AN ASSESSMENT OF FLEXIBLE PAVEMENT FAILURE AND ENGINEERING PROPERTIES OF SUB-GRADE MATERIALS ALONG ZUBA- GWAGWALADA CARRIAGEWAY, FEDERAL CAPITAL TERRITORY, NIGERIA.

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY (M. TECH) GEOGRAPHY WITH ENVIRONMENTAL MANAGEMENT (ENVIRONMENTAL DEVELOPMENT PLANNING).

February 2009

DECLARATION

This is to affirm that I, **EGBUNU MUSA ADAMU** with Reg. No. **M.TECH/SSSE/2005/1323** carried out this project titled "An assessment of flexible pavement failure and engineering properties of sub-grade materials along Zuba- Gwagwalada carriageway, Federal Capital Territory, Nigeria. The thesis is a part of the requirement for the Award of the Degree of Master of Technology (M.TECH) in Environmental Development Planning of the Department of Geography, School of Science and Science Education, Federal University of Technology Minna. Within current knowledge, this same thesis has never been produced elsewhere by other researchers.

Egbunu, Musa A.

28.05.09

Date

CERTIFICATION

This thesis titled: An assessment of flexible pavement failure and engineering properties of sub-grade materials along Zuba- Gwagwalada carriageway, Federal Capital Territory, Nigeria" by Egbunu, Musa Adamu (M.Tech/SSSE/2005/1323) meets the regulations governing the award of the degree of M. Tech of the Federal University of Technology, Minna and is approved for its contribution to scientific knowledge and literacy presentation.

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DEDICATION

To Omniscience God, for making me a mustard seed and to my late parents, Amichi Obagudu, Hadiza Odaudu and Egbunu Musa, for their complete blessings.

ACKNOWLEDGMENT

Since the conception of this topic, I have received immense support and experience from the works of a vast galaxy of Highway Engineers and Scientists who have done much to enrich the subject matter of Environmental Development Planning and Transportation Engineering within the past three decades. However, no amount of footnoting can ever repay the debt I owe them.

My interest in the subject aroused when I was a Pupil Engineer on Dawaki-Bwoi Flood Detention Dam in 1995 where, strict compliance on geotechnical materials specification was a rule of thumb. Subsequently, I also had the opportunity of been listed on construction projects particularly, the failed Benin - Shagamu carriageway as well as listening to series of lectures delivered by Professors E.O. Olofin of the Bayero University Kano, Clifford Teme of the Rivers State University of Science and Technology, Siyan Malomo of the Geological Survey Agency of Nigeria Abuja, Akin Mabogunje of the Regional Centre for Development Studies, Ibadan and Dr. Wole Alade of GIS Global Solutions, Illinois, USA. I also imbibed further interest from the classroom lectures of Professors. A.M. Baba and G.N. Nsofor on different aspects of the subject; though, these lectures were in their general form because of academic calendar limitation at that time. I wish to register my indebtedness to all of them.

Indeed, no word of gratitude is sufficient to appreciate the dedicated supervision and encouragement I have received from my major supervisor - Dr. P.S. Akinyeye whose healthy support has led to this production. I am also thankful to my Childhood friends in persons of Dr. Ben Astsumbe and Abdul Ali for their thoughtful wishes. The contribution of my living icons in persons of Engr. Yahaya Bawuro, Chief Chike Nwunne of the Federal

Ministry of Environment, Abuja, Prof. Hillary Inyang of the African University and Engr. Olatunji Oshanisi is also acknowledged. The immeasurable assistance offered by the management staff of the pavement evaluation unit Kaduna, will forever remain fresh in me. God alone shall repay them for their time honoured tutelage.

Suffice to add here, that the lush experience I have derived from the Post-graduate curricular of the Federal University of Technology, Minna has undoubtedly distilled my perception of environmental principles and management in a wide sense. I wish the ideal remains sustainable.

However, it must be emphasized that, I am wholly responsible for any human error which may arise from the study and not these respected personalities mentioned above. Finally, but never the least, I beg to acknowledge my sincere gratitude to the authors listed in the reference section from whose intellectual rights I have borrowed copyright materials.

ABSTRACT

The increasing dependency on inland carriageways for transportation system in the Federal Capital Territory of Abuja necessitates its prime demand by commuters for performance efficiency, but unfortunately, the Zuba-Gwagwalada carriageway, which is a major link between the Federal Capital Territory's Northern and Southern parts of Nigeria, has repeatedly failed. Its short-lived conditions has always led to uncompromised accidents, delays in travel time, mechanical break down and high cost of maintenance amongst others. This study aimed at assessing the flexible pavement probable failure factors and the engineering properties of its sub-grade materials which provide the mechanical support for the carriageway system within km1+200 – km19+300. A combination of spot environmental hazards, traffic spectrum and Geotechnical analytical methods was adopted. The primary data used for the assessment were derived from the field through ground truthing, insitu profiling and laboratory analyses while the secondary data were sourced from publications of the Federal Ministry of Works and American Association of Transport and Highways Officials (AASTHO). Study results indicate that effects of environmental hazards were less significant but average daily traffic spectrum of 3,510 undoubtedly exceeds standard average design maxima of 1,025 for a single carriageway such as the Zuba-Gwagwalada. Similarly, log characteristics of the failed sub-grade cross sections of km1+200 - km16+900 indicate mosaic profiles which range from loesal to sandy, chaley as well as marley conditions of A7-6 AASTHO classification. These classes of sub-grade materials are generally poor in providing mechanical support to applied loads. This fundamental limitation amongst other factors, notably excessive axial loads and contractual aberrations led to the continued failure of the carriageway. However, the control cross section of km16+900 – km19+300 which falls within A2-6 of AASTHO classifications are rated good economic sub-grade materials which suggests its stability conditions over time. The provision of a minimum 2m key trench granitic rubble fills and sand filters within weak sub-grades and road beds, strict adherence to EIA and geotechnical guidelines, and the expansion of inter-modal access to assimilate the combined supplies of traffic and axle loads amongst others have been recommended by the author as possible solutions to the intractable failures.

TABLE OF CONTENTS

TITLE **PAGE**

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

LIST OF TABLES

TABLE OF CONTENTS

CHAPTER TWO: REVIEW OF RELATED LITERATURE

CHAPTER THREE: MATERIALS AND METHODS

CHAPTER FOUR: RESULTS

LIST OF FIGURES

LIST OF PLATES

APPENDICES

CHAPTER ONE

1.1 INTRODUCTION

The principle of equal access from all parts of the country was foremost in the seven-point criterion that necessitated the relocation of Nigeria's Federal Capital Territory from Lagos to Abuja in 1975 (Mabogunje 2006). By this provincial distinction, Abuja was meant to become the hub of a functional National City centre to Nigerians and foreigners, as well. The other six planned criteria designed to satisfy the development of the Federal Capital policy are listed below:-

i. Equal citizenship
ii. Environmental conservation
iii. Aesthetic beauty or appeal
iv. Functional city
v. Effective regional development
vi. Rapid national economic growth.

Clearly, the cardinal objectives listed above call for constant travel demands to the city centre of the Federal Capital territory of Abuja through major media such as carriageways, air lines, railways, express package carriers, pipelines and, to probably inland waterways. The World Bank country report on development (2004) however, noted the highest degree of dependency on motor vehicles for inter-corridor transport and regional economic activities, necessitating the demand for more functional roads in Africa. Ironically, most carriageways in Nigeria that were constructed over a decade ago are undergoing spot imperfections in the form of minor to major failures particularly, within the study section of km.1+200 to Km.18+100 on Zuba – Gwagwalada Federal Trunk road. The repetitive failure has led to economic losses, uncompromised accidents, delays in travel-time, mechanical breakdown and opportunistic robbery incidences, thus underscoring the objective of an effective user-service transport system.

According to the Highways Department of the Federal Transportation Agency (2006), several factors account for road failures; notably amongst which are listed below:-

i. Material properties and variability
ii. Construction quality
iii. Live load
iv. Environment
v. Maintenance level

Given these mosaic factors as noted above, the solution to carriageway problems in Nigeria is not amenable to easy answers. Ironically, many of the techniques associated with design and management of today's engineering infrastructures and public facilities in Nigeria are still based on everyday experience, rather than the 21st century-driven knowledge in interrelationships between development science and local environmental attributes. This intractable trend underpins 'quick wins' technical solution to enduring carriageways system is worrisome. However, sustainable carriage way integrity, as vendored in Plates i – ii can be achieved through courteous environmental development planning system which is rooted to accommodate a confluence of development issues on the environment, technology, state policies and public interests.

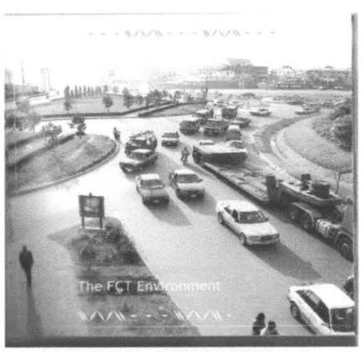


Plate i Ideal Carriageway System

Source: Author's Field Work, 2007

Plate ii Ideal Carriageway System

Source: Author's Field Work, 2007

Usually, traffic spectrum determinants are either derived from the statistics of vehicle registration, fuel consumption and socio-economic factors (e.g. population growth, development growth and growth of industries, etc.)

Thus, environmental development planning by necessity in flexible pavement performance study, as undertaken by this work is prompted by the need to finding sustainable solution to short-lived carriageway system through transport geography principle.

1.2 BACKGROUND TO THE STUDY

A carriageway, as a structure is designed to carry traffic load without deformation, skid and abrasion within design life cycle. If it under performs, it is said to have failed. Many roads in today's Nigeria including, the study sections are failing, thus underscoring the realization of their prime objective of improving socio-economic connections between towns and cities. Because carriageways are an essential part of passenger and freight transportation, there is always considerable interest about them, especially if deleterious conditions such as alligator cracks, potholes, raveling and base shears set in without immediate repairs. Current failure conditions within km1+200km. 18+100 on Zuba – Gwagwalada carriageway as captured in Plates iii -iv remain a major concern to Commuters and Transport Geographers alike.

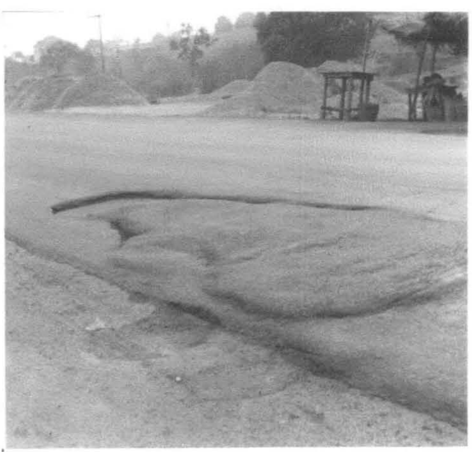


Plate iii **Surface Raveling**

Source: Author's Field Work, Zuba – Gwagwalada carriageway 2007

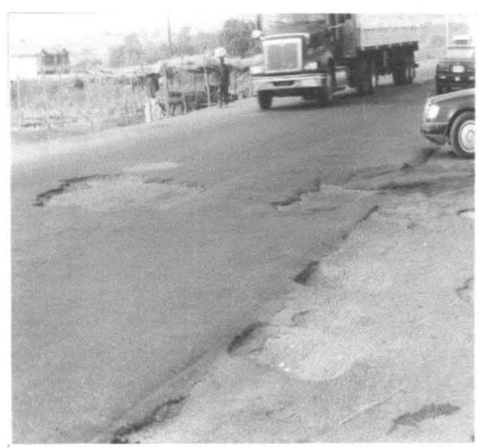


Plate iv **Pothole Manifestations**

Source: Author's Field Work, Zuba – Gwagwalada carriageway, 2007

The Zuba – Gwagwalada carriageway which was constructed by Messrs Dumex Nigeria Limited in 1983 is a major transit destination to Nigeria's Federal Capital Territory, as well as a major link between the North and Southern parts of the country. Its utility function, as noted by Federal Ministry of Transportation and further corroborated by Road Transport Workers (2001) showed structural competence up to mid-nineties but regrettably, dropped towards the turn of the millennia; most sections of the route, particularly the study sections of km.1+200–km.19+300 has remained severely uncompromised despite routine spot maintenance efforts.

Most economies are increasingly dependent on carriageways for transporting freight and passengers. Transportation has become so pervasive in domestic and international trade and market economics, that real growth is practically impossible without recourse to roads, railways, air and seaport services. Thus, a good roadway is as basic economic hub for regional and international competitiveness in the 21st century to as the railways and power plants were to the 18th century industrial revolution in Europe and America. Efficient carriageway system is therefore, important to lubricate the wheel of trade and to allow the benefits of economic growth to be distributed across those living in nation's integral process. While there is a tendency for emphasis to remain on the pure efficiency network advantage, notions of sustainable performance integrity also require these gains to be spread in a socially acceptable manner. The demand for these gains through inter-corridor constructions and increase in usage brings with it problems of frequent pavement failures and vulnerability to accidents.

1.3 INFLUENCE OF LOCAL SUB-GRADE PROPERTIES ON CARRIAGEWAY SUSTAINABILITY.

Soils shear very near the surface of the earth and they are essentially the products of the action of weather and climate. Weathering of rocks exsitu leads to the formation of residual soils which may be eroded, transported or simply piled, just as deposited soil. The engineering properties, origin and occurrence in the ground vis-à-vis strength performance of these deposited soils are of interest to the 21st century environmental development planner and manager (Paskin et al, 1996). The focal list of this research therefore, is to set down what is known to be one of the most interesting and important aspects of relational soil mechanics to carriageway integrity.

Admittedly, all local environments are unique but it is also very helpful to understand them in terms of boundary characteristics and interrelationships. These attributes are fundamental to their behavioural accounting, which form the common thread between Engineers and Environmental Scientists. In development planning parlance, it is believed that the range of environment over which the safety and reliability of engineering infrastructures and facilities can be based are relatively narrow. For example, a good failure resistance in either cretaceous chalk sub-grade of either Lokoja – Nigeria or South Eastern England or Ocean Lavas of India would not necessarily be good indicator for similar roadbed in either Nguru-Nigeria, Antarctica Falkland Island or the muskeg terrain of Northern Europe, former USSR or Nigeria's Niger Delta, which is characterized by fossilized organic matter.

This postulation was validated by Staechle (2003) through the application of forensic science on Rod Fox Road in Minnesota and Oak Drive in St. Louis, USA. The findings significantly demonstrated that, for failure to occur, the contribution of environmental effects cannot be ignored, as it was established beyond doubt that, compliance with established design specification codes and standard in Minnesota never necessarily prevented failure in St. Louis, USA because, the guarantee of laterite maximum performance under varied environmental conditions such as temperature, geology and rainfall intensity, even accelerated more failure in Minnesota than mechanically related issues such s axial load, which is a primary design criteria.

An objective assessment of flexible pavement performance without due consideration to wholesale attributes listed in paragraph three above and in particular, specific regional sub-grade conditions would necessarily amount to limited conclusion. Broadus et al (1989) noted that, a thorough understanding of road bed behaviours in conjunction with other key management plans would be necessary, as they often influence the choice for an endurable roadbed development alternative, such as:

i. Granular base.
ii. Cement stabilized base
iii. Chemical stabilized base
iv. Bituminous stabilized base

The foregoing therefore, explains the necessity for interrelationships examination between sub-grade strength indices and carriageway serviceability integrity.

This study, within its scope therefore, aims at providing explanation to such pertinent question at least, in part to causes of perennial imperfections within Km1+200–Km19+300 on Zuba–Gwagwalada carriageway in the Federal Capital Territory of Abuja, through sub-grade performance characteristics investigation. In real nature, soils occur in a large variety, but those that exhibit similar behavioural attributes can be put together to constitute a particular group, based on valid bulk test results. Confirmatory results from such tests are termed index properties of the soils. These properties are of great significance in development planning and engineering practice because engineering structures such as roads, buildings, dams, etc are founded on undisturbed, natural soil deposits, otherwise known as environmental sub-grades, which naturally bear the volumetric pressure as well as mechanical support for pavement overlay. The technical validity of this postulation appears to agree with Michael's (1998) findings on structural instability of engineering infrastructures, such as the leaning tower of Pisa, which was attributed to error in initial foundation consideration; while short-lived pavements and buildings in parts of West Africa, particularly within the coastlines, occurred not necessarily by faulty design of its builders or because of any structural flaws in the infrastructures per se, but because they were built on unstable sub-grades, part of which flowed out from underneath, leading to veneer creep, in the case of Barnawa - Kaduna Estate collapse (1982) and episodic carriageway failures in Nigeria and Ghana within 1978-1988, and 1989-1999.

1.4 RELEVANCE OF STUDY

Worried by functional failures of Nigeria roads, successive governments in the past one and half decades embarked on a set of local and medium term actions through statutory agencies such as the Federal Ministry of Works (FMW) and the Petroleum Trust Fund (PTF) to abate pavement degradation of Nigeria roads, summarized in Table 1.1 below:

Table 1.1: **Distribution of Nigeria's Road Network (in Kilometer)**

Road Types	Federal Roads	State Roads	Local Gov't Roads	Total
Paved Roads	26,500	10,400	-	36,900
Urban Roads	5,600	20,100	-	25,700
Main Rural Roads	-	-	72,800	72,800
Village Access Roads	-	-	35,900	35,900
Total	**32,100**	**30,500**	**108,700**	**171,300**

Source:- Road Vision 2000 steering Committee Information Brochure

Besides the massive rehabilitation works implementation by these agencies, other remedial approaches such as vegetal control, desilting catch basins and repairs, base seals and ISS 2500 liquid stabilizer application were also adopted. These direct-process controls were also complimented by inputs from individuals, communities and Non-Governmental Organization (NGOs), in emergency circumstances as reflected in Plate v –vi.

Ironically, the services of these schemes were either short lived or restrictive, that they could not be left to uncoordinated structure. The quest for enduring carriageway integrity, occasioned by countrywide degradation and public outcries particularly, by the Road Transport Workers in 2001 led to the creation of the Federal Roads Maintenance Agency (FERMA) on 30th November 2002. The Agency was particularly charged with the responsibility of providing normative engineering services on Federal Highways, associated with:-

- Resurfacing
- Restoration
- Rehabilitation
- Reconstruction

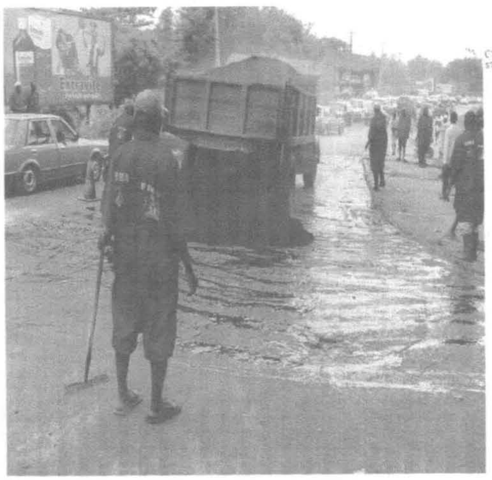


Plate v **Major Maintenance Works**

Source: Author's Field Work, Zuba – Gwagwalada carriageway 2007

Plate vi **NGO Road Fill Support**

Source: Author's Field Work, Zuba – Gwagwalada carriageway, 2007

Admittedly, some phenomenal growth have been witnessed from the operation 500 roads executed by the Agency between creation to date, but by pavement integrity standard, the success level is below ideal, based on short-lived performances as independently reported by the Obasanjo Economic Direction Publication of April 2000 and the Corporate Nigeria Annual Report of 2007. Today, about 45% of these roads are either in poor or deplorable conditions.

From time to time, we may be close to solution in engineering problems, but more often than not, competing equations that require alternative choice emerge. Some of these choices are very important in a sense though, while others are less so. Yet, we apply them all the time with limited success, especially in Nigeria roads circumstance.

A deeper understanding of key local environmental attributes such as sub-grades and their relational impacts on sustainable carriageway system can immeasurably reduce search efforts for enduring solution with better precision. But because a variety of considerations may influence the choice of a solution, there is frequently disagreement about which solution is best. However, our personal choices will often depend strongly on our convictions about which considerations are most important, which suggests why this study, particularly list environmental dynamics as an approach to finding a generic solution to road failure problem in Nigeria, using km1+200 to km19+300 of Zuba – Gwagwalada carriageway.

A single work such as this cannot explore all aspects of carriageway concerns though, but here, the emphasis is on the effectiveness or otherwise of the native sub grade materials that shaped the morphology of the route natural environment. In a real sense, this should probably be the most fundamental inescapable factor because carriageways on one hand are not built in vacuums; just as we cannot for instance, guarantee safe homes or dams on land with unstable foundation. Foundation geology of the physical environment then, is the logical point to start in developing an understanding of the many road failure issues; such clarification will then provide a basis for development planning contingency that would either direct, sustain or manage carriageways efficiently and in a sustainable manner too.

In emphasizing the modal role of the foregoing, Lord Dening, 1962 in his paramount of foundation engineering noted that "sub-grade materials competence remain the sum total of carriageway operative strength because, in as much as one cannot put something on nothing and expect it to stand, so, also will weak sub-grades remain critical barriers to efficient carriageway system.

1.5 STATEMENT OF RESEARCH PROBLEM

Admittedly, some phenomenal growth has been witnessed from the FERMA "Operation 500 Roads" repairs and maintenance of 26,400km by year 2005 through direct labour and corporate contracts. But judging by structural integrity and sustainability question, most of these roads performance standards are still far from ideal, as captured in Plates iii –iv. Regrettably, Km1+200 – Km19+300 of the study sections have repeatedly failed, resulting to functional failures in form of, potholes, and geometric cracks. These failure trends and indeed, all other forms of pavement failure in Nigeria portend socio-economic disruption and narrowed justification for public expenditure.

1.6 RESEARCH QUESTION

The research seeks to address the basic question of "what is the cause of the repeated failure of flexible pavement on Km 1+200 – Km19+300 of Zuba – Gwagwalada highways in FCT, Abuja? And how can the trend be reversed?

1.7 AIM OF THE STUDY

The specific aim of the study is to assess a possible effect of engineering properties of sub-grade materials on flexible pavement failures within km1+200 and Km19+300 on Zuba – Gwagwalada carriageway system.

1.8 SPECIFIC OBJECTIVES

i. To objectively identify possible environmental problems that pose limitations to sustained user- efficiency of the Zuba – Gwagwalada carriageway system.
ii. To identify the pattern of traffic spectrum on the carriageway.
iii. To examine log characteristics of the sub-grade for the carriageway system
iv. To identify possible causes of frequent failures along the road.
v. To make relevant recommendations on management system.

1.9 STUDY JUSTIFICATION

i. Sub-grades naturally bear the volumetric pressure and act as mechanical support for pavement overlay. An investigation into its operative strength through its engineering indices is expected to offer explanations at least, in part to probable cause of unexpected failures on Zuba – Gwagwalada carriageway.

ii. Many of the techniques associated with design and management of today's engineering infrastructures and public facilities in Nigeria are still based on everyday experience, or near copyright rather than on discrete knowledge of interrelationships between development science and technology, which could lessen efforts in the search for enduring carriageway structures.

iii. Road construction, operation and maintenance require some degree of understanding of environmental geology as mistakes could result from gaps in that knowledge.

iv. Zuba – Gwagwalada route is a high standard inter district link and thus central to socio-economic gains distribution within FCT and other parts of Nigeria.

v. Government's huge investment on the recovery of this failed road sections calls for participatory input to address the underlying problems through research development and technology.

vi. An effective user-service carriageway within the Nigerian nation's capital is fundamental to the transportation of goods and services which are integrals of economic growth and development while ineffective carriageway system portend socio-economic disruption through reduced scales in activities.

vii. As a nation, we have great opportunity and responsibility at our disposal to address issues of public interest through research and development. By this effort, it would be possible to put road transport back on track of high performance that is synonymous with Nigeria's socio-economic development goals.

1.10 ASSUMPTIONS OF THE STUDY

The study assumes:-

1) That, current underperformance scenario within Zuba – Gwagwalada carriageway system is reversible if output result is communicated to stakeholders.
2) That, development policy managers and highway engineers will be receptive to new ideas and trends in environmental management.
3) That, human and material resources directed towards set objectives could lead to efficient and sustainable management.

1.11 STUDY LIMITATION

Several factors constituted barriers to this study but worthy of note is time-scale. Because of the multiple factors associated with road failures, several measurable criteria over time are required to validate inferential statements. Particularly, as they relate to environmental concerns.

1.12 GEOGRAPHY OF STUDY AREAS

1.12i LOCATION AND RELIEF

The study site in Fig. 1.1 lies on km1+200–Km19 + 300 of the Zuba – Gwagwalada carriageway; its specific quadrant corresponds to latitude 303,546,335E and 101,253544N of the 32 UTM. Its route elevations rose from 259.197 at Giri junction and 240.035 at Giri Gwako and Spurring to 313.199 at the University of Abuja Staff Quarters with a gradual drop at Giri Tsauni to 240.035. A panoramic view of Giri catchment area in Plates 7 and 8 portrays the picture of a ribbon development within undulated rocky knobs that overlook Tunga Maje and Gwagwalada; altimetric heights reaching 900m in locations such as Giri Tsauni and Giri Gauta are common, due to either isolated outcrop masses or ridge bands that rose from the area up to Kuje and environs; these morphological structures categorize the area under gently undulating environment.

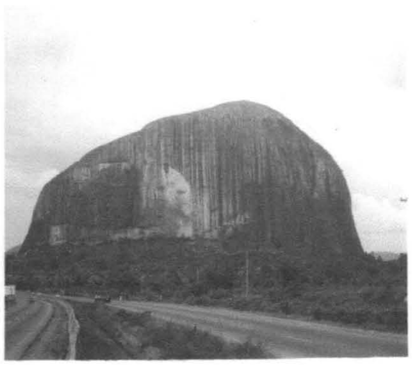


Plate vii. **Project Environment**

Source: Author's work on Zuba – Gwagwalada carriageway, 2007

Plate viii. **Project Environment**

Source: Author's work on Zuba – Gwagwalada carriageway, 2007

In the areas of rugged terrain to the South, North and North East, in Plate vii and viii constraints to carriageway development are severe. They do however; add geographic diversity to the gently undulating landscape of the area. In most other areas within the site such as the Airport, Kuje and Gwagwalada, where 4% dips are common rock structure does not portray the existence of any major development constraint. These rocks are generally of medium to high strengths, which would present minimal engineering problems during construction projects.

ii Climate

Although climatic information on the Federal Capital Territory is rather scanty, data extrapolated from adjacent weather stations revealed that the area around Gwagwalada has temperatures ranging from 21^0 – 26.7^0C. yearly and a total annual rainfall of approximately 1,650mm. This area also lies within the region classified in the Site Selection Report No. 2 by IPA (1978) as climatically ideal for human comfort. About 60% of the annual rains fall during the month of July, August and September. This factor is of significance in the planning of drainage for the disposal of storm water. Another climatic characteristic of this area is the frequent occurrence of squall lines heralded by thunder storms, lightening, strong winds and rainfall of high intensity. This climatic phenomenon often causes serious damage to building and it is essential to bear this in mind when designing building for the new town.

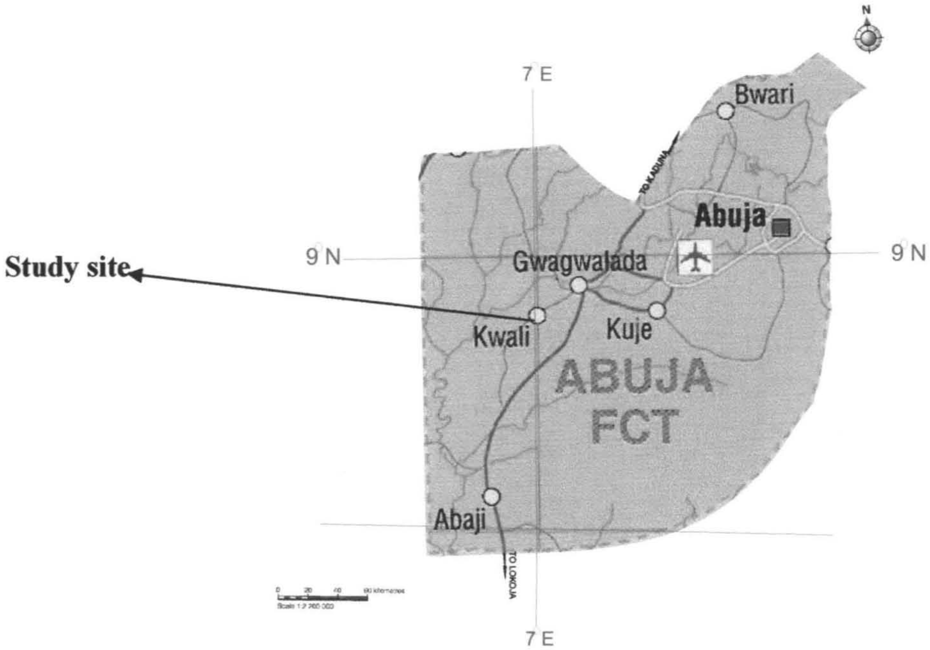


Fig 1.1. Location Map of study site

Source: Satod Cartographic Consultants (2000)

iii. Geology

Gwagwalada area is almost predominantly underlain by Precambrian migmatite, gneisses, granites and schist's of the crystalline basement complex. Schist belt outcrops along the south-western merging of the area and apart from this schist belt, which is most unsatisfactory bedrock in the area, this area is ideal for building foundations and is free from geological hazards within the limits of present knowledge. Quaternary alluvium deposits are found in the Usuman river channel and this is a source of fine sand which is used for building purposes.

iv. Soils and Vegetation

The soil in the area shows a high degree of variability, comprising mainly of sand, silt, clay and gravel. The incidence of soil erosion is quite moderate because of protective vegetation cover; however any uncontrolled clearance would result in accelerated erosion, much of which is evident along roads and footpaths in the area. The vegetation can be classified as Park Savannah with scattered trees and tall grasses. There are however, some wooded areas along interfluves between the Usuma and Iku Rivers, and their tributaries within the area. Due to this type of vegetation, the area is quite ideal for the development of the new towns since constraints on site clearance are very limited.

v. Drainage

The drainage pattern is parallel in a gravity flow system from the Gwagwalada ridge-band. Surface flows are super-critical and coarse in nature towards the carriageway route, where road embankment reduces their violent effect. However, during heavy rains, ramp over flows across the road is experienced leading to downstream spout head gully development. Because of the impermeable rocky nature of the foot slope plain, a more active sub-terreranal pressure within road bedding planes develops; this activity often gives rise to a hastened break down of the carriageway structure, particularly at locations where inadequate pressure relief drainage systems are neither provided nor ineffective.

The Gwagwalada River which runs South –East within the downstream areas is the major drainage basin with an approximate 20km^2 watershed net. Evidence of active flood within the area is marked by a series of loesal deposits and ephemeric channels. The most important tributaries are the Iku, Wuye and Gbihndna rivers, which drain the Zuba – Gwagwalada basement complex. Slopes within the Zuba Gwagwalada area are generally long and gentle, ranging up to 4% in most areas.

The Iku River which takes its source from the Abuja hill is also a significant within the vicinity. Flash flooding is characteristic of all streams in this area particularly, during the rainy season. It is obvious that flood is a major environmental hazard in this area because of high rainfall intensity on hard pans. The need for planned drainage network therefore, is a necessity. The Wuye and Gbihndna Rivers are the major perennial rivers in the area but their flows are extremely low during dry seasons. Other minor Rivers that occur within the watershed are normally ephemeric, with drainage textures that range from either course on stable plains to turbulence in incised valleys.

vi Hydrology and Hydrogeology

River Usuma which is a tributary of the river Gurara is the largest and major river within this area. For most part of the year, except during the peak of the raining season, the Usuma River around Gwagwalada is quite shallow. Although, no reliable hydrological records have been kept for the area, Gauff Consultants (2001) have indicated that the Usuma River in its present form would have to be carefully studied to ascertain its potentials. The quality of the water in the river around Gwagwalada is heavily polluted because of the high iron and ammonia contents. The ammonia is derived from cattle waste materials. The river is used by the settlements around for bathing, and other domestic purposes. The Wuye River is a smaller river and it is to the east of Gwagwalada village and A2 road. The volume of water is small but its possibility for irrigation purpose was affirmed by Gauff Consultants (2001). Flash flooding is characteristic of all streams in this area particularly during the raining season. It is obvious that flooding is a major environmental hazard in this area which could pose likely limitation to sustainable construction projects.

There exists in these areas some underground water potential but more detailed investigations have to be carried out to establish their permeabilities, thickness of the aquifers, dimension of topographic and subsurface catchments and ground water recharge rates. Test boreholes would have to be sunk to obtain more useful data on the quantity of the underground water. Some wells exist in Tunga Maje and Gwagwalada villages; measurements made in September, 2007 and April, 2008 by the author gave water levels of 2.43m and 7.13m respectively.

vii Land Use

Apart from the villages of Gwagwalada and Giri, the adjoining areas lie within an agricultural zone. Most of the land is heavily cultivated under the adjusted practice, often referred to shifting cultivation. The primary food and cash crops in these regions are yams and sorghum. Although, maize, cowpeas and groundnuts are commonly grown but grazing is heavy, judging by continued influx of pastoral Fulanis while rice and sugarcane form minor components of the farming system. However, the Kuje region has some measures of human activities in small farm settlements. Substantial farming and lumbering also take place as major land use activities. Most cultivations and lumbering occur in the vicinity of existing settlements. Several outpost settlements are linked with feeder roads. The published average population of the area by NPC (2006) is 158,618. Gwari is the predominant tribe, with pockets of Hausa and Fulani populations. Most large settlements are nucleated; although smaller ones take rectilinear forms. Local houses are built with traditional mud while structured ones are built of modern brick materials. Lifestyle and economic growth improvement is evident due to 9.3% growth rate in population between 1991 – 2006 and the provision of affordable housing scheme and ancillary infrastructures by the government and private entrepreneurs.

Viii Road Network

Road Network within the area are grouped into three categories. First, is the asphalt or flexible pavement overlay. Second, are the bituminous surface- dressed arteries while the third category is the earth or feeder access roads. While most of these roads are interlinked, they none the less underscore top user-services because of their general poor conditions.

1.13 DEFINITION OF TERMS

An important aspect of this study is the definition of terms used. Understanding them would eliminate confusion and misinterpretation of information. The AASHTO based these definitions on existing guidelines of the ASTM, while the FMW and Nigeria COMEG definitions are based on tropical environment.

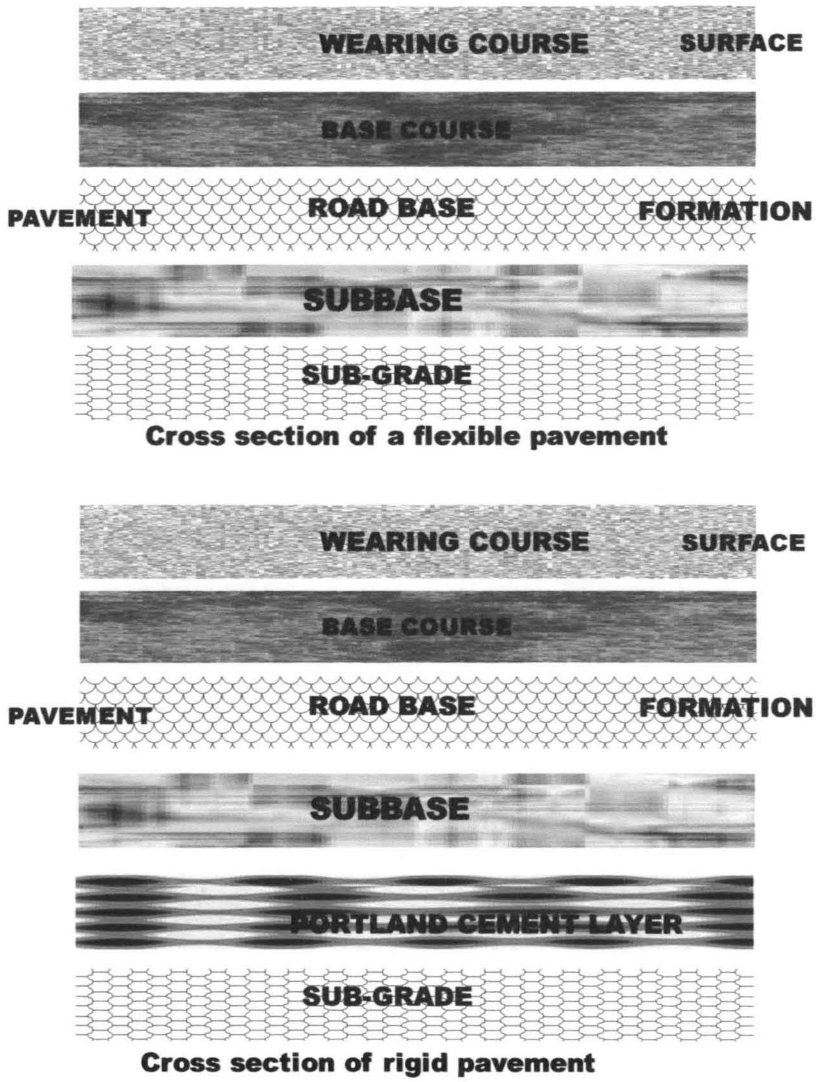


Fig. 1.3 **Typical Flexible and Rigid Pavements**

A flexible pavement may include the following five layers (from base to top)

(1) Prepared roadbed,

(2) Sub-base course, typically form compacted granular material.

(3) Base course, which provides structural support to the pavement, made from aggregates such as crushed gravel, which may be treated with fly ash, cement or asphalt,

(4) Drainage layer, which is part of the base, made with select aggregates or fabrics with sufficient geo textiles and

1.13i *Pavement Structure*

A pavement structure as illustrated in Fig 1.2 consists of a series of layers, beginning with the native soil that constitutes the prepared roadbed (or sub-grade), overlaid by the sub-base and base layers. The strength of these layers increases vertically from the sub-grade to conform to the increasing requirements of stress and load distribution by the base course as depicted in Fig.1.3. This practice contributes to lower economical and efficient use of materials by avoiding "over designing" the lower layers. Some of these layers may be omitted, depending on the strength of native soil and material availability.

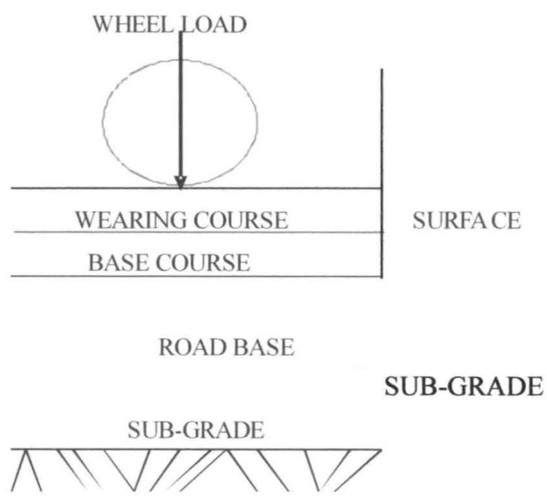


Fig. 1.2 **Typical Pavement Structure**

An asphalt pavement that is placed directly on the sub-grade is known as a full-depth asphalt pavement. In this case, the thickness of the base and sub-base is simply replaced by appropriate "layers" of asphalt concrete to form a thicker layer than would otherwise be required. In the case of asphalt pavements and this reduces the strength of the base and sub-base. Fig 1.3 illustrates typical flexible and rigid pavements.

(5) Surface course mixture of bituminous materials and aggregates. The proportion of bituminous materials and aggregates as well as the gradation, strength, abrasion, and other characteristics of the aggregates determine the resistance to cracking and skidding. The surface mix must however, be properly compacted.

Rigid pavements on the other hand, usually consists of four major layers, visa

(1) Prepared roadbed (as for flexible pavements);

(2) Sub-base course, with characteristics similar to those for flexible pavements, with the exception that, often lean concrete sub-base are constructed to reduce erosion of the bottom side of the slabs, the joints between slabs, and the edges of the slabs;

(3) Base course, which may contain a drainage layer (often the base and sub-base are combined into one supporting layer with or without a drainage layer); and

(4) Pavement slab, which is a concrete mixed with Portland cement, aggregates, and various optional admixtures. The interlock of aggregates provides the mechanism with which loads are transferred in Portland-cement and concrete pavement (aggregate interlock).

The proportion of Portland cement and aggregates as well as the gradation, strength, abrasion, and other characteristics of the other characteristics of the aggregates determine the resistance to cracking and skidding; the slab may be reinforced with steel and joint sealants.

1.13ii Sub grade materials as defined by this study basically refer the operative strength characteristics described below.

1.13iii. *Atterberg Limits:* These are boundary conditions for determining liquid and plastic limits of soil. They also provide the necessary clues regarding the plasticity index. Atterberg limits rely on the concept that a fine-grained soil can exist in a solid, semi-solid and plastic state.

1.13iv. *California Bearing Ratio:* This refers to a comparative estimate of the strength of the sub-grade by measuring the relationship between load and penetration on the soil with the aid of CBR machine.

1.13v . *Geologic Foundation (Base Course):* A layer or layers of specific or selected granular material of designed thickness, constructed on the distributing load to provide drainage, or minimize heaving, cracks or erosion.

1.13vi. *Base Cross Drain:* A subsurface drainage that is usually perpendicular to the roadway alignment, designed to drain infiltrated water; it is often needed at bridge abutments, toll plazas, and across roads on long downgrades.

1.13vii. *Dense-graded Base:* A mixture of primary sand and gravel, that is well graded from coarse to fine materials, (usually unstabilized, but sometimes, asphalt or cement stabilized).

1.13viii. *Drainage aggregate:* Is an open-graded aggregate with high permeability.

1.13ix *Ground water:* Free water in sub-grade soil, often controlled by deep ditches or deep under drains.

1.13x. *Headwall:* A protective structure at an edge drain outlet.

1.13xi. *Infiltration:* Free water in the pavement structural elements entering through cracks joints, or permeable paving.

1.13xii. *Outlet*: The point of discharge of an edge drain may be the pipe or the headwall.

1.13xiii. *Outlet pipe:* The lateral connection from edge drain to the outlet, usually a solid pipe and usually strong to prevent damage.

1.13iv. *Compaction Test*: These are tests carried out to obtain the moisture-density relationship for a given compaction on a particular soil.

1.13v *Deformation:* Refers to pavement failure that occurs under static load conditions, and the initial resistance is only manifested under dynamic (fast moving traffic) loading. It is a function of both particle and binder friction. Inter-particle friction is dependent on the roughness of the surface of the particles and inters granular contact pressure. It is lower if two binders are present and particles are kept apart.

1.13vi. *Disintegration*: Refers to weathering of integral components of pavement. To prevent this type of failures, the binder must be of high degree of adhesive bond between the aggregate particles. Disintegration is minimized by high binder content. Resurfacing can thoroughly bind the particles. In addition, the film formed would be more resistant to hardening thus, less liable to brittleness at early lifecycle. But care must be taken to ensure that binder content is not so great as to cause a lowering of stability.

1.13vii. *Fracture:* These are observable cracks within joints that have lost their sealing effects. Usually, sealing works at appropriate locations will ensure a tight wearing as proving against surface infiltration of water.

1.13viii. *Grain Size Distribution:* The grain size distribution refers to void ratio of soil; it provides useful information for alternative design options such as the adoption of either cement or asphaltic concretes for a given construction work. Well-graded soil requires less cement paste to fill the voids because there is less water per unit volume of concrete mix in uniform aggregates.

1.13ix. *Liquid Limit:* The liquid limit is a measure of moisture content at which the soil can thrive under its own weight. It is expressed as a percentage by weight of oven-dried soil at the boundary between liquid and plastic stages.

1.13x. *Plastic Limit:* This is the limit of a soil at which liquid content minimal; it is expressed as a percentage by means of oven drying at the boundary between plastic and semi-liquid states. The water content at this boundary is arbitrary defined as the lowest water content at which the soil can be rolled into the thread of about 3mm diameter.

1.13xi. *Pavement:* Pavement includes all elements from the wearing surface of a roadway to the sub-grade. It also includes the surface pavement (of either asphalt or concrete make); the base may include permeable base and sub-base.

1.13xii. *Permeable base:* A free draining layer in the pavement designed to rapidly remove free water from most elements of pavement is usually placed between the surface of the pavement and a separator/filter layer. It may be an aggregate or aggregate stabilized with either Portland cement or asphalt, usually with permeability of more than 300mm/day

1.13xiii. *Prefabricated Geo-composite Edge Drains:* An edge drain consisting of a drainage core covered with geo-textile. It may include drainage aggregate or sand as a part of the installation.

1.13xiv. *Sealant filter layer (Aggregate or geo-textile):* A geo-textile or aggregate sub-based layer, that separates a permeable base layer from an adjacent soil (or aggregate) containing fines, aimed at preventing these fines from contaminating the drainage aggregate; they must however, meet the filter criteria for drainage filters.

1.13xv. *Stabilized aggregate:* Aggregate that contains an asphlatic or cement binder.

1.13vi. *Sub-base:* The layer or layers of specified or selected material of designed thickness, placed on a sub-grade to support a base course.

1.13xvii. *Sub-grade*: This is the native soil that supports the pavement.

1.13xviii. A deep surface drain located at a sufficient depth to intercept and lower the ground water to a required design level.

1.13xix. *Surface Course:* This is the uppermost layer of a flexible pavement and probably, the most important aspect since it is the one, which motorists ride upon. The surfacing otherwise called base course is meant to:-

1. Provide a safe and comfortable riding surface for the traffic.

2. To protect the sub-layer underneath from the effects of mechanical imperfections.
3. To protect the pavement from disintegration caused by axial loads. It is made up of crystalline crushed stone on which asphalt is laid.

1.13xx. *Road Base*: This is normally the thickest element of the pavement and is the most important layer of a flexible pavement. It is expected to bear the burden of distributing the applied surface loads and also ensure that the bearing capacity of the sub-grade is not exceeded. The materials used in the road base must always be of a high quality.

1.13xxi. *Sub-Base:* This is normally an extension of the road base. Usually, it serves to:

1. Distribute the applied load to the sub-grade.
2. Act as platform on which subsequent layers can be constructed
3. Tend to carry operational traffic
4. Act as drainage layer of filter.

1.13xxii. *Sub-Grade:* It is the natural soil mantle level, which acts as platform on which subsequent layers are constructed, as shown in Fig. 1.3. Laterite is utilized to construct the sub-base, road base and base course layers; the geotechnical properties of the laterite deposits will determine its suitability for usage as sub-base, road-base and base course and operative competence as well.

1.14 ABREVIATIONS AND THEIR MEANIINGS AS USED IN THE STUDY

AASHTO = American Association of State Highway Official
ASTM= American Society for testing of Materials and Transportation
CAPA = Colorado Asphalt Pavement Association.
CBR = California Bearing Ratio
CH = Inorganic clay of high plasticity
CL = Inorganic clay of low to medium plasticity
COMI = Council for Mining and Engineering Geology
DGB= Densed Graded Base
FCT = Federal Capital Territory
FERMA = Federal Roads Maintenance Agency
FMW= Federal Ministry of Work
GC = Clay gravel, poorly graded gravel – sandy – clay mixture
GM = Silty Gravels, poorly graded gravel – sand – silt mixtures
GP = poorly graded gravel, gravel – sand mixtures, little or no fines
IPA= International Planners Associate
LL= Liquid Limit
MH = Inorganic silt, micaceous fine sandy soil
ML = Inorganic silt and very fine sands, clay fine sand with slightly plasticity.
NPC= National Population Council
OH = Organic Clay of medium to high plasticity
OL = Organic silt and organic silt clay of low plasticity
PEU = Pavement Evaluation Unit
PGED= Prefabricated Geo-composite Edge Drain
PL = Plastic Limit
PTF = Petroleum Trust Fund
PSI = Present Serviceability Index
SC = Clay sand, poorly graded sand – clay mixture
SM = Silt sand poorly graded sand – silt mixture
SP = poorly graded sands, gravelly sands, little or no fines
SW = Well graded sands, gravelly sands little or no fines.
UTM = Universal Traverse Merialur

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 INTRODUCTION

Carriageway as a structural media is designed to provide efficient transportation system within planned lifecycle. If it underperforms prior to its withdrawal period, it is then said to have failed. The general purpose of a carriageway therefore, is to satisfactorily accommodate the mobility needs of human. Within specific context, such as underperformance or failure, certain fundamental questions such as which carriageway is failing, what is responsible for the failure, by what factors, at what degrees of failure and influence and what should be the restoration plan process, and how, are certainly not amenable to easy answers.

Responses to these questions, are however, largely rooted in literatures; hence, a recourse to either ongoing or past publications on pavement failure investigations becomes relevant in obtaining clues towards streamlining investigation scope and methodical design, that will help to identify critical areas of the study that are worthy of emphasis, and making inferential judgment on causes of failures, effects and materials specification necessary for successful implementation of the study. Based on the foregoing therefore, two levels of reviews were carried out, as listed below:

i. Panoramic review of pavement development studies, results and conclusions reached. Particularly those levels that firmed up pavement failure incidences, causes and suggested solutions.

ii. Those aspects that examined experimental procedures adopted by various workers in similar or related studies.

The panoramic overview of these various workers research under varied objectives and circumstances as attempted in this chapter therefore, is expected to provide clues on types and occurrences of carriageway failure, causes, impacts, responsiveness, methodology and level of investigations. Until recent decades, references to road failure problems in Nigeria were scanty due to research gaps but the need for carriageway sustainability necessitated select studies whose findings can now be found in major reports of Shell Development Company (1970), Messrs Dumex (1973) Federal Ministry of Works (1975-95), Road Research and Development Agency (1990), World Bank grant implementation on the establishment of pavement evaluation Unit, Kaduna (1985-1990) and the Federal Roads Maintenance Agency (2004).

2.2 EVOLUTIONARY PROCESS OF ROAD DEVELOPMENT

Road Development, which was pioneered by Tresquet in 1825 originated from the ancient Roman Empires; the increasing need for better transportation system such as auto vehicles and locomotives of the 1830s as against chariots and wheeled vehicles however, led to the evolution of modern highway engineering (Dobb, 1951 and Rowstow, 1960).

Evidence that streets were surfaced with brick-sized concrete blocks bedded on sand in Belgium in the 1930s exist though, but it is reasonably accepted that the modern paved stone era commenced in Rotterdam, immediately after the second World War II. Traditionally, Dutch city streets were surfaced with brick but the shortage of coal throughout northern Europe, following the war led to a shortfall in the number of bricks needed for the more pressing demand for housing reconstruction. The Rotterdam city engineers therefore, adopted concrete pavers as a temporary substitute, which led to all Dutch authorities acceptance of concrete technology, such that by 1970, about 15,000,000m^2 of concrete pavers were installed annually. More recently however, there has been a dimensional modification by the Dutch for both concrete and bricks which explains the term "Holland Stone" referred to in the USA, to describe rectangular concrete paving units.

The Dutch experience was paralleled in West Germany through the 1950s and 1960s with the 1963 recession, leading to many German building block manufacturers switching to paving units in order to keep their machines in production. A fundamental difference between developments in the two countries is that, West Germany manufacturers preferred proprietary shapes, which led to the establishment of shape-oriented promotional groups, which has recorded a significant international impact.

Eventually, all other countries and regions such as Nigeria either adopted a mix of Dutch or German tradition or integrating elements of both common pavers introduced to new regions by German industrial interests, such as Julius Berger shape licensors, pavers plant manufacturers and installation equipment designers – but as markets matured, the more straightforward Dutch tradition frequency predominated. For example, shell pavers were introduced into Nigeria in the late 1960s and by 1973, almost the shell Nigeria production comprised paves of either West Germany origin, or near copies, whereas by 1990, over 90% of Nigeria pavers were rectangular and followed Dutch tradition.

Of course, many European city streets have been surfaced with small element systems for 200 years or more and indeed, Roman Empire city streets were usually surfaced with some stone units over 200 years ago. The essential factors in the modern resurgence of pavers are mass production, low cost units manufactured to accurate dimensions to facilitate cost effective installations. Also, modern pavers are engineered to allow for safety by fast and heavy traffic, while at the same time, being compatible with the needs of commuters, in terms of slip, skid, abrasion and durability.

In Nigeria, roads or highways evolution must be tried to advent of the British during the colonial rule. The different road types present in the country today are:-

- Earth (un-surfaced) roads which serve as feeder roads.
- Surface treated roads.
- Asphaltic pavement roads
- Cement concrete roads (at the road intersections or Airports).

2.3 CARRIAGEWAY STUDIES IN NIGERIA

Shell Development Company carried out one of the first independent studies on carriageway integrity in Nigeria in 1972. The study considered the Ado–Odo-Oke- Odan- Idiroko bound carriageway. The investigation procedure, which was later presented to the International Conference on Structural Design of Asphalt pavements in Michigan, USA (1977) formed the basis for local design of overlays. The objective of the study was to determine appropriate refinement estimates to underperforming overlays in South-Western Nigeria, while the criteria listed below guided the methodical process.

i. Determining appropriate mix estimate of existing structure by deflection measurement of the sub-grade modular.
ii. Determining whether original design life criterion was based on either sub-grade strain or asphalt strain.
iii. Correlating derived overlay thickness against either the asphalt or sub-grade strain against the original design lifecycle.
iv. Adopting the procedural techniques listed above, and investigating some 21 trial pin holes through the methodical process described below. An elongated service period of 10-20 years was achieved.

2.4 ASHALT UPGRADE REFINEMENT

In determining **a** possible design method for asphalt refinement upgrade as defined by section 2.2 objective of Shell Development Company study in 1972, the first procedure was to obtain the design criteria by preparing a separate chart of the type EN, specifically made for mix code S_1-F_2-*100*, *w-MAAT* = 15^0C and $h_2 = 200$ mm as shown in Table 2.2. From this, the original design life of the pavement for $E_3 = 4 \times 10^7$ (N/M^2) and H_1 EN = 180 mm was found to be $N_{D1} = 2 \times 10^6$. So, the derived residual life of N_{D1}-N_{A1} which was $= 2 \times 10^6 - 1.5 \times 10^6$ yielded 0.5×10^6 as presented in Table 2.2.- 3

Where:

EN= Traffic-sub-grade modulus

Subsequently, a chart of the type HN in Fig. 2.1 was also prepared for the given parameters of mix code, w-MAAT and sub-grade modulus. For the experimental cross section, this was achieved by tracing curves for N = 10^6, 10^7 and 10^8 and w-MAAT = 15^0C from Charts HT 6, 14 and 22 ($E_3 = 2.5 \times 10^7$ N/m^2) and HT 30.38 and 46 ($E_3 = 5 \times 10^7$ N/M^2) on a transparency and drawing in the curves for $E^3 = 4 \times 10^7$ as shown in Figure. 2.2. The position of the latter curves for h_2 = 200 mm was checked for accuracy and the asphalt thickness for h_2 was 200mm as reflected by the envelopes in Figure 2.2 while the thickness of the unbound layer was found to be about 200mm and the asphalt mix type assumed to be represented by the mix code S1-F2-100. The value of $_W$-M.AAT, derived from the values of MAAT using appropriate chart, was found to be 15^0c. The traffic historical value was estimated at $N_{A1} = 3 \times 10^6$ and 7×10^6 respectively. These data were recorded in worksheet format, as vendored in Table 2.1. While values of H_1 and E_3; (N/M^2) at 4×10^7 N/m^2 envelops were derived as reflected in Figure 2.1-2.

Based on permissible sub-grade strain data criteria vendored in Table 2.2 and by synthesizing the sub- grade value for overlay of $ND_2 = N_{A2}$ provided 3×10^6 and 7×10^6, which assured the redesign of the overlay for an extended period of 10 and 20 years respectively, which represents the elongated lifespan refinement plan.

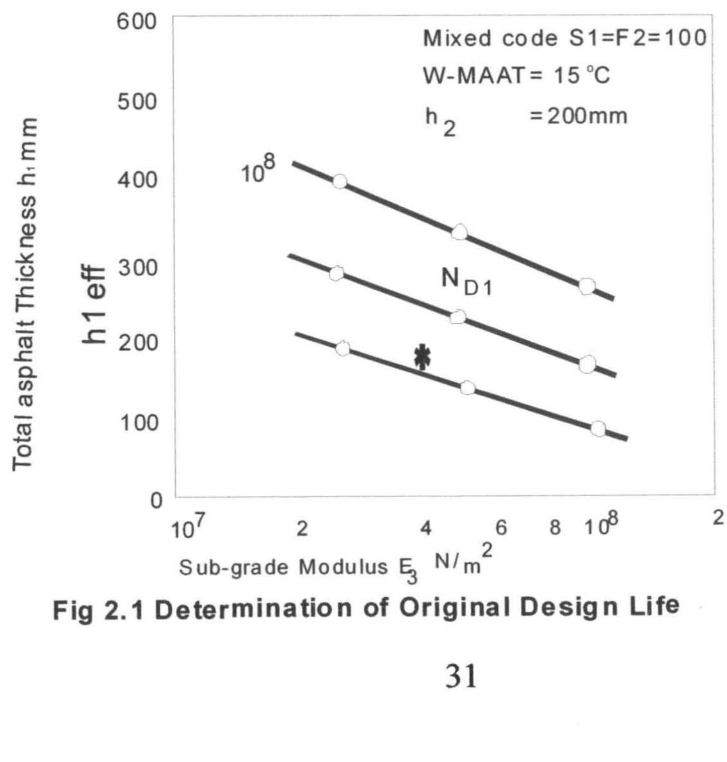


Fig 2.1 Determination of Original Design Life

Reactions from Highway Engineering scholars such as Deckar (1975), Abbot (1977), Breen (1979, and Chamberlain (1981) faulted the Shell study approach described above, noting that the methodical application could only be meaningful in service pavements of 300 ADT, but its relevance to design application in the 80s which marked enormous traffic profile in Nigeria was inadvertent. However, on both sides of this procedural weakness and strengthened arguments, some major works on technical refinements have been published by the Roads Research and Development Agency (1987) and the Geological Surveys Agency of Nigeria (1995 and 2001).

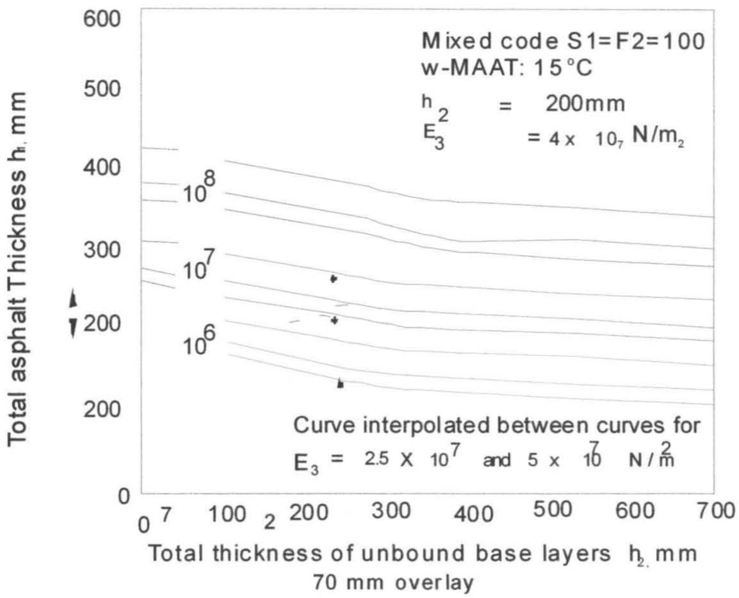


Fig. 2.2 Determination of Overlay Thickness

2.5 FATIGUE – LIFE STUDY DESIGN

Koenig (1995) attempted the development of further understanding on measurable fatigue characteristics of Nigerian asphalt concrete mixes associated with failed overlays within Lafia – Akwanga - Jos carriageway system through stress application method in the laboratory. In this study, an 18 asphalt core with little or no cracking from the master test sections as listed in Table 2.3 were separated into two groups. The first group firmed up specimen with void content values of 2-5%, while the other group was made up of 5-10% voided cores. Three samples were further selected from some of the master test sections with void contents within the range values specified above.

By applying constant stress to these samples at room temperature of 80^0f, over triple sounding, their respective stress differentials against the number of individual load applications to failure states were recorded and plotted in a log envelop. A simple linear regression was then fitted to these data as vendored in Fig. 2.3. The results derived thereon are stated below:-

Group 1 Air voids between 2 – 5%

$= 4.252$

$N_f = 1.6531 \times 10^{12} = 1$

With regression coefficient R^2, Nf = 0.946

Group 2 Air voids between 5 – 10% $= 3.164$

$N_f = 1.255 \times 10^{11} = 1$

With regression coefficient R^2, Nf = 0.410

But the final regression analysis resulted to a coefficient of 0.317, given an Nf of 2.637 with a void ratio of 2.619.

These comparative results appear to agree with the works of earlier scholars such as Hudson (1977), Undalin (1982), Elkins (1985) and Meyer (1990), but that of Meyer (1995) which reported air voids of 2.110% seem most realistic because it has a higher inclination to the Dumex (1982) output, which favours a void content of somewhat 2-10% ceiling for Nigerian roads.

Table 2.2 Summary of Fatigue Test Experiment

MTS	Core No	Applied Stress	% air void	Number of Blow to fail	Testing Temperature
1-2	Pit 2 Core 2	11.668	3.7	Not fully crushed 80282	85°F
1-2	Pit 2 Core 1	17.503	4.0	31469	85°F
1-2	Pit 1 Core 4	23.335	4.7	19446	85°F
1-3	Pit 2 Core 2 No. 2	35	7.2	2546	85°F
1-3	Pit 2 Core 2 No. 1	40	6.5	2784	85°F
1-3	Pit 3 Core 1	29.171	7.3	38234	85°F
2-1	Pit 1 Core 3	25	9.8	1919	80°F
2-4	Pit 2 Core 2	35	8.5	27577	80°F
2-4	Pit 2 Core 3 PIT 2	30	9.4	45386	80°F
3-1	Core 1 No. 2	35	7.4	37803	80°F
3-1	PIT 2 Core 2	40	7.4	4904	80°F
3-1	PIT 2 Core 3	45	7.6	3846	80°F
3-1	PIT 1 Core 3 NO 1	40	4.0	856	81°F
4-2	PIT 1 Core 1 NO 1	45	3.7	442	81°F
5-4	PIT 2 Core 2	30	3.2	544	80°F
5-4	PIT 2 Core 4	35	8.2	857	80°F
5-4	PIT 2 Core 1	40	2.7	455	80°F
6-2	PIT 2 Core 1 NO 1	55.0	8.7	8831	80°F
6-3	PIT 1 Core 3	43.1	8.6	44348	80°F
6-3	PIT 1 Core 2	6.00	8.5	4006	80°F

Source: Summary of Fatigue Test Program on Lafia – Akwanga – Jos Road (Konig, 1995).

2.6 SUB-GRADE CELL PRESSURE AND CLIMATIC EFFECTS ON CARRIAGE WAY SURFACE DEFLECTIONS.

A preliminary attempt to predict the influence of sub-grade cell pressure on carriageway surface deflection in Nigeria was reported by the Federal Ministry of Works Triennial Technical Committee in 1995. The Agency's effort was aimed at finding a common solution to reported cases of surface deflections through comparative basin matching. The report noted a positive correlation of sub-grade with rates of surfaced deflections but further cautioned that three fundamental engineering properties of the pavement layers must be determined. These properties are the thickness, the poison's ratio, and the elastic moduli. Following this postulation, a route study was undertaken on Zaria - Kano Road by the Pavement Evaluation Unit (PEU, 1997) to determine if a relationship could be established to predict the influence of sub-grade modulus on identified five major deflection spots by using the dynaflect deflection device through basin matching procedure.

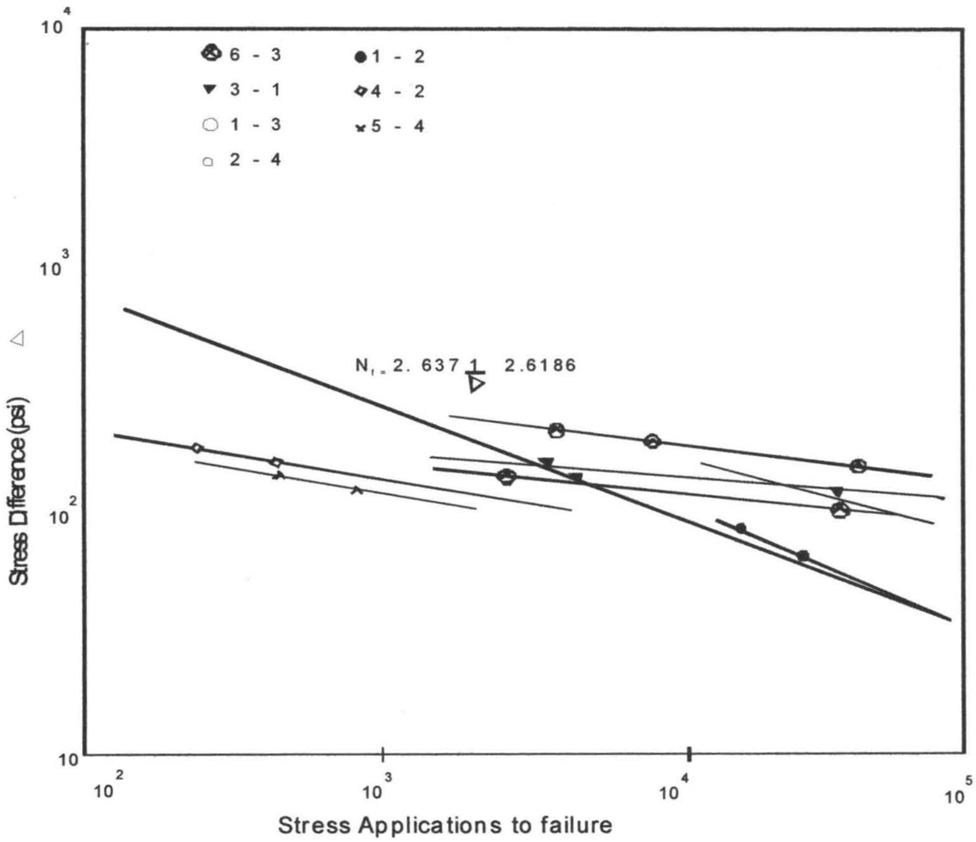


Fig 2.3 Stress Applications to failure for Cores From Master Test Sections

The study output reported that experience with basin matching of pavement structures in northern Nigeria as demonstrated by the PEU and other workers, previous research of Malomo, 1994, Teme (1996) and Braun (1995) yielded limited conclusions. The presence of a rigid bottom at reasonable depths below the pavement should therefore, be a fundamental consideration. This discovery led to the adoption of sub-grade depth probing as a major criterion in the design and maintenance of load bearing engineering facilities such as roads, housing and Dams in Nigeria.

However, the views of Atibu et al (1997) differ slightly from other workers reported above largely, due to environmental peculiarities. In his exclusive study on selected flexible pavement sections in Kenya, which was taken to represent tropical environment, he argued that sub-grade influence, alone is inadequate to describe pavements underperformance, unless they are accompanied by climatic considerations, which enhance distress features such as cracking, rutting, potholes, patching, etc. His finding further contended that flexible pavements deteriorate with repetitions of wheel load and axles, from significant number of commercial vehicles on the roads, which are often quite overloaded, thereby leading to premature pavement failures. This classical output which provided supporting data, and upon analysis proved that, as expected, higher pavement deflection levels were likely to be obtained during periods of high rainfall and high temperatures; in exhortation, the study further re-emphasized the need for rational climatic regime consideration.

In a strengthened effort, Pattie (1998) on impact of axle load study in Abidjan submitted that load distribution capacity of individual sub-base layers is a function of both their thickness and the mechanical stiffness of the materials in them. The overall thickness of the pavement as well as that of the individual layers according to him would depend on the traffic to be carried, the climate, the quality of the sub-grade and the mechanical properties of the materials in the pavement layers. But Writh and Paquette (1996) in their regional Highway administration study noted that differences between pavement engineering in developing countries and industrialized countries exist, apart from climatic differences. Contending that these differences are the greater variability in construction materials, quality of construction and the large fluctuations in the volume and weight of road traffic that are typically encountered in developing countries. In their opinion, a possible methodical design option was suggested for new flexible pavements, as classified below

1) Empirical and semi-empirical methods
2) Analytical or theoretical methods

Never the less, both empirical and semi-empirical methods are based on past experiences and may include laboratory or field tests of the sub- grade and pavement materials. The principle of these methods, include the California Bearing Ratio (CBR), the AASHTO method, Asphalt Institute Design Method, TRRL Roads notes 31 and the French CEBTP design manual, which have been devised specifically for pavements in tropical developing countries. The specification further stressed that the total thickness of a pavement and individual layer is related to the CBR-Values of the sub-grade for any particular wheel loads as shown in Fig 2.4 In infirmity, the Writh and Paquette (1996) study concluded that both the empirical and semi-empirical design methods for pavements are satisfactory, so long as the materials and conditions of loading for which they were developed do not change considerably. But they further cautioned that the analytical or theoretical method of design for flexible pavements, which are based upon certain laws of mechanics, will require a measurable knowledge of certain mechanical properties of the pavement and sub-grade materials such as the modulus of elasticity, poison's ratio, fatigue behaviour and permanent deformation characteristics. The views of Atibu (2000) differ slightly though, noting that the most influencing factor in the design of highway pavement is the soil type of the sub-grade. He further contended that in both the empirical and analytical methods of flexible pavement design, there are limiting design criteria such as:

1. Functional classification of the roadway being designed
2. Traffic volume and composition.
3. Design speed
4. Material properties

5. Topography
6. Cost and availability of funds
7. Size and performance characteristics of the vehicles that will use the facility.
8. Human sensory capabilities of drivers
9. Safety considerations
10. Social and environmental concerns.

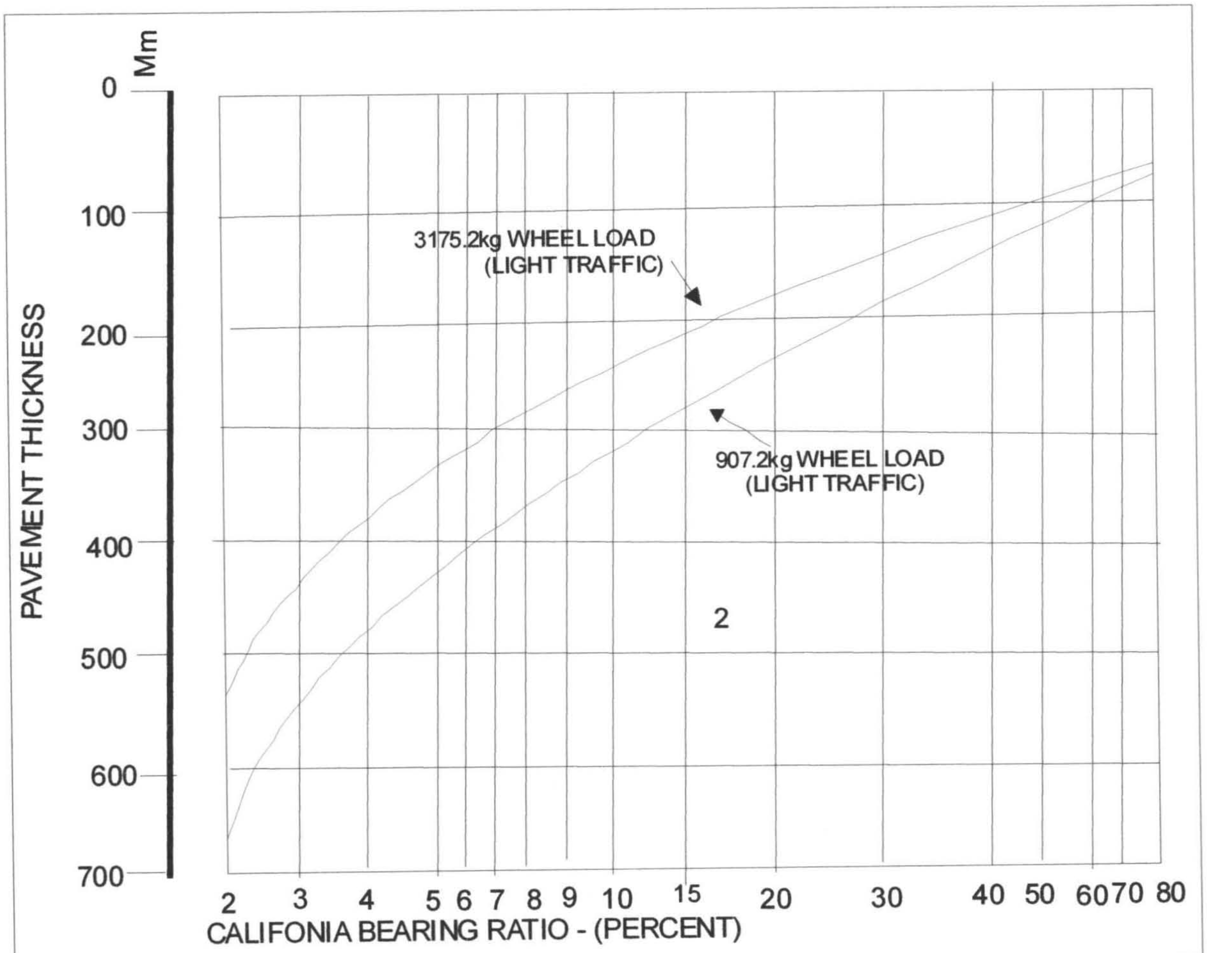


Fig2.4: SPECIFIC CBR VALUES PER PAVEMENT THICKNESS.

Source: Air Field Pavement Development and Design Department, USA (1999)

2.7 MATERIAL SPECIFICATIONS

Townsend et al (2001) carried out remarkable analyses of material specifications for roads in use in some African countries including Nigeria, using the two American specifications (AASHTO and the Army Corps of Engineers). Their findings noted that many pavement failures have resulted from indiscriminate use of latrites, through the adoption of specifications and classification systems developed for temperate climates.

Similar views were expressed by Mitchell (2002) and Sitar (2003) but they further added that on the basis of jurisdiction or level of governmental unit which has the overriding influence in the construction and operation of the policy system, highways should be classified into three classes of 1, II, and III, corresponding to heavy traffic, medium traffic and low traffic.In their opinion, these classifications as presented in Table 2.3 should constitute the basic criteria for appropriate base materials.

Table 2.3 Recommended Criteria for selection of Base Course materials (After Townsend et al, 1982).

	Road Classification			**Current FMW**
Criteria	**Class 1 (Heavy Traffic)**	**Class II (Medium Traffic)**	**Class III (Traffic)**	**(Low Specification)**
Design CBR	80 or 100 (minimum)	60 or 70 (minimum)	50 (minimum)	**80 (minimum 30 Sub-base)**
Liquid Limit (LL)	35 or 35	40 (maximum)		**25 (maximum 45 (sub-base)**
(LL) x (Z Passing 0.075mm)	600 (maximum)	900 (maximum)	1250 (Maximum)	**125-375 (for gravel base) 500-625 (for sandy base)**
Plasticity Index (PI)	10 or 15	(maximum)	-	**20 (maximum) 25 sub-base**
(PI) x (Z passing 0.075)	**350 minimum 350 – 400**	**500 maximum**		**100-300 (for gravel base) 400-500 (for sandy clay base)**

Source: Federal Ministry of Works (1995)

Fig. 2.4: SPECIFIC CBR VALUES PER PAVEMENT THICKNESS.

2.8 PAVEMENT PERFORMANCE IN TROPICAL ENVIRONMENT

At a time when carriageway failures were unprecedented in Africa, the University of Minnesota Centre for Transportation Studies (1989) undertook four levels of investigations to establish the structural behaviours of these flexible pavements under tropical conditions. Benkelman Deflection, Pavement Distortion, Pavement Cracks and Traffic load measurements constitute the candidate investigation components. The six roads selected for the experiment which are believed to represent tropical environment were the Thika Road (ES1), Langata Road (ES2), Belle Vue Road (E3), General motors Road (ES4), Ken chic Road and the KMC Rod (ES6).

The methods adopted in each case are described below:-

(a) Benkelman Deflection Measurements

Benkelman used deflection beams to determine elastic deflections by round deflection procedure (Gichaga, 1989). Tests were carried out on twenty marked test points on a 60 meter road section (using five cross-sections spaced at 15m equal intervals) and these points were used every time the test series was run. A test truck of 7 ton capacity was loaded to give a rear axle load of 6350kg and rear tyre pressures were set at 586 kN/m^2 and tyre size used was 900 x 20D. An Equivalent Standard Axle was taken as 8165kg (18000Ib).

(b) Pavement Distortion Measurements

Pavement settlement and rutting were determined by precise leveling at 1.8m straight edge respectively.

(c) Pavement Cracking Measurement

Pavement cracking investigation was achieved by measuring the length of visible surface cracks within a square meter enclosure at selected test points.

(d) **Traffic Load Studies**

These were carried out to establish an ADT (Average Daily Traffic), vehicle classification and axle loadings by manual counting and load meter readings respectively.

2.9 TYPES OF PAVEMENT FAILURES

Based on common carriageway failures, two broad types of pavement distress are universally recognized; these are structural and functional failures. While structural failures manifest in form of collapse within the components of pavement structure, at such magnitude that renders the road incapable of sustaining imposed loads upon it surface, functional failures on the other hand, may or may not be accompanied by structural failure but, manifests in a form that the discomfort and delays to passengers due to roughness and high stress on the pavement plane are experienced within affected across sections.

Obviously, the degree of distress on both categories is gradational and their severity is largely a matter of opinion of the observant. However, the difference between the two types of failures is important, such that Engineers and Scientists must be able to distinguish between them. A functional failure is said to have occurred if, for an example, the surface of a high trafficked pavement which received repeated maintenance as shown in Plates iv, may later develop rough spots as a result of breakdown in the bituminous-flexible overlay (functional failure) without structural failures of the overlay, perhaps due to either environmental factors or excessive axial loads.

Maintenance measure on the latter may consist of resurfacing to restore smooth riding quality on the pavement. But the structural type of failure may require a complete rebuilding or reconstruction of the road. The cause of either of these failure conditions may be three folds. Firstly, over loading, which includes excessive gross load, high repetitive loads and high type of traffic pressure could cause either structural or functional failure. Secondly, climatic or environmental conditions may cause surface irregularity and structural weakness to develop, e.g. frost, heaving, volumetric change of soil due to wetting or improper drainage. Thirdly, disintegration of the pavement materials due to ineffective operatives' strength of the geologic foundation may also cause shears in base course materials, thus generating fines, which may cause unstable mix. Sub-grades susceptible to unfavorable bed conditions or seism city and bad construction practices could also have pronounced effects on such short-lived carriageway system for example, raveling of the sub-grade during construction, which permits the accumulation of water and subsequent weakening of the sub-grade after practical completion of construction can also lead to pavement deterioration. In order to forestall undesirable degradation, routine inspection must be accompanied by strict evaluation and determination of discrete engineering properties of sub base to prevent structural collapse.

2.10 FACTORS OF PAVEMENT FAILURE

The following factors often act in concert to bring about pavement failures. They are:

1. Excessive loading
2. Environment
3. Rainfall
4. Temperature
5. Wind
6. Drainage condition
7. Properties of roadbed (Sub-grade)
8. Design

It is acknowledged in practice though, that difficulties are often found to exist in the establishment of a singular accounting attribute on carriageway failures. Elimination of other factors therefore, could lead to limited knowledge, as expressed in the major factors below.

2.10 i Excessive Loading:

Excessive traffic loading plays significant role in pavement failure particularly, if it exceeds the design specification of the pavement; such situation would precipitate gradual weakness of supporting layers, resulting in cracks, raveling, potholes development and ultimately, total collapse of the pavement structure.

2.10 ii Environment:

Large pavement surfaces are exposed to weather and traffic under the combined effects of temperature changes, rainfall intensity wind blows, freezing and thawing oxidation, sinkholes and proximitic mining; this scenario often shortens life-span of pavements, increase roughness, accelerate loosened materials on the surface and eventually destroys the pavement.

2.10 iii Rainfall

It is a well established factor that rainfall significantly accounts for the elevation of water table, erosive scours and infiltration. As runoff water infiltrates into base and sub-base, a reduction of supporting strength occurs. Also, when free water completely fills these layers, their voids and phreatic boundaries between inter-layers would be opened. Heavy wheel loads applied on such pavements could produce deleterious impacts comparable to water hammer type of action. The pulsating water pressure that builds up at such times under impacts does not only cause erosion but also strip asphalt from stabilized bituminous bases and sub-bases. The erosive action can also shear cement treated bases, weakens base course by disintegrating the external structure of grained materials in the aggregate mixtures over stressed sub-grades; where total thickness are inadequate. This action could also cause a number of other detrimental effects such as rutting, alligator cracks, spout gullies and accelerated shoulder wears.

2.10 iv Temperature:

This has a direct influence on the performance of the pavement and supporting base and sub-base course in both flexible and rigid pavements. Sudden temperature variations accompanied by fluctuations in soil moisture cause deformations in pavement system, which may result in cracking, spoiling or event he blow of some slabs. Low temperature on the other hand, causes soil shrinkage most especially in cohesive soils. This may be accompanied by cracks, which are filled with water resulting in decrease of the soil bearing capacity. It is the value of air temperature that actually determines to a large extent, the types and amount of bitumen that should be used on inflexible pavements. Also, the variation in temperature between the top and bottom surfaces of the pavements affects its deflection and the load bearing capacity.

2.10 v Wind:

The type of wind fetch contributes to the moisture evaporation from soil; it sets in motion in the form of waves which could erode embankments and earth shoulders. Winds causing sand-storms may also have severe effects on pavements if particle sand penetrates through the cracks or joints of the pavement; which could precipitate widening cracks and uncompromised expansion joints effects.

2.10 vi Drainage Condition:

Drainage plays significant roles in the performance integrity of carriageways because its exclusion from pavement design could precipitate premature failure of pavement systems thereby, resulting in life-cycle costs. Drainage problems are prevalent within low-lying ecosystem, clay dominant environment as well as reaches dominated by shale, marl and mudstone contents.

2.10 vii Properties of Roadbed Soil (Sub-Grade)

The paramount of sub-grade properties can best be understood from the objective of this study. Sub-grade properties are crucial to pavement performance because of their fundamental roles in supporting pavement by distributing imposed loads, providing drainage, and or minimizing heave action, cracks or erosion. Thus, naturally dense graded aggregates are noted for longer life-cycle function while the contrary leads to premature failures of paved asphaltic or cement system.

2.10 viii Design

Variability often occurs in other failure attributes discussed above though, but these variables could be managed and or controlled from a design philosophy. The variability assures that a sound design would necessarily have considered economic cost, thickness and type of sub-base materials, traffic profile, weathering and high performance life span.

This study therefore, aims at accessing major aspects of operative strength of the underlain materials otherwise known as sub-grade which bears the volumetric pressure and mechanical support for pavement overlay in the believe that,

1. So far as something is taken out of the natural environment, for purposes of either construction mining, agriculture, or water abstraction without planned compensation, real impacts would set in over time and
2. Most often, the natural sub-grade materials that bear carriageway overlays may exhibit weak properties in operative strength, which could precipitate road failure. But carriageway sub-grade system must neither fail nor degrade much within design lifecycle. If it does, then it becomes necessary to carry out investigation on failure indices, prior to recourse to the 4Rs operation, listed below.
   i. Resurfacing
   ii. Restoration
   iii. Rehabilitation
   iv. Reconstruction

The foregoing therefore, justifies the objective of the study, which seeks to establish a possible relationship between flexible pavement failure and sub-grade operative strength.

2.11 ANALYSIS OF STUDY OUTPUT

Based on procedural test evaluation as defined by the respective objectives above, the study output yielded the following clarifications:

i) That, Benkelman deflections alone would not be sufficient to describe the structural condition of a pavement structure because of the large variability of the deflection data. But, when deflection data are collected regularly over the same test points, it would be possible to detect from the onset of deterioration of the pavement when such measurements are accompanied with measurements of cracking, rutting and other visual condition features.

ii) Pavements deteriorate with repetitions of traffic loading and the rate of deterioration depends on various environmental factors and the pavement type. It is for example observed that although, ESI carried heavier traffic than SE2 but the ES2 truck deteriorated faster than ESI; the deterioration in this case may be considered to be a direct function of cracking and rutting and other distress features such as potholes and raveling; It was further observed; that the substantial fraction of commercial vehicles using the road sections tested were greatly overloaded, thereby causing early pavement failure. The control of axle loading on vehicles, which often is a major problem to enforcement officers in the tropic was advocated.

iii) The factors which are however, pertinent in describing tropical climate therefore, include temperature, rainfall, sunshine etc; an analysis of the results of the test series for ES1 gave the following relationships relating to rebound (elastic) deflection of the pavement and rainfall and air temperature.

a) Outside Lane (slow lane)

$d=32 +0.16r$; correlation coefficient =0.66

$d=11 +2.58t$; correlation coefficient =0.61

$d=5 +0.11r + 1.5t$; correlation coefficient =0.73

b) $d=21 +0.11r$ correlation coefficient =0.54

$d=3+1.48t$; correlation coefficient =0.42

$d=10+0.09r + 0.65t$; correlation coefficient =0.56 where,

d=3 point moving of average monthly mean elastic deflection (mm^2)

r=3 point moving average of monthly mean air temperature (^0X).

These expressions suggest that higher deflections, which would be associated with weakness, are likely to be obtained during months of high rainfall and high temperatures. Evidence supporting these observations indicates that during rainy seasons, most flexible pavements display severe distress features, which lead to pavement failure if they are not rectified.

The other factor, which was not described in detail in the study as observed by Amowai (1993) concerns the behaviours of materials used for road construction. In his thoughtful opinion, there is need to intensify the study of the characteristics of road construction materials in the tropic. Such studies according to him should be comprehensive, incorporating the effects of various elements that define tropical environment. Also, it should be both field and laboratory based. Designers should therefore, endeavour to carry out comprehensive investigations on sub-grade soils to ensure that the designed pavement structure is laid on a stable sub-grade or a sub-grade whose behaviour is well documented to help in maintaining the pavement structure at an acceptable level of serviceability.

2.12 SUB-GRADE MATERIALS EVALUATION

Prompted by widespread carriageway failure, an independent study by Agada et al (1995) was undertaken to investigate the characteristics of sub-grade materials at failure sites in South-Western Nigeria through laboratory and field base analyses.

These material indices are:-

- i Natural moisture content (NMC)
- ii Grain size analysis
- iii Atterberg limits (liquid and plastic limits)
- iv Proctor compaction test
- v California bearing ratio (CBR)

While the specific roads were:-

- a Ibadan- Ilorin Road
- b Oyo - Iseyin Road
- c Ibadan - Ife Road
- d Ife - Iilesha Road
- e Ilesha - Oshogbo Road
- f. Ibadan – Idiavunre Road
- g. Iwo – Ede Road

h. Ede – Oshogbo Road

i. Oshogbo – Ila Arangun Road

2.13 i STUDY OUTPUT

Output from the study is summarized in Tables 2.4 and 2.5 respectively. These summaries are further reviewed in section 2.7.ii.

Table 2.4 Points of Pavements Failures along Highways in part of Southwestern Nigeria

Table 2.0.5 Points of Pavements Failure Along Highways in Parts of Southwestern Nigeria

Highway	Site No	Km	Point of Failure	Failure Types
Ibadan - Ilorin	R1	10	Road cut	Heaving surface,
- do -	R2	11	Embankment	Rutting and/or
- do -	R3	23	- do -	Differential
- do -	R4	49	Plain	Settlement
- do -	R5	68	Embankment	
Oyo - Iseyin	R6	7	Valley	Pitting, shear
- do -	R7	11	- do -	failure and longi -
- do -	R8	20	Plain	tudinal crack
Ibadan - Ife	R9	35	Road cut	Shear failure
Ife - Ilesha	R10	10	Valley	Heaving
Ilesha - Oshogbo	R11	9	- do -	Pitting, Heaving
Ibadan - Idiayunre	R12	6	- do -	Shear failure
- do -	R13	9	Embankment	Rutting, Pitting
- do -	R14	8	- do -	
Iwo - Ede	R15	13	Road cut	Heaving
- do -	R16	15	Plain	Shear failure
- do -	R17	16	Plain	
Ede - Oshogbo	R18	10	Embankment	Distress
Oshogbo - Ilaorangun	R19	5	Road cut	Distress
- do -	R20	49	- do -	Shear failure

Source: Agada and Teme (1996)

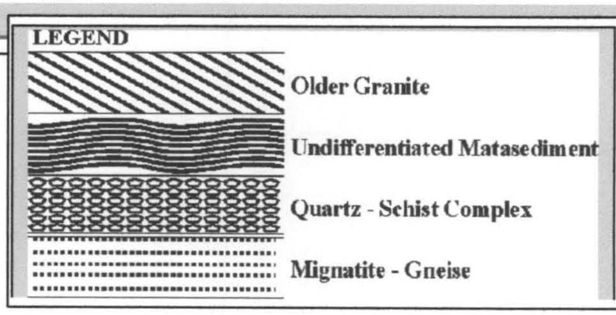
2.13 ii SUMMARY OF STUDY FINDINGS

Generally, materials of the AASHTO classification groups A-1-a, A-1-b, A-2-4, A-2-5 and A-3 were rated good sub-grade materials when properly drained and compacted under moderately thick pavements of the type suitable for the traffic to be carried, but the competence of clayey granular materials like A-2-6 and A-2-7 which range from fair to poor in Table 2.6. were questionable Pertinently, as observed in Table 2.6, most of the sub-grade materials investigated in the study area were relatively good, yet progressive failures were recorded.

Table 2.5 Classification of Highway sub-grade Materials Used in Parts of Southwestern Nigeria

Location	Sample No	Z 10	Passing 40	200	Atterberg Limits LL	P1	SOIL Class AASHTO	USC	CBR (Z) Unsoaked	Soaked	Z Free Swell	Geology	Rating as Subgrade
Ibadan-to-Ilorin	R1	57	19	5	45	8	A-2-5(0)	SM	180	48	0.09		Good
	R2	60	26	4	25	13	A-2-6(0)	SC	77	58	0.260		Fair
	R3	70	28	5	27	12	A-1-6(5)	SC	155	37	0.98		Poor
	R4	66	27	4	6	2	A-1-b(14)	SM	130	104	0.024		Excellent
	R5	79	21	3	17	5	A-1-b(12)	SM	154	40	0.055		- do -
Oyo-Iseyin	R6	55	11	1	23	2	A-1-b(12)	SM	110	8	Negligible		- do -
	R7	94	31	4	9	4	A-1-b(13)	SM	100	7	-do-		- do
Oyo-Iseyin	R8	77	35	6	19	6	A-1-b(10)	SM	131	7	-do-		- do -
Ibadan-Ife	R9	59	25	6	49	18	A-2-7(0)	SM/SC	61	4	0.64		Poor
Ife-Ilesha	R10	57	21	5	50	15	A-2-7(0)	SM/SC	22	6	0.35		- do -
Ilesha Oshogbo	R11	76	46	12	41	17	A-2-7(0)	SC	36	7	0.78		- do -
Ibadan-Idiayunre	R12	71	33	9	24	17	A-2-6(0)	SC	39	5	0.66		Fair
	R13	69	25	2	17	9	A-2-4(0)	SM	83	5	0.15		V.Good
	R14	74	29	5	24	17	A-2-6(0)	SC	76	6	0.53		Fair
Iwo-Ede	R15	67	30	6	22	17	A-2-6(0)	SC	97	64	0.81		Fair
	R16	51	14	1	24	1	A-2-b(0)	SM	93	57	0.008		Excellent
	R17	52	15	1	20	8	A-2-4(0)	SM					V. Good
Ede-Oshogbo	R18	66	26	4	7	3	A-1-4(0)	SW	89	56	0.08		Excellent
Oshogbo-Ilorunga	R19	76	44	13	74	12	A-2-6(0)	SC	149	134	2.60		Poor
	R20	68	31	5	19	5	A-2-b(0)	SW	87	45	Negilible		Excellent

Source: Agada and Teme (1996)



These failures may have been occasioned to an extent by the local geology of the area over which the pavements were built. The study opined that, for a meaningful correlation between geology and pavement performance rating, it is logical for materials from road cuts and plains to be investigated since these are exsitu, which explains in part, why only samples from sites R1, R4, R6, R7, R8, R9, R10, R11, R12, E15, R17, R19, and R20 were considered as reported in Tables 2.0.5-6. Similarly, at road cuts, it was observed that weathering intensity decreased with depth, perhaps, due to exposure, thus giving rise to three main horizons – laterite, mottled and pallid zones (Gidiasu 1975, 1976). It was also noted that in the study area, road failure occurrences were more rampant when the roads rested directly on the friable, incoherent materials of the mottled and pallid zones.

However, from Tables 2.4 and Table 2.5, it is logical to assume that road failures cannot be ascribed to one particular rock type or geological formation but more failures tend to occur over metamorphic terrains than over igneous terrains in the study area. In the other roads, pavement failures were mostly located near less capacity culverts and relatively thin embankments, resulting to poor drainage. Almost over 60% of all failures were observed to have occurred on embankments. Materials from these embankments were found to be generally good; hence the pavement failures could probably have resulted from compaction inadequacy, violent haulage loads or inadequate drainage facilities.

Based on these study notes, the following ameliorative suggestions were made.

(i) That, in order to arrest the high rate of pavement failures in the study area, both short and long -term solutions are required. For short term solutions, proper maintenance programmes in form of constructing suitable overlays, and periodically clearing verges and shoulders for adequate drainage were advocated.

(ii) It was also thought that, much attention should be paid to the compaction of embankment materials and more studies should be directed at the suitability of materials for embankment construction. Irrespective of rock type, roads in the tropical zones should be confined to the highly laterised horizons (if available at site) for good pavement performance or in the alternative, stabilization of the materials may be necessary, since it is often difficult to forecast future traffic volumes and hence changes in vehicle loading, especially, in developing countries.

(iii) The issue of buoyant design should also be viewed with necessity to accommodate some inestimable misuses during pavement projected life by adopting a generous "safety factor". Design limitation should come under legislation, for enforcement.

(iv) Regulations enforcement was also viewed with concern, noting that vehicles heavier than those, for which particular roads have been designed, should be prevented from using such roads. In the alternative, heavy tolls imposition on heavier –than – normal vehicles were advocated so that constant maintenance programmes can be carried out as soon as deterioration road sets in.

2.14 INDIGENOUS CHALLENGE

Following extensive field observations, the Nigerian Petroleum Trust Fund Report of 1991 indicated that measurable carriageway stability within design life cycle was nowhere assured in Nigeria. On the contrary, however, Forstad (1992) and Clarke (1995) submitted that the degrees of polarized carriageway efficiency as typified by the Nigerian experience were normal engineering challenges in countries under economic transition. These short-lived conditions as noted by the latter was validated by studies of the Minnesota's Centre for Transportation (1989) and Wright (1997) in the Kenyan circumstance and Breech (1998), in the Ghana and Nigeria's events.

Burdened by perennial carriageway imperfections on Nigeria's carriageways systems, the Ministry of Transportation (2005) carried out a comprehensive study on carriageway failure within Km 0 + 000 – km 80 + 000 on Kaduna – Abuja dual carriageway and Kano Jigawa arteries. A summary of output endeavor is discussed heretofore, while their engineering index, as reported by the study is summarized in Tables 2.0.7 and 2.0.8 respectively.

These Tables reflect the range of values of important engineering properties of the lateritic soils encountered in the upper layers of the sub-grade mantle or fills within the failed sections.

Table 2.6 **Range of Important Engineering Properties of Sub-Grade (Upper Layers) Failed Sections.**

S/N	ENGINEERING PROPERTIES	RANGE OF VALUE	REMARKS
1	Percentage passing BS Sieve No.200	27 – 66	Specification requirement was not met in 12 out of the 13 locations tested – They are generally either too fine clayey or silty to poor soils.
2	Liquid Limit %	45 – 55	Specification requirements were met in 8 out of the 13 locations tested; they are adjudged fair soils.
3	Plasticity Index %	17 – 32	Specification requirements were met in 9 out of the 13 locations tested, and as such, adjudged fair, though.
4	Group Index	0 – 17	8 out of the 13 locations tested have group indices greater than 4, which are rated as poor (.1 5–9) and very poor (G.I. 10–20) for sub-grade/filling.
5	CBR %	5 – 7	Specification is silent on CBR but values of 5 – 7% are acceptable.
6	Relative Compaction %	90 – 93	Specification requirements were not met in all the 5 locations tested. They are thus rated poor.
7.	MC above optimum	4.2 – 10.1	Observed in the 5 locations tested, i.e. CH 19 + 715LHS, CH 30 + 590RHS, CH 36 + 200RHS, CH 42 + 375 RHS, CH 49 + 620 RHS.
8	AASHTO Class		A-2-7, A-6, A-7-5, A-7-6

Source: Ministry of Transportation, 2006

From Table 2.6, it is observed that although, the sub-grade or fill soils encountered fulfilled the specification requirements for liquid limits for economic values and plasticity indices at most locations but, their particles are too fine, considering the proportion passing BS sieve No. 200 which is greater than 35%. They constitute mainly of A-7-5 and A-7-6 AASHTO classification group with high group indices that are predominantly clayey. These soils often undergo extreme high volumetric changes upon entry and withdrawal of water (swelling and shrinkage characteristics). Excess moisture content (moisture content above optimum) was also observed at all the five locations investigated. These phenomena were thought to have triggered off early distresses such as cracks, base shear, rutting and other defects on the pavement surface and other layers.

2.15 SUMMARIZED RESULTS OF LATERITE SUB-GRADE SOILS AT LOWER LAYERS

Table 2.7 below is an indication of the range of values of important engineering properties of the lateritic soils encountered in the lower layers of the sub-grade fills of the failed sections as extracted from the summary.

Table 2.7 **Strength Properties Index Ratings**

S/N	Engineering Properties	Range of Values	Remarks
1	Percentage passing BS Sieve No.200	10 – 76	**Specification requirement was not met in 27 out of the 32 samples tested – generally, too fine clayey/silty soil its rating is considered Poor.**
2	Liquid Limit %	NP – 54	**Specification requirements were met in 24 out of the 32 l samples tested. Its adjudged a Fair rating**
3	Plasticity Index %	NP – 32	**Specification requirements were met in 29 out of the 32 samples tested. fair rating**
4	Group Index	0 – 17	**21 out of the 32 locations tested have group index greater than 4 which are rated as poor (gl 5 – 9) and very poor (g.i. 10 – 20) for sub-grade/filling.**
5	AASHTO Class		A-1b, A-2-4, A-2-6, A-2-7, A-4, A-6, A-7-5, A-7-6

Source: Ministry of Transportation, 2006

2.16 STABLE SECTIONS OF ASPHALTIC WEARING COURSE

Table 2.8 below indicates the range of values of important engineering properties of the asphaltic wearing course in the Stable Sections extracted from the summary. The Table (2.9) indicates that major engineering indices such as wearing course thickness, stability, viscosity, bitumen ratio as well as asphaltic concrete strength satisfied standard requirements, which explains in part, why these sections present serviceability index was affirmed. The defects encountered on air voids could be considered as a minor attribute, which could be possibly corrected at early stages. However, the CBR portraits as revealed by Table 2.10 clearly points to the fact that when moisture conditions are not regulated the expected lifecycle of the pavement will drop appreciably, the CBR values would also be lowered accordingly, which could precipitate early failure incidence.

Table 2.8 **Void Vs Asphalt Concrete Mixture**

S/N	Engineering Properties	Range of Values	Remarks
1	Thickness, mm	36 – 48	**Wearing thickness requirement was met in all the 3 locations tested, considering shortfall of 6mm and also very high binder thickness at CH. 91 + 150RHS. PSI is rated good.**
2	Air voids, %	7.0 – 8.5	**The specification was not met in the 2 locations tested. The PSI is rated poor.**
3	Stability, Kg	457 – 681	**The Specification was met in the 3 locations tested and thus rated a good PSI**
4	Flow, mm	3 – 5	**The specification was met in 3 locations tested. the 5 index is rated good.**
5	Bitumen Content %	5.2 – 6.2	**The specification was met in all the 4 locations tested. Ok**
6	AC Aggregates Grading		**Aggregates Grading within the specification envelop in 3 out of the 4 locations tested good.**

Source: Ministry of Transportation. 2005

2.17 Material Specifications in Some West African Countries

The specification for base materials being followed in some West African countries as reported in an engineering study titled "Laterite and Lateritic soil of African" by the Agency for International Development in 1998, are given in Table 2.10 below.

Table 2.9 **CBR Requirements**

CBR VALUES			
Road	**At OMC**	**1% below OMC**	**2% below OMC**
Jigawa Jahun	56	106	**128**
Gwaram Basirka	65	126	**150**
Rano Ruram	58	118	**142**
Karaiye Rogo	**74**	**113**	**133**

Source: Ministry of Transportation 2005

The level of acceptability of these specifications varies from country to country though. While the minimum CBR mostly adopted varies from 50 to 85%, the upper limits of plasticity index and percentage passing No. 200 BS sieve are 25 and 30% respectively. The general nature of these base materials specifications cast doubt on its adoption, bearing the heterogenic nature of African soils. Rather, a better envelop as reported by the Nigeria Pavement Evaluation Unit (2005) would be ideal.

Table 2.10 Base Materials Specifications in Some West African Countries

Country	Soaked CBR	L.L	P.I
Republic of Malawi	85	30 min	**6 min**
Republic of Niger	80 min	-	**12 max**
Mali	50	-	**6 – 16**
Ivory Coast	60	-	**12**
Cameroon	80	-	**1 – 25**
Gabon	**60 min**	-	**20 max**

Source: Agency for International Development (1998)

However, Godwin (1998) in his study on long lasting highway pavement in Louisiana, USA contrasts to the West African submission, contesting that, contemporary pavement design should be based on procedures recommended by the American Association of State Highway and Transportation Officials (AASHTO) Design Guide. In his opinion, such pavements, which are typically designed for a 20-year period, should be reviewed for a 50 year service period. The 50-year period according to his report is considered a realistic length of service, in view of fundamental advantages such as serviceability index and lesser maintenance cost, lesser project budget and troubling efforts in generating baseline data for design and projected traffic profile. However, Tsidzi (1990) in support of this version cautioned that, even if such design would require initial higher cost of implementation, sustainable lifecycle remains a fundamental criterion for pavement design stressing but that Highway Engineers should not lose sight of other service parameters such as:

- Thickness of the various pavement layers
- Quality of construction materials and dedicated supervision
- Drainage
- Maintenance practice, including the type and timing of maintenance actions.
- Properties of roadbed soil (Sub-grade).
- Environmental consideration, such as rainfall and temperature
- Number and weight of axle loads to which the pavement is subjected.

2.18 PAVEMENT INTEGRITY ASSESSMENT CRITERIA

Decker (1995) on the other hand, reported various parameters that could be employed in the evaluation of pavement performance, listing tyre pressure of commercial vehicles, wheel or axle configuration, temperatures and sub-grade indices as fundamental. The report further added that structural conditions of a pavement may also be assessed by measuring surface cracking, permanent deformation, transient surface deflection and curvature. In agreement with Decker's study (1995) Godwin (1998), further advocated for the rating system developed by AASHTO, which involves measurements of permanent deformation, riding quality and the extent of cracking and patching. This system known as the Serviceability Concept, in his opinion gives a measure of the present state of fitness of a pavement to carry traffic comfortably, safely and economically. The present serviceability index expression in the form of equation is given thus below:

$P_{S1} - 5.03 - 1.91 \log (1+SV) - 0.01 (C+P)^{12} - 1.38 (RD)^2$

Where: P = Present serviceability Index (PSI%)

SV = Mean slope variance in both wheel paths (i.e. riding quality %)

C + P = Cracking and patching (Per $30.48m^2$ of surface area)

The report noted that an initial value of P for flexible pavement is $4.2m^2$ and is considered necessary for repairs if the PS1 drops to about 2.2%. Riding comfort, cracking, patching and rutting in wheel paths (asphalt bleeding) are advocated as indices of pavement performance in this study. It is however, opined that a rut depth of about 20mm in pavement should be adjudged a failed pavement.

2.19 CONCLUDING SUMMARY

a. It would be noted from major details in Chapter Two that not much of the reviewed works directly related to the Zuba- Gwagwalada case study, perhaps due to differences in environmental conditions but it has undoubtedly, enhanced further understanding on problems of short-lived carriageways, which shall be used to formulate methodical activities.

b. A major problem which still limits scientists' full understanding of carriageway underperformance study in the tropics is that of consensus on methodology, which informs the current harmonic trials being carried out by the Roads Maintenance Agencies and Captains in the industry, as reported by Mannion (1989), Pigeon (1991). Aborewa (2001), Papacosta (2004) and Annettee (2006).

The foregoing therefore, probably suggests why each methodical process was fashioned towards specific subject interest. For example, while Breen (1977) suggested void content, Towsend and Konig (1995) favour materials specifications. Decker and Konig (2000) on the other hand, postulated the deflection and structural conditions method for heave deferential problems. However, the works of Ofomota (1989) and the Kenya scenario by the Minnesota Centre for Transportation (1989) on one hand, and Malomo (1992), Teme (1999), Adegoke (2000) and the Federal Transportation Agency (2002) on the other hand, which independently applied bore logging methods would seem closely applicable to the Zuba - Gwagwalada case study. This study shall therefore, take similar precedence but with cognizance of geographic inclination, because environmental development planning and management discipline constitutes the first order basis for the study.

CHAPTER THREE

MATERIALS AND METHODS

3.1 INTRODUCTION

Methodology sets out to specify or list procedures as well as required scope of activities that will lead to output. The various studies by past workers as reviewed in Chapter Two have undoubtedly enriched understanding on approaches to adopt for this study. However, it is necessary to emphasize that investigating case studies such as pavement failure and sub-grade strength performance analysis would require various approaches because of scholarly discipline, knowledge of scope of works, local circumstance and objective(s) assigned to the study. But one fact stands out clear from the literatures reviewed in Chapter Two; that is, the inescapable role of both physical (field) sampling and analytical laboratory exercises. Because many aspects of the processes have not yet attained evolutionary finality in Africa, many scientists depend on both environmental and engineering indices of sub-grade strength to design, explain and sustainably manage civil structures such as carriageways, which explains why a broad-based approach as depicted in Fig 3.1 was adopted. The broad base approach is a simple but logical mixed grill of field conditions survey and laboratory analyses of geotechnical materials, they are believed to define more appropriately the basic procedural framework that could offer realistic clues to premature carriageway failure rather than logarithymitic synthesis.

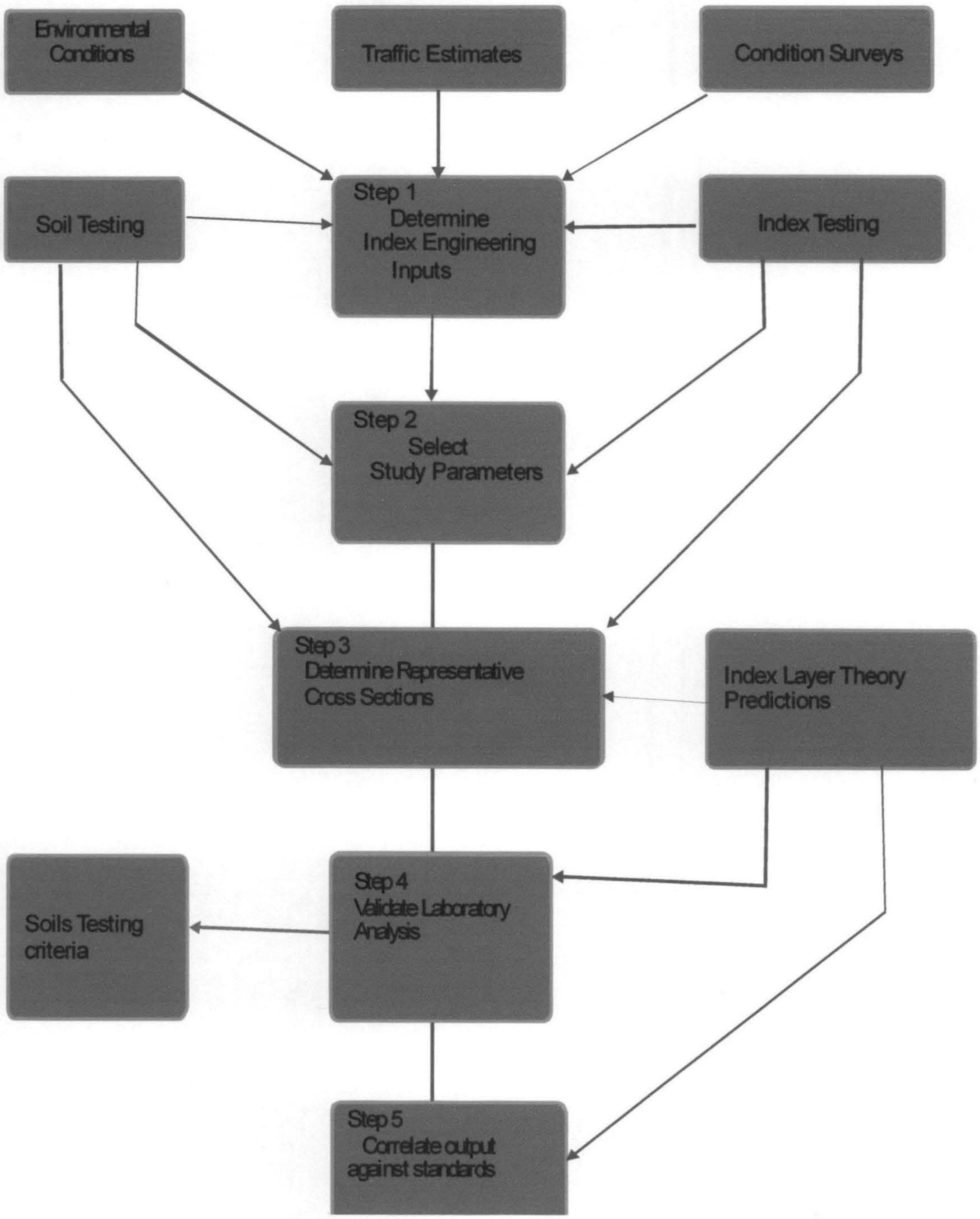


Fig. 3.1 **Data Requirement Flowchart**

Adapted from Texas (2001) Research and Development Foundation

3.2 DATA SOURCES

In recognition of main and broad objectives of the study and the need to accomplish procedural tasks noted in section 3.1, both primary and secondary data were sourced involving three levels of activities at prior, during and post field endeavours, as described below. These procedures were further guided by determinants of exsitu soil parameters such as its nature, previous history, drainage conditions, form of construction as well as traffic stream and loading.

3.3 PRIMARY DATA

Acquisition of GIS data set, quadrants and thematic maps synthesis, literature reviews and work plan (programme) formed the basis for study start-up activities. However, in order to develop acquaintance with the physical setting, the former was preceded with a reconnaissance survey. This latter exercise was repeated twice to assure familiarity with details on both local environmental conditions and major failure spots. The basis was to also enhance field equipment requirements, listed under section 3.2 as well as exsitu log specifications.

3.4 MATERIALS

The set of major instruments and materials listed below were used for field operations; while laboratory procedure adopted are discussed under section 3.5

1. Manual auger borer
2. Light mechanical drill
3. CORIM T. VLF List
4. Munsel Colour chart
5. GPS
6. Dutch cone penetrometer
7. Sample boxes/tools for collecting disturbed and undisturbed samples
8. SAS 300B ABEM Terrammeter
9. SAS 300E ABEM Terrammeter

10. Measuring tape
11. Digital Camera
12. Polythene Skirts
13. Shovel/Trovel
14. Safety Tools and Helmets
15. Thematic Maps

3. 5. SECONDARY DATA

Based on pre-field reconnaissance experience, consultations were extensively made with the sources listed below, much of which is cited under acknowledgement:

1. Periodic Articles
2. Subject books
3. Encyclopedias
4. Reference Journals/books
5. Government document/gazettes
6. Online data base
7. Thematic Maps
8. Personal contacts
9. Subject Experts/Organisations.

3.6 SAMPLING FRAMEWORK

Much of the pertinent environmental factors which could possibly impact on carriageway integrity have been generally outlined in chapter one, under, section 1.6 and thus need not be necessarily repeated here, but only those attributes that are generally considered likely impacts within local environment as listed hereunder.

3.7 ENVIRONMENTAL DATA

i. Climate

ii Groundwater table

iii Flood

iv Mud flow

v Drainage

vi Slope

vii Sink holes

viii Streams

ix Proximitic mining

3.8 TRAFFIC DATA

The statistical method was adopted for traffic census. Its summarized statistical results in Table 4.2 were entered into standard form A1 classified traffic format (Appendix 3.1), obtained from the Federal Highways Department of the Transportation Ministry. The process was continuously maintained for a period of fourteen hours (14hrs) for 7 days (July 3 – 10, 2007). Each day was complemented by a 2-man staff who had acquired the National Diploma Certificate in Maths/Statistics from the Polytechnic. The essence of the complementary staff was to ensure continuity, in case of fatigue which could cause error of oversight.

The sum of daily average traffic was obtained by adding the sum of all the enumerated class of vehicles and dividing the derived value by 7 that is, number of days per week) as mathematically expressed hereunder.

$$PCU/Day = \frac{Tv}{DW_7}$$

Where:

PCU/Day = Passenger Car Unit/Day

Tv = Sum of Average Daily Traffic (Total volume)

DW_7 = No of days/per week

N

Results derived from this exercise are summarized in Table 4.2 and supported by graphical illustration in Fig 4.1. This Table should actually display a seventh row which would include motorcycles or auto-cycles, but only items on rows 1-6 comprising of commercial vehicles were considered because the former has no significant effect on carriageway system design.

3.9 SAMPLING FRAMEWORK

The field investigation listing was strictly guided by both the study objectives and the British code of Engineering practice CP 2001; where applicable however, the General Specification, Vol. II of the Federal Ministry of Works was adopted. The entire exercise consisted of marked 26 profile locations for light mechanical auger drilling, within 3.3m depth over 19.3km lateral distance at approximately 25m setback from the route alignment center line. However, after detailed consultations with the project major supervisor, 18 out of these 26 spatially marked profiles were actually selected for final presentation and laboratory analyses, as specified in Table 3.1. The philosophy was purely based on Present Serviceability Index (PSI) of the carriageway system and active failed cross sections. The procedure described above varied at some locations though, because of the need to strike or attain the sub-grade mantle or water table, which is the basis for the study. Exsitu samples of approximate equal volumes were taken from representative profiles at random as typified in Plates ix-x.

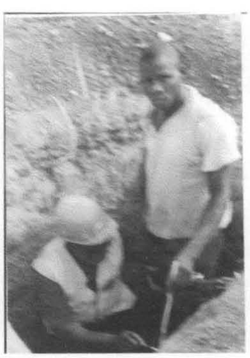


Plate ix **Quadrant Exsitu Sampling**

Source: Author's Field work, Zuba – Gwagwalada carriageway, 2007

Plate x **Quadrant Exsitu Sampling**

Source: Author's Field work, Zuba – Gwagwalada carriageway, 2007

3.10 TRAFFIC LOAD ALONG ZUBA GWAGWALADA ROAD

Traffic profile in terms of axial loads, volume and frequency is central to stress changes and ageing effects on carriageway system. The determination of profile influence could help in part, to establish reasonable estimate of the likely causes of surface failures such as cracking, rutting, bleeding, peeling, alligator cracks and potholes.

There was neither consistent available traffic data for the Zuba – Gwagwalada area, nor from the Federal Capital Territory Administrative Office or from the Federal Transportation Agency. In the absence of these base line data, existing vehicular traffic along the road was enumerated based on a seven-day, fourteen hour traffic count on the road at the Airport Junction of Giri Gauta in Gwagwalada between 19 October 2007 and 26 October 2007.

In each case, these samples were tightly secured in double polythene skirts and transported to the laboratory in bulked manner. Finally, they were scaled down to sub samples by quartering for purposes of referral analyses as specified by respective engineering index evaluation.

Table 3.1 Route Specifications and Sample Collection

Change (km)	TBM	Coordinates		Evaluation	Remarks
		Easting	Northing		
1+200	AP54	303,546.335	1,004253.544	350.341	COE ZUBA
3+500	AP50	302,445.777	1,001,942.075	331.800	TP2 Within Tunga Maje
6+350	AP44	300,760.686	999,546.001	229.400	TP3 Observable drainage line
8+400	AP41	299,283.595	998,303.086	291.704	TP4 Widespread sand minning
10+250	AP36	297,796.221	997,039.084	252.535	TP5
11+190	AP34	297,338.252	996,524.601	259,197	TP6 at Giri Junction Gwako
12+150	AP64	296,808.780	995422.853	240.035	TP6 at Gwako notable sinkhole +culverts
17+500	AP73	293,743.425	990,952.007	313.199	TP8 at Uni Abuja staff quarters
19+300	AP76	292,309.694	989,998.874	240.035	TP9 and study at Gir Tsauni

Source: Author's fieldwork 2007

3.11 METHOD OF DATA ANALYSIS

INTRODUCTION

Confirmatory laboratory analyses for the selected engineering properties, as generated from the field were conducted in accordance with the Federal Ministry of Transportation procedure and the British standard specifications BS 1377 "Methods of testing soils for civil engineering purposes".

In this study, the emphasis is on local environment, traffic stream and operative strength of the sub-grade materials. The inescapable laboratory parameters investigated include, sieve analysis, Atterberg limit test, compaction test and California Bearing Ratio (CBR) test. The apparatus and procedures used for the analytical work are described in section 3.8 – 3.1.4.

3.12 LABORATORY METHODS

Followed by physical inspections of the samples, confirmatory classification tests were carried out in the laboratory, according to the British standard specifications BS 1377 "Methods of testing soils for civil engineering purposes". The key parameters investigated are listed below: While their results are summarized in Table 4.3.

1. Grain size (sieve) analysis
2. Atterberg Limits
3. Compaction
4. California Bearing Ratio (CBR)

3.13 SIEVE ANALYSIS

Aim: To determine the grain-size of the soil samples.

Apparatus: This includes, ten sieve sizes in the order of 5.0mm; 3.35mm; 2.0mm; 1.18mm; 0.85mm; 0.6mm; 0.425mm; 0.3mm; 0.150mm; a sieve shaker, wire brush and electronic weighing machine.

Procedure: The soil samples were oven dried and 200g of each sample was collected and soaked in water for 24 hours for effective flocculation into individual particles. Thereafter, the soaked samples were washed through sieve size 0.075mm to remove the silt and clay-sized particles. The part of the soil samples retained on the sieve was oven dried and weighed and the difference in weight was recorded.

The sieves were brushed carefully to remove any stalked particle and each of the sieves was weighed including the pan. They were then arranged from top to bottom in order of decreasing sieve size, with sieve 5.0mm at the top and the pan at the bottom. The remaining dry soil sample was poured into the top of the stack of sieves and was covered and mounted on an electronic sieve shaker. The sieve shaker was then allowed to vibrate the stack of sieves for about 10 minutes to ensure proper particle distribution. After that, each of the sieves and the retained particles were weighed and recorded accordingly in standard sheet in Appendix 4.1. The exercise was preceded with graphical plotting against respective results which yielded defined envelop in Fig. 4. 6 – 4.9.

3.14 ATTERBERG LIMITS TEST

The liquid limit test using the Cone Penetrometer method and plastic limit tests formed the major tests conducted on moisture thresholds.

Aim: To provide the basis for determining the liquid, plastic limits as well as information on plasticity index.

3.15 LIQUID LIMIT TEST

Apparatus: A flat glass plate (with a convenient size of 10mm thick, 500mm square); two palette knives (a convenient size is on having a blade 200mm long and 300mm wide); a Penetrometer with a cone of stainless steel approximately 35mm long, with a smooth, polished surface and an angle of $30+1^0$; a metal cup approximately 55mm diameter and 40mm deep with the rim parallel to the flat base; an evaporating dish (about 150mm diameter); a wash bottle or a beaker, containing distilled water; an airtight container.

Procedure: The sample taken from dried soil material passing the 0.425mm sieve then placed on the flat glass and mixed thoroughly with distilled water, using the palette knives until the mass formed a thick homogenous paste. The paste was then allowed to stand in airtight container for about 24 hours to allow the water permeate throughout the soil mass. The sample was then removed from the container and remixed for about 10 minutes. The remixed soil was struck off, to give a smooth surface. The cone was then lowered so that it just touched the surface of the soil. When the cone was in the correct position, a slight movement of the cup marked the surface of the soil and the reading of the dial gauge was noted to the nearest 0.1mm. The cone was then released for a period of about 5 seconds. Afterwards, the cone was locked in position; the dial gauge was once more lowered to the new position of the cones shaft and the reading noted to the nearest 0.1mm. The moisture content of the sample at each penetration was obtained by weighing the wet sample, oven-drying it and reweighing. The difference between the weight of the wet-sample + container and dry-sample + container was recorded as the moisture content. A graph of penetration against moisture content was plotted and the moisture content at 20mm penetration was taken as the liquid limit, in Table 4.4.

3.16 PLASTIC LIMIT TEST

Apparatus: A flat glass plate, two palette knives, apparatus for the moisture content determination of fine grained soils, a length of metal rod 3mm in diameter and about 100mm long.

A sample of about 20g was taken from material passing 0.425mm sieve was obtained. The air dried soil sample was thoroughly mixed with distilled water on the glass plate until it became homogenous and plastic enough to be shaped into a ball. The ball of soil was molded between the fingers and rolled between the palms of the hands until the heat of the hands dried the soil sufficiently and slight cracks appeared on the surface. From this sample, two sub-samples of about 10g each were weighed while separate determination was carried out on each. The soil was formed into a thread of about 6mm in diameter, between the first finger and the thumb of each hand. The thread was then rolled between the tips of the fingers of one hand and the surface of the glass plate. At this point, the moisture content of each sub-sample was obtained and their average was interpreted as the plastic limit, as vendored in Appendix 3.3.

3.17 COMPACTION TEST

Aim: To establish clues on Maximum Dry Density (MDD) and optimum moisture content under ideal field condition.

Apparatus: A cylindrical metal mould (with internal diameter of 150mm, internal effective height of 115.5mm and volume of 1000cm^3), 4.5kg metal rammer (diameter 50mm), electronic weighing balance (readable and accurate to 1g), a palette knife, a large metal tray of a straight edge.

Procedure: The soil sample was air-dried and about 6kg of soil was obtained from it and was placed on the metal tray. This sample was then mixed thoroughly with water of about 10% of the sample weight. The mould with base plate was weighed to the nearest 1g. The mould was then placed on concrete floor and the moist soil sample was compacted into the mould, with the extension attached. The soil was later compacted in five layers. Each layer received 25 blows were uniformly distributed over the surface of soil sample. The soil was later trimmed at the top of the mould, using the straight edge and subsequently weighed. To determine the wet bulk density. The moisture content of the soil sample was determined and the dry density was then calculated. This procedure was repeated over successively by adding four. After the variable test, details of dry density were plotted against moisture content, to determine the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC) in Appendix 3.5.

3.18 CALIFORNIA BEARING RATIO (CBR) TEST

Aim: To obtain an estimate of the sub-grade strength by measuring the relationship between load and penetration on the soil, using a CBR machine.

Apparatus: A cylindrical mould (150mm diameter) with a base plate, a collar, a loading frame, a 50mm diameter plunger, proving ring, dial gauges and 147mm diameter surcharge weight.

Procedure: The soil sample was prepared to be at its optimum moisture content and was carefully compacted in the mould. Surcharge weight was placed in position on the top of the soil sample in the mould to prevent heaving up of the soil while the plunger penetrates into the soil sample. The plunger was then brought in contact with the soil sample and readings on the proving ring dial and other dials were set at zero. The plunger was then made to penetrate through the soil sample at the rate of 1.25mm per minute. The pressure applied and the corresponding penetrations were recorded in standard format in Appendix 3.5 while its graphical envelop is illustrated in Fig 4.12.

Details of all tiers of investigation are summarized and discussed in chapter four.

CHAPTER FOUR

RESULTS

4.1 INTRODUCTION

This chapter is the heart of the study and thus presents results of the various levels of activities undertaken, as defined by the primary objective of the research in chapter one and methodical specification in chapter three. These results, as discussed in section by section are weighed against standard specification envelops, which helped at least, in part, to establish inferential statements on the performance integrity of operative strength indices, which is the fundamental criterion for the study.

4.2 CARRIAGEWAY PROFILE

The carriageway cross sections investigated is 19.3km. Fig. 4.1 defines its location within km1 + 200 to km19 + 300 on Zuba – Gwagwalada Highway in the

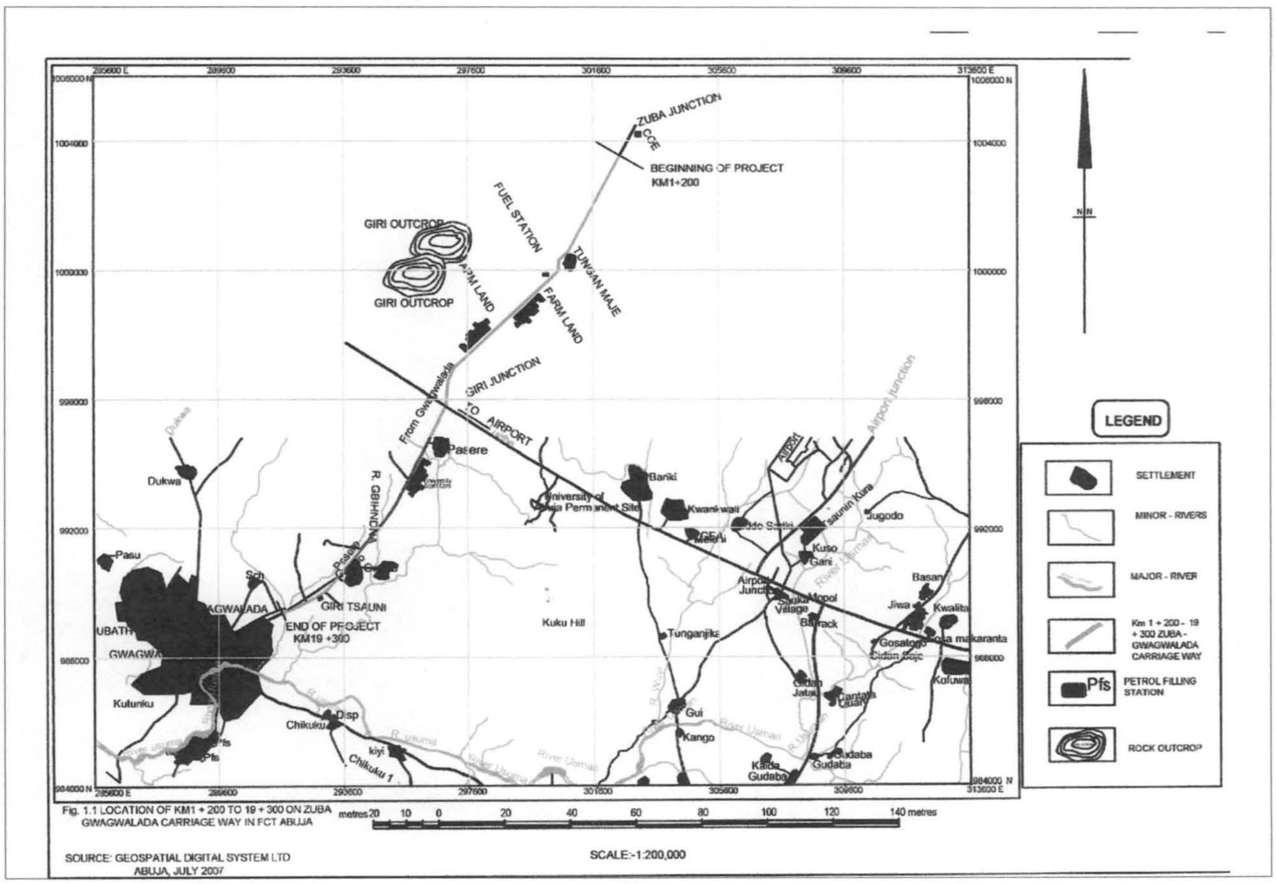


Fig 4.1 Carriageway Location

Federal Capital Territory (FCT) of Abuja. While 18.1km constitute the failed section, the remaining 1.2km forms the functional, otherwise known as the control section investigated respectively. The route's significant landmarks are specified in Table 1.1 while failed sections of current conditions are vendored in Plates xi. – xii

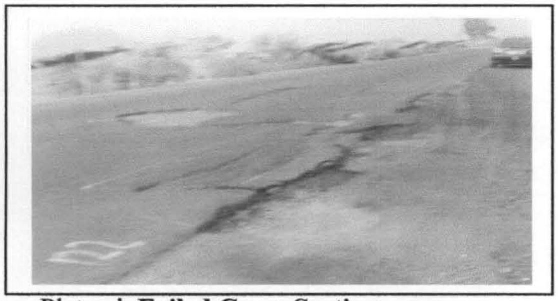


Plate xi. **Failed Cross Section**

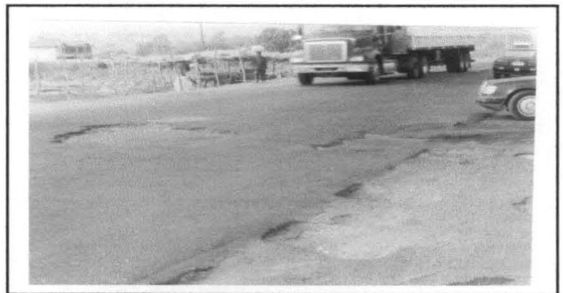


Plate xii. **Failed Cross Section**

Source: Carriageway field work Zuba- Gwagwalada, 2007

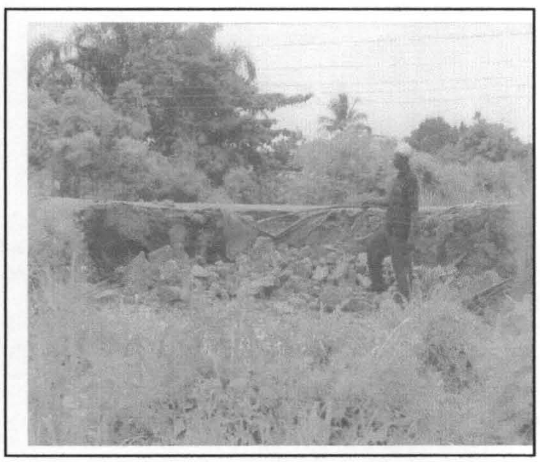


Plate xiii **Shoulder failure**

Plate ix **Base Shears within Sub - Grade**

Source: Author's field work, Zuba -Gwagwalada, 2007

All GPS reading at any descriptive points fall within the geographic zone of UTM 3. The undulating transect is hemmed by legion of ribbon settlements and ridge outcrops towards the South-East. It is a single carriageway, constructed by Messrs Dumez Nigeria Limited in 1983. Its geometric features, as measured are summarized in Table 4.1-4.2 and Fig 4.1.

The Zuba – Gwagwalada Carriageway as typified in Fig. 4.2 is not a full depth asphalt pavement, which implies that it is a granular base while its sub-base are untreated.

Table 4.1 Route Geometry

S/N	Description	Geometry
1	Wearing course thickness (flexible pavement)	**100mm**
2	Base course (Granulated stones)	**150mm**
3	Sub-Base (laterite)	**200mm**
4	Carriageway width	**7.3mm**
5	Number of lanes	**2**
6	Maximum super elevation	**8%**
7	Slope	**2.5%**
8	Shoulder width cross fall	**5%**
9	Inner shoulder width	**2.75m**
10	Outer Shoulder width	**1m**
11	Width of median	**Nil**
12	Base materials	**Laterite fill**
13	Sub-grade materials	**Laterite fill**
14	Sub-grade sealing/capping	**Nil**
15	Geology	**Undifferentiated basement complex**

Source: Author's Field Work 2007

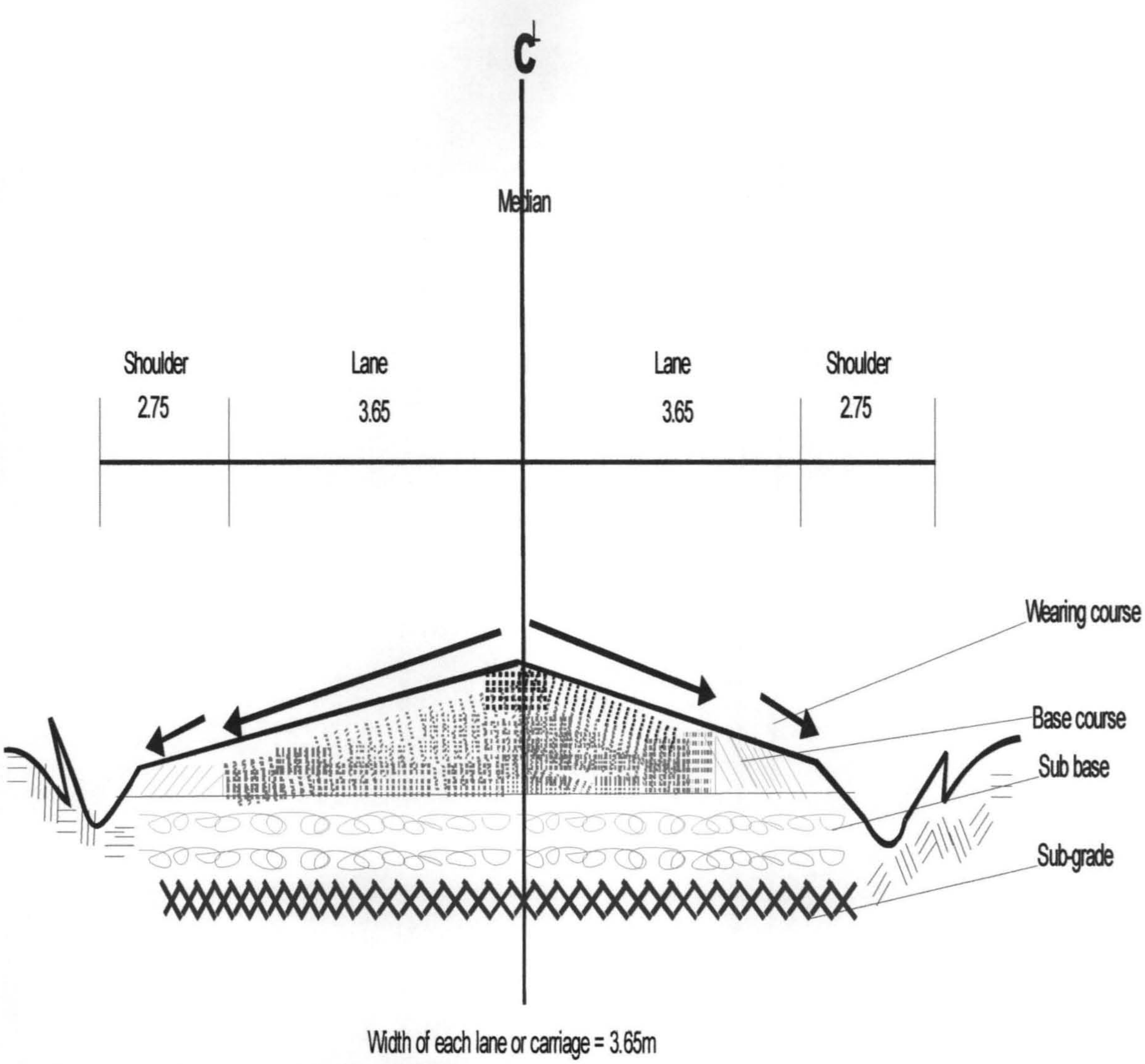


Fig. 4.2 Geometry of Zuba – Gwagwalada carriageway

4.3 ENVIRONMENTAL ATTRIBUTES

The Nigerian Roads Research and Development Agency Report of (1998) emphasized that "in as much as the role of dense sub-grade remains important to pavement performance because of its mechanical support to pavements, load distribution and drainage relieve, its design philosophy must also ensure that environmental constituents as well as traffic spectrum are not undermined, in order to enhance a high performance and long lasting pavement". It is in line with this principle that an assessment of key environmental attributes, which are thought to have a direct bearing on pavement performance as listed in section 3.4 was undertaken, in order to ascertain their roles or inactions in pavement failure within the study area. These key environmental attributes are temperature, rainfall, oxidation, ground water table, flood, mudflow, drainage slope, sinkholes, springs and proximity mining. Measurable data derived from them are summarized in Table 4.1 and discussed in their order of occurrence and influence levels.

Table 4.2 **Route Specifications**

Chainage (km)	TBM	Coordinates		Evaluation	Land marks	Remark
1+200	AP54	303,546.335	1,004253.544	350.341	COE ZUBA	Major estate
3+500	AP50	302,445.777	1,001,942.075	331.800	TP2 Within Tunga Maje	New town settlement
6+350	AP44	300,760.686	999,546.001	229.400	TP3 Observable drainage lines	Farm land
8+400	AP41	299,283.595	998,303.086	291.704	TP4 Widespread sand mining	Fuel station
10+250	AP36	297,796.221	997,039.084	252.535	TP5	Farm land
11+190	AP34	297,338.252	996,524.601	259,197	TP6 at Giri Gauta Junction	Road trunk
12+150	AP64	296,808.780	995422.853	240.035	TP7 at Gwako notable sinkhole +culverts	Mixed land use
17+500	AP73	293,743.425	990,952.007	313.199	TP8 at Uni Abuja staff quarters	Structured estate
19+300	AP76	292,309.694	989,998.874	240.035	TP9 end of study at Gir Tsauni	Institutional Area

Source: Author's Fieldwork (2007)

4.4 TEMPERATURE, RAINFALL AND OXIDATION

The annual temperature of Zuba – Gwagwalada, as reported by the Meteorological Agency of Nigeria (2006) ranges between 21^0c – 26.7^0c while mean annual rainfall is approximately 1650mm, with the months of July to September, accounting for 60% of the precipitation. These temperature values as noted above accounted significantly for seasonal bitumen oxidation, wearing coarse deflection, shrinkages, asphalt stripping, uncompromising alligator cracks and wearing coarse disintegration depicted in Plates xi – xviii. The incidence of high rainfall as reported above, acting in concert with temperature is believed to have given rise to free water (run-off) infiltration within permeable sub-base boundaries and inter layers of the carriageway system which generated high volumetric content of sub-base moisture that led to deleterious instability and localized base shears.

4.5 CANDIDATE ENVIRONMENTAL ATTRIBUTES

Table 4.3 below lists the candidate environmental attributes survey undertaken within defined spatial points.

Table 4.3 CANDIDATE ENVIRONMENTAL ATTRIBUTES

S/N	Candidate Environmental Attributes within Specific Locations (km)						
	Environmental Attributes	km1+200 to 6+400	km6+400 to12+800	km12+ 800 to 17+500	km17+500 to19+300	Km19 + 300	**Total**
1	Sinkholes		4	2	12		**18**
2	Streams		-	1	2		**4**
3	Proximitic Mining		-	1	1		**2**
4	**Drainage structures**		-	-	1		-

Source: Author's Field work, Zuba - Gwagwalada carriageway (Sept, 2007)

From Table 4.3, a total of 18 sinkholes were identified within the 18.1km failed cross section, while none was identified within the 1.2km stable section, otherwise referred to as "the control unit". This level of sinkholes was occasioned by ephemeric surface water stress, which compelled natives to abstract alternative underground sources for multiple uses such as domestic, gardening and livestock needs. The four streams or water courses identified arose from coarse gravity flows from foot slopes through incised channels and thus generally lack prolonged retention thresholds that are normally associated with perennial Rivers. Two granites mining spots were identified but could not be matched with measurable mine fields which usually utilize industrial hammers that often trigger ground vibration and structural failures within vicinities. Only a 2m x 2m box culvert was identified within km 12 + 800, where the Wuye River crosses. This culvert seldom overtops the carriageway, especially after major rains because of inadequate capacity. It is unfortunate that despite the widespread run-off from legion of foot slopes within the undulated carriageway structure, drainage system were not installed to regulate the unprecedented coarse flows.

4.6 TRAFFIC SPECTRUM

An examination of the results of the average hourly traffic distribution shows that the bulk of the vehicles using the existing route are cars and lightweight commercial vehicles. However, a sizeable number of heavy trucks and trailers were noticed on the route throughout the duration of the Traffic Census. This can be attributed to the large economic activities occurring between the South – Western Nigerian States and the Northern towns of Kaduna, Kano, Jos and Abuja, and this route form a major link between the South-West/South-South and the Northern regions of Nigeria.

Field details of the traffic count at the above locations are summarized in Table 4.4 below.

Table 4.4 **Summary of Average Daily Traffic**

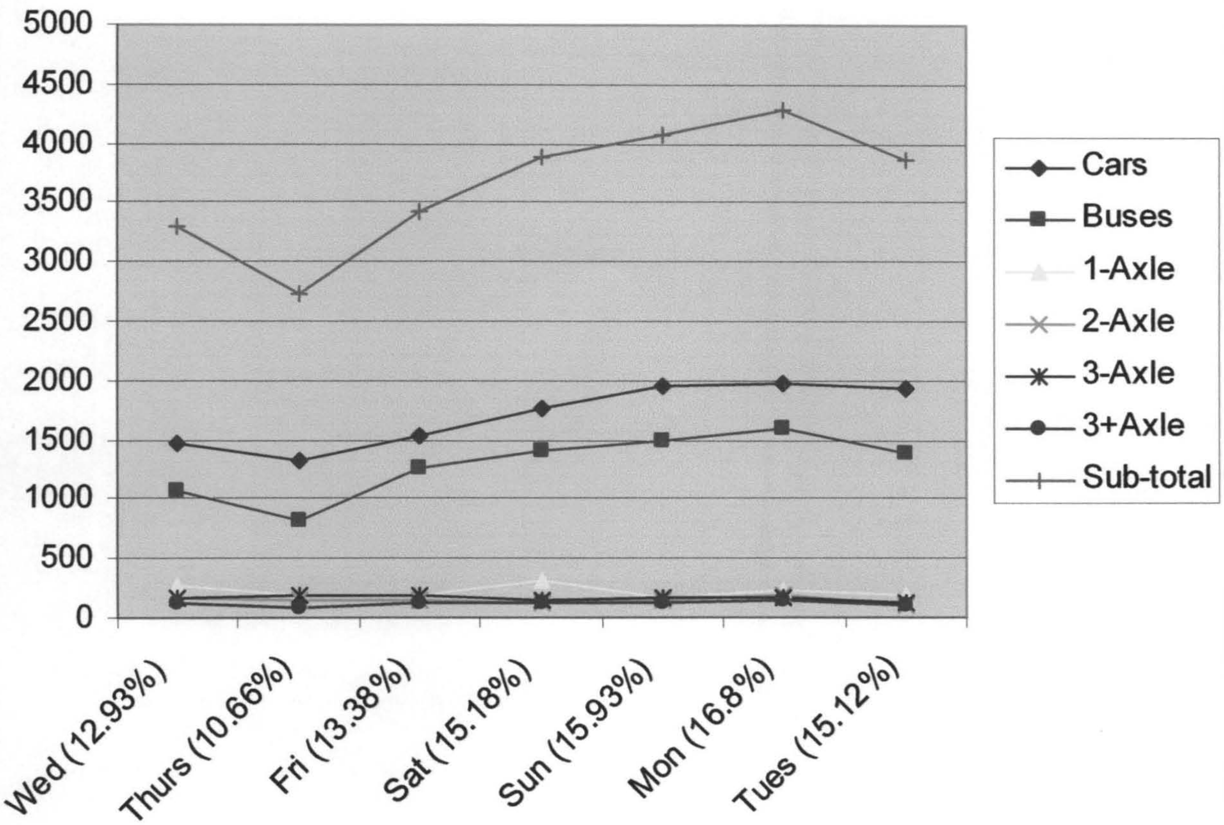
S/NO	VEHICLE DESCRIPTION	DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	SUB-TOTAL
		Wed	Thurs	Fri	Sat	Sun	Mon	Tues	
1	Cars	1475	1320	1532	1761	1951	1966	1942	11947
2	Buses	1075	811	1253	1406	1496	1597	1396	9034
3.	1-Axle	277	181	191	310	177	237	183	1556
4.	2-Axle	168	140	143	134	154	183	110	1032
5.	3-Axle	174	186	182	143	173	167	130	1155
6.	3+Axle	135	87	117	124	120	145	102	830
	Sub-total	3304	2725	3418	3878	4071	4295	3863	25,554

Source: Author's Fieldwork, October, 2007

The current traffic value which ranges from 2725 to 4295 vehicles per day in Table 4.4 is overwhelmingly undesirable, because it is an indication of extreme stress and strain on a single lane flexible pavement. Worst still, both daily and weekly average values of all axial traffic in Fig 4.3 which represents 53.3% of spectrum optima underscores the design philosophy of a single carriageway mark.

It is important to emphasize that the Federal Ministry of Transportation Revised Policy Manual, Part 1 of 1997 defines the Zuba - Gwagwalada carriageway system as a sub-urban route with an expected mean daily traffic capacity range of 850-1200, exceeding 3 Tonnes loaded weight. This posture, coupled with weak sub-grade could possibly have influenced the short-lived operational efficiency of the carriageway, as vendored in Plates xv-xvi.

Fig 4.1 Average Daily Traffic



Until the planned dual carriage system with integral relief structures are implemented, the problem of premature failure under this circumstance will persist, particularly, within weak depositional and pallid quadrants investigated.

Plate xv. Base Shears **Plate xvi. Deep Pot Hole**

Source: Author's field work, Zuba -Gwagwalada, 2007

4.7 EFFECTS OF UNDESIRABLE TRAFFIC PROFILE

Considering the recorded traffic spectrum in Fig. 4.3i during the period of the study and having taken account of all possible avenues of the current posture, the Zuba - Gwagwalada carriageway is assumed to fall within road category D of the FMW Highway design manual. This category of carriageway unfortunately, was not originally designed for the present serviceability index.

It is instructive to note that the Independent Reports of PTF Collaborative Study (1995) Volume Two on Federal Highways rehabilitation as well as the Chelsea College, London Monitoring and Assessment research Centre (MARC 2000) cautioned that "an undesirable level of axle load over prolonged period is capable of destroying carriageway structure prematurely. Aspect of the report also showed that an annual growth rate of 3.5 percent is ideal. But comparing current Nigeria's GNDP with average traffic output of 25,554 would suggest an annual average growth rate of 15 percent, which is an indication of tremendous strain on the Zuba – Gwagwalada carriageway.

4.8 SOILS

The freely drained sands and the inter-dunal pelagic soils constitute the major surface soils in the study area while the pallid and mottled clay form a major component of the sub-grade. In a semi-arid environment such as the Zuba – Gwagwalada, where the author carried out investigations on carriageway failure, moisture content drops appreciably during hot season, leading to extreme shrinkage. A contrasting effect of cell expansion is also experienced during wet season, resulting to prolonged heave, rutting, base shears, surface deflections and cracking. While these behavioural activities may not be noticed at all in the normal course, any structure such as carriageway that may be placed on such a soil will experience a hastened damage.

Different construction agencies employ different techniques to overcome this hazard but unfortunately without scientific basis to support their approaches because of the morph dynamic nature of specific environments. A few of the recommendations that have found a place in Nigeria's circumstance on carriageway construction in such critical ecosystems are:

1. A safe bearing capacity value not exceeding 50kn/m^2 (0.5kg/cm^2).
2. A minimum depth of foundation of 2m.
3. The bottom of the foundation trench to be filled with sand or murum or broken stones; sand filters on sides of trenches are also ideal.
4. Reinforced concrete sands to be used at the foundation, plinth and lintels (in the case of super structure).

4.9 LOG CHARACTERISTICS OF SUB-GRADE MATERIALS

Both cohesionless and cohesive materials as well as void bands were encountered within the Zuba – Gwagwalada areas investigated. The general pattern is fashioned after the very simple weathered profile of the underlying sedimentary rocks of the cretaceous age. Sections intersected by meander flood channels with concomitant deposition of river alluvium on their adjacent beds also occurred within surveyed valleys. In a general sense, the subsoil types encountered within defined traverse exhibit appreciable similarity and shall therefore, be described together but a much-pronounced emphasis shall be laid on differences in either failure or stable attributes.

The part of the study location of km1 + 200 – km120+000 where the weathered products described in paragraph one above, which makes up the first area of the sub-grade investigation, may be divided into two zones. The first zone spans through km12 + 000 – km17-500. This zone constitutes the exposed sand stratum, occurring to relatively shallow depths and ranging between 0.2m to 0.15m in places; this sand is uniformly but poorly graded and silty in nature. The material is thought to be a weathered product of pedogenic degradation, with the cohesive nature, being partly preserved in some reaches, giving the sand materials some form of coarse grains in pseudo plasticity. They are generally in loose state, which practically predispose them to weak structure and failure; they are also unsuitable sub-grade materials for practical engineering structures such as highways, bridges, houses, etc. Here also, multiple voids were recorded through field-process lens. Approximately, six hollow fans occurred between 65mm in almost beneath B-horizon and close to A-horizon. It was thought from further exsitu analysis of oxidation in the voids, that occurrence was influenced by high salinity content, which created hollows in the process of dissolution. Little wonder therefore, that weak sub-angular structure, base, shears, spout heads, alligator cracks and diaphragm drills in extreme cases were prevalent at varying cross sections. Other expert's opinion however, asserts that the hollow fans incidence particularly, diaphragm drills which are purely of local origin are a quintessential example of weak sub-grades which could have been adequately contained through engineered soil-lift interchange.

Soil profiles opened at sites of each soil group in Fig. 4.4i – ix have shown little distinctive differentiation in horizons within the 100cm depth. The soil most commonly occurring in the area is the loessal soil which is also the most significant for agricultural activities, and other land uses, than the pallid and marley types of soils, which are localized and mostly found within dune and inter-dunal depressions).

Field studies also revealed that the loessal soil is characterized by weak angular blocky structures, sandy texture, presence of diffuse boundary, and micro spores, and is generally porous; also, the colour was found to be 5 yr (5/8) as correlated to the Munsell colour chart, which gives yellowish-red as the colour. There are also few plant roots as a result of the surface capping of the soil. The mid slope soil (pallid) has weak and blocky texture, sandy structure, presence of micro spores, surface capping and diffuse boundary; the colour, according to Munsell colour chart was found to be 7-5 yr (5/6) which is a strong brown. The marley textured however, is characterized by massive and crumb structures, sandy clay texture, diffuse boundary, presence of both micro and macro spores, mottles; the colour correlated to Munsell colour chart was found to be between 5 yr (5/1) that is, Yr (3/4) which is dark-brown. This soil group was also found to be generally hard and compact; as was observed within control sections of km18 + 100 – 19 + 300.

4.9i INSITU BORE LOGS

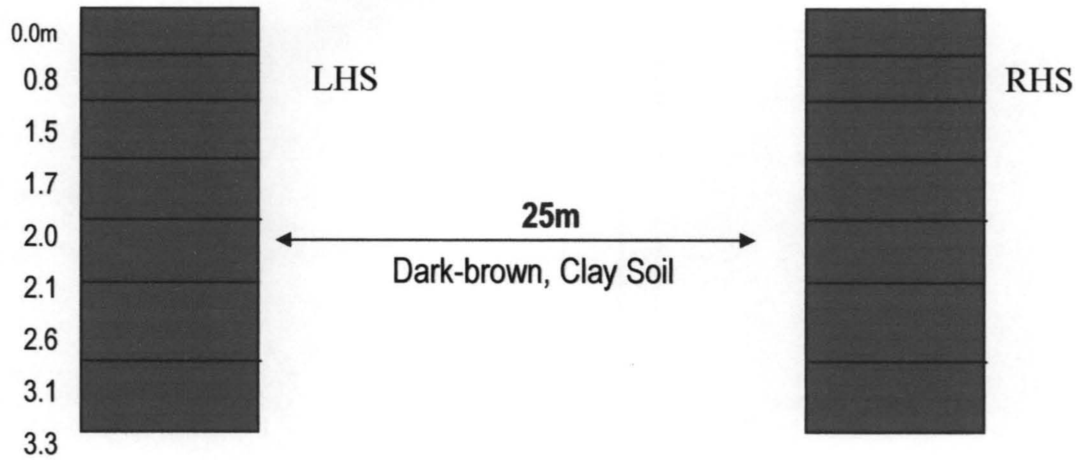


Fig 4.i: TP1
Location: km1 + 200 FCE – Zuba – Tunga Maje

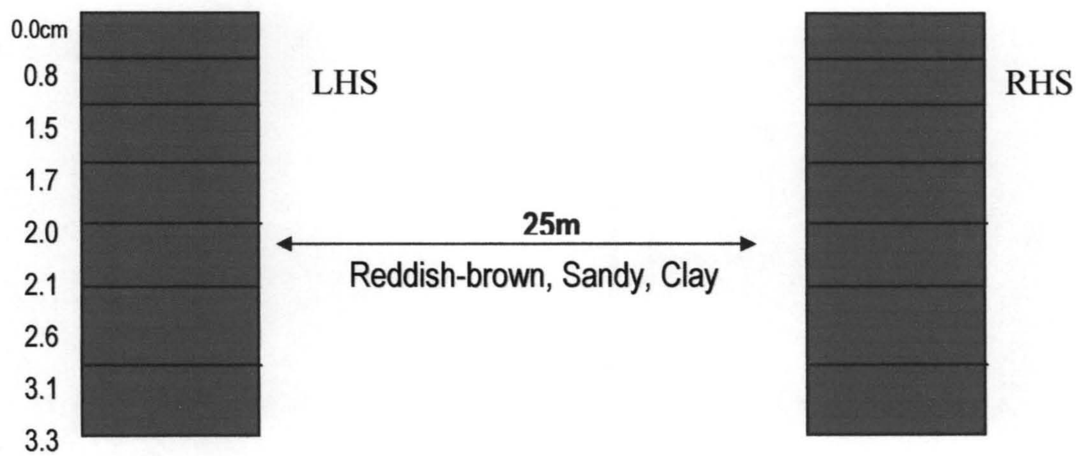


Fig 4.4ii: TP2
Location: km1 + 500 AIRPORT JUNCTIONS – GIRI TUKUNYA

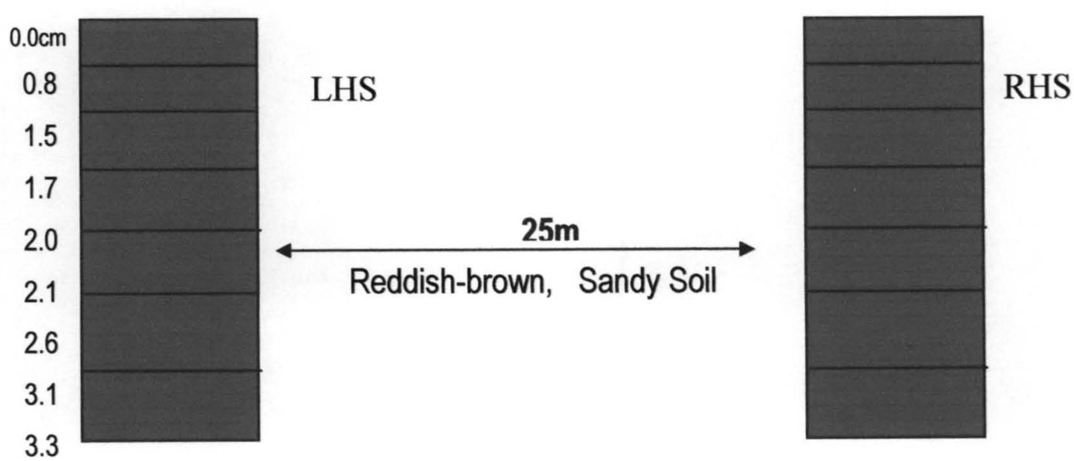


Fig 4.4iii: TP3

Location: km 6 + 350

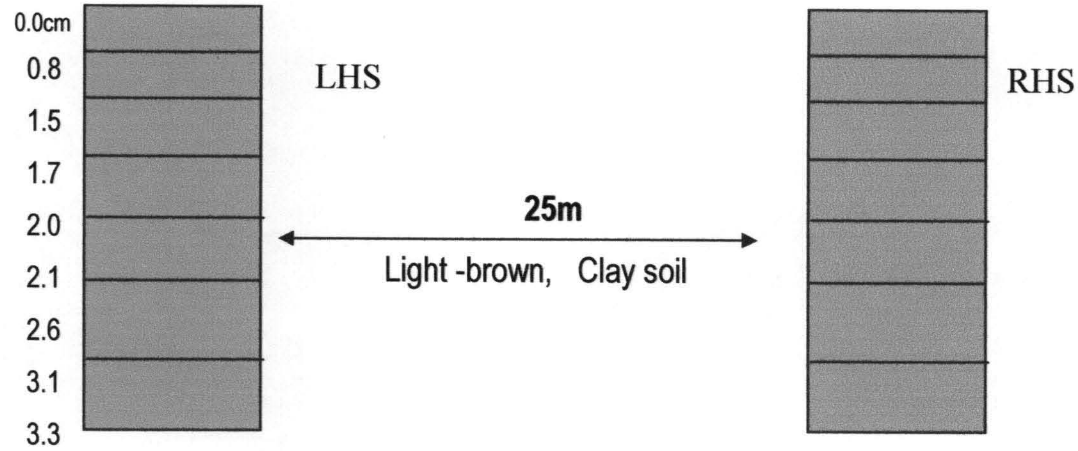


Fig 4.4iv: TP4

Location: km 8 +400

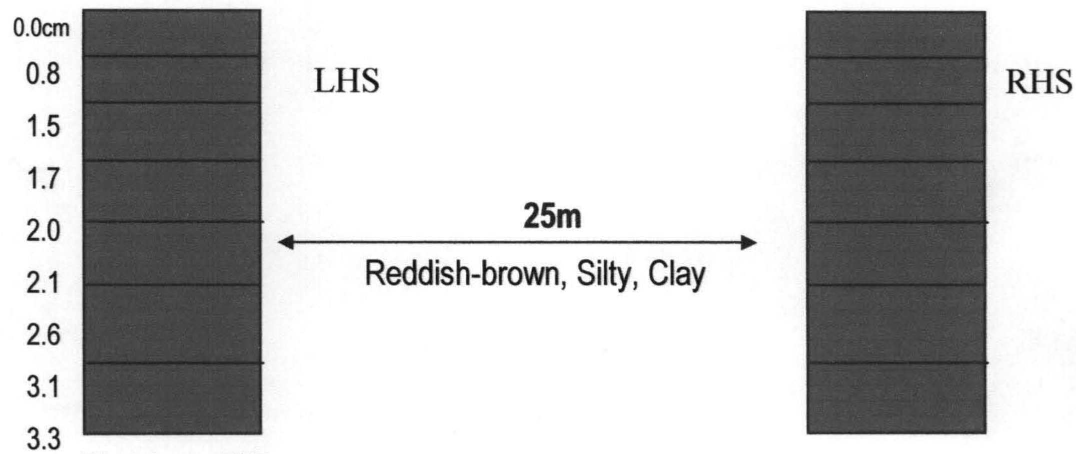


Fig 4.4v: TP5

Location: km 10+250

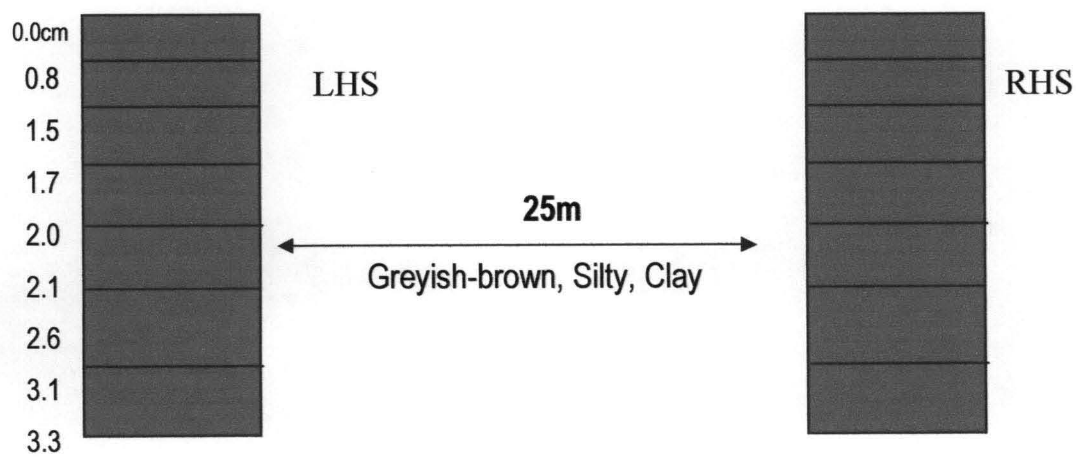


Fig 4.4vi: TP6

Location: km 11+190

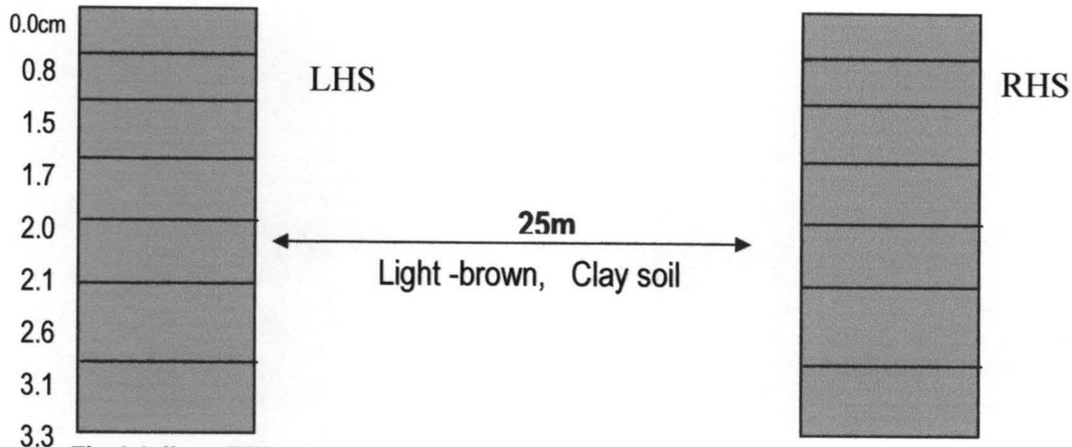


Fig 4.4vii: TP7

Location: km 12+ 150

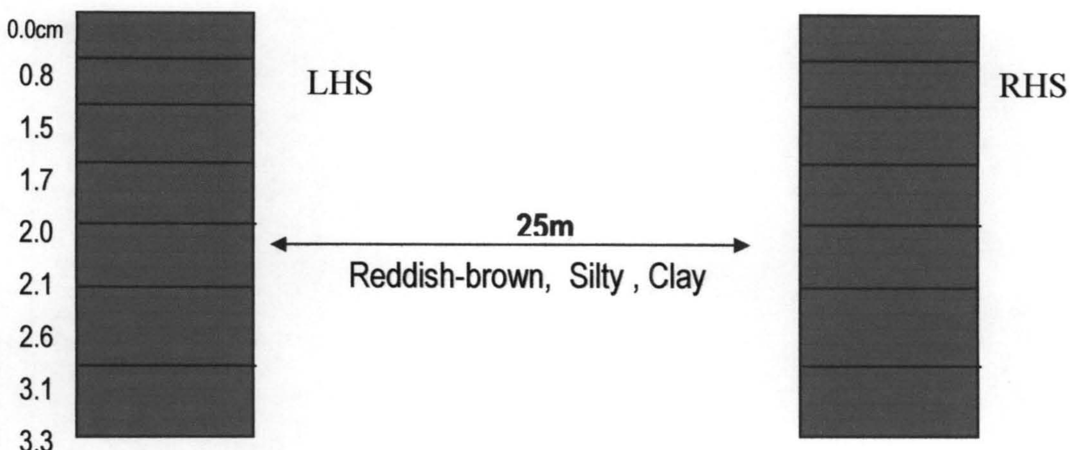


Fig 4.4viii: TP8

Location: km 17+500

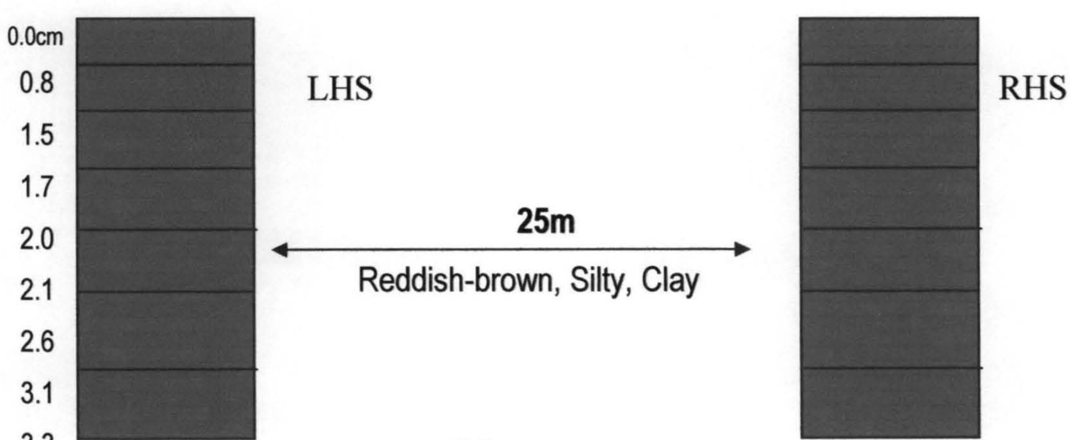


Fig 4.4ix TP9 - CONTROL PROFILE

Location: km 19 + 300

The second cross section investigated, span through km 12+000-km17+500, Within this transect, an average of 6.42cm thick of micaceous clay was encountered; the trend dominantly extended into Borehole 17 + 500 but gradually degenerated into either Marley, mud shale or dilatic states within Km.18+10. Here, ground water was encountered within 4.2m depth but with much higher tables on road embankment. Both alluvium and loesal drift materials were also appreciably recorded within this traverse. Soils from these areas are commonly mined by natives for either pottery craft or bricks as depicted in Plate 17-18. It is not sure if the observed high water table was as a result of the dominant clay content but investigation from Geological Survey Agency's mapping project of 2005 point to a likely joint effect within the ridge zone.

The third segment of the study point falls within km18+100 – km19 + 300. This, 1.2km quadrant constitutes the 'control point' designed to verify whether the problem of premature pavement failure was of either a general nature or spot origin. The section, which is adjudged stable, apparently bears the same pavement material though, but their strength properties are more favourably desired as manifested from their gradual change from superficial top sand drift laterite and cementation effectiveness, due to actions of iron oxides and hydrated aluminum oxides that gave rise to partial lateritic desiccation from firm to stiffy gravelly condition.

Exsitu results from "control Bore log" in Table 4.4 as described above further exhibit effective drainage and particles gradation, which suggest that the carriageway failure trend as observed in Plates xi – xviii could not have been attributed to a general characteristic of sub-grades within the failed cross sections. The foregoing therefore implies that the veritable poor drainage conditions and soil variability, acting in concert with other candidate environmental factors could possibly have accelerated failure processes of the Zuba – Gwagwalada carriageway sections investigated. A poor drainage network particularly in clay soils for example, accounts for seasonal behavioural variability such as low permeability and columnal changes (during wet season) and high shrinkages (during dry season). Given such type of columunal variations within marley sub-grade conditions, some sort of progressive weakness and instability in mechanical support would set in.

Similar evidence supporting problems of foundation variables on Nigeria carriageway systems have been reported by Teme (1989) on Ibilo – Owo road, Essiet (1994) on Kirikasama (Yobe) and Wambai – Kano roads, Edet (1997) on Odukpani – Itu highway, Nedeco (1998) on Katsina- Ala- Donga carriageway and more recently, Malomo (2002) on Mararaba – Keffi bound road. In these spatial locations, two major trends are ironically accompanied by their short-lived phenomenon. First, is a cell pressure involvement in clays which spark-off dilatancy and high base shear conditions. Secondly, a doubling traffic spectrum recorded against their original design.

The veritable poor drainage texture and weak sub–grade indices derived from field verifications acting in concert with other candidate factors, particularly, doubling traffic pressure in Table 4.4 suggest that their possible roles actually led to overbearing stress that posed barriers to serviceability competence of the Zuba – Gwagwalada Carriageway system.

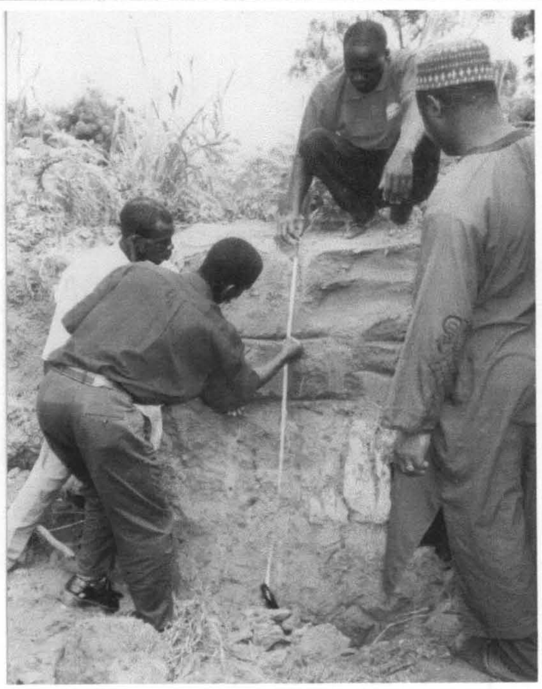


Plate xvii **Insitu Borelog within Failed Carriageway Section**
Source: Author's field work Zuba -Gwagwalada 2007

It is not sure though, if the recorded high water table at 4.2m depth within km 12+150 was as a result of low permeability attribute of clays in water retention but further investigation from the Geological Survey Agency's local mapping report (2005) point to a likely fault effect within the Zuba – Gwagwalada ridge zone. The dominance in either of these candidate factors in engineering infrastructures, such as houses, carriageway, bridges and rail lines portend structural instability.

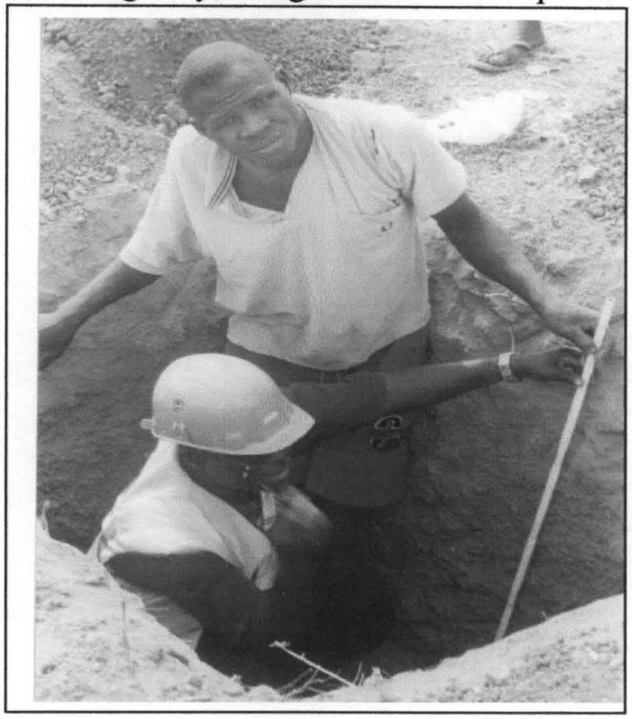


Plate xviii. **Stable Section insitu of the Carriageway**
Source: Author's field work, Zuba -Gwagwalada, 2007

4.10 ENGINEERING PROPERTIES OF ZUBA – GWAGWALADA CARRIAGE WAY

Table 4.5 is a summary of analytical results of engineering indices within the investigated sections of Zuba – Gwagwalada carriageway while sections 4.1.2. – 4.1.2-iv offer explanatory details. Based on unified soil classification system vendored in Tables 4.5 and 4.6, a general rating for the sampled materials was established, as recorded in the appropriate columns in Table 4.3. Major explanatory notes on both physical and insitu attributes have been offered in section 4.1.4 and thus need not be necessarily discussed here but to rather note that, the collective output under these sub topics and derived laboratory results actually provided data for informed judgment on the possible factors underpinning operative efficiency of the carriageway.

Table 4.5: SUMMARY OF ENGINEERING INDICES OF SOIL TEST RESULTS

							¾'	#7	#36	#200			
CH.1+200 RHS	SG	2.1	Dark Brown clayey soil	1.617	15.3	1	100	99	94	71	44	20	A-7-6
00 RHS	SG	2.1	Light Brown clayey soil	1.706	13.6	1	100	100	100	88	44	18	A-4(5)
CH.3+500 RHS	SG	1.5	Red Brown sandy clay	1.640	12.7	3	97	78	71	66	29	15	A-6(8)
CH.3+500 RHS	SG	1.5	Red Brown sandy clay	1.877	12.0	5	97	78	71	66	52	37	A-7-6(25)
CH.6+350 RHS	SG	1.7	Red Brown sandy soil	1.562	18.2	2	100	97	61	36	63	36	A-7-6(17)
CH.6+350 RHS	SG	1.7	Light Brown clayey soil	1.750	13.6	2	100	99	82	68	52	37	A-7-6(5)
CH.8+400 RHS	SG	1.5	Red Brown sandy clay	1.571	20.0	5	100	98	91	50	40	21	A-6(6)
CH.8+400 RHS	SG	1.5	Reddish Brownish clay	1.470	20.4	1	100	96	79	38	35	18	A-6(2)
CH.10+250 RHS	SG	2.0	Red Brown sandy clay	1.778	14.0	4	100	98	83	52	43	17	A-7-6(0)
CH.10+250 RHS	SG	2.0	Grayish silt clay soil	1.787	14.3	5	100	94	73	57	50	23	A-7-6(0)
CH.11+190 RHS	SG	2.6	Red Brown sandy clay	1.753	12.4	2	100	97	80	55	51	30	A-7-6
CH.11+190 RHS	SG	2.6	Red Brown sandy clay	1.831	12.7	3	100	78	50	52	32	30	A-7-6
CH.12+150 RHS	SG	3.1	Red Brown sandy soil	1.886	8.2	10	100	97	69	39	47	32	A-7-6(4)
CH.12+150 RHS	SG	3.1	Light Brown clayey soil	1.929	11.3	15	97	91	80	50	47	17	A-7-6(3)
CH.17+500 RHS	SG	3.3	Grayish silt clay soil	1.794	15.4	5	100	99	84	46	58	43	A-7-6
CH.17+500 RHS	SG	3.3	Red Brown Sandy clay	1.765	15.4	4	100	99	84	46	56	37	A-7-6
CH.19+300 RHS	SG	0.8	Red Brown Sandy Clay	1.777	13.3	13	97	71	50	29	33	11	A-2-6
CH.19+300 RHS	SG	0.8	Red Brown Sandy Clay	1.776	13.2	3	100	98	84	56	54	34	A-4

Source: Author's Field Work on Zuba -Gwagwalada carriageway (September 2007)

4.11 SIEVE ANALYSES

Sieve analyses are concerned with the investigation of grain size distribution in term of sand, silt and clay proportions. Their occurrence and gradation influence to a large extent, the sustainability or collapsibility of overlaid structures because of their influence in providing mechanical support and infiltration capacity.

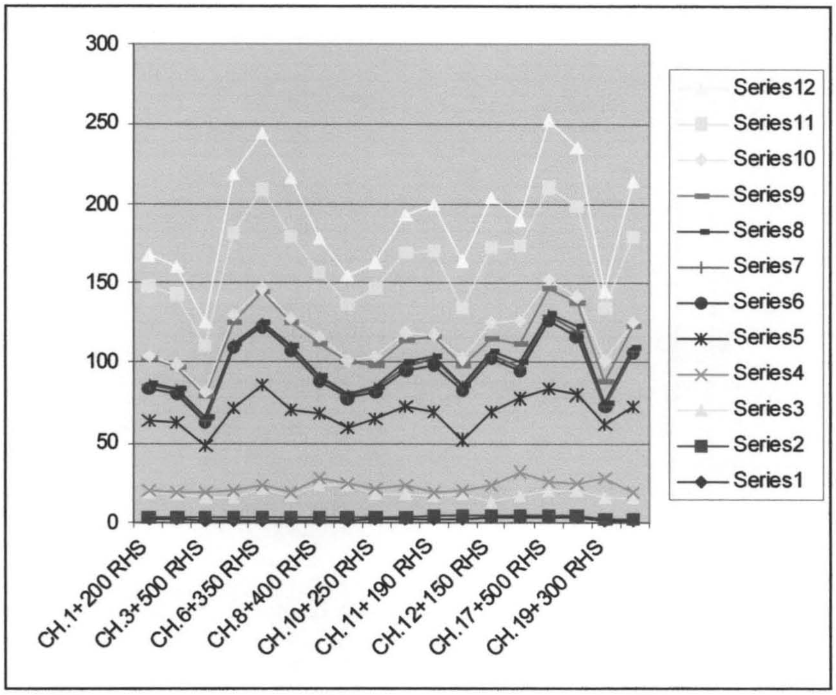


Fig 4.5 **Area Chart: Engineering Indices of Soil Test Results**

Results of sieve analyses in Table 4.5, as supported by graphical envelopes of Figs. 4.6 – 4.9 revealed two types of distribution curves. While Fig. 4.6 indicates a fairly graded distribution, Figs. 4.7 – 4-8 are marked by coarse voids which reflect very poor gradations. Most samples within the failed sections of Km1+120 – km16+900 tended towards this characteristics; an appreciably degree of normative engineering efforts would have to be effected in order to enhance their suitability competence for a sustainable carriageway structure. However, the 'control sections' of km16 + 900 – km19 + 300 in Fig 4.9 on the other hand, demonstrated appreciable degree of operative competence, which would require minimal routine maintenance in event of failure.

Further more, average results of Figs. 4.6 – 4.9 shows that for the same clay content or plasticity index within 8-29% and higher proportions of coarse sand experienced greater failure than those with higher proportions of silt. For instance, in decreasing the sand proportion in Fig. 4.7 from 90% to zero and in the same time, increasing its silt proportion from zero to 90% resulted in a major negative deviation from tolerable collapsible scale, measured under an applied pressure of $100kg/m^2$, which ranged between 5-10% for the range of the dry unit weights used.

4.12 ATTERBERG LIMITS

Result of most insitu materials investigated in Table 4.4 fall within soils of A – 7 – 6 AASHTO classification. This observable group of A7- 6 is rated poor plasticity index in comparison with the Federal Ministry of Transportation specifications in Table 4.5 which specifies average requirement of 50% mark for liquid limits and 30%, in the case of plastic limits. The observed sub-grade materials structural inadequacy, would necessarily imply that an average of 20% granular materials would have to be introduced as stabilizing agent in order to regain optimum engineering values.

Table 4.6 Comparative Rating of Zuba - Gwagwalada Sub-Grade Materials

Location	Liquid Limit (%)	British Soil Classification	Unified Soil Classification	AASHTO	General Rating	Sample Description	Profile
KM 1 + 200 – km 3 + 500	40–52.0	CL/GCL/SML	CL	A-7-6	Fair	Reddish-Brown, lateritic, silty, sandy, gravelly, clay	sub-grade
KM 6 + 350 – km 8 + 400	52.0-35.0	CL/GCL/SML	CL	A-7-6	Fair	Reddish-Brown, lateritic, silty, sandy, gravelly, clay	sub-grade
KM 10 + 250 – km 11 + 190	43.0-52.0	CL/GCL/SML	CL	A-7-5	Very poor to Fair	Reddish-Brown, lateritic, silty, sandy, gravelly, clay	sub-grade
KM 12 +150 – km 16 + 000	47.0 – 58.0	CL/GCL/SML	CL	A-7-5	Very poor to fair	Reddish-Brown, lateritic, silty, sandy, gravelly, clay	sub-grade
KM 1 7+ 500 – km 18 + 200	35.0–36.0	MI/GCI/SP	ML/GC	A-7-5	Very Poor to fair	Reddish-Brown, lateritic, silty, sandy, gravelly, clay	sub-grade
KM 1 9+ 300	56.0	MI/GCI/SP	ML/GC	A-7-7	Good	Reddish-Brown, lateritic, silty, sandy, gravelly, clay	sub-grade

Source: Author's Field work Zuba – Gwagwalada Carriageway (Sept. 2007)

FEDERAL MINISTRY OF TRANSPORTATION
PAVEMENT EVALUATION UNIT, KADUNA

Particle Size Distribution

Location ZUBA-GWAGWALDA FCT Boring No 1 Failed cross section Sample No KM 1 + 200 Date of Test OCT. 2007

Description SUB-GRADE SAMPLE FROM FAILED SECTION

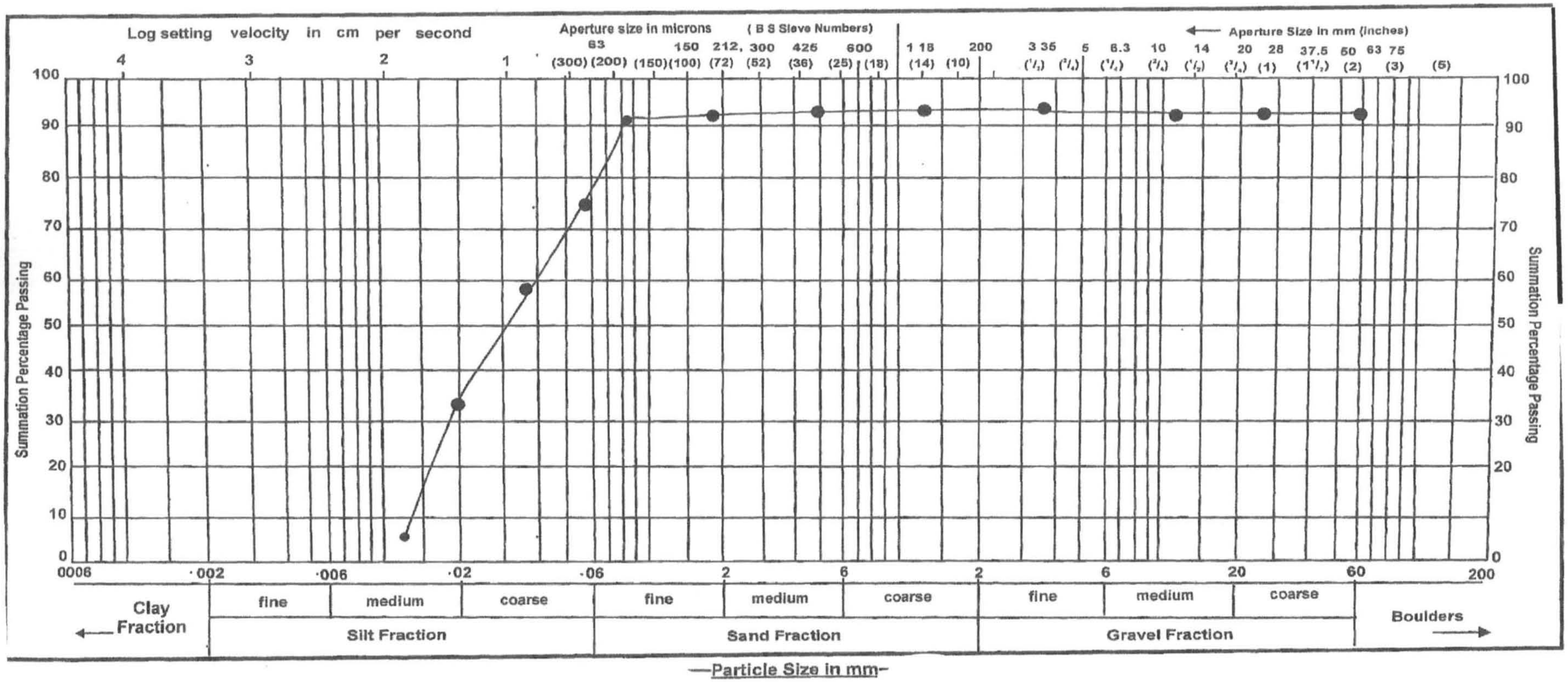


Fig. 4.6: Particle Size Distribution of Failed cross section
Source: Author's fieldwork, 2007

FEDERAL MINISTRY OF TRANSPORTATION
PAVEMENT EVALUATION UNIT, KADUNA

Particle Size Distribution

Location ZUBA-GWAGWALDA FCT Boring No 3 Failed cross section Sample No KM 6 + 350 Date of Test OCT. 2007

Description SUB-GRADE SAMPLE FROM FAILED SECTION

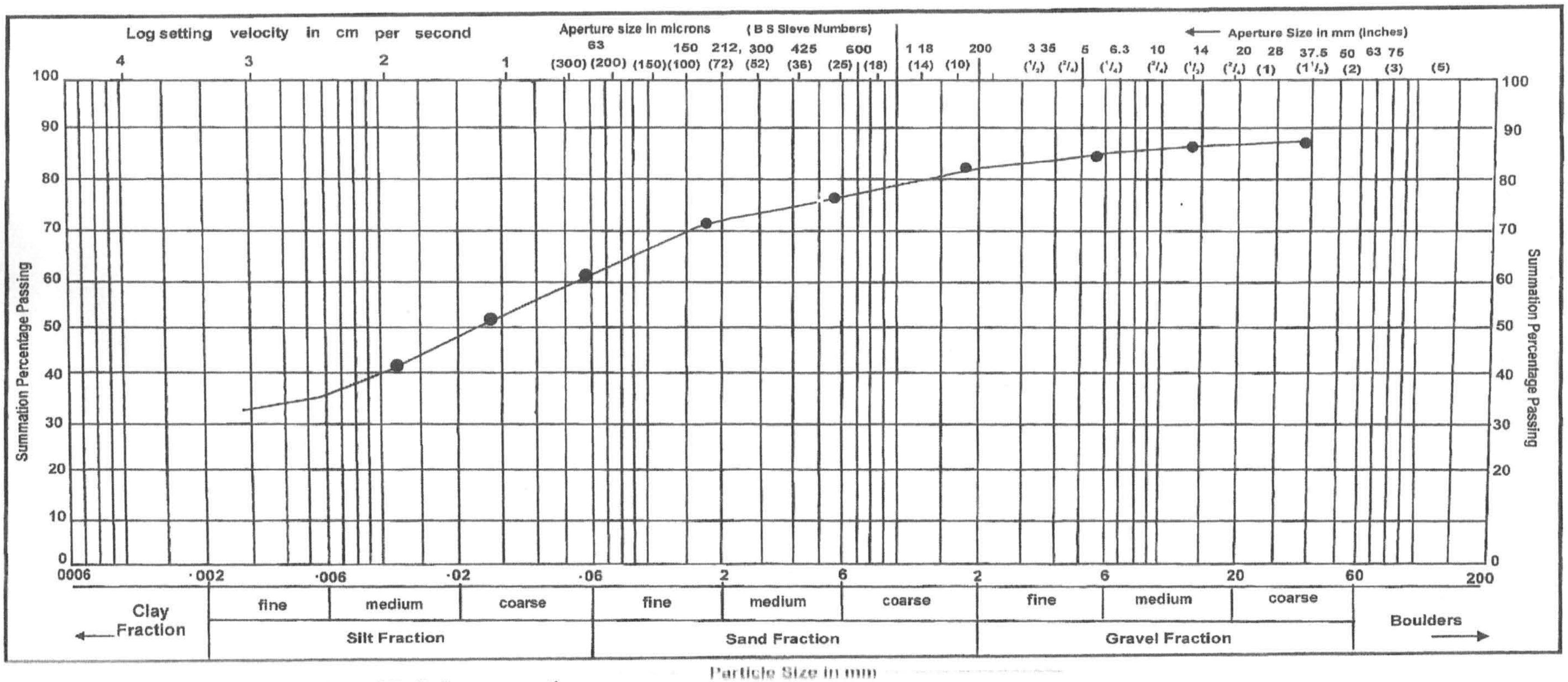


Fig. 4.7: Particle Size Distribution of Failed cross section
Source: Author's fieldwork, 2007

FEDERAL MINISTRY OF TRANSPORTATION
PAVEMENT EVALUATION UNIT, KADUNA

Particle Size Distribution

Location ZUBA-GWAGWALDA FCT Boring No 9 stable cross section Sample No KM 17 + 500 Date of Test OCT. 2007

Description SUB-GRADE SAMPLE FROM FAILED SECTION

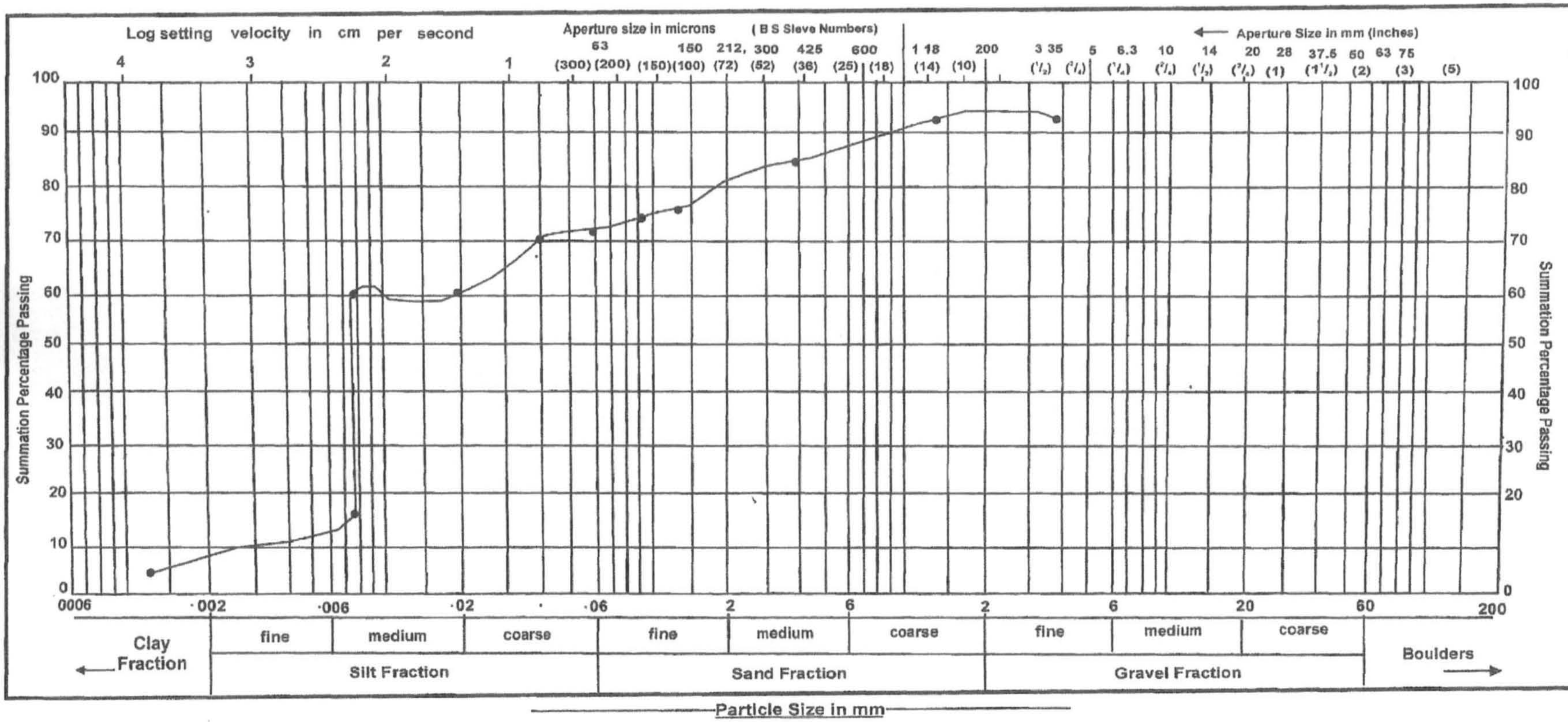


Fig. 4.9: Particle Size Distribution of 'control' cross section
Fig. 4.8: Particle Size Distribution of Failed cross section
Source: Author's fieldwork, 2007

FEDERAL MINISTRY OF TRANSPORTATION
PAVEMENT EVALUATION UNIT, KADUNA

Particle Size Distribution

Location ZUBA-GWAGWALDA FCT Boring No 9 stable cross section Sample No KM 17 + 500 Date of Test C

Description SUB-GRADE SAMPLE FROM FAILED SECTION

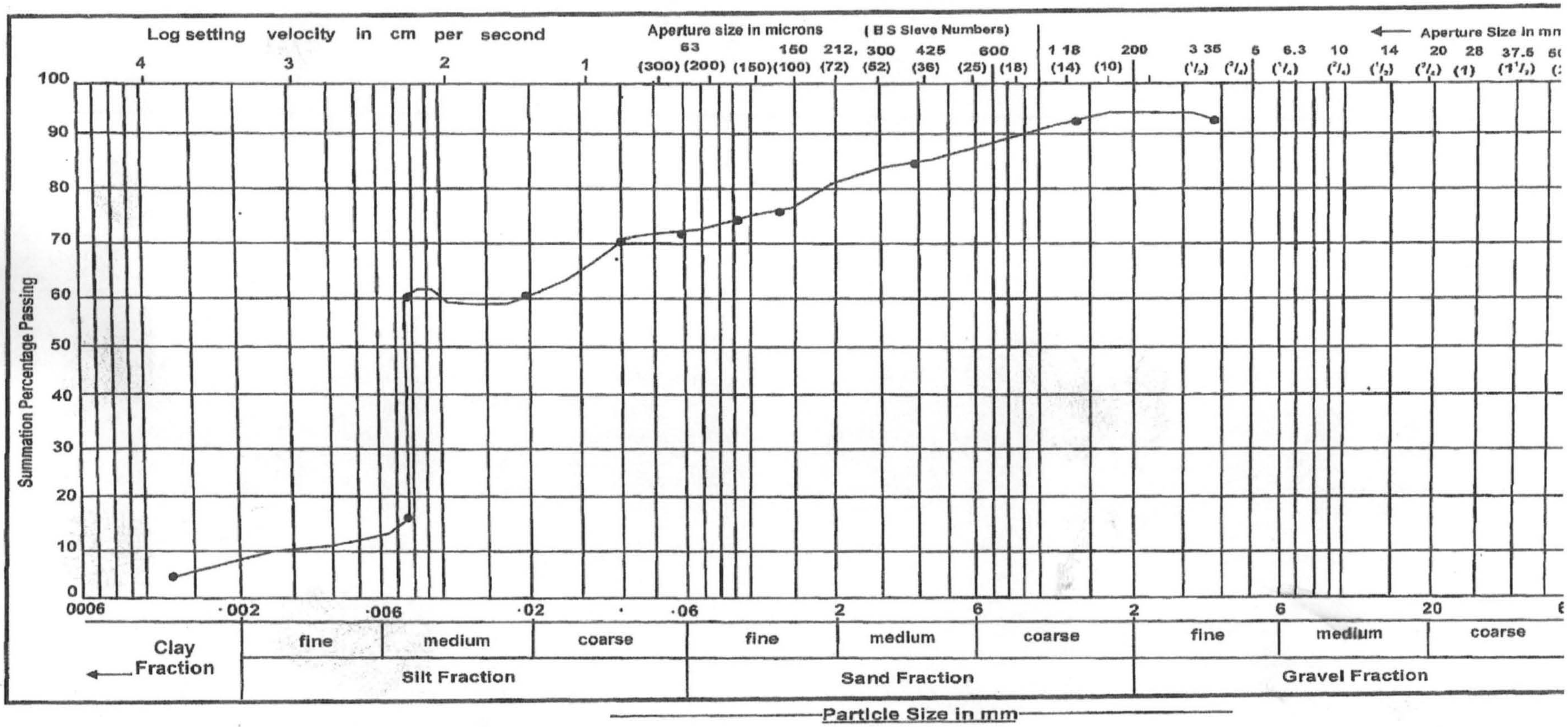


Fig. 4.9: Particle Size Distribution of 'control' cross section

Source: Author's Fieldwork, 2007

FEDERAL MINISTRY OF WORKS AND HOUSING
PAVEMENT EVALUATION UNIT KADUNA
COMBINED COMPACTION/C.B.R OR C.B.R TEST/MOISTURE CONTENT

DATE: OCT. 2007
OPERATOR: Messrs. Monday &
COMPACTION STANDARD B.S.C

SOIL: SUB - GRADE
JOB: ZUBA - GWAGWALADA
STABLIZER

KM 1 + 200 LHS

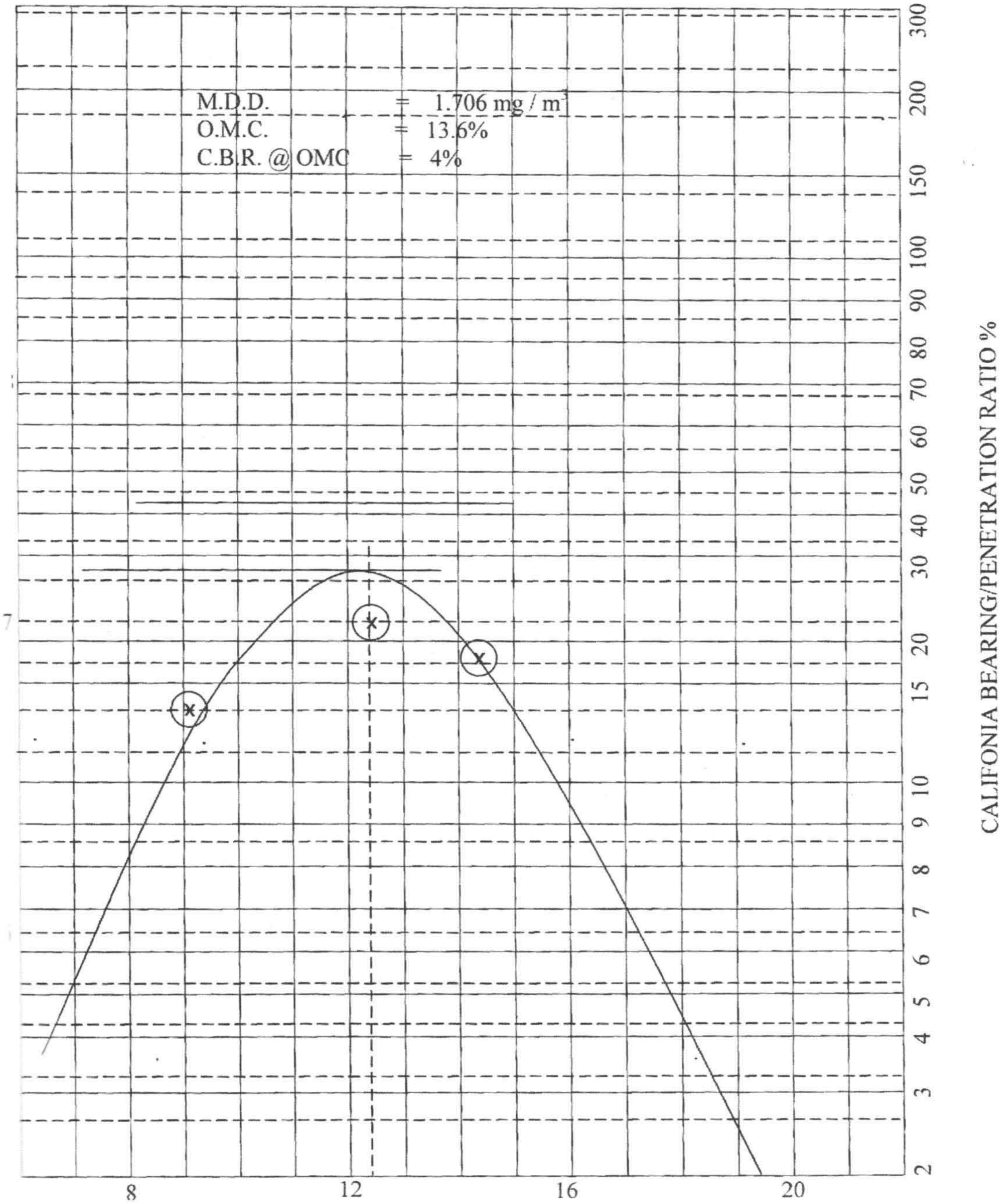


Fig. 4.10: Atterberg Limits of Failed cross section
Source: Author's fieldwork, 2007

4.13 COMPACTION TEST

A summary of the compaction tests carried out on various remoulded samples from sub-grade materials are listed in Table 4.4; these results vary markedly from the central mark tendencies in Table 4.6. this would necessarily imply that high dry densities ranging from 1.617mg/m^3 – 1.177mg/m^3 are practically achievable at moisture contents ranging between 15% - 13.2%, under the West African Standard Compaction, which implies that, under field condition, an influence must be exerted at 15% - 13.2% moisture compaction threshold; in other words, at lower values of moisture content, the field soils would tend to resist compaction but an optimum increase in values would enhance ease of workability, that would result to the attainment of higher dry densities. In the alternative of extreme moisture content circumstance, the attainable dry density would decrease and thus increase volumetric content of moisture, which could possibly break down the aggregated structure into dilatic state. Compaction test is important in highway construction because it provides the criteria for sustainable mechanical support, possible.

The relevant sections of Federal Ministry of Transportation and the unified Air Field soil Specifications adopted in comparing the results of Zuba – Gwagwalada sub-grade materials are summarized in Tables 4.7 and 4.8 below.

Table 4.7: **Summary of Some FMT Specification Requirements**

Clause(s)	Specification	Remarks
6201, 6122	**Materials Suitable for Sub-grade** % Passing Sieve 200 >35% Liquid Limit (LL) >50% Plasticity Index (PI) > 30% Relative Compaction < 100% of BS (Top 150mm)	Specification is silent on CBR; but CBR of 6% minimum is recommended

FEDERAL MINISTRY OF WORKS AND HOUSING
PAVEMENT EVALUATION UNIT KADUNA
COMBINED COMPACTION/C.B.R OR C.B.R TEST/MOISTURE CONTENT

DATE: OCT. 2007
OPERATOR: Messrs. Monday &
COMPACTION STANDARD B.S.C

SOIL: SUB - GRADE
JOB: ZUBA - GWAGWALADA
STABLIZER

CH 17 + 500 LHS

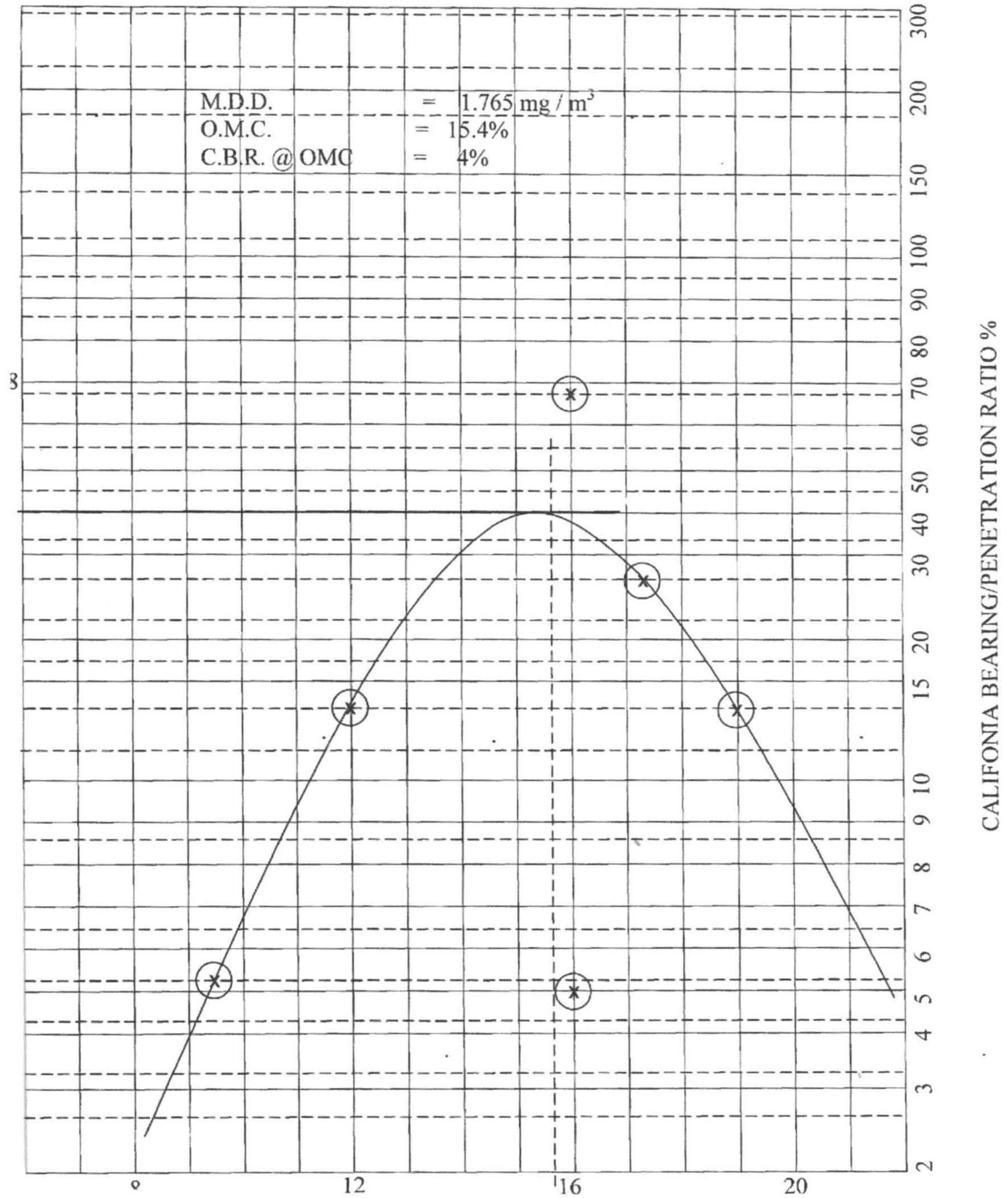


Fig. 4.11: Compaction Test of 'Control' cross section
Source: Author's Fieldwork, 2007

4.14 CALIFORNIA BEARING RATIO

Results of CBR tests, as summarized in Table 4.8 generally indicate poor strength values for an economic pavement performance requirement of 71.30%. Thus, the derived range of 1 – 15% when weighed against unified specifications in Table 4.6 is a reflection of strength deficiency within the carriageway sub-grade structure, which undoubtedly accounted in part, to the short-lived performance of the carriageway. The 60-67% record in the control section validates its economic competence for carriageway projects, which, in part, explains why failure incidence within this cross section is much minimal.

Table 4.8: **Summary of Unified Soil Ratings for CBR Investigation**

CBR No	General Rating	CLASSIFICATION SYSTEM		
		Uses	Unified	AAASHTO
0 – 3	Very Poor	Sub-Grade	OIL, CIL, MIL, OL	A5, A6, A7
3 – 7	Poor to fair	Sub-Grade	OIL, CIL, MIL, OL	A4, A5, A6, A7
7 – 20	Fair	Sub-base	OL, CL, ML, SC, SM, SP	A2, A4, A6, A7
20 – 50	Good	Base, sub-base	GW, GC, SW, SM, SO, GP	Alb, A2-5, A3, A2-6
>50	Excellent	Base	GW, GM	A12, A2-4, A3

Sources: CBR Flexible Pavement Design Method for Airfield Vol. 104

CL = Clay of low plasticity, GCL = Very clayed gravel (clay of low plasticity, SML = Very silty sand, MI = Silt of intermediate plasticity, GC = Clay gravel poorly graded gravel – sand – clay mixture, ML = Inorganic silt and very fine sand, SP = Poorly grade sands gravelly sand. *Source:- After, Weltman & Head (1983).*

4.15 CAUSES OF ROAD FAILURE ON THE ZUBA – GWAGWALADA CARRIAGEWAY

A combination of environmental and mechanical factors led to the short-lived on Zuba – Gwagwalada carriageway. The most critical environmental factor lies in the weak operative strength of the sub-grad materials which cannot provide realistic mechanical support to applied load. The mechanical factor is concerned with over bearing traffic spectrum. Inadequate drainage structure and construction aberrations that undermined environmental limitation also contributed significantly to the non sustainability aspiration.

FEDERAL MINISTRY OF WORKS AND HOUSING
PAVEMENT EVALUATION UNIT KADUNA
COMBINED COMPACTION/C.B.R OR C.B.R TEST/MOISTURE CONTENT

DATE: OCT. 2007
OPERATOR: Messrs. Monday &
COMPACTION STANDARD B.S.C

SOIL: SUB - GRADE
JOB: ZUBA - GWAGWALADA
STABLIZER

CH 19 + 300 RHS

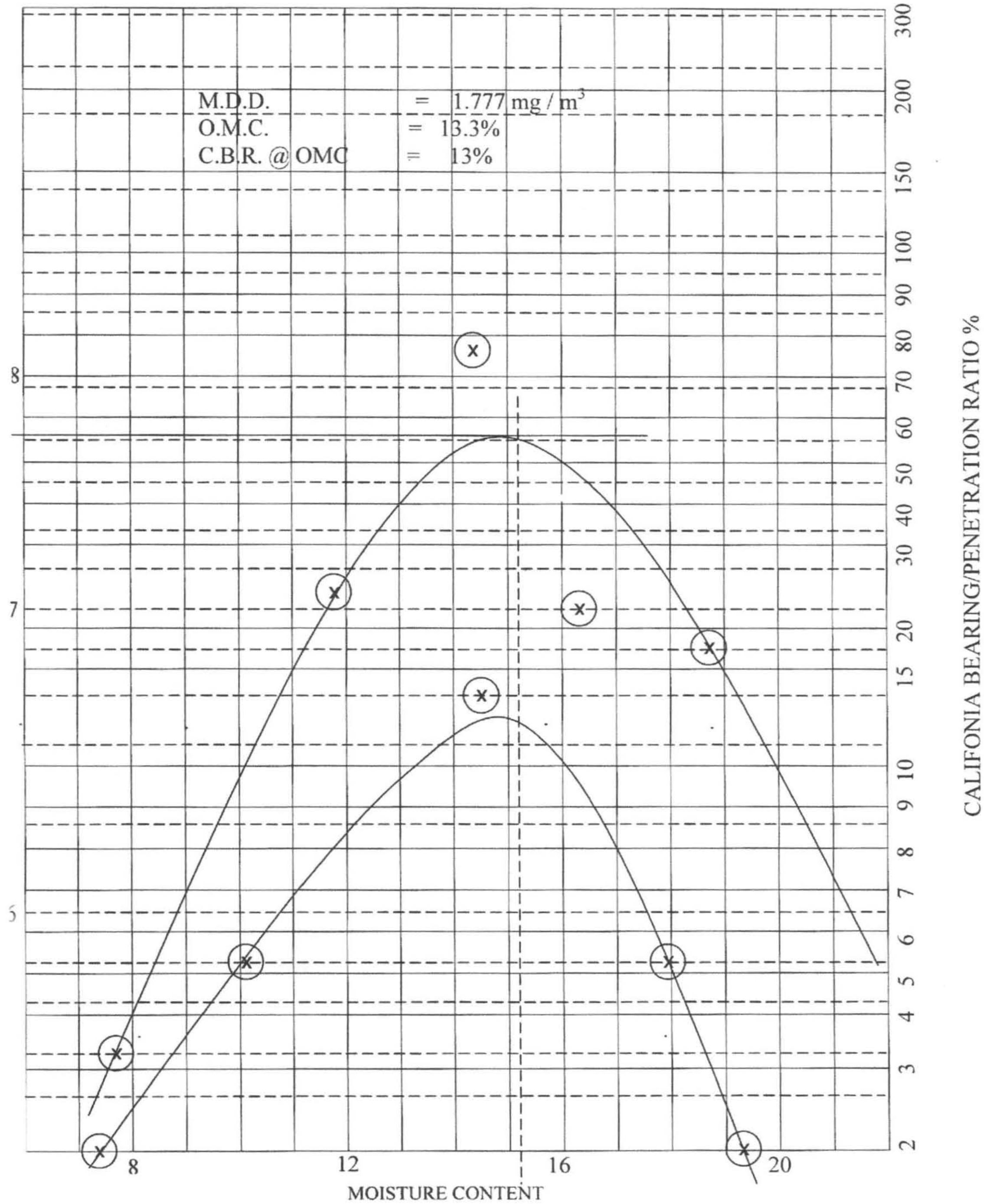


Fig. 4.12: California Bearing Ratio of 'Control cross section
Source; Author's fieldwork, 2007

flows from foot slopes through incised channels and thus generally lack prolonged retention thresholds that are normally associated with perennial Rivers. Two granite mining spots were identified but could not be matched with measurable mine fields which usually utilize industrial hammers that often trigger ground vibration and structural failures within vicinities. Only a 2m x 2m box culvert was identified within km 12 + 800, where the Wuye River crosses. This culvert seldom overtops the carriageway, especially after major rains because of inadequate capacity. It is unfortunate that despite the widespread run-off from legion of foot slopes within the undulated carriageway structure, drainage system were not installed to regulate the unprecedented coarse flows.

5.1.3 TRAFFIC SPECTRUM

The situational assessment of traffic spectrum along Zuba-Gwagwalada carriageway system in Table 4.4 and back-up graphic in Fig. 4.3i reflect an undesirable trend. Considering the recorded traffic spectrum in Fig. 4.3i during the period of the study and having taken account of all possible avenues of the current portrait, the Zuba - Gwagwalada carriageway is assumed to fall within road category D of the FMW Highway design manual. This category of carriageway unfortunately, was not originally designed for the present serviceability index.

It is also instructive to note that the Independent Reports of PTF Collaborative Study (1995) Volume Two on Federal Highways rehabilitation as well as the Chelsea College, London Monitoring and Assessment research Centre (MARC 2000) cautioned that "an undesirable level of axle load over prolonged period is capable of destroying carriageway structure prematurely. Aspect of the report also showed that an annual growth rate of 3.5 percent is ideal. But comparing current Nigeria's GNDP with average traffic output of 25,554 would suggest an annual average growth rate of 15 percent, which is an indication of tremendous strain on the Zuba – Gwagwalada carriageway.

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 DISCUSSION

5.1.1 Flexible Pavement Conditions

The span of carriageway cross sections investigated by this study was 19.3km, as supported by Fig4.1 while Table 4.1 and Fig 4.2 are specifications of their respective geometric values. It is not a full depth pavement which implies that the base as well as sub-grade upon which the flexible pavement rests is granular and never received major normative engineering works. Similarly, various forms of failures as vendored in plates xi – xiv were severe; notable among the failure manifestations are potholes, alligator cracks, raveling, surface deflections, shoulder erosion and base shears.

5.1.2 Influence of Environmental Attributes

Measurable environmental attributes that impacted negatively to the carriageway sustainability are natural and human – induced factors. Notable amongst the former is the high annual temperature range of 21^0c -26^0c, which acted in concert with an average annual rainfall of 1650mm to heralding bitumen oxidation and subsequently, leading to the flexible pavement disintegration, infiltration and localized base shears, as observed in Plates xi and xiii. The effects of human induced environmental hazards, as summarized in Table 4.3 are less significant but a general statement about them can only be offered in the foregoing.

From Table 4.3, a total of 18 sinkholes were identified within the 18.1km failed cross section, while none was identified within the 1.2km stable section, otherwise referred to as "the control unit". This level of sinkholes was occasioned by ephemeric surface water stress, which compelled natives to abstract alternative underground sources for multiple uses such as domestic, gardening and livestock needs. The four streams or water courses identified arose from coarse gravity

5.1.4 SOIL TYPES

The type and nature of local soils encountered as revealed by exsitu and insitu profiling in Figs 4.4i – 4.4ix and Plate xvii are summarized in the foregoing discussion. The freely drained sands and the inter-dunal pelagic soils constitute the major surface soils in the study area while the pallid and mottled clay form a major component of the sub-grade. In a semi-arid environment such as the Zuba – Gwagwalada, where the author carried out investigations on carriageway failure, moisture content drops appreciably during hot season, leading to extreme shrinkage. A contrasting effect of cell expansion is also experienced during wet season, resulting to prolonged heave, rutting, base shears, surface deflections and cracking. While these behavioural activities may not be noticed at all in the normal course, any structure such as carriageway that may be placed on such a soil will experience a hastened damage.

5.1.5 LOG CHARACTERISTICS OF SUB-GRADE ENGINEERING PROPERTIES

Table 4.5 indicates a summary of analytical results of sub-grade engineering properties within km1+200 – km19+300 of Zuba-Gwagwalada carriageway system. The key parameters investigated are Sieve analyses, Atterberg limits, Compaction tests and the California bearing ratio.

Results of sieve analyses in Table 4.5, as supported by graphical envelopes of Figs. 4.6 – 4.9 revealed two types of distribution curves. While Fig. 4.6 indicates a fairly graded distribution, Figs. 4.7 – 4-8 are marked by coarse voids which reflect very poor gradations. Most samples within the failed sections of Km1+120 – km16+900 tended towards this characteristics; an appreciably degree of normative engineering efforts would have to be effected in order to enhance their suitability competence for a sustainable carriageway structure. However, the 'control sections' of km16 + 900 – km19 + 300 in Fig 4.9 on the other hand, demonstrated appreciable degree of operative competence, which would require minimal routine maintenance in event of failure.

Furthermore, average results of Figs. 4.6 – 4.9 shows that for the same clay content or plasticity index within 8-29% and higher proportions of coarse sand experienced greater failure than those with higher proportions of silt. For instance, in decreasing the sand proportion in Fig. 4.7 from 90% to zero and in the same time, increasing its silt proportion from zero to 90% resulted in a major negative deviation from tolerable collapsible scale, measured under an applied pressure of $100kg/m^2$, which ranged between 5-10% for the range of the dry unit weights used.

Results of Atterberg limits of most sampled insitu materials in Table 4.4 fall within soils of A – 7 – 6 AASHTO classification. This observed group of A7- 6 is generally a rated poor plasticity index in comparison with the Federal Ministry of Transportation specifications in Table 4.5 which specifies average requirement of 50% mark for liquid limits and 30%, in the case of plastic limits. The observed sub-grade materials structural inadequacy would necessarily imply that an average of 20% granular materials would have to be introduced as stabilizing agent in order to regain optimum engineering values.

A summary of the compaction tests carried out on various remoulded samples from sub-grade materials are listed in Table 4.4; these results however, vary markedly from the central mark tendencies in Table 4.6. This would necessarily imply that high dry densities ranging from $1.617mg/m^3$ – $1.177mg/m^3$ are practically achievable at moisture contents ranging between 15% - 13.2%, under the West African Standard Compaction, which implies that, under field condition, an influence must be exerted at 15% - 13.2% moisture compaction threshold; in other words, at lower values of moisture content, the field soils would tend to resist compaction but an optimum increase in values would enhance ease of workability, that would result to the attainment of higher dry densities. In the alternative of extreme moisture content circumstance, the attainable dry density would decrease and thus increase volumetric content of moisture, which could possibly break down the aggregated structure into dilatic state. Compaction test is important in highway construction because it provides the criteria for sustainable mechanical support, permissible.

Results of CBR tests, as summarized in Table 4.8 generally indicate poor strength values for an economic pavement performance requirement of 71.30%. Thus, the derived range of 1 – 15% when weighed against unified specifications in Table 4.6 is a reflection of strength deficiency within the carriageway sub-grade structure, which undoubtedly accounted in part, to the short-lived performance of the carriageway. The 60-67% record in the control section validates its economic competence for carriageway projects, which, in part, explains why failure incidence within this cross section is much minimal.

5.2 SUMMARY

It has been established from the various results discussed under section 5.1 that the Zuba-Gwagwalada flexible pavement carriageway failure trend resulted from a number of factors. While the effects of local environmental hazards may be considered less significant, the effects of an overbearing traffic spectrum and the generally poor sub-grade engineering properties remain undoubtedly major factors that often hasten its failure trend. The bulked operative strength indices of sampled sub-grade materials in Table 4.4 are generally poor, weak and inadequate to provide the much desired mechanical support for major engineering projects such as carriageway flexible pavement overlay. This is true particularly, when laboratory results from failed cross-sections of Km1+200 – km17+500 were weighed against control point at Km19+300 as well as standard specifications of the Federal Ministry of Works and AASTHO. It was observed from this comparative result that, the Present Serviceability Index (PSI) of the latter, which served the same purpose of load bearing (traffic spectrum) and supposedly engineered to the same standards, was adequate as reflected by its measurable functional and structural efficiency, as well as foundation stability. The performance integrity of the former was marked by wide spread instability and failures as validated by measurable values from field and laboratory investigations. It would be logical therefore, to infer that these weak sub-grade engineering properties strongly exert enormous influence on the flexible pavement's premature failure or short-lived user services.

Perhaps, a further corroboration could be found in environmental science where, it is believed that in as much as engineering structures such as roads, buildings, dams, rail lines, airport runways, etc cetera that are founded on undisturbed or natural soil deposits could manifest a large variety of behavioural differences, even within a 10cm cross-sectional mapping. These behavioural variations under poor management system could influence either premature failure or underperformance of built structures, depending on the degree of uses, which they are put and design lifespan, as it is, in the case of Zuba-Gwagwalada carriageway system.

A combination of environmental and mechanical factors led to the short-lived failure trend experienced on Zuba – Gwagwalada carriageway. The most critical environmental factor lies in the weak operative strength of the sub-grade materials which cannot provide realistic mechanical support to applied loads. The mechanical factor is concerned with over bearing traffic spectrum. Inadequate drainage structures and construction aberrations that undermined environmental limitation also contributed significantly to the non sustainability aspiration

5.3 CONCLUSION

The conclusion drawn from this study therefore, is that, the premature failure incidence frequently experienced on Zuba - Gwagwalada carriageway resulted mostly from an intractable weak sub-grade that cannot provide adequate mechanical support for its overlain flexible pavement; other factors include overbearing traffic and to a less extent, environmental substrates such as temperature, rainfall, oxidation, construction aberration and poor drainage facilities. It would therefore, be practically impossible to rectify the constant flexible pavement failure to a sustainable standard without a carefully planned normative engineering design that takes cognizance of critical environment restoration need.

5.4 RECOMMENDATIONS

1. In weak sub-grade environment, where operative deficiency become overriding concern, such as the Zuba - Gwagwalada carriageway system, either of a three engineering treatments would restore effective bearing strength, as well as stability factor. One option is to lay a buoyant capping on top of the weak sub-grade with a 1-2% Portland cement aggregate before sub-base materials overlay. Other available options are either to increase the thickness of the sub-base or by complete soil lift interchange process. In either case, CBR values of the sub-grade as specified in Table 4.0.4 and 4.0.6 would be the guiding principle.
2. In the event of uncompromising degradation through mud flows, shale mobility and spout gullies, full-depth asphalt construction would be a better economic option because they are less susceptible to progressive deformation in unbound base layers and climatic vagaries.
3. In urban areas such as the Federal Capital Territory of Abuja, an inter-modal access, rather than a single route access should be employed; this consideration would however, necessitate the construction of multiple carriage lanes, preferably six, to accommodate the combined supplies of road ways and axle loads.
4. The growing demand for public infrastructures such as roads should prompt new approaches to their operations and management techniques, particularly in today's Nigeria, where rail transportation system is deficient. Private investors' concession mechanism would seem more desirable, as the capacity of government to construct, operate and maintain roads is becoming overwhelmingly saddled.

5. Regional transportation planning business requires a vast array of data acquisition on carriageway geometry, traffic density, travel demand, local environmental conditions, geology, service amenities, to mention but a few. A GIS technology is considered well suited to effectively enhance sustainability aspirations, as well as the sharing of transportation-related data needs.
6. Undesirable moisture content within carriageway sub-grade and base create cell pressures, which often entrain their operational efficiency. Drainage should therefore, be rapid as much as practicable first, by avoiding 'bathtub" design to prevent either rainfall or ground water accumulation within pavement layers. Secondly, the choice and application of good roadbed materials should remain a rule of thumb.
7. In development projects such as roads, contractors with pecuniary desires rather than service integrity should be sanctioned.
8. It is virtually impossible to rectify road failure to such a standard that deficiencies in operative strength, drainage aberrations or construction quality will not be compensated adequately. It is therefore, logical to adhere strictly, first, to guidelines provided by Environmental Assessors' report in order to prevent possible problems at early stages; secondly, to operational instructions provided by Geotechnical Engineers and thirdly, to maintenance schedule.
9. Since user - service demand on Zuba - Gwagwalada access route is a continuum, both medium and long term maintenance plans should be developed and enforced in order to maximize its full scale operational efficiency. Such contingency plan should examine bitumen chemistry in terms of stiffness, fatique and viscous mix ratio.
10. It would appear, therefore, to admit that while useful literatures exist on the subject of this study, it is equally necessary to acknowledge the need to

clarify and harmonize methodologies, and expand on the aspects covered by this study for technical completeness through multiple spatial examples.

11. Seers (1999) on "the meaning of Development" noted that "the effectiveness or otherwise of management plans depends on application, monitoring and evaluation of original design concept". It is therefore, necessary to constantly monitor live loads and the enforcement of such basic factors that are capable of influencing stress changes, original design concept, freight demands and state policy responsiveness. In the light of the foregoing therefore, axle load should be constantly monitored while spurred research and development as undertaken by this study should be sustained.
12. Although, the poor sub-grade relationships that yielded positively with flexible pavement failure under Zuba–Gwagwalada (FCT) local environment appear basically valid but more indepth study on asphalt versus temperature relationships is needed to establish their agreement.
13. In as much as the present study has indicated a number of necessary requirements for further investigations, one of the few more important areas should be the relative importance of mainstreaming Environmental development Planning and Management values into public infrastructures, and the less reliance on copy design from UK and the USA, in view of disparities in environmental conditions and indigenous development needs.

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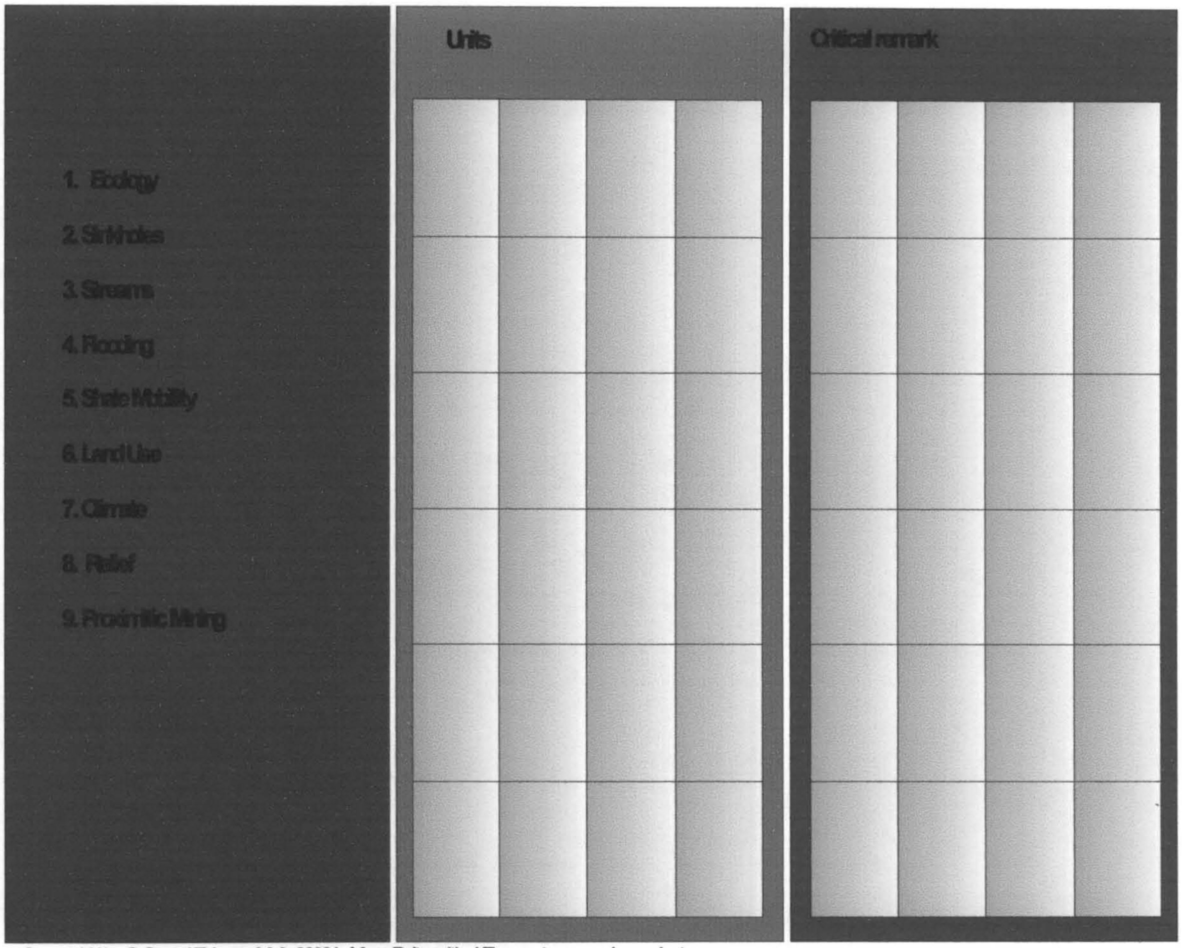
APPENDIX 3. 1

S/N | LOCATION | SCENARIO | MAGNITIDE | IMPACTED CONSTITUENT | DATE

MANAGEMENT CONTROL | FOOT NOTE | AUTHORITY

Environmental Damage Assessment Chart



Source: Wale, O.O. and Egbunu, M.A. 2006 in Niger Delta critical Eco-system mapping project.

APPENDIX 3.2

FORM A 1

CLASSIFIED TRAFFIC CENSUS	Location:				State:	Site No.
	Direction: From		to			
	Weather:	Day:		Date:		

Hour ending					
(I) Motorcycles and Autocycles					
(ii) Passenger cars and Loading Taxis					
(iii) Pick -up and other small commercials vehicles					
(iv) Two-Axle Lorries, Tippers etc					
(v) Buses, Coaches and Mammy Wagons					
(vi) Vehicles with more than Two Axles					
Hourly Totals					

Source: Federal Ministry of Works Classified Traffic Census

APPENDIX 3.3

FEDERAL MINISTRY OF TRANSPORTATION

PAVEMENT EVALUATION UNIT, KADUNA
DETERMINATION OF MOISTURE/DENSITY RELATION OF A SOIL TO SUB GRADE

Operator:.............................. Date:.. File:..............................

Location:

Test No	1		2		3					
Wt. of cylinder + wet soil. W_4 kg										
Wt. of cylinder W_5 kg										
Wt. of set soil $W_4 - W_5$ kg										
Wet. of soil density D^w Mg/M_3										
Container No.										
Wt of wet soil + container W/kg										
Wt of dried soil + container W/kg										
Wt of container W/kg										
Wt of moisture $W_1 - W_2$ kg										
Wt of dried soil $W_2 - W_2$ kg										
Moisture content m% (Av)										
Dry density D_s Mg/M^3										

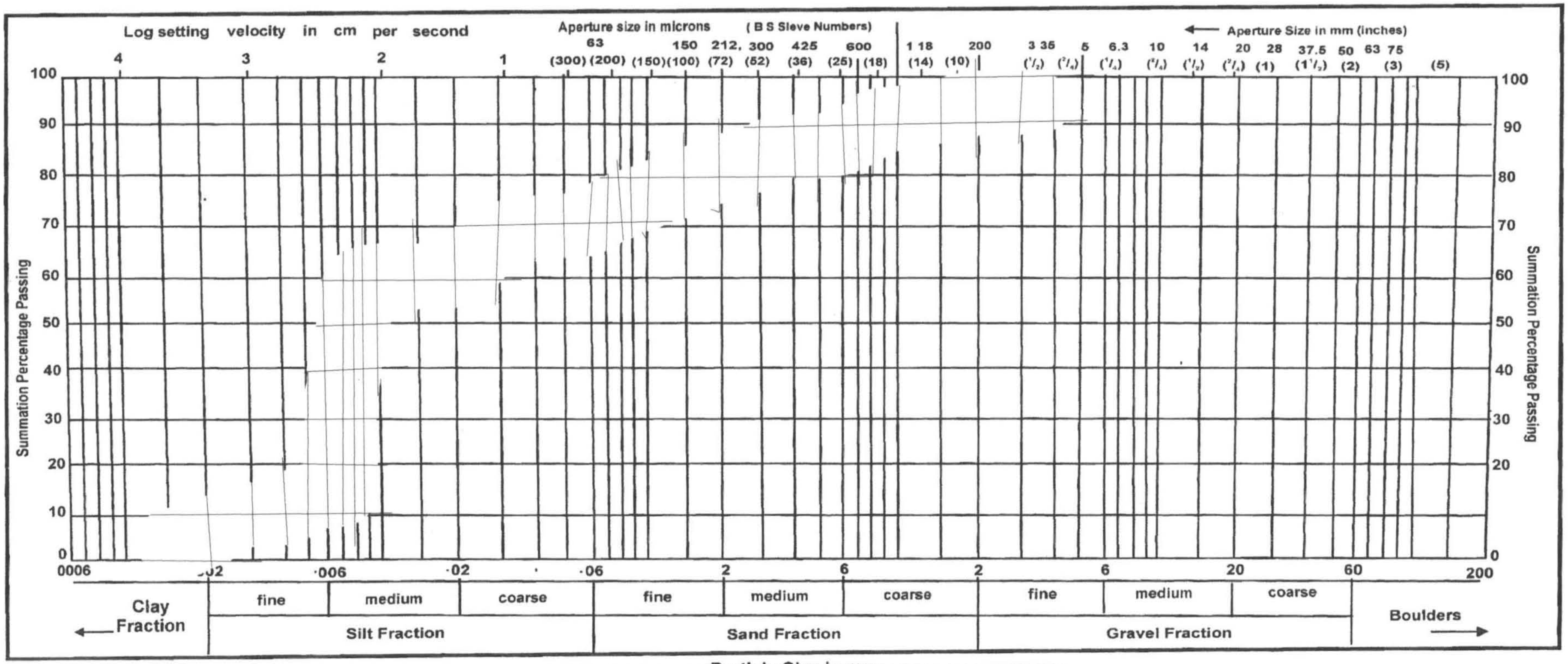
APPENDIX 3.4

FEDERAL MINISTRY OF TRANSPORTATION
PAVEMENT EVALUATION UNIT, KADUNA

Particle Size Distribution

Locatior.________________ Boring No________________ Sample No________________ Date of Test________________

Description________________________________



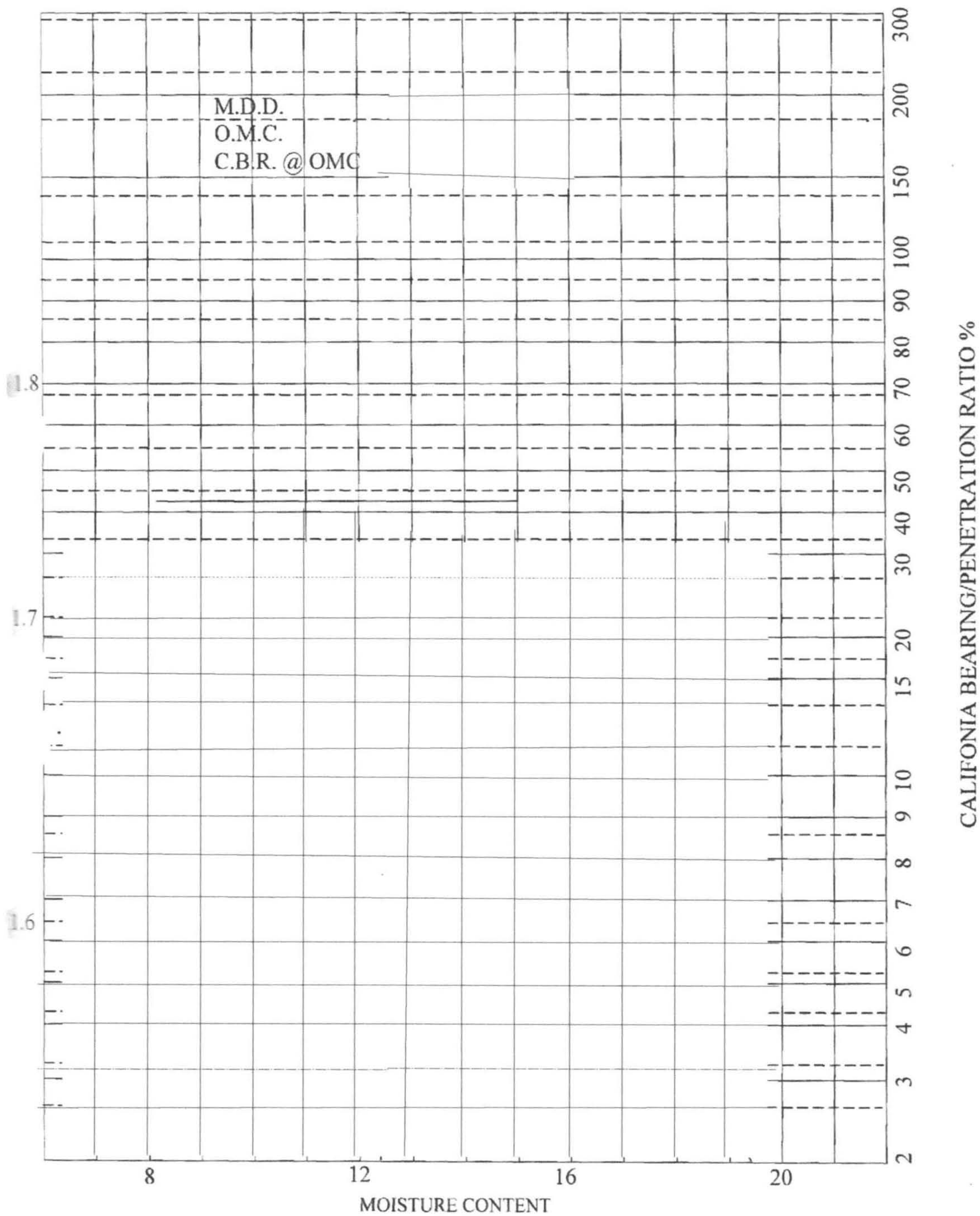
Particle Size in mm

APPENDIX 3.5

FEDERAL MINISTRY OF WORKS AND HOUSING
PAVEMENT EVALUATION UNIT KADUNA
COMBINED COMPACTION/C.B.R OR C.B.R TEST/MOISTURE CONTENT

DATE:
OPERATOR:
COMPACTION STANDARD B.S.C

SOIL: SUB - GRADE
JOB:



Appendix 4.1 Atterberg Limits of Failed Cross section

FEDERAL MINISTRY OF TRANSPORTATION

PAVEMENT EVALUATION UNIT, KADUNA
DETERMINATION OF MOISTURE/DENSITY
RELATION OF A SOIL TO SUB GRADE

Operator:...Messrs. DALHATU & CO.... Date:....OCT. 2007.................... File:STUDENT RESEARCH PROJECT

Location: Zuba-Gwagwalada Carriageway

Test No **1+ 200**	1		2		3					
Wt. of cylinder + wet soil. W_4 kg	89.70		90.85		92.75					
Wt. of cylinder W_5 kg	46	78	46	48	47	42				
Wt. of set soil $W_4 - W_5$ kg	42	92	44	37	45	33				
Wet. of soil density D^w Mg/M_3	1	86	1	93	1	96				
Container No.	A150	G43	B15	306	510	449				
Wt of wet soil + container W/kg	60.4	64.7	57.2	69.1	80.0	76.0				
Wt of dried soil + container W/kg	56.1	60.2	53.0	62.7	72.7	67.0				
Wt of container W/kg	16.7	16.8	16.6	16.8	16.8	16.6				
Wt of moisture $W_1 - W_2$ kg	4.3	4.5	4.2	4.4	7.3	9.0				
Wt of dried soil $W_2 - W_2$ kg	39.4	43.4	36.4	45.9	55.9	50.4				
Moisture content m% (Av)	10.9 10.4 10.6		12.9 13.9 13.4		13.1 17.9 15.5					
Dry density D_s Mg/M^3	1	68	1	70	1	69				

Appendix 4.2: Compaction Bearing Ratio of Failed cross Section

FEDERAL MINISTRY OF TRANSPORTATION

PAVEMENT EVALUATION UNIT, KADUNA
DETERMINATION OF MOISTURE/DENSITY
RELATION OF A SOIL TO SUB GRADE

Operator:...Messrs. DALHATU & CO.... Date:...OCT. 2007..................... File:STUDENT RESEARCH PROJECT

Location: Zuba-Gwagwalada Carriageway

Test No **6+ 350**	1		2		3		4			
Wt. of cylinder + wet soil. W_4 kg	89	75	94	25	94	45	94	25		
Wt. of cylinder W_5 kg	45	768	47	02	46	52	47	96		
Wt. of set soil $W_4 - W_5$ kg	43	99	47	23	47	93	46	29		
Wet. of soil density D^W Mg/M_3	1	91	2	05	2	08	2	01		
Container No.	A55	R44	A129	A6	A01	A164	K5	A49		
Wt of wet soil + container W/kg	77.7	79.6	46.2	61.7	59.4	59.6	63.3	62.4		
Wt of dried soil + container W/kg	73.8	75.1	43.4	57.5	54.4	54.0	57.8	56.2		
Wt of container W/kg	16.5	16.4	16.7	16.4	16.7	16.3	16.3	16.6		
Wt of moisture $W_1 - W_2$ kg	3.9	4.5	2.8	4.2	5.0	5.6	6.5	6.2		
Wt of dried soil $W_2 - W_2$ kg	57.3	58.7	26.7	41.1	37.7	37.7	41.5	39.6		
Moisture content m%	6.8	7.7	10.5	10.2	13.3	14.9	15.7	15.7		
(Av)	7.3		10.4		14.1		15.5			
Dry density D_s Mg/M^3	1	78	1	86	1	82	1	74		

FEDERAL MINISTRY OF TRANSPORTATION

PAVEMENT EVALUATION UNIT, KADUNA
DETERMINATION OF MOISTURE/DENSITY
RELATION OF A SOIL TO SUB GRADE

Operator:...Messrs. DALHATU & CO.... Date:...OCT. 2007.................... File:STUDENT RESEARCH PROJECT

Location: Zuba-Gwagwalada Carriageway

Test No **12+ 150**	1		2		3		4			
Wt. of cylinder + wet soil. W_4 kg	87	20	92	90	96	40	96	60		
Wt. of cylinder W_5 kg	46	40	47	48	47	86	49	02		
Wt. of set soil $W_4 - W_5$ kg	40	80	45	42	48	54	47	58		
Wet. of soil density D^w Mg/M_3	1	7	1	97	2	11	2	07		
Container No.	R710	307	R13	R32	B12	F6	B1	B23		
Wt of wet soil + container W/kg	75.1	66.0	55.2	68.2	58.3	56.7	55.8	67.1		
Wt of dried soil + container W/kg	71.3	63.2	50.9	57.1	53.0	51.6	50.2	60.1		
Wt of container W/kg	16.5	16.3	16.5	16.8	16.3	16.6	16.6	16.8		
Wt of moisture $W_1 - W_2$ kg	3.8	3.7	4.3	5.1	5.3	5.1	5.6	7.0		
Wt of dried soil $W_2 - W_2$ kg	54.8	46.9	34.4	40.3	36.7	35.0	33.6	43.3		
Moisture content %	6.9	7.9	15.5	12.7	14.4	14.6	16.7	16.2		
(Av)	7.4		12.6		14.5		16.5			
Dry density D_s Mg/M^3	1.65		1.75		1.84		1.78			