their AASHTO Classification

Observations were made on important engineering properties in the South East zone and compared with specification requirement; the extract is shown in Tables 4.7a and 4.7b:

Table 4.7a Range of Important Engineering Properties of Sub Base in South South

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	5-60	Specification requirement was not met in 17 out of 45 locations collated
2	Liquid Limit (LL)	NP-61	Specification requirement was not met in 20 out of 45 locations collated
3	Plasticity Index (PI)	NP-36	Specification requirement was not met in 25 out of 45 locations collated
4	AASHTO Classification	A-2-4, A-2-6, A-6 A-2-7, A-7-6	

Table 4.7a shows that the specification requirement of percentage passing BS No. 200 sieve was not met in 17 locations; liquid limit requirement was not met in 20 locations, while the plasticity index requirement was not met in 25 out of 45 locations collated. Good quality soils were used for sub-base in some locations. Agbor, Auchi/Irua/Delta, and Oluku, have A-6, A-7-5and A-7-6 respectively. The soil samples were moderate to highly plastic in most locations with high liquid limit thus making them to be susceptible to high volume changes upon contact or withdrawal of moistures. This region has stone base and soil cement as their base course.

Table 4.7b Range of Important Engineering Properties of Sub grade in South South

S/N	ENGINEERING PROPERTIES	RANGE OF VALUES (from data collected)	REMARKS
1	Proportion passing BS No. 200 sieve	15-60	Specification requirement was not met in 6 out of 47 locations collated
2	Liquid Limit (LL)	NP-70	Specification requirement was not met in 5 out of 47 locations collated
3	Plasticity Index (PI)	NP-44	Specification requirement was not met in 3 out of 47 locations collated
4	AASHTO Classification	A-2-4, A-2-6, A-4 A-2-7, A-2-5, A-6 A-7-6, A-7-5	

Table 4.7b shows that the specification requirement of percentage passing BS No. 200 sieve was not met in 6 locations; liquid limit requirement was not met in 5 locations, while the plasticity index requirement was not met in 3 out of 47 locations collated. Good quality soils were used for sub-grade in most locations. Irrua, Auchi, Agbor, and Itu have moderately high value of liquid limit thus making the soils to be susceptible to high volume changes upon contact or withdrawal of moistures. This region has stone base as their base course.

However, from the study of formation and general characteristics of geological deposits and relating them to important engineering properties of soils the following observations can be made:

Areas with Alluvium (Qa) soil from the Quartenary Era, have A-2-4, A-2-6, A-2-7 classifications (e.g Abaji, Lokoja, Shagamu, Adoru, and Makurdi areas. See Figs. 2.6, 4.1-

4.7 and Table 3.3), while areas with sands and clays (Qp) from coastal plain sands are mainly A-7-5, A-7-6 classifications (e.g Owerri, Ikeja, Ikorodu, and Otta areas. See Figs. 2.6, 4.4, 4.5, as well as 4.7 and Table 3.3) with few locations having A-2-4, A-2-6, A-2-7 (e.g. Benin city, and Ikot Ekpene areas).

Also, sands and clays (Qc) from Chad formation of Quaternary Era have A-2-4, A-4 and A-6 (e.g. Damaturu, Maiduguri, and Bama areas; See Figs. 2.6, 4.2, as well as 4.7 and Table 3.3).

Sands, clays, and shales (Ti) of Illaro formation from the Tertiary era are of A-7-5 classification (e.g Itu and Umuahia; see Fig. 2.6, Fig. 4.5, Fig. 4.7 and Table 3.3).

Shales, and roundstone (Kro) of Nkporo shale group formed from Cretaceous era have A-7-5, A-2-7 and A-6 classifications (e.g. Auchi, Oturkpo areas See Figs. 2.6, and 4.1, as well as Table 3.1). Shales, and limestone (Kwn) of Agwu-Ndeaboh shale group formed from cretaceous era have A-6, A-2-7, and A-7-5 (e.g. Aliade, Enugu area See Figs. 2.6, 4.1, as well as Fig. 4.5 and Table 3.3). Black shale and siltstone (Kea) of Eze Aku shale group formed from cretaceous era have A-2-6, A-7-6 classifications (e.g Wukari, and Zakibiam area See Figs. 2.6, 4.1, as well as 4.7 and Table 3.3).

Granitoids (Pcg) of older granites series in basement complex formed from Pan Africa era are mainly A-7-6, A-7-5 with few A-6, A-2-6 classifications (e.g Minna, Abuja-Kaduna, Kachia, Bukuru, Mainchi, Gimi, Gaya, Zaria, Rano, Kano).

Gneiss migmatate complex (Pcb) of Migmatate Gneiss schist complex formed from Basement complex of Precambrian era have A-2-4, A-2-6, A-2-7, A-7-5, and A-7-6 classifications (e.g. Ibadan, Ogbomosho, Ikirun, Bauchi, Funtua, Keffi, Plateau areas See Figs. 2.6, 4.2, 4.4, as well as 4.7 and Table 3.3).

Meta-sediments/Volcanics Gneiss formed from Migmatate Gneiss schist complex of Basement era have A-4, A-6, A-7-5, and A-7-6 classifications (Malumfashi, Mainchi, Abuja-Kaduna, Oluku-Ondo Border areas (See Figs. 2.6, 4.2, 4.3, 4.4, as well as 4.7 and Table 3.3).

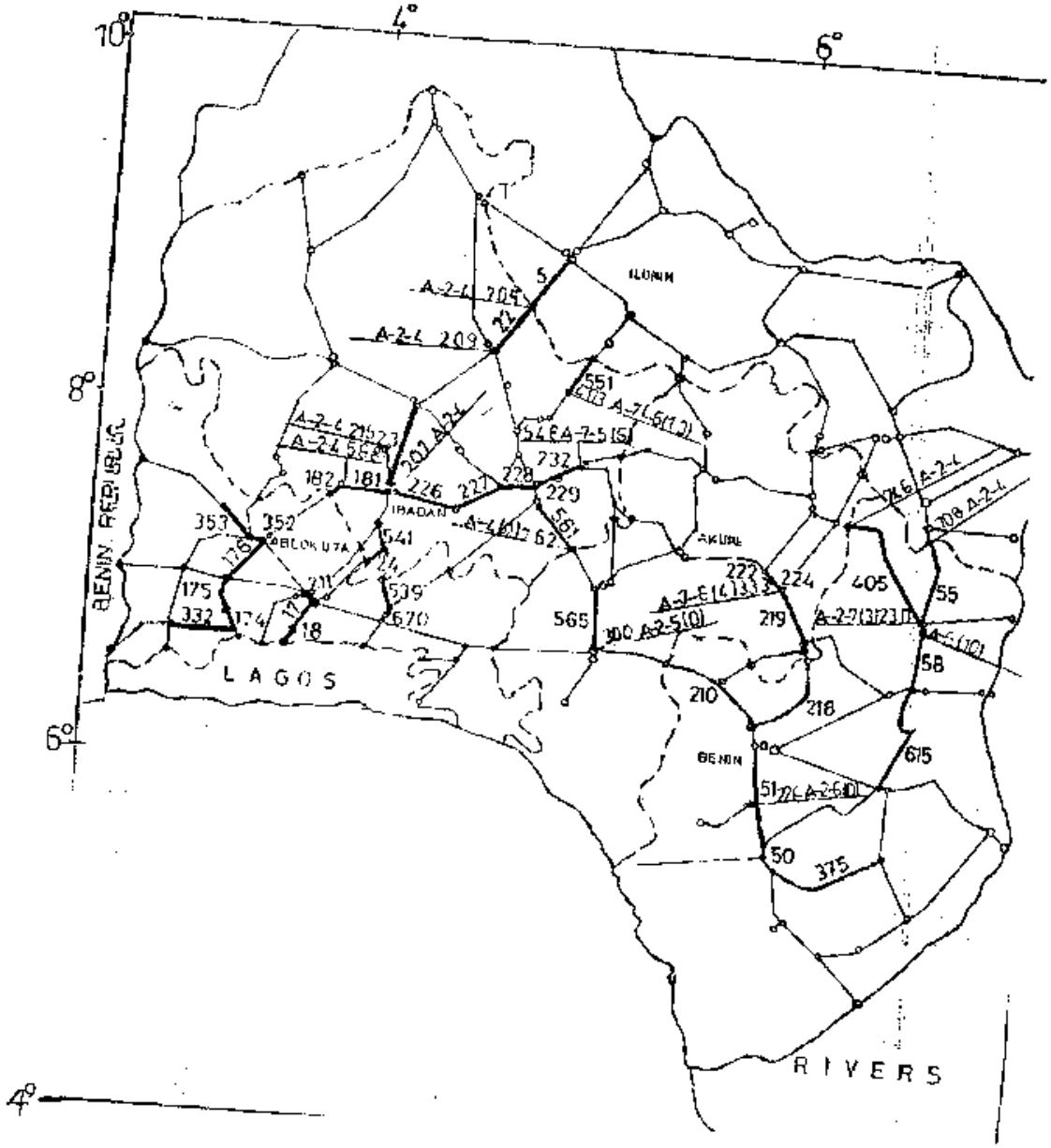


Figure 4.6 Links and Station evaluated in Region 3 with their AASHTO Classification

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The Nigerian General specification requirements of materials to be used for base course and sub-base recommends that: If % passing BS No. 200 sieve is greater than 35 % there is no need for further tests and the material should be rejected. This implies that any soil material that does not fall within A-1, A-3, A-2 and all the subgroup of A-2 should not be used for both lateritic base and sub-base on highways.

Generally speaking, it is observed that the lower the Atterberg limits, the better the materials. The sub-grade material to be used on our highway should have a liquid limit and the plasticity index that is less than or equal to 50 % and 30 %, respectively. Any road with sub-grade/fill material or borrow pit material having value of liquid limit or plasticity limit higher than the specification, the contractor need to scout for good material that will not be detrimental to the road. The usage of material not meeting specification requirement leads to early failure of highways.

In North Central Zone, the soils used for base courses were generally of good quality except in few locations (i.e Abaji-Lokoja/Abuja-Keffi, Otukpa and Yelewa with A-4, A-7-6 and A-6 materials, respectively). Stone base materials were mostly used in Niger and Abuja-Keffi and this resulted in not having base course data for them.

Suitable soil samples were used for sub-base except in the filling locations: Lambata, Pandogari/Suleija/Funimata, Abuja-Keffi/Nasarawa-Loko/Otukpa/Minna with A-6, A-7-5 and A-7-6 respectively. The sub base materials are clayey, and moderate to highly plastic in their locations. Such materials are susceptible to high volume changes upon contact or withdrawal of moisture.

The sub grade materials are too fine (percentage passing BS No. 200 sieve was greater than 35 in 25 locations). The soils used for sub-grade were suitable except in few locations: Lambata, Suleija, Abuja-Keffi, Nasarawa Loko, Otukpa, Minna where the specifications were not met.

North East Zone: The specification requirement was met in all the four locations collated for base course. It can be concluded that the soils were of good quality. Cement stabilization was used in most of the locations.

The soil materials used for sub-base were of good quality except in few locations where the specification was not met like Maiduguri/Bauchi/Damaturu/Bama, Potiskum and Dikwa with A-4, A-6, and A-7-5, respectively. The soils are moderately plastic (i.e., with high liquid limit). These materials are susceptible to high volume changes upon contact or withdrawal of moisture. They also loose strength in the presence of water.

Good quality materials were used for sub-grade except in few locations where the specification was not met like Jalingo, Damboa (Bornu), Jimeta Numan, and Dikwa with high value of liquid limit and plasticity index. These materials are susceptible to high volume changes upon contact or withdrawal of moisture.

North West Zone: It can be concluded that base-course were of good quality except in Kaduna-Kachia, Funtua-Dayi, Malunfashi-Dabai-Dayi-Bakori, Funtua-Zaria where A-4, A-6, and A-7-5 materials were used.

Suitable materials were used for sub-base in most locations except in Kaduna-Suleija, Kaduna-Bukuru, Kachia, Zaria, Katabu, Wasaga with A-4, A-6, and A-7-5 that did not meet specifications. The soils are moderately plastic; which makes them susceptible to high volume changes upon contact or withdrawal of moisture.

Good quality materials were used for sub-grade in most locations except in Kafancha, Kachia, Kaboro, Kankia, Kunchi, Gamayin, Sokoto where the percentage passing BS No. 200 sieve was greater than 35 and not meeting specifications, with high value of liquid limit, the material was too fine. Thus they are susceptible to high volume changes upon contact or withdrawal of moisture.

South West Zone: The base-course materials are of good quality. The liquid limit is high in Shagamu, Ijebu Ode, Ikirun, and Ilesa. Good quality materials were used for sub-base in most locations except in Ifon and Ikeja with A-7-6 and A-7-5, respectively. The specification requirement of percentage passing BS No. 200 sieve was not met in 3 locations. The liquid limit is high in Ikeja, Ikorodu Lagos/Ogun border with Ibadan, and Ikirun; making them susceptible to high volume changes upon contact or withdrawal of moisture.

Good quality materials were used for sub-grade in all locations. The liquid limit was slightly high in Ikeja Gbagan Ijebu, Ilesa, Ibadan, and Ikirun. Thus the soils are susceptible to high volume changes upon contact or withdrawal of moisture.

South East Zone: stone base and soil cement were used because of the nature of the soils in the zone. The soils are of shale, limestone, roundstone, blackshale and siltstone. Good quality materials were used for sub-base in some locations. Akwa-Ekwolobia, Aba, Umuahia, Enugu-Portharcourt have A-7-6 and A-7-5 soils respectively. The soil sample was highly plastic in most locations with high liquid limit thus making them susceptible to high volume changes upon contact or withdrawal of moisture.

The materials used for sub-grade are suitable but of high liquid limit in Ekwu-oko-umu-Ibinta, Aba, Abakaliki, Ogikwe, Emene, Enugu-PortHarcourt. Thus the soils are susceptible to high volume changes upon contact or withdrawal of moisture. Specification requirement of the percentage passing BS No. 200 sieve was not met in 25 locations.

South South Zone: stone base and soil cement were also used as base courses. Good quality materials were used for sub-base in some locations except in Agbor, Auchi/Irua/Delta, and Oluku, with A-6, A-7-5 and A-7-6, respectively. The soil samples were moderate to highly plastic in most location with high liquid limit.

Suitable materials were used for sub-grade in most locations. Irrua, Auchi, Agbor, and Itu have moderately high value of liquid limit thus making the soils to be susceptible to high volume changes upon contact or withdrawal of moisture.

From the geological point of view, it can be concluded that Alluvium (Qa) soils have A-2-4, A-2-6 and A-2-7 classifications; Sands and clays (Qp) from coastal plain sands are mainly A-7-5 and A-7-6 classifications with few locations having A-2-4, A-2-6 and A-2-7. Also, sands and clays (Qc) from Chad formation have A-2-4, A-4 and A-6. However, sands, clays, and shales (Ti) of Illaro formation are of A-7-5 classification.

Shales, and roundstone (Kro) of Nkporo shale group have A-7-5, A-2-7 and A-6 classifications; also shales and limestone (Kwn) of Agwu-Ndeaboh shale group have A-6, A-2-7, and A-7-5; while black shale and siltstone (Kea) of Eze Aku shale group have A-2-6, A-7-6 classifications.

Granitoids (Pcg) of older granites series are mainly A-7-6, A-7-5 with few A-6, A-2-6 classifications; Gneiss migmatate complex (Pcb) have A-2-4, A-2-6, A-2-7, A-7-5, and A-7-6 classifications; Meta- sediments/Volcanics Gneiss have A-4, A-6, A-7-5, and A-7-6 classifications

5.2 Recommendation

From the Nigerian General specification requirements of materials to be used for base course and sub-base which recommend that: If % passing BS No. 200 sieve is greater than 35 % there is no need for further tests and the material should be rejected. This implies that any soil material that does not fall within A-1, A-3, A-2 and all the subgroup of A-2 should not be used for both lateritic base and sub-base on highways.

The sub-grade material to be used on our highway should have a liquid limit and the plasticity index that is less than or equal to 50 % and 30 %, respectively. Any road with sub-grade/fill material or borrow pit material having value of liquid limit or plasticity limit higher than the specification, the contractor needs to scout for good material that will not be detrimental to the road. The usage of material not meeting specification requirement leads to early failure of highways.

Stone base materials need to be discouraged where there is good material in order to safe cost of construction.

The distance of the good material to the site should be used in calculating the Bill of Engineering measurement (BEME) for the Federal Ministry of Works.

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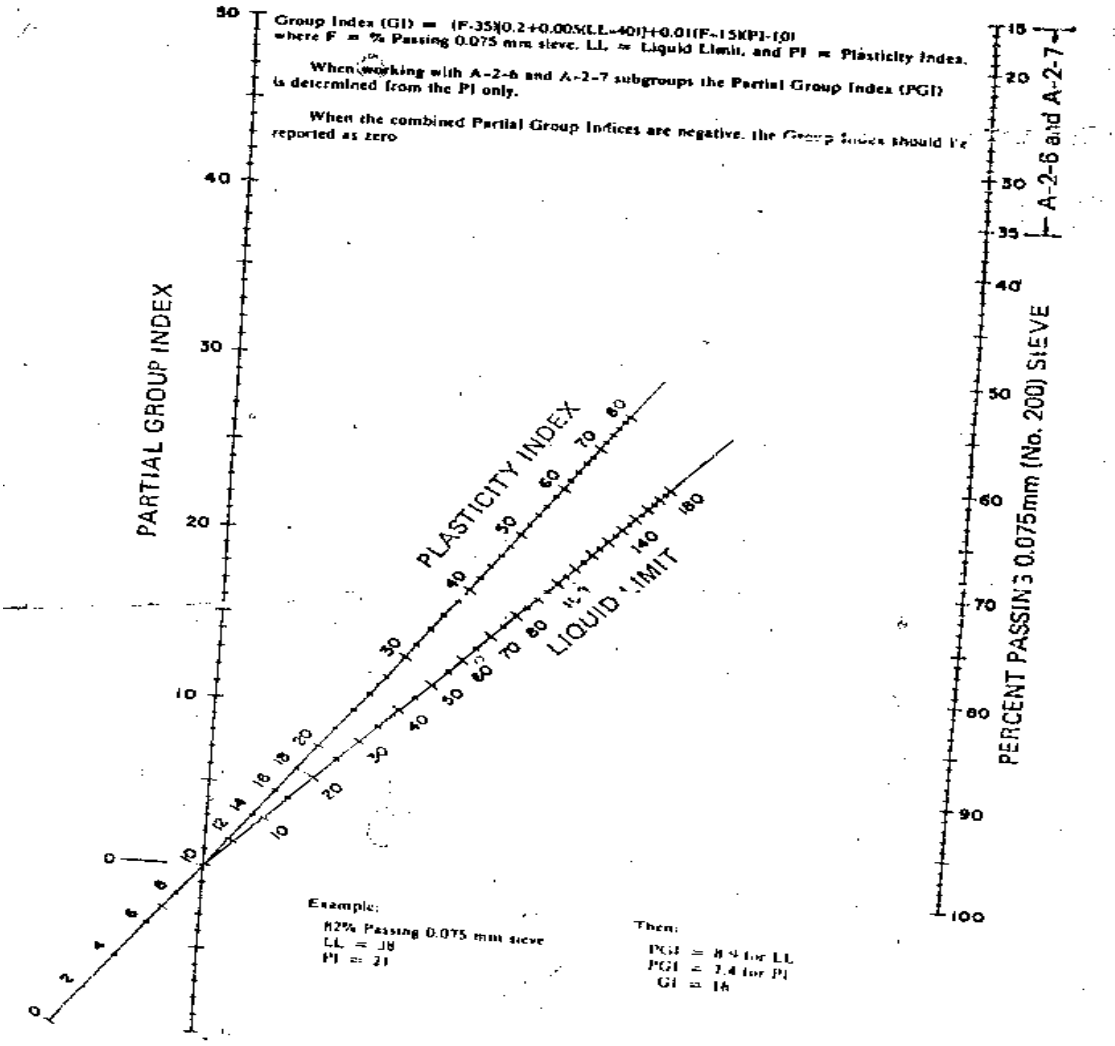


Figure III-6. Group Index Chart.

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Figure: 3.1 Group Index Chart

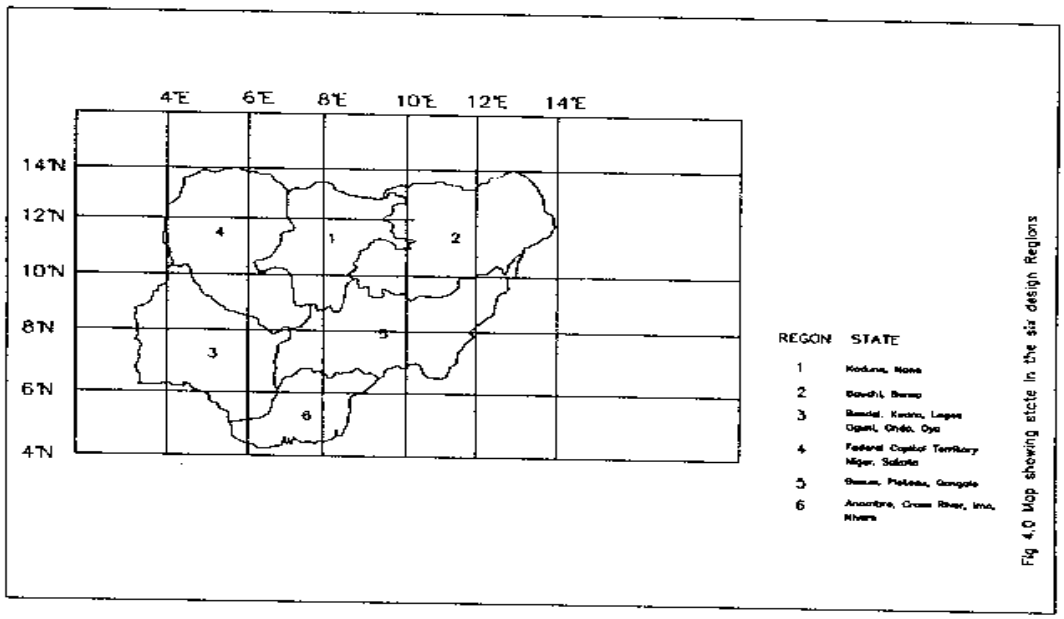


Figure 4.0 Map showing States in the six Design Regions

Figure 4.7 Soil Distribution on Nigerian Trunk Roads