INVESTIGATION INTO THE MAJOR CAUSES OF PAVEMENT FAILURE IN IFITE ROAD.

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CERTIFICATION

This is to certify that this project topic titled "Investigation into the Major Causes of Pavement Failure in Ifite Road" was undertaken by Obidike Valentine Chukwuka with registration number (NAU/2017224016) in the Department of Civil Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.

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APPROVAL PAGE

This research work "Investigation into the Major Causes of Pavement Failure in Ifite Road" has been assessed and approved by department of civil engineering Nnamdi Azikiwe University.

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DEDICATION

This work is dedicated to Almighty God for the gift of life and also for guiding me through school. I also want to dedicate this work to my lovely Family who served as a real source of inspiration toward my academic pursuit.

ACKNOWLEDGEMENTS

Special thanks go to Almighty God for giving me the strength to complete this work and also for His guidance and protection throughout my sojourn in Nnamdi Azikiwe University.

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ABSTRACT

The study was undertaken to investigate the major causes of pavement failure in Ifite Road. Four samples of soils within the failed section of the pavement designated as A, B, C and D were subjected to geotechnical testing. The samples were collected along Miracle Junction, Yahoo Junction, Commissioner Quarters and First Market respectively. The geotechnical test that was performed on the samples are sieve analysis test, compaction and CBR test. Results obtained from sieve analysis test classified the samples as A-2 for samples A, C, D and A-4 for B, according to AASHTO Soil Classification System. The maximum dry unit weight of the samples were 16.90kN/m^3, 18.87kN/m^3, 17.30kN/m^3 and 15.84kN/m^3, the optimum moisture content of the samples were 12.08%, 12.53%, 11.17% and 14.21% respectively. The soaked CBR of the samples are for samples A, B, C, D respectively. The samples failed to meet the requirements given by Federal Ministry of Works and Housing, (1997) for use as sub-grade material. The study therefore concluded that poor geotechnical properties of the foundation soil is the major cause of failure along Ifite-Unizik Road Awka Anambra State, Nigeria.

Other factors like poor drainage, poor construction and poor maintenance also contributed pavement failure along the road.

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Road infrastructures are essential prerequisite for communication, social integration and economic developments (Akindele,2015). In Nigeria where roads account for more than 90% of Sthe movement of people, goods and services, road network are essential for national security (Akindele,2015). Roads transport gain popularity due to its ability to provide accessibility through door to door services and its suitability for short haulage of passengers and freight (Owolabi,2012). Roads transport is the most affordable and efficient means of transport to majority of people as other modes of transportation are either expensive relatively underdeveloped, thus resulting to rise in construction of roads. Consequently, there is an excessive axle loads which could be attributable to growth in traffic (Owolabi,2012). These excessive loads could induce substantial amount of stress on the road resulting to failures or distresses (Owolabi,2014).

Roads failures are discontinuity in a road pavement resulting in cracks, potholes, bulges and depression (Aigbedion,2017). According to (FMW& H,1997), failed roads are characterized by potholes, polishing/pavement surface wash, block and longitudinal cracks, drainage collapse, depression/ sinking of roadways, over flooding of the carriage way, gullies and trenches, rutting and raveling. Failures of highway pavement are a major experience which occurs on Nigeria roads (Osuolale, et al.,2012). The failure of highway pavement is dated back to the colonial period (Chukwueze,2015). These failures have been attributed to some factors such as properties of construction materials, sub-grade condition, environmental conditions, traffic condition, traffic loadings, lack of drainage and poor workmanship (Arumala and Akpokodje,2012; Jegede, 2014; Madedor,2014;Ogundipe,2008).

Ifite road is a one-lane single carriage way located at the outskirt of Nnamdi Azikiwe University Awka Anambra State Nigeria. The roads passes through places such as Yahoo Junction, Commissioner quarters, First and Second Markets terminating at a stepped terrain in Aroma.

These road majorly used by student and lecturers of Nnamdi Azikiwe University is characterized by severe pavement distresses ranging from large potholes, alligator cracking, collapse and clogging of drainage channels evident in regions especially Commissioner quarters and Second market. Occurrence of these failures is a major problem to both motorist and pedestrians as this failures could contribute significantly to loss of live, properties and human injuries through accidents, impedance of human movement and flow of economic activities, encouragement of armed robberies along affected regions, environmental pollution and degradation and a host of other negative consequences. Therefore, it is necessary to ascertain the major factors responsible for occurrence of failures along the road under consideration as this will serve as an aid in proffering solution to the major causes of failures along the road.

1.2 Statement of Problem

The growing loss in serviceability of Ifite road is a major concern to road users. Ifite road is characterized by severe pavement distresses ranging from large potholes, alligator cracking, and collapse and clogging of drainage channels evident in regions especially Commissioner Quarters and Second market. Occurrence of these failures is a major problem to both motorist and pedestrians as these failures could contribute significantly to loss of live, properties and human injuries through accidents, impedance of human movement and flow of economic activities, encouragement of armed robberies along affected regions, environmental pollution and degradation and a host of other negative consequences.

One of the foremost consequences of distresses present in Ifite road is the delay in travel time caused by reduction in vehicular speed. Travel time of student and lecturers of Nnamdi Azikiwe University Awka Anambra State have been adversely affected by the presence of this distresses particularly the deep crevice (potholes) present at Commissioner Quarters and Yahoo junction. These developments have resulted to poor service delivery on the part of the lecturers and non-attendance of students especially during important courses.

Notable of some of the effect is damage of essential part of both private and commercial vehicle. Presence of some of this distresses contribute significantly to damage of essential part of mobility aid resulting to commitment of huge amount of financial resources in their repair and maintenance. This situation is a cause to worry particularly to commercial vehicle owners as a result of reduction in their earning ability.

In other to avert continual deterioration of the road and its attendant consequence to road users, delay in academic activities of the neighboring university as a result of delay in travel time, it is extremely important that the major causes of these failures should be investigated.

Therefore, this study will investigate and proffer solutions to the major causes of pavement failures in Ifite road.

1.3 Aim and Objectives of Study

The aim of the study is investigation into the major causes of pavement failure in Ifite road while the objectives are:

1 To identify the type of structural failures commonly experienced along Ifite road.
2 To investigate into the causes of pavement failures.
3 Carry out geotechnical investigation of samples collected along the failed section of Ifite road.
4 Make recommendation on mitigation of identified road failure and the associated effects.

1.4 Scope of Study

This study will investigate the major causes of pavement failures in Ifite road and proffer solution to some of the identified causes. Disturbed samples of soils from failed section of the road will be collected and subjected to geotechnical investigation. Some of these investigations are: sieve analysis test, compaction and California bearing ratio test. The thickness of the existing pavement layers provided will be investigated. Investigation of the thickness of the existing pavement layers provided to withstand the present axle load will be done through redesigning of the pavement. The redesign of the pavement will involve conducting of traffic count survey so as to estimate the present traffic load and design of the pavement so as to specify the appropriate thickness capable of withstanding the present axle loads.

1.5 Significance of Study

Key findings obtained from investigation of the major cause of pavement failures in Ifite road will be significant in the following ways:

1. Mitigate accident, road side robbery and vehicular damage caused by the road failure.
2. Ensure pavement durability through improved service life.
3. Serve as a reference or body of knowledge for further studies or remedies of pavement distresses.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

Cities in the developing nations are not only showing a rapid population growth, but also a change in their residents' way of life. This obviously implies that there is a need for a corresponding expansion of infrastructures and services (Haile Mekonnen,2014). For the development of infrastructure in Ifite Awka, there has been a massive increase in funds allocated for road construction over the last decade. The background history of Ifite Awka roads in the 19th and 20th centuries show that there were many small roads, trails and foot paths whereas the construction of modern roads started by the end of the 19th century . Variations in road quality across countries reflect both fundamental economic and geographic conditions, as well as the influence of institutional design and financing flows. According to(Gwilliam,2008), GDP per capita is the factor most strongly correlated with the percentage of the main road network in good condition, reflecting effort devoted to the paved roads in the network.Climate and terrain, on the other hand, are the factors that best predict the percentage of the main and rural network in poor condition, because difficult climate and terrain speed the rate of deterioration. But, economic and geographic peculiarities do not explain all the variations in road quality across countries. Even controlling for income and climate, substantial variation can be seen in road quality across countries (Gwilliam, 2008).

Pavement deterioration is the process by which distresses develop in pavement under the combined effects of traffic loading and environmental conditions. Deterioration of pavement greatly affects serviceability, safety and riding quality of the road. After construction, roads deteriorate with age as a result of use and therefore, they need to be maintained to ensure that the requirements for safety, efficiency and durability are satisfied. Normally, new paved roads deteriorate very slowly in the first ten to fifteen years of their life, and then go on to deteriorate much more rapidly unless timely maintenance is undertaken. These deteriorations were contributed to many reasons such as excessive loads, climatic changes, poor drainage and low-quality pavement materials. The most common road distresses are cracks, potholes, rutting, raveling, depressions and damaged edges. These distresses affect the safety and riding quality on the pavement as they may lead to premature failure and traffic hazards. Before going into maintenance strategies, engineers must look into the causes of road deterioration.

Major Nigeria highways are known to fail shortly after construction, without performing its function before its design life, and have been traced to several factors. These include poor construction material, poor design and specification, road usage, poor drainage and geotechnical factors (Ebiloma and Rimtip,2019;Madu Uyaelumuo and Orji,2018).

The pavement structure is expected to posses' desirable characteristics for it to perform satisfactorily during its service life and this feature includes: adequate skid resistance, durability, favorable light reflecting characteristics, minimum noise pollution, good riding surface, long design life with low repair cost, and impermeable surface and structural efficiency Kadeyali,1997).

Pavement are usually composed of bitumen (binder), aggregate (crushed gravel and sand) and filler materials (quarry dust or stone dust) with the bitumen acting as the most chemically active and energetically expensive constituents while rigid pavement are composed of aggregate (sand and crushed rock), binder (cement), water and reinforcement with the cement acting as the most chemically active and energetically expensive constituents. Rigid pavement possess flexural rigidity such that the stress generated due to traffic load are not transferred from grain to grain to the lower layers but rather depends solely on the concrete slab which transfers the load to a wider area in accordance with the design. However, in flexible pavement wheel load transfer does not depend on the flexural strength but rather depends on the grain to grain contact of the aggregate (Kadeyali,1997). Therefore the flexural strength of flexible pavement is relatively low compared to that of the rigid pavement.

2.2 Flexible Pavement

Flexible pavement is one of the commonly constructed pavement structures due to its relative economy in construction and service life (Kadeyali,1997). In a flexible pavement, stresses generated by wheel load are transmitted to a lower layer (usually sub-grade) by grain to grain transfer mechanism as it does not rely on its flexural strength for load transfer. Flexible pavement consist of a bituminous surface placed over a layer of granular material and a layer of suitable mixture of fine and coarse aggregate resting on the natural compacted sub-grade acting as the pavement foundation (Kadeyali,1997). Flexible pavements are mostly of bituminous material acting as the binding agent such that it remains in contact with the underlying materials even when minor deficiencies occurs.

Flexible pavements are further divided into three subgroup namely: high type, intermediate and low type (Neeraj and Kumar,2019). High type pavements have surface course that sufficiently support the anticipated traffic load without visible distress due to fatigue and they are not vulnerable to unfavorable weather condition. Intermediate type pavements have surface course that moderately support anticipated traffic load with likelihood of the pavement developing distress and this mainly due to the quality of the treated surface as their treated surface are low compared to the high type pavements (Neeraj and Kumar,2019). Low type pavements are highly vulnerable to environmental conditions, marginally support expected traffic load with high possibility of distress been developed. This type of flexible pavement is used mainly for low cost roads and have wearing course ranging from untreated to loosed natural materials to surface treated earth.

2.2.1 Structural Component of Flexible Pavement

The structural component of a flexible pavement includes: sub-grade or prepared road bed, sub-base, base course and wearing course, all these components are superimposed on each other and perform distinct functions (Kadeyali,1997). The performance of each component largely dictates the performance of the flexible pavements and as a result proper evaluation of these components is required for effective pavement performance and service life.

2.2.1.1 Sub-grade

The sub-grade is one of the most important structural components of a flexible pavement. It is a natural compacted earth lying beneath other layers and act as interface between the pavement and the underlying soil (Kadeyali,1997). It is referred to as the pavement foundation as it transmits the expected traffic load to the underlying soil of sufficient bearing capacity. The sub-grade consists mainly of earth material and must be compacted to the desirable density, near the optimum moisture content. The strength and stiffness of the sub-grade considerably influences the performance of a pavement structure (Chandravali,2019). The stiffness is referred to as the degree of resistance upon loading and it depends primarily upon the soil properties, existing stress conditions and soil stress history (Susanka,2016).

2.2.1.2 Sub-base

The sub-base is a layer of material above the sub-grade and beneath the base course and they function primarily to provide structural support, improve drainage and reduce intrusion of fines from the sub-grade to the pavement structure (Kadeyali,1997). The structural capacity of the wearing course can be used to determine whether a sub-base can be dispensed with. If the pavement is constructed over a high quality wearing surface, stiff sub-grade may not require additional features offered by a sub-base layer and in such condition, sub-base may be dispensed with.

2.2.1.3 Base-course

The base-course is a layer of materials directly above the sub-base and beneath the wearing or surface course, it reduces the magnitude or intensity of the load transmitted to the underlying pavements layers (Kadeyali,1997). It provides additional load distribution mechanism and contributes to sub-surface drainage. It may be composed of crushed stone, crushed slug and other untreated or stabilized materials.

2.2.1.4 Wearing Course

Wearing course is a layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete. The functions and requirements of this layer are: It provides characteristics such as friction, smoothness, drainage. Also, it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade, it must be tough to resist the distortion under traffic and provide a smooth and skid resistant riding surface, it must be water proof to protect the entire base and sub-grade from the weakening effect of water.

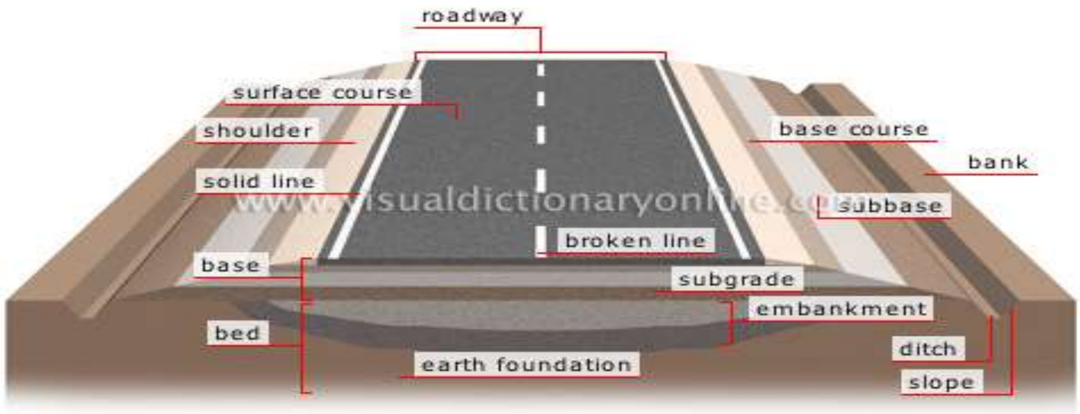


Plate 2.0: Components of Flexible Pavement (Neeraj and Kumar,2019).

2.3 Durability of Flexible Pavement

Flexible pavement consists mainly of layered materials which include the sub-grade, base course, sub-base and the surface course and the strength and durability of the pavement is largely dependent on the nature of the various components (Obeta and Njoku,2016). The sub-grade (regardless of the nature of frost susceptibility or fluctuation in water table) functions primarily as the pavement foundation providing a favorable platform for the construction of the pavement. The sub-base whether natural or stabilized with Portland cement, asphalt, lime, flyash, act as a support the base course, prevent the intrusion of fine grained sub-grade soil into the base course and ensuring the drainage of free water (Obeta and Njoku,2016). The base course which comprises chiefly of good quality aggregates (bound or unbound) provides an important portion of the structural capacity of the pavement bearing significant amount of the wheel load transmitted to it through the pavement surface and transferring this load to the underlying layers (sub-base) while the surface course typically made of asphaltic concrete (wearing course) withstand skidding, traffic abrasion and disintegration effect of climate Christopher et al (2006). It is therefore evident that the durability of pavement is affected by the nature of these materials expressed in terms of strength, moisture content, drainage and spatial variability.

The opposition of a pavement to weathering and abrasive action of traffic within its design life is used to gauge the durability of a pavement (Obeta and Njoku,2016). Depending on the factor of concern, it can be gauged using the thin-film oven test, rolling thin-film oven test, pressure ageing vessel method and concept of durability index from the Marshal test. With regards to asphalt paving materials, durability can also be defined as the resistance posed by these materials in the asphalt pavement structure to adverse effects of environmental conditions such as water, ageing and temperature variations for a lengthy period without any substantial deterioration while taking into account a given volume of traffic loading (Scholz and Brown,1996). Thus, pavement durability is also the measure of how asphalt binder physical properties change with age (age hardening).

Reactions such as oxidation, volatilization, polymerization, Thixotropy, syneresis and separation are closely associated with age hardening. According to Pavement interactive (2014), oxidation, a reaction of oxygen with asphalt binder, raises the viscosity of the binder making it more stiff and brittle while volatilization results in the evaporation of lighter components of the binder. Combination of like molecules to form larger molecule believed to cause progressive hardening is referred to as polymerization. Thixotropy which is a reversible reaction is thought to result from hydrophilic suspended particles that form a lattice structure throughout the asphalt binder while a form of bleeding which hardens the asphalt is termed syneresis.

2.4 Flexible Pavement Evaluation

Normally, the term pavement refers to the surface layer (M.T. Highway,2016). With respect to highway design, it refers to pavement overall thickness including wearing (surfacing) course, base course and sub-base course. It is hard and tough coating layered over the natural sub-grade in order to provide stable and leveled surface for vehicles. It is an arrangement comprising of superimposed layers of processed materials over the natural sub-grade which its main function is to transmit and distribute the vehicles' axle loads to the sub-grade. The structure of pavement should provide suitable riding quality surface, adequate skid resistance and least noise pollution (Mathew and Rao,2017).

Flexible pavement design is the process of selecting the most effectual and inexpensive composition of flexible pavement courses or layers (taking cognizance of the pavement thickness and type of selected materials and increasing traffic axle load to be carried and handled during the pavements' design life) to fit the sub-grade foundation (Shamil and Flamarz,2017). Flexible pavement structure design differs from building and bridges design owing of the fact that the design of pavement hitherto is based on semi-empirical or empirical method and there is no rationalistic design method. Flexible pavement design consists mainly from two steps or parts: Material mix design to be utilized in each course of pavement and pavement thickness design comprising of each layer of components (Shamil and Flamarz,2017).

The major factors to be given priority in the flexible pavement design are: Traffic volume, climate and weather conditions along the year, road geometric design, Position, sub-grade and drainage. Road repairs is one of the important components of the complete road system, repairs might still be required regardless of the quality of highway design and construction, the degree of repairs might depend on several factors which include pavement type (Sorum et al.,2014). Pavement failure and deterioration process starts immediately during vehicular usage, the failure and deterioration process starts very slowly therefore, it may not be visible and over the time it get faster and accelerates at quicker rates. Implementing effective and efficient technique in planning, designing, construction and maintenance of highway pavement can aid in reducing pavement failures and deterioration, this can be achieved through testing and inspection of early failures in pavements (Shamil and Flamarz,2017). Through the determination of causes of failure and deterioration, future reoccurrence can be prevented. The main understanding of flexible failures which can be derived from thorough assessment and inquiry could be important in reducing the costs related to pavement failures and deterioration in the future. In many cases, the failure and deterioration of flexible pavement structure can be directly supported by inadequate maintenance and inadequate programs of assessment. Under a limited budget, it is very paramount to reduce the maintenance costs. For the mentioned purpose, it is necessary to consider and select a simple way or method for inspection and assessment of flexible pavement failures (Zumrawi,2015).

Joint action of traffic load volume and load, weather conditions and changes, drainage and environmental agent are generally responsible for Flexible pavement failure and deterioration.

Generally the flexible pavement fails and deteriorates at very fast rate when compared to rigid pavement because the foregoing factors. Flexible pavement may continually fail and deteriorate under severe exposure to harsh weather and other environmental factors even in the absence of traffic load. Rate of failure and deterioration of flexible pavement rapidly increase with more water retained within the void spaces of the pavement layers. Oxidation and aging of asphalt binder also lead to the failure and deterioration of the asphalt surfacing (M.T. Highway,2016).

2.5 Factors Influencing Performance of Flexible Pavement

The principal factors affecting flexible pavement performance (Adlinge and Gupta,2004) include:

2.5.1 Traffic Volume and Load

It is the most important and leading factor affecting flexible pavement performance. The flexible pavement performance is majorly affected by the traffic loading intensity, loading arrangement and heavy vehicles load repetitions number (Adlinge and Gupta,2004).

2.5.2 Moisture

Moisture substantially affect the flexible pavement by weakening the natural gravel materials particularly the sub-grade support strength (Adlinge and Gupta,2004). Moisture enters the flexible pavement structure through voids and cracks in pavement surface, laterally through sub-grade soil and from the water table by the action of capillary (Adlinge and Gupta,2004). The results of moisture entry are lubrication of particles, interlock loss between the particles and later particles, displacement which cause flexible pavement failure and deterioration.

2.5.3 Sub-Grade Soil

Sub-grade is the natural compacted underlying soil that support and handle the applied vehicles wheel loads. Very weak sub-grade will fail to support and handle the vehicles wheel loads, which cause the pavement to deform resulting to eventual failure of the flexible pavement (Adlinge and Gupta,2004). If the flexible pavement designer fails to take into account the difference in natural composition of sub-grade soil, significant discrepancy in the flexible pavement performance will be observed.

2.5.4 Construction Quality

Failure to provide sufficient compaction, unsuitable moisture content or conditions during the pavement construction, materials quality, and providing accurate flexible pavement layers thickness (after completion of compaction) will have direct effect on the performance of the flexible pavement (Adlinge and Gupta,2004). It is absolutely important to provide competent staff, good and adequate inspection and effective quality control during construction.

2.5.5 Maintenance

Irrespective of how sound a flexible pavement is designed and constructed, it will start to deteriorate and fail over time (Adlinge and Gupta,2004). The performance of flexible pavement depends on what type of maintenance, when to be done and approach employed.

2.5.6 Environmental Factors

Climatic factors, particularly temperature and moisture influence the performance of flexible pavements (Adlinge and Gupta,2004). These factors over time have been considered in pavement design and practice because they may change the deterioration of pavement materials and stiffness, thus affecting pavement performance. For instance, the choice of asphalt binder is very much related to local temperature conditions to satisfy structural and functional requirements. Although proper design of a pavement includes consideration of climatic factors, distresses caused by the environment are unavoidable and occasionally vital. Researchers have studied the impact of climate on pavement performance, (Tighe et al.,2008) performed an analysis on flexible pavements in Canada and proposed that deterioration in rutting, longitudinal cracking, and fatigue (alligator) cracking will be accelerated by climate change. (Kim et al.,2005), discovered that climatic factors affect transverse cracking on flexible pavements. In addition, the results for the international roughness index (IRI) are inconclusive; although some researchers have found it to be susceptible to climate change (Graves and Mahboub,2016), others proposed that the IRI is not susceptible to climate change (Kim et al.,2005). In most studies, climate was only represented by a general climate (e.g., combination of temperature, precipitation, and other climate factors), and thus it is relatively unknown which climatic inputs caused the major differences in the results and which were less important. A recent study conducted by (Byram et al.,2012) ascertained that temperature is the most influential factor for flexible pavements (Byram et al.,2012).

Pavement temperature is believed to have an impact on asphalt rutting, age hardening, and thermal cracking (Willway and Baldachin,2012). Due to the viscos-elastic nature of bituminous binders, temperature plays an important role in the stiffness and rutting performance of asphalt pavement. Increased asphalt rutting is expected under greater asphalt temperatures, especially when the traffic volume is large and the traffic speed is slow. Nevertheless, the effect of temperature is smaller on rutting in granular materials and sub-grade soil. Flexible pavements are more prone to age hardening under increased pavement temperature (Ishai,1987). Age hardening is undesirable on the road surface because it can reduce the ability of the pavement to flex under traffic (Ishai,1987). As a result of age hardening, the asphalt surface becomes brittle and vulnerable to cracking. When pavements cool, cracking begins to propagate because of thermal tensile stress. In general, there are two different types of thermal cracking: low-temperature transverse cracking and thermal fatigue cracking. The former is caused by the shrinkage of asphalt because of cold extremes, whereas the latter results from asphalt aging and residual stress because of a large number of loading cycles.

2.6 Classification of Nigeria Roads

Nigeria has about 200,000 km of roads spread all over the country (CBN,2010). These roads are made up of over 32,000km of federal roads spread over the thirty six states and the federal capital; over 30,000 km of state roads and over 130,000 km of local government roads (see Table 2.0). Within the states, the local government roads are further classified into urban and rural roads.

Table 2.0: Road Ownership in Nigeria Shown by Distance Covered CBN (2010).

Members	Federal (km)	State Road (km)	Local Government Roads (km)	Total	Percentage (%)
Paved main	26,500	10,400		36,900	19%

roads					
Unpaid main roads	5,600	20,100		25,700	13%
Urban roads			21,900	21,900	11%
Main rural roads			72,800	72,800	38%
Village access roads			35,900	35,900	19%
Total	32,100	30,500	130,600	193,200	100%
Percentage	17%	16%	67%	100%	

2.6.1 Federal Roads

In one of its publications in June 2011, the federal ministry of works reported that it had over thirty five thousand kilometers of federal roads and bridges in the thirty six states of the federation and the federal capital territory, Abuja. These roads are divided into the federal trunk 'A' roads and the federal trunk 'F' roads. The federal trunk 'A' roads are those under the federal government ownership and they are developed and maintained by the federal government while the federal trunk 'F' roads are those that were formerly under the state ownership, but were taken over by the federal government, with a view to upgrading them to federal highway standards (Nnanna et al. ,2003). The faults on most of the Nigerian federal roads are; depressions on the road surfaces, presence of pot holes and cracks, development of gulley due to erosion, washing away of the road shoulders, faulty street lights, faulty drainage systems , faulty traffic signals and wiping off of pavement markings.

2.6.2 State Roads

The state roads are classified as the state trunk 'B' roads. These are the roads under the ownership and management of the various state governments.

2.6.3 Local Government Roads

These are classified as the local government trunk 'C' roads. They are the roads under the ownership and management of the local governments in the country. These roads are divided into the urban, rural and village access roads.

2.6.4 Urban Roads

In Nigeria, these are the roads that are in the urban areas. They account for over twenty one kilometers of Nigerian roads. They include township streets, lanes, cul-de-sac and avenues. Most of these roads are tarred while some are still un-tarred. In the state capitals the advanced urban roads possess traffic facilities like street lights, drainage facilities, pavement markings and traffic signals. In this country, the main faults on most of our urban roads are almost the same as the ones on the federal and state roads; they are; depressions on the road surfaces, presence of pot holes and cracks, development of gulley due to erosion, washing away of the road shoulders, faulty street lights, faulty drainage systems, faulty traffic signals and wiping off of pavement markings.

2.6.5 Rural Roads

In Nigeria, rural roads account for over 72,000 km of roads in the country. These are roads that are found in the remote country parts of the nation. They are mainly earth roads, but with recent developments in the rural areas some of them are now lightly tarred. Here, most of the faults on our urban roads are also available on our rural roads. Faults like the depression of the road surfaces, presence of potholes, cracks, gulley and the wearing away of the road surfaces are rampant.

2.6.6 Village Access Roads

In the local governments these are minor roads that provide access within the various villages we have in the country. They are mainly earth roads. The level of under development of these roads reduces them to the level of foot paths. The village access roads account for 35000km of Nigerian roads.

2.7 Review of Types of Road Failures

Pavement distress can be classified as follows:

2.7.1 Alligator Cracking

Alligator cracking are series of interconnected cracks caused by fatigue failure of the hot mix asphalt surface under repeated traffic loading (Mehedi and Mohd,2020). As the number and magnitude of loads increases, longitudinal cracks begin to develop and after repeated loading, these longitudinal cracks connect forming many sided-angled pieces that develop into a pattern which takes the shape of an alligator or crocodile (Mehedi and Mohd,2020). This cracking is likely due to infiltration of water into the pavement.

Plate 2.1 : Alligator Mapping Along Commissioner Quarters Ifite Road.

2.7.2 Transverse Cracking

These are cracks perpendicular to the pavement centerline Mehedi and Mohd (2020). This cracks are caused by shrinkage of hot mix asphalt surface due to low temperature or asphalt binder hardening, it is also referred to as thermal cracking.

Plate 2.2: Photograph of Transverse Cracking (source:Field)

2.7.3 Block Cracking

This cracking is mainly caused by shrinkage of the asphalt concrete and daily temperature cycling and it is not load associated (Mehedi and Mohd ,2020). The occurrence of block cracking usually indicates that the asphalt has hardened significantly. This cracking usually occurs over a large portion of pavement area.

Plate 2.3: Photograph of Block Cracking (Mehedi and Mohd,2020).

2.7.4 Longitudinal Cracking

These are cracking that occurs in the surface of road and runs lengthwise along the pavement. It can consist of a single crack or as a series of parallel cracks. This crack occurs as a result of asphalt hardening, diurnal temperature fluctuations and reflection of a crack or joint in the road pavement (Mehedi and Mohd,2020).

Plate 2.4: Photograph of Longitudinal Cracking (Mehedi and Mohd,2020).

2.7.5 Slippage Cracking

Due to poor bonding between pavement layers, slippage cracking appears as crescent-shaped (half-moon) or wave-like cracking (Mehedi and Mohd,2020). This type of pavement can be caused by poor bonding of material with an underlying layer or a low strength surface mix and may be exacerbated by continual traffic breaking or wheel turning (Mehedi and Mohd,2020). This cracking create rough riding surface, voids and bulges and will begin incurring heavier and heavier impact forces from traffic, which will increase the damage. This will cause potentially larger damage subsequently; especially as water channeling and penetration damage the pavement base and advance the deterioration.

Plate 2.5: Photograph of Slippage Cracking (Mehedi and Mohd,2020).

2.7.6 Corrugating and Shoving

Corrugation and shoving are two defects that usually occur in flexible pavements. It is caused by weak sub-grade conditions, improper rolling, poor mixing, temperature effect of bitumen and weak bottom layers (Mehedi and Mohd,2020). Corrugation is characterized by formation of ripples or waves on the flexible pavement generally perpendicular to the traffic flow. It occurs at the points where traffic starts and stops.

Plate 2.6: Photograph of Corrugation and Shoving (Mehedi and Mohd,2020).

2.7.7 Potholes

A pothole is a defect created on the road surface as a result of the primary failure in the asphalt pavement used in road making, which leads to the structural failure of the road surface (Mehedi and Mohd,2020). The asphalt pavement failure occurs due to the presence of water in the underlying soil structure and the presence of traffic passing over the affected area on the road (Mehedi and Mohd,2020). The water in the underlying soil structure can come from floods, underground erosions or cracks from the road surface.

Plate 2.7: Photograph of Pothole along miracle junction ifite road (source: Field).

2.7.8 Raveling

Raveling refers to the progressive disintegration of hot mix asphalt layer from the surface downward as a result of the dislodgement of aggregate particles (Mehedi and Mohd,2020). It is caused by loss of bond between aggregate particles and the asphalt binder as a result of dust coating on the aggregate particle particles that forces the asphalt binder to bond with the dust rather than the aggregate, it is also caused by aggregate separation where the fine particle are missing from the aggregate matrix, then the asphalt binder is only able to bind the remaining coarse particles at their relatively few contact points. Inadequate compaction during construction also causes raveling as high density are required to develop sufficient cohesion within the hot mix asphalt.

Plate 2.8: Photograph of Raveling (Mehedi and Mohd,2020).

2.7.9 Depression

Depressions are localized pavement surface with slightly lower elevations than the surrounding pavement (Mehedi and Mohd,2020). They are very noticeable after infiltration of water as a result of rainfall; they are caused by frost heave, uneven sub-base or sub-grade settlement resulting from inadequate compaction during construction (Mehedi and Mohd,2020). Depression can be repaired by removing the affected pavement then digging out and replacing the area of poor sub-grade patch over the repaired sub-grade.

Plate 2.9: Photograph of Depression 9Mehedi and Mohd,2020).

2.7.10 Water Bleeding

Water bleeding of pavement occurs when water seeps out of joints or cracks or through an excessively porous hot mix asphalt layer, it is caused by inadequate compaction during construction or poor mix design, high water table and poor drainage, low air void content (Mehedi and Mohd, 2020).

Plate 2.10: Photograph of Water Bleeding (Mehedi and Mohd ,2020).

2.7.11 Rutting

A rut is a permanent longitudinal surface depression that occurs in the wheel paths of a flexible pavement due to the passage of traffic (Mehedi and Mohd,2020). Ruts accumulate incrementally with traffic volume; rut depth at any location is measured as the vertical distance between the top of the heave and the bottom of the depression, rut are caused primarily by asphalt layer problems, structural layer problems and weak sub-grade problems (Mehedi and Mohd,2020).

Plate 2.11: Photograph of Rutting (Mehedi and Mohd,2020).

2.8 Causes of Highway Failures

Below are some of the major causes of highway failures:

2.8.1 Poor Design and Construction

(Paul and Radnor,2012) in their work titled "Highway Engineering" stated that road design involves more than substituting data or taking values from a design chart, they also argued that many design methods in use are either entirely or partially empirical and may not give the desired result unless prior knowledge of the environment is known and rooms for adjustment in design created during construction. They disclosed that this has been discovered from many experimental roads. In addition they pointed out that all over the world, despite the level of technology; the numbers of design methods available have no hard and fast rule attached to them in designing flexible pavement.

(Abynayaka,2008) who worked on the prediction of road construction failure in developing countries, reasoned the same way with (Paul and Radnor,2012) by attributing faulty design to the fact that tests under which the specification for materials and equipment to be used are based and performed are in different environments. Again, he stated that there is a tendency of under-forecasting of the of traffic volume due to the developing nature of towns and cities in developing countries. Consequently this may result to under design and hence possible over stressing of the road pavement structure and eventually failure. They further disclosed that in Nigeria, award of contracts is most of the times based on no special ethics but on compassionate grounds. Thus constructions of roads, they said, are put in the hands of people with little or not technical know-how and hence early failure of roads. He further disclosed that majority of the specifications for a particular road contract is ignored during construction. This is for the contractor to maximize profit as against producing good quality road with longer life span. He particularly described how the dimension for roadways, pavement thickness and requirements for asphalt mixes are reduced in order to make profit ad save time in some Nigerian roads.

Failures like cracking in rigid pavement are caused by inadequate curing of concrete, settlement, movement or restraint at joints may also lead to the development of cracks and subsequent failure. Most of the roads in the country are designed in the ministries or by consultants some of who are not within the environment of the road work. This leads to a situation where preliminary studies of the environment that will help the design and construction decisions are not done. This leads to poor understanding of the road environment which subsequently leads to poor road design and construction. (Oguara,2010), then said that to save the road network from total collapse, requires good and efficient management which had to be done in a pragmatic and organized frame work.

2.8.2 Poor Geotechnical Characteristics of Soil Samples.

(Oglesby, Clarkson and Gary,1982) in their description of the characteristics of soils for highway pavements, denoted that it is very important to understand the basement soil (or sub-grade) and other materials used in construction of pavement structures for highways and other transportation facilities as the sub-grade is the supporting structure upon which the pavement surface and its special under courses rests and both the sub-grade and these special under courses (Base course, sub-base and wearing course) are of rock origin. According to them, the moisture content and moisture irrigation in soils is a function of the Geologic makeup (the sedimentology: texture and structure, porosity & permeability etc) of the sub-grade soil and the moisture water content and migration characteristics of the soil mass and it's reaction to water affects it's strength and this is a function of its grain size and mineralogy.

(Gidigasu ,1983), in his review suggested that inadequate width of the shoulders which provide lateral support to the pavement would also lead to road failure especially when the shoulders are made of cohesive soils and worst still, when such soil are not properly compacted. Penetration of rain water during the wet season and higher water table weakens the material in the road pavement and during the dry season evaporation of soil water from the clayey shoulder material causes soil moisture suction under the road, both conditions tends to increase the deterioration of the pavement.

(Graham and Shields,1984) investigated the complex properties of postglacial clay at Winnipeg in Canada. After sampling and laboratory analysis, the geotechnical properties of this clay were confirmed to be troublesome causing major negative impacts on civil engineering structures and construction in the city. The identified problems include; house foundation movements, low stability of riverbanks, poor highway pavement performance, difficult excavation, and a high incidence of water main breaks.

(Jegede,1997) investigated a case of long-term and frequent highway pavement failure induced by poor soil properties, at a locality along the F209 highway at Ado-Ekiti. After the laboratory soil mechanics tests carried out on the disturbed soil samples collected from the failed sections of the road identified poor soil bearing capacity, poor Sub-grade quality of materials like kaolinite and montemorrilonite (clays) as the root of the problem.

(Okagbue and Uma,1988) in their geological and hydro-geological survey of a problematic section of the Port- Harcourt- Enugu expressway, covering Lokpaukwu, Lokpanta and Leru areas, were able to prove that the road problem is linked to the geological and hydro-geological conditions of the area. As it was evident that the problematic section of the road is built on a considerably jointed, fractured and weathered shale formation as a sub grade, at the foot of an escarpment having a high concentration of natural groundwater discharge resulting in increased groundwater storage, high water table, constant wetting of pavement Sub-grade and subsequent deterioration. (Alexander and Maxwell,1996) worked on controlling shrinkages cracking from expansive clay sub-grades. They pointed out that pavements built on sub-grades of expansive clay soils are affected by volume changes through seasoned wetting and drying cycles. These clays are highly reactive to moisture which results in clays showing significant volume change as a direct result of moisture content variation.

2.8.3 Poor Maintenance Operations/Functions

According to (Paul and Radnor ,2012), road maintenance includes physical maintenance, activities such as patching, filling of joints, moving, and also traffic services like painting, pavement markings, erecting signs and litter control. However, the Asphalt Institute (1976) in her manual series disclosed that road maintenance is limited and the maintenance man is does is just to make one dollar out of two dollar worth of job; this is not good and safe for our roads.

(John and Gordon,2014) in their engineering manual captioned “A practical Guide to Earth Road Construction and Maintenance”, noted that each road in which the natural soil is used as a running surface is not easy to maintain, particularly during the rainy season due to slippery surfaces, tendency to form corrugations that transverse the road or longitudinal rutting. They were also of the opinion that the need for road maintenance arises when the road develops cracks, raveling or twisting pavement surface.

Even if the roads are well built they need adequate maintenance for sustainability. One of the main problems of highway development in Nigeria is maintenance. The roads are rarely maintained and whenever maintenance is attempted it is done haphazardly. According to (Oguara ,2010), the financing of the maintenance, rehabilitation and conservation of the roads network in Nigeria had always been left to the government at the federal, state and local government levels who because of their lack of maintenance culture do not release funds for road maintenance at the appropriate time. The road network was therefore left to deteriorate to the extent that portion

s of the federal trunk A roads became impassable. (Igomu,2011) stated that roads world wide were considered critical infrastructure in any nation's life and were paid premium attention. He said that was not the case with Nigeria, as many of the roads had exceeded their structural life and had become huge slaughter slabs as they had been denied all forms of maintenance. Adequate fund are not budgeted for maintenance in Nigeria. Budgetary process is cumbersome and agencies in charge of maintenance are not well monitored for efficient work.

2.8.4 Traffic Effects and Human Impacts on Roads

According to (Paul and Radnor,2012) Traffic causes stress on road pavement as well as accelerating the distress caused by other factors. They are of the view that increased traffic flow repeatedly leads the road surface and the amount of pavement deformation increases as the number of load application increases.

Similarly, the Anambra state Ministry of Works and Housing (ANSMWH), (1998) attributed road failure to human impacts on the roads. It was disclosed that corporate bodies like power Holding Company of Nigeria (PHCN), Nigerian Telecommunication (NITEL), Water Corporation, etc. impact the roads without proper repair. It was stated that for example Water Corporation, in an attempt to lay down water pipes for water supply to the consumers cut across the road and when the road is reinstalled the job will not be well done, thus leading to road pavement distress and causing discomfort to road users. It was clear that this indiscriminate cutting across the roads results to complete road failures in the long run.

(Ibrahim,2011), a Nigerian Daily Times Online reporter, reported an interaction with the head of the Federal Road Maintenance Agency (FERMA), in Jos on the 30th day of May 2011, Mr. Ifeanyi Nweke, who commented that "One other challenge is knowing the causes of the failure of our roads, considering the quantum of loads that ply the roads on a daily basis". Our roads are constructed not to carry loads above 42 tones but the failure of our rail system has made it imperative for the transporters to carry goods above what is expected," he said. He thus called for the re-introduction of weigh-bridges on the roads to put a check on road users who carry goods beyond the limit. "Besides, many of these roads were constructed a long time ago and cannot stand the kind of weight being carried on them on daily basis. If the Federal Government re-introduces the system, more revenue will be generated from law-breakers who will be taxed for the extra loads they carry.

2.8.5 Environmental and Climatic Factors

(Paul and Radnor,2012) pointed out that most of the defects credited to traffic are actually initiated by environmental and climatic factors, and are later developed by traffic. According to the shrinkage cracks which sometimes occur initially at the underside of a road pavement due to temperature and moisture changes are often found to increase in size on the last load applied to it by traffic. They concluded that temperature change, moisture differences and soil characteristic, which vary in different regions, contribute to the problems of road failure.

TRRL (1991) in a report on road research disclosed that climatic factors can also affect the strength of road structure. It was stated that temperature fluctuation and acid rain attack on the base material of the road in waterlogged areas can weaken the sub-base of the road materials through capillary action, thereby reducing the supporting power of the road pavement.

(World Bank,1991) in a paper titled “Nigeria Highway Sector Study” supported the view of TRRL (1991). Here it was stated that in some parts of Nigeria, temperature could rise as high as 350c in the day time and as low as 250c at Night. This fluctuation in temperature, according to it, induces stress on the road pavement. This results in cracking of poorly mixed asphalted road pavements. It was further stated that this high temperature could reduce the bond stiffness of the surface of the flexible road pavement leading to rutting under traffic. This means road failure Abynayaka (2008) stated that when roads are poorly drained, such factors like erosion can take place leading to ejection of materials out of the road pavement.

2.9 Effect of Highway Failures

Deformation affects the safety and riding quality on the pavement as it may lead to water bleeding thus increasing the chance of aquaplaning and is a traffic hazard. Cracking just like inadequate joint sealant allow water to penetrate into the sub base and the sub grade and tends to soften the sub base and the sub grade. The water most of the time tends to weaken the soil and in rigid pavement tend to rust the reinforcement. Some of the main effects are enumerated below:

2.9.1 Accidents

The rate of accident on Nigerian roads due to the nature of the road is alarming. (Obi,2010) puts it this way 'As the land becomes increasing restive because of the constant spillage of blood on Lagos roads, residence of the city are rising up to say, enough is enough.' He stated that driving on Lagos roads, especially on the express roads, was becoming increasingly dangerous. Hardly did a day pass without a truck induced accident. It was either a petrol tanker collided with a car, exploded and hundred were burnt or a car runs into a parked trailer and lives were lost.

World health organization said that Nigeria had the world's third-highest number of road traffic deaths, behind China and India. It noted that traffic fatalities kill nearly 50,000 people a year in Nigeria (Igomu,2011). The corps marshal of the federal road safety commission said a total of 4,372 people were killed in road accident in Nigeria in 2011. The Ogun state command of the federal road safety commission, in a report released in 2011, disclosed a chilling data on accidents on the busy Lagos-Ibadan expressway. According to the statistics, between January 2009 and July 2011, over 833 people died on the road while 6,103 had been injured in 2,264 accidents on that road. On the same road, between January and July 2011 alone, 217 travelers lost their lives in 559 accidents, while 1,434 were injured. The federal road safety corps marshal on 9th march 2012 at the FRSC public lecture in Abuja said that a total of 6,012 road accidents involving trailers and tankers in which 5,531 people died were recorded between 2007 and 2010 (Bashir,2012). The frequent accidents on the road are due largely to the neglect of the road by the federal government.

2.9.2 Increase in Faulty Vehicle

One of the main causes of many rackety vehicles on the Nigerian roads is because of the nature of the roads. It has been shown that vehicles wear down faster in less developed countries of Africa like Nigeria than is obtainable in civilized economies. This is evident in second handed vehicles that are shipped from developed economies to Africa which are in most cases here considered as new vehicles. One of the reasons for this is the situation of our roads. This brings a lot of hardship to road users hence (Igomu,2011) stated that the hard times faced on the disintegrating roads have continued to raise pertinent questions that had remained unanswered. He said that the extent of damage done to cars due to their morbid state was also enormous, not to mention the loss of productive man-hour.

2.9.3 Waste of Journey Time

Useful time is wasted in plying faulty roads. The nature of roads in Nigeria is one of the main causes of excessive traffic congestion on our roads (Okigbo,2012). Some of the times opposite coming vehicles will have to share the same lane. Some of them do this to avoid pot holes, pavement gulley and other defected parts of the road way. This makes movement on the roads very slow and as such causes the waste of precious time. When the motorist decides to be on his own lane that is littered with cracks and potholes he must have to unduly slowdown in order to save the vehicle from avoidable damages.

2.9.5 Aid to Crime (Robbery)

In 2010, the author was confronted by armed bandits on a road between Bida and Lambata in Niger state of Nigeria. This was made possible by the nature of the road. The robbers had to hide in the bush at the point where the road was bad, so that the drivers must make a temporary stop at that point to save their vehicle from unnecessary damage. At that point in time the robbers will jump out from the bush and attack the vehicle. Bad roads are another contributor to the incessant armed robbery and kidnapping that has been taking place in Nigeria. It encourages the robbers to hide at bad spots of the road and waylay motorists on the road. It will be very difficult if not impossible to stop the motorists against their wishes if the roads were in motorable condition.

2.9.6 Soil Erosion

The nature of the road is a veritable source of the erosion of the soil on the road way. The nature of the roads result to the deformation of the road way like potholes , cracks and in some cases complete scraping of the road way. These lead to the penetration of the soil by water which in most cases enable water to wash away the surface of the road way. In JUNE 2011, on the Oshodi- Apapa expressway, hell was literally unleashed on commuters by flood which virtually took over the length of the expressway. Initially, when the rain started as a light shower and turned into a torrential downpour that submerged the city (Igomu,2011). The high level of devastation of this flood was mainly due to inadequate drainage by the road sides. For days while the flood ravaged, road users were practically sacked from the expressway while the number of broken down vehicles outnumbered those that were able to wade through the deluge. This effect is not only limited to the Apapa-Oshodi expressway. A detailed check through Lagos and other parts of Nigeria reveals stretches of roads that have degenerated into death trap, with most requiring total reconstruction.

2.10 Remedies to Highway Failures

2.10.1 Provision of Adequate and Appropriate Design

The construction of a road starts from conception, planning and design. Without a good design of the road the functionality of the road may not be achieved. Even when the construction and supervision is adequate without the design process well done the end product in the form of a road project will not be functional (Okigbo,2012). The agencies in charge of road work in the country like the ministry of works and the professional bodies whose works relate to road constructions in country will be made to be more proactive in the activities leading to the design and construction of roads in the country. They should be able to give appropriate supervision, direction and control to road design consultants and road construction companies in the country.

2.10.2 Adequate Soil Test

One of the main reasons why highways in the country fail is that adequate knowledge of the soil situation is not obtained before the commencement of the road work Okigbo (2012). Knowledge of the soil situation helps both at the design and construction stage of the road. The sub-grade should be tested and found to be adequate before usage. The soil for sub base and base course even the material for the wearing course and the pavement must be found to meet the standard before they will be accepted for usage in road construction work.

2.10.3 Decongestion of Roads

Roads need the decongestion of traffic. Obstacles like cracks, potholes and abandoned vehicles on the roads lead to slow movement of vehicles on the road which leads to the congestion of traffic on the roads (Okigbo,2012). Therefore one way of decongesting the roads of traffic is by removing those obstacles like cracks, potholes and abandoned vehicles from the road. Decongestion can also be achieved by the diversion of traffics to other traffic modes like the railways, waterways and air transport.

2.10.4 Use of Well Trained Professionals

Those who will be able to realize the problems of the Nigerian roads, their causes and proffer solutions should be sought. The problems arise from faulty design, lack of drainages, and very thin coatings that are easily washed away by floods and hardly withstand heavy traffic (Okigbo

,2012). These faults could be easily detected and dealt with if well trained and qualified engineers are enlisted for road work in the country.

Engineering professional bodies like COREN should be involved in both the training and the supervision of highway engineers both in the school stage and in the direct construction work on our roads. This will also extend to collaboration between the professional bodies and government agencies that are in charge of road maintenance (Okigbo,2012). This manifested in august 2011 when the minister for works received the members of the Nigerian society of engineers in Abuja. The minister declared his willingness to collaborate with the Nigerian society of engineers on road sector transformations. He described the bad state of the Nigerian roads as contributing to the low productivity and poor economic development of the country (Onuoha and Oriakhi,2011).

2.10.5 Enhanced use of other Transportation Mode

Other modes of transportation like the rail lines and waterways should be developed to reduce the pressure on the road transportation mode in the country. The director general of the Nigerian institute of transport technology Tuesday 16th august 2011 stated that the absence of sound rail transport system, over loaded trucks and general road abuse arising from poor maintenance are the reasons for the poor state of roads in Nigeria. He said that the above factors had to be addressed if roads in Nigeria were to last longer. He stated that the Nigerian roads that were designed to last twenty years' experience a reduced longevity because of lack of control over the loading usage and the crumbling of the Nigerian railway system. It was reported that 95% of the movements today in Nigeria were done by road, while the remaining 5% percent of movements in the country are done by air, rail and sea. If the other transport modes in the country are activated fully this trend will be changed and our roads saved from undue deterioration.

2.11 Review of Works on Investigation of Pavement Failures

(Okigbo,2012) investigated the causes of road failures in Nigeria. The causes of failures in Nigeria roads were articulated and their effects to the citizen, government and the economy of the country were highlighted and a solution to the problems was given in the form of recommendations. Some of the identified causes were; poor design and construction, poor maintenance of already built highways, use of low quality materials in construction, poor workmanship and poor supervision of construction work and the plying of heavy traffic that were not meant for the road on the road. Some of the recommendations to remedy the situation are;

Use of the appropriate design of the roads, avoiding unnecessary congestion of the roads with traffic especially heavy traffics that were not meant for the roads, prompt maintenance of the roads, application of suitable construction material in the construction of roads, applying appropriate tests to the soil in road construction, use of qualified engineering personnel in road construction and the application of sanctions for highway failures.

(Onouha, et al.,2014) evaluated the causes of road failures along Enugu-Onitsha expressway, south eastern Nigeria. The study adopted a survey design which employed the use of a well-structured questionnaire to gather information on the causes and effects of the road failure. To determine the sample size, volumetric analysis was used and the data so generated was analyzed using One-way Analysis of Variance and Post HOC test. The ANOVA shows that the variation among the causes is not significantly different while the Post HOC test ranked the causative factors treated. The work thus concluded that all the factors listed contribute to the failure of the road with inadequate maintenance, mismanagement by the government and old age of the road pavement being the major factors responsible for failure of the road. The study therefore recommends that there should be Quality Determination for materials during construction, Effective Maintenance Programme (routine or preventive maintenance, periodic maintenance, and disaster maintenance or major repairs of our roads) and Establishment of an Active Maintenance Crew.

CHAPTER THREE

MATERIALS AND METHODS

This chapter presents the materials and method used to actualize the research aim. Disturbed soil samples collected at different location within the failed section of the road was subjected to laboratory testing. The structural integrity of the existing pavement was evaluated through analysis of the soil samples A, B, C, D. Below is a presentation of study materials and method used to accomplish the aim of the study.

3.1 Collection and Preservation of Materials.

Disturbed soil samples collected at four different locations within the failed section of the road. These samples were designated as A, B, C and D. These samples were collected at the lowest traffic volume at a depth of 0.5 – 1.0m below the top surface of the failed section. After collection, the samples were stored and kept in the laboratory for test in accordance with BS 1377 (1990) and the Nigeria general specification for roads and bridges (1997) was used to evaluate sample properties such as Sieve analysis, Compaction and California bearing ratio.

3.2 Description of Study Area

Ifite road located within Anambra North local government area is a one-lane single carriage way used by student, lecturers, private and commercial motorist. The road is classified as trunk Broad since it is constructed and maintained by the state government. Ifite road passes through places like Yahoo junction, Commissioner quarters, first and Second market terminating at a stepped terrain in Aroma. The road is used majorly by student and lecturers of Nnamdi Azikiwe University due to its proximity and eased of accessibility to the study center. Ifite road are lies within longitude 6^o45^lE to 7^o30^lE and latitude 6^o00^lN to 6^o30^lN.

3.3 Laboratory Investigation

This section presents the experimental procedure and laboratory tests that were adopted for the project work. The tests was conducted for the soil samples collected at three different locations within the failed section of the road and this tests include: Sieve analysis test, Compaction test and California bearing ratio test. The above listed tests were carried out at Civil Engineering

Laboratory situated in Nnamdi Azikiwe University Awka Anambra State, Nigeria. Below is a description of test procedures and apparatus:

3.3.1 Sieve Analysis Test

Sieve analysis is a procedure used to assess the particle size distribution of a granular material Atkinson, (2000). The size distribution is often of critical importance to the behaviour of the material during use. Sieve analysis can performed on any type of non-organic or organic granular material including sand, crushed rock, clay, granite, feldspar and a wide range of manufactured powders, grains and seed down to minimum size depending on the exact method. The standard grain size analysis test determines the relative proportion of different grain sizes as they are distributed among certain size ranges.

The apparatus needed for this experiment is listed below:

1. Stack of sieves including pan and cover.
2. Mechanical sieve shaker.
3. Weighing balance of 0.01g sensitivity.
4. Hand brush
5. Mortar and pestle (Used for crushing if the sample is conglomerated or lumped)
6. Thermostatically controlled Oven (With temperature of about 80^{O}C-110^{O}C).
7. Masking tape for identification of sample.
8. Exercise book and pen for recording of result.
9. The calculation for attaining Coefficient of uniformity and Coefficient of curvature are outlined below.

Percentage retained (%) $= \frac{\text{massofsoilretainedinthesieve(g)}}{\text{totalmassofsoilsample(g)}} \times 100$

Cumulative percentage retained = $\sum \text{Percentageretained}$ (%)

Cumulative Percentage Finer (%) = 100-Cummulative percentage retained.

Coefficient of Curvature $=\frac{D60}{D10}$

Coefficient of Uniformity $=\frac{(D30)2}{D10 \times D60}$

Where

D10= particle size such that 10% of the soil is finer than the size

D30= particle size such that 30% of the soil is finer than the size.

D60= particle size such that 60% of the soil is finer than the size**.**

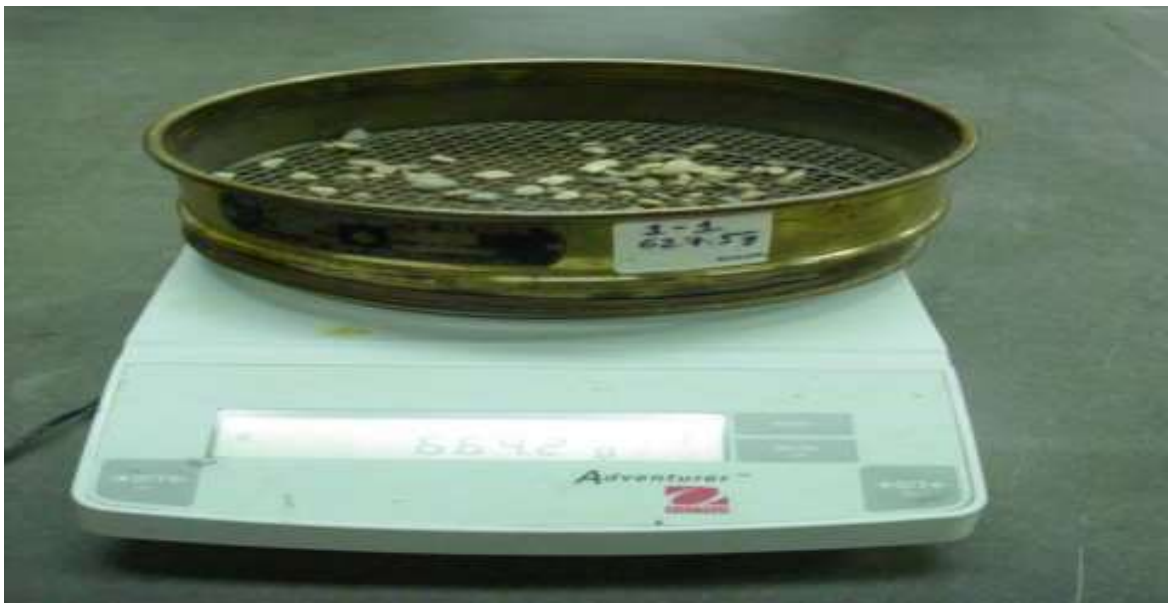


Plate 3.1: Apparatus for Particle Size Distribution Test (Source: Braja, 2006).

Plate 3.2: Apparatus for Particle Size Distribution Test Source: (Braja,2006).

Test Procedure

1 The stack of sieves to be used for the experiment was properly cleaned using hand brush.

2 About 500g of air-dried soil sample was weighed with the aid of a weighing balance.

3 The weighed soil sample was poured into 75um sieve and wash under a steady supply of water until clear water start coming out from the sieve after passing through the soil sample.

4 After washing pour the washed soil sample into a pre-weighed plate and dry it inside the thermostatically controlled oven at a controlled temperature of 80-110^{O}C for 16-24hrs.

5 The sample was removed from the oven and the weight was determine (net weight) by deducting the weight of plate from the weight of plate and soil.

6 The stacks of sieve was arranged in the ascending order, placed in a mechanical sieve shaker, and thereafter the sample was poured and connected to the shaker for about 10-15 minute.

7 The sieve shaker was disconnected and the mass retained on each of the sieve sizes was determined.

8 The percentage retained, Cumulative percentage retained and Cumulative percentage finer was determined.

9 The graph of sieve Cumulative percentage finer against sieve sizes was plotted.

10 D10, D30 and D60 were determined from the plotted graph.

11 The Coefficient of Curvature and Coefficient of Uniformity was determined and used to classify the soil adopting the American Association of State Highway and Transportation Official (AASHTO) and Unified Soil Classification System (USCS) respectively.

Plate 3.3: Arrangement of Stack of Sieves on a Mechanical Sieve Shaker

3.3.2 Compaction Test

Compaction is the process of increasing the bulk density of the soil by driving out air. It involves the densification of soils by mechanical means thereby increasing the dry density of the soil. According to Shruthi (2017) Compaction of soil is the process by which the soil solid are packed more closely together by mechanical means, thus increasing it dry density. It could also be stated as the process of packing the soil particle more closely together usually by tamping, rolling or other mechanical means, thus increasing the dry density of the soil. It is achieved through the reduction of the volume of air void in the soil with little or no reduction in water content. The process must not be confused with consolidation in which water is squeezed out under the action of steady static load. Consolidation is a natural process and result in dense packing of the soil.

In civil engineering practice soil compaction is essential for the following reasons:

1. Increasing the bearing strength of foundation
2. Provide stability to slope and foundation.
3. Prevention of undesirable settlement of structures
4. Reduction of water seepage from structure

The compaction methods to be adopted for this research is British Standard Light for the disturbed soil samples collected at three different locations within the study area.

Details of British Standard Compaction Process

Table 3.0 Details of Compaction Mould

Type	Diameter (mm)	Height (mm)	Volume(cm^3)
British Standard	105	115.5	1000

Table 3.1 Details of Compaction Procedure

Type of test	Mould (cm^3)	Rammer(kg)	Drop (mm)	No of layers	Blow per layer
BS light	1000	2.5	300	3	27
BS heavy	1000	4.5	450	5	27

The mechanical energy applied in each type of British Standard in term of work done is given as follows:

British Standard Light

Mechanical energy = $\frac{\textbf{Weight of rammer} \times \textbf{no of layers} \times \textbf{no of blows} \times \textbf{height of drop}}{\textbf{Volume of mould}}$

$= \frac{2.5g \times 3layers \times 27blows \times 300mm}{1000}$ **= 60.75kgm =60.75× 9.81Nm=596j**

Work done per unit volume of soil =$\frac{596}{1000}$ **=596kj/m**^{3}

The apparatus used for the test are as follows:

1. Compaction mould with a detachable base plate and removable extension collar.
2. Metal rammer (either 2.5kg or 4.5kg)
3. Measuring Cylinder 200ml or 500ml
4. Large Metal tray (600mm×600mm ×600mm)
5. Balance up to 10kg readable to 1g
6. Small tools such as palette knife, steel straight edge about 300mm long.
7. Drying oven temperature of 105-110^{O}C
8. Apparatus for moisture content determination

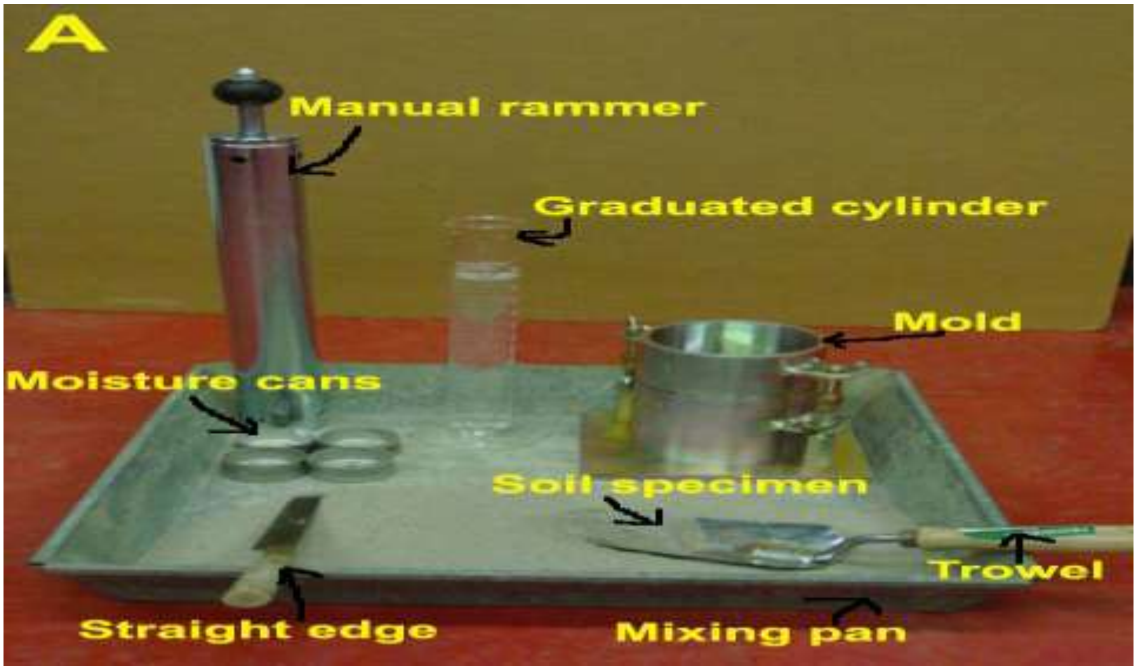


Plate 3.4: Apparatus employed for Compaction Test.

Test Procedure.

1. Check to see if the mould, extension collar and base plate are clean and dry. Measure the dimension and weigh to the nearest 1kg check if the rammer falls freely.
2. Grease the internal surface of the mould
3. Attach the extension collar to the mould.
4. Weigh about 3kg of the soil sample on a weighing balance
5. Add about 4% water to the soil sample, mixing it thoroughly and separating the soil into three layers for British Standard Light and five layers for British Standard Heavy.
6. Pour the wet soil into the mould and compact by applying the required no of blow using either a 2.5kg or 4.5kg rammer falling freely from a height of 300mm. The blow must be distributed uniformly over the surface of the mould.
7. After completion of the compaction operation remove the extension collar and level carefully the top of the mould by means of a straight edge.
8. Weigh the mould with the compacted soil to the nearest 1kg, record the weight as W_2.
9. Determine the moisture content of the representative sample of the specimen; record the moisture content as M.
10. Repeat the procedure for 8%, 12%, 16% and 20% of water to be added and record the value obtained.
11. Plot the graph of dry density against moisture content and determine the maximum dry density (MDD) of the soil at the corresponding optimum moisture content (OMC).

The Computation of the result obtained is as follows:

Determination of Dry Density (P_d).

Wt of mould (kg) = W_1

Wt of mould + wet soil (kg) = W_2

Wt of wet soil (kg) = W_2-W_1

Volume of mould (M^3) = W_4

Bulk Density (kg/m^3) = $\frac{\text{Wt of wet soil (kg)}}{\text{Vol of mould (m3)}} = \frac{W2-W1}{W4}$

Moisture Content (%) = $\frac{\text{mosture content (top)+ moisture content (bottom)}}{2}$

Dry Density (kg/m^3) = $\frac{\text{Bulk density}}{\text{1+moisture content (\%)}} = \frac{\text{Pb}}{1+w/100}$

Determination of Moisture Content (w) for top and bottom respectively.

Wt of tin (kg) = W_1

Wt of tin + wet soil = W_2

Wet of wet soil (kg) = $W_3 = W_2 - W_1$

Wt of tin + dry soil (kg) = W_4

Wt of dry soil (kg) = $W_5 = W_4 - W_1$

Wt of water (kg) = $W_6 = W_3 - W_5$

Moisture Content (%) = $\frac{\text{Wt of water}}{\text{Wt of dry soil}} \times 100 = \frac{W6}{W5} \times 100$

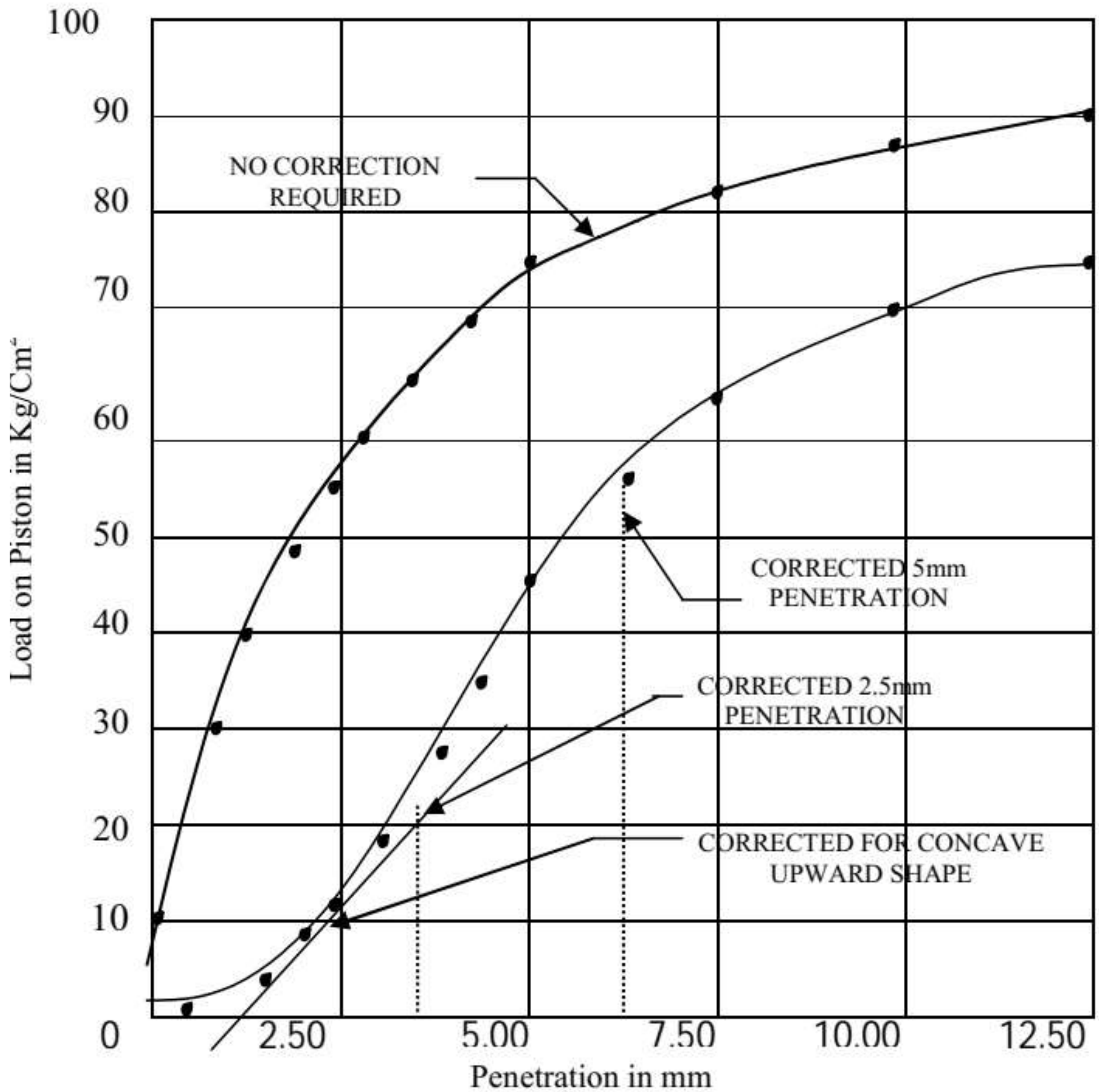
Plate 3.5: Arrangement of Mould Assembly

Plate 3.6: Manual Compaction of Soil Sample

3.3.3 California Bearing Ratio Test

The California bearing ratio test was originally developed by the California division of highway in 1938, for the design of highway thickness. The test is used for evaluating the suitability of materials used in sub-grade, sub-base and base course respectively. The test result has been correlated with the thickness of various materials required for flexible pavement construction. The test may be conducted on a prepared specimen in a mould or on the soil in-situ condition.

In the test the load required to push a plunger into a soil specimen at a controlled rate is measured, then the load on the plunger at a certain depth is recorded as a percentage of a standardized load. The load necessary to push a plunger to a certain depth into the soil is expressed as a percentage of the load required to force the same plunger to the same depth into a standard sample of compacted crush stone. The construction of highway pavement requires a California Bearing Ratio value for 2.5mm and 5mm penetration respectively, with that of 2.5mm penetration being comparatively higher than that of 5mm penetration. The Federal Ministry of work Standard Specification for roads and bridges (1997) state that road construction material should have a CBR value of 10%, 20% and 80% for use as sub-grade, sub-base and base course respectively. The material to be used for the test will be subjected to 48 hours soaking in other to ascertain it behavior under worst condition (flooding as a result of intense rainfall).



Load vs. Penetration curve

Table 3.2: Standard load adopted for different penetration on a standard material with CBR value of 100%.

Penetration of plunger (mm)	Standard Load (kg)
2	1150
2.5	1320
4	1760
5	2000
6	2220
7.5	2630
8	2650
10	3180
12.5	3600

1. The apparatus used for the test are outlined below:
2. A cylindrical corrosion resistant mould 152mm×127mm having a diameter of 150-152mm with a detachable base plate and a removable extension collar.
3. A compressive device for static compaction of applying a force of at least 300KN
4. Metal plugs 150mm $\pm$ 0,5mm and 50mm thick.
5. Metal rammer 2.5kg or 4.5kg.
6. Dial gauge of 0.01g sensitivity.
7. Soaking tank.
8. A steel rod of about 16mm diameter and 600mm long and a straight edge of 300mm steel stripe and 3mm thick with one beveled edge.
9. Weighing balance of 25kg accuracy and a spatula.
10. Filter paper
11. Apparatus for moisture content determination.
12. Masking tape used for identification of moisture content tins.

13. Exercise book and pen for recording.

Plate 3.7: California Bearing Ratio (CBR) Test Machine.

Test Procedure

The methods used for California Bearing Ratio Test are:

1. Compression with tamping.
2. Recompaction with known maximum dry unit weight (MDUW) and optimum moisture content (OMC).
3. For this course of study the method for recompacted sample with known maximum dry unit weight (MDUW) and optimum moisture content (OMC) is to be adopted and the procedure is outlined below:

4. Carry out Compaction test using 6kg of soil sample, varying the moisture content at a particular percentage say 4%, determine the maximum dry density and optimum moisture content.
5. Clean properly and grease the internal surface of the CBR mould.
6. Weigh 6kg of soil mixing with the optimum moisture content determined from compaction test.
7. Divide the soil into 3 equal layer (CBR light) and seal in an airtight container until requested for use.
8. Stand the mould assembly in a solid base, place the first soil portion and compact using 2.5kg rammer for 27 even blows.
9. Repeat using the remaining four portion of soil in turn so that the level of the soil is not more than 6mm above the top of the mould body.
10. Remove the collar and trim the soil flush with mould with the scrapper or knife edge.
11. Weigh the mould, soil and base plate to the nearest kg.

Preparation for Soaking

Soil may soften when load is placed on it due to flooding or increase in moisture content. Soaking of the sample is done primarily to determine the strength (load bearing strength) of the soil under worst condition (rainy season).Below are the list of apparatus used for CBR Soaking:

1. Perforated base plate fitted to CBR mould in place of normal base plate.
2. Perforated swell plate with an adjustable stem to provide a sealing for the stem of the dial gauge.
3. Tripod mounting to support dial gauge
4. Soaking tank
5. Annular Surcharge discs with internal diameter of 52-54mm and external diameter of 145mm to 150 mm.
6. Petroleum jelly.
7. The Soaking procedures are enumerated as follows:
8. Remove the base plate and replace with perforated base plate.

9. Fit the collar to the other end of the mould, pack the screw thread with petroleum jelly to make it water tight.
10. Place the mould assembly in soaking, place the filter paper in the sample, the perforated swell plate, and then annular surcharge disc.
11. Mount dial gauge on top of the extension collar, secure the dial gauge in place and adjust the stem in the perforated base plate to give zero.
12. Fill the immersion tank with water just below the extension collar. Start the timer when water has just covered the base plate.
13. Record the time taken for water to appear at the top of the sample if it does occur within two days. Flood the top of the sample and leave to soak for a day.
14. Plot the swelling against elapsed time or square root of time. Flattening curve indicates that swelling is complete.
15. Take off the dial gauge and its support; remove the mould assembly and leave to drain for 15min.
16. Remove the Surcharge discs, perforated plate and collar, then fit the other base plate.
17. Weigh the sample + mould + base plate if density is required after soaking is completed.
18. If the sample has swollen, trim it to the level of the mould and reweigh
19. Test the sample by adjusting the dial gauge to start at zero and take the reading at interval of 0.5mm for every 30seconds till 7mm penetration.
20. Record the load at penetration of 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5 and 7.0mm and express this force as percentage of the standard load.
21. Calculate the CBR for 2.5 and 5mm penetration; repeat the same procedure for top and bottom, the higher CBR value will be used as the CBR for the material.
22. Plot the graph of force (KN) against penetration (mm).
23. The normal curve is convex upward, but if the initial part is concave upward applies the necessary correction to the curve.

Mathematically it is expressed as $\frac{\text{test load}}{\text{standard load}} \times 100$

Where

$$\text{Test load} = \text{dial gauge reading} \times \text{proof ring constant}$$

CHAPTER FOUR

RESULTS AND DISCUSSION

During the course of the study, certain findings were obtained from the geotechnical investigation of samples collected within the failed section of the road under study. These results were valuable in classifying and determining the strength parameters of the samples which was collected at the failed sections of the flexible pavement.

4.1 Results

4.1.1 Soil Test Results

Summary of the engineering properties of the disturbed soil samples collected at the sub-grade level of the failed pavement structure is presented in Table 4.1 below.

Table 4.1 Engineering Properties of the Soil Samples

Sample Number	**A**	**B**	**C**	**D**
Sample Description	**Reddish Brown**	**Reddish Brown**	**Reddish Brown**	**Reddish Brown**
AASHTO Classification System	**A-2**	**A-4**	**A-2**	**A-2**
% Passing Sieve No 200 (0.075mm)	**18.61**	**38.86**	**21.46**	**22.07**
Sub-grade Rating	**Good**	**Fair**	**Good**	**Good**

Maximum Dry Unit Weight (kN/m^3)	**16.19**	**18.87**	**17.30**	**15.84**
Optimum Moisture Content (%)	**12.08**	**12.53**	**11.17**	**14.21**
Soaked CBR 48hours (%)	**5**	**4**	**8**	**7**

3.2 Particle Size Distribution (Sieve Analysis)

The following results were obtained after the sieve analysis of the different soil samples and the graphical representation is shown below.

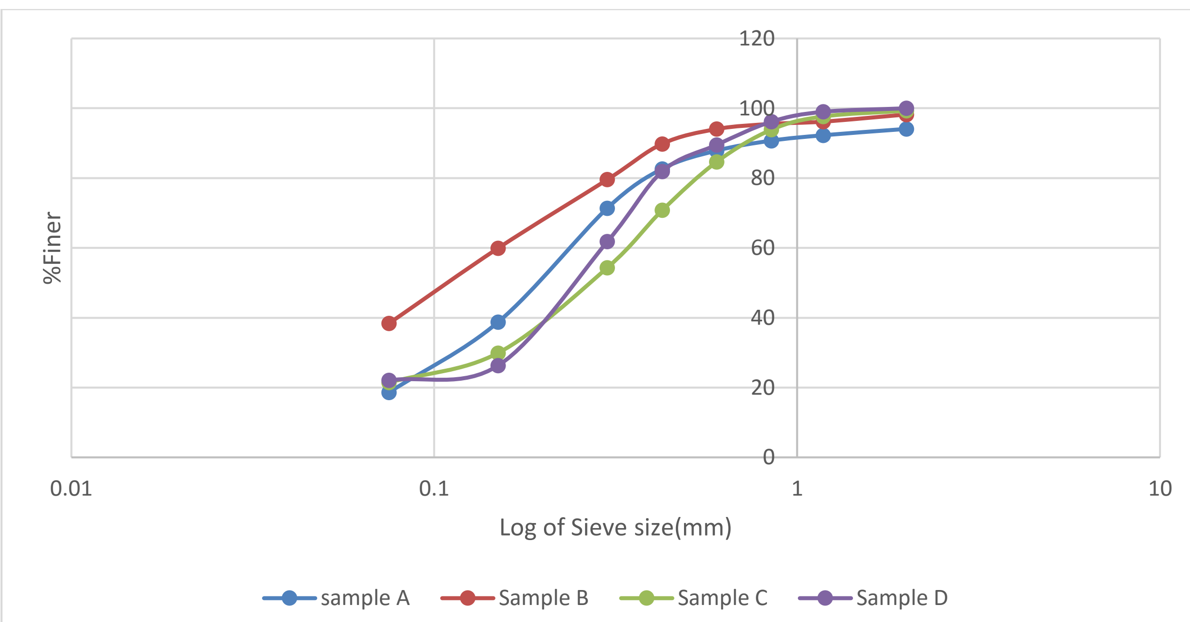


Fig 4.2.3: Particle Size Distribution Graph for Samples

Figure 4.2.3 is the semi logarithmic plot of the particle size distribution of the soil samples. From the graph of Figure 4.2.3, the percentage passing Sieve No 200 (0.075mm) are 18.61%, 38.86%, 21.46%, and 22.07% respectively. According to AASHTO Classification System, the samples A, C and D are classified as A-2 while sample B is classified as A-4. According to the Federal Ministry of work Standard Specification for roads and bridges (1997), since more than 35% of the samples passes through sieve No 200 (0.075mm), sample B does not satisfy the requirement of a good sub-grade material for road construction. According to AASHTO classification of soil samples for highway, A-1 and A-2 soils are excellent and good soils for highway, while A-3 to A-7 soils are fair to poor soils. The result obtained classified the samples A, C and D as good soils due to the fact that less than 35% passes through sieve No 200 while sample B was classified as fair soil due to the substantial amount of finer materials passes through sieve No 200 (0.075mm). Clay is a problematic soil due to its porosity, low permeability and low shear strength. The presence of clay in the sample B tested could be responsible for instability of the pavement structure.

4.3 Sub-grade Strength Evaluation

The following results were obtained after the compaction test of different samples and the graphical representation shown below:

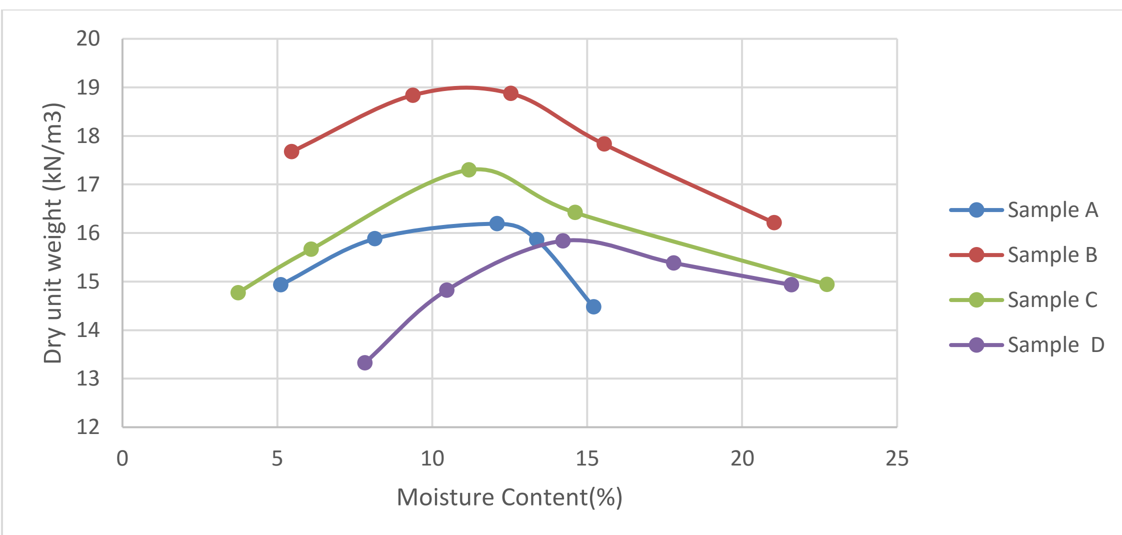


Figure 4.2: Compaction Curve for the Samples

4.3.1 Compaction Test

The compaction characteristics of the sub-grade soil samples collected at different location within the failed section of the pavement structure measures the strength of the sub-grade. The maximum dry unit weight of samples A, B, C and D are 16.9kN/m^3, 18.87kN/m^3, 17.3kN/m^3 and 15.84kN/m^3 which shows that all the samples are within range, while the optimum moisture content of the sub-grade tested are 12.08%, 12.53% 11.17% and 14.21% as shown in figure 4.2

4.3.2 California Bearing Ratio Test

After carrying out the CBR test for all the samples, graphical representation where obtained.

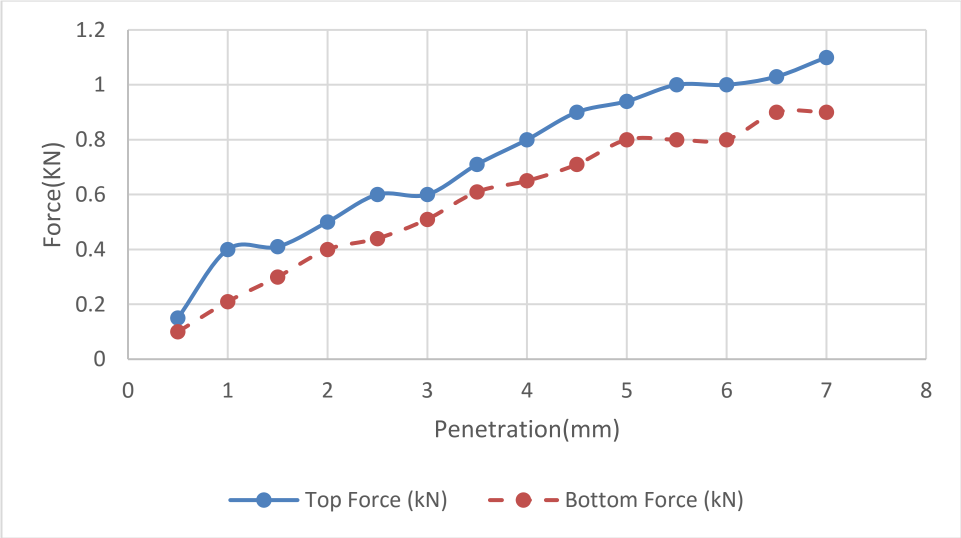


Figure 4.3: Chart Showing the Soaked CBR of the Sample A

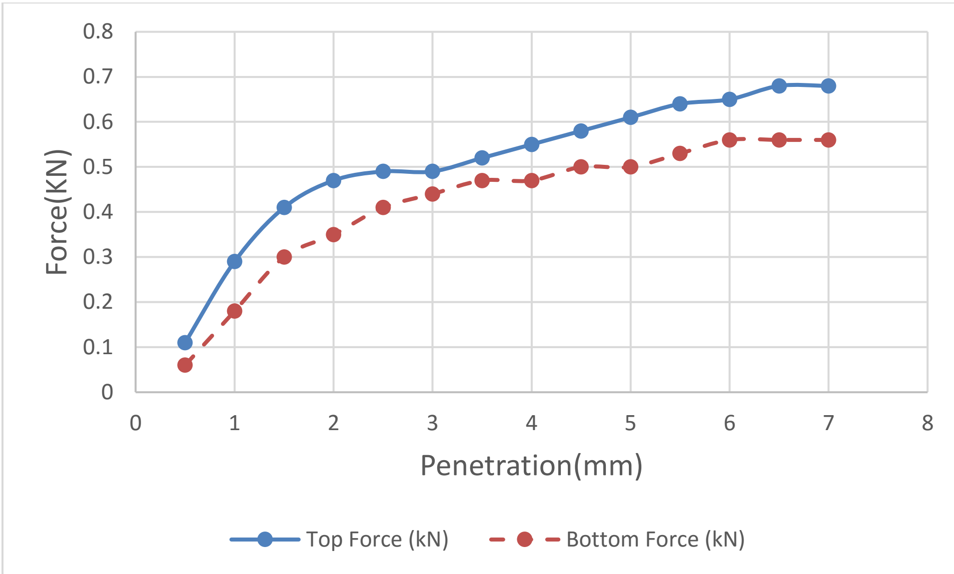


Figure 4.4: Chart Showing the Soaked CBR of the Sample B

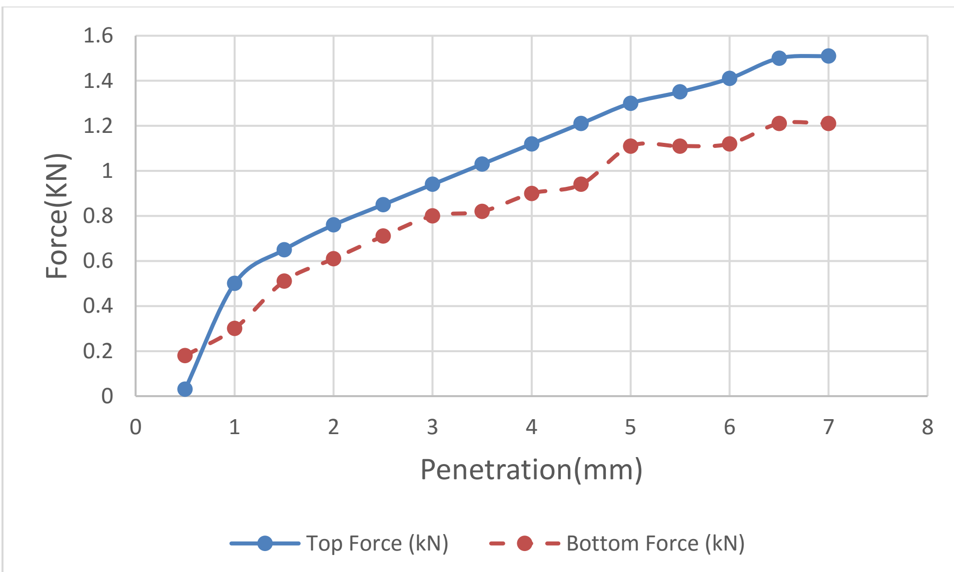


Figure 4.5: Chart Showing the Soaked CBR of the Sample C

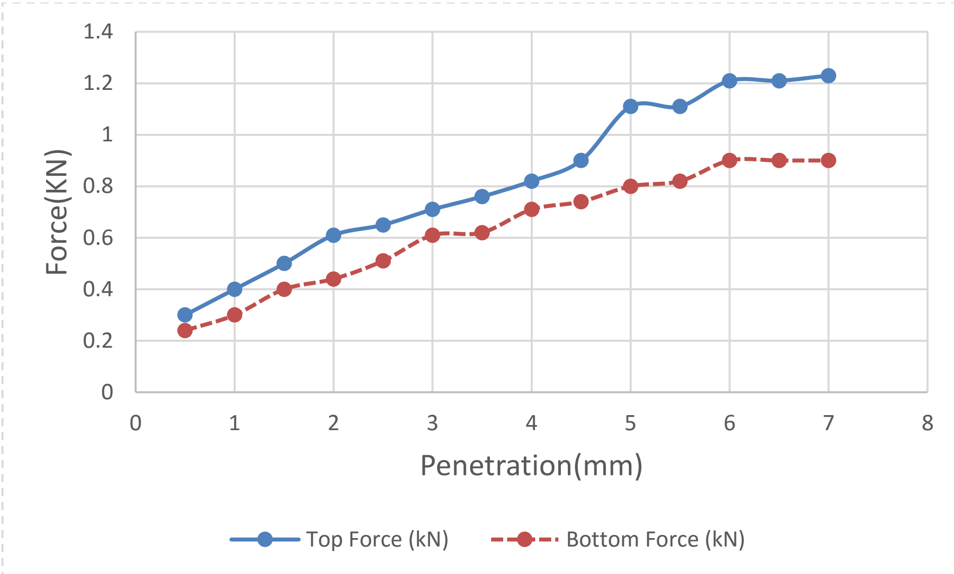


Figure 4.6: Chart Showing the Soaked CBR of the Sample D

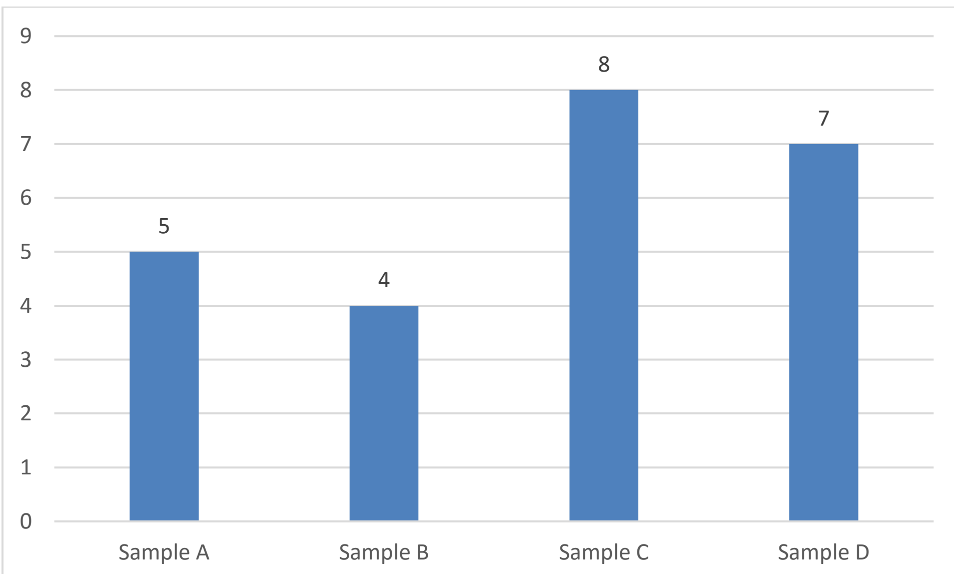


Figure 4.8: Soaked CBR Values of the Samples

According to Alo and Oni (2018), the dry unit weight of soil is an index of the soil strength and shares a direct relationship with the CBR of the soil. The soaked CBR values of the samples are 5%, 4%, 8% and 7% respectively, which ranged from 4% to 8%. The values do not meet the requirement given by Federal Ministry of Works and Housing (2013) which state that the soaked CBR of sub-grade soil must exceed 15%. The closeness in the sub-grade CBR values of the samples is an indication that the road was built on similar sub-grade material. The low CBR values of the samples may be attributed to the significant amount of clayey soil present in the samples. Clayey characteristics in any material used as a supporting layer in highway construction will impair the strength characteristics of the pavement especially when present in appreciable quantity.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the findings obtained on investigation of the causes of failures along Ifite road, Awka Anambra State, Nigeria, the following conclusion can be drawn.

1. Geotechnical investigation of the samples collected at four different locations within the failed pavement structure revealed that poor geotechnical properties of the underlying soil layers (sub-grade soil) were responsible for the structural failures along Ifite road. The soaked CBR values of the sub-grade soils also contributed to the failures of the roads. Such low strength soil will not provide a stable compacted bed. Based on the findings of the study, the sub-grade soil samples were poor lateritic soils which therefore contributed to the failure of the road.

2. Pavements deteriorate under traffic loads and climate effects. This fact, together with the weak subgrade soil and poor drainage system, could be major causes of the road's fast deterioration in Ifite

3. It was pointed out that understanding the causes of pavement deterioration will significantly contribute to the proper selection of effective maintenance technique results in prolonged service life of roads and significant savings for the government.

5.2 Recommendation

The recommendation on findings obtained from investigation into the causes of failures along Ifite road, Awka Anambra State, Nigeria is as follows:

1 Treatment of sub-grade soils of the existing pavement structure either by stabilization using granular materials like stone dust or excavation and importation of materials

with better geotechnical properties should be carefully carried out during rehabilitation or reconstruction work.

2 To enhance the structural effectiveness of the base and surface course, it is necessary to increase the thickness of the respective pavement layers either by scarifying and laying of new asphalt layer with considerable thickness as this will help improve the service performance of the pavement.

3 To forestall road failures in Nigeria, road construction materials must be adequately tested and treated prior to use as this will avert problems during or after construction works.

4 It is also important to carry out adequate routine and periodic maintenance of the road as this will enhance the service life of roads and ensure optimum performance.

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APPENDICES

APPENDIX A

Particle Size Distribution Test

Table A1: Sieve Analysis Test Results for Sample A

Sieve size (mm)	weight of soil retained(g)	% weight of soil retained	cummulative % weight retained	Percent Finer (%)
2	29.57	5.91	5.91	94.09
1.18	9.1	1.82	7.73	92.27
0.85	7.63	1.53	9.26	90.74
0.6	14.32	2.86	12.12	87.88
0.425	26.01	5.2	17.32	82.68
0.3	56.37	11.27	28.59	71.41
0.15	163.23	32.65	61.24	38.76
0.075	100.72	20.14	81.38	18.61
Tray	93.05	18.61	100	0
	500			

Table A2: Sieve Analysis Test Results for Sample B

Sieve size (mm)	weight of soil retained(g)	% weight of soil retained	cummulative % weight retained	Percent Finer (%)
2	8.92	1.78	1.78	98.22
1.18	10.24	2.05	3.83	96.17
0.85	3.22	0.64	4.47	95.53
0.6	7.38	1.48	5.95	94.05
0.425	21.16	4.23	10.18	89.82
0.3	51.19	10.24	20.42	79.58
0.15	98.21	19.64	40.06	59.94
0.075	107.87	21.57	61.63	38.36
Tray	191.81	38.36	100	0
	500			

Table A3: Sieve Analysis Test Results for Sample C

Sieve size (mm)	weight of soil retained(g)	% weight of soil retained	cummulative % weight retained	Percent Finer (%)
2	3.41	0.68	0.68	99.32
1.18	8.34	1.67	2.35	97.65
0.85	18.84	3.77	6.12	93.88
0.6	46.18	9.24	15.36	84.64
0.425	69.25	13.85	29.21	70.79
0.3	82.21	16.44	45.65	54.35
0.15	122.14	24.43	70.08	29.92
0.075	42.31	8.46	78.54	21.46
Tray	107.32	21.46	100	0
	500			

Table A4: Sieve Analysis Test Results for Sample D

Sieve size (mm)	Mass Retainted (g)	% Mass Retained	Cum % Retained	Cum % Finer
2	0.02	0.004	0.004	99.99
1.18	5.01	1.002	1.006	98.99
0.85	14.07	2.814	3.82	96.18
0.6	33.28	6.656	10.476	89.52
0.425	38.14	7.628	18.104	81.90
0.3	100.4	20.08	38.184	61.82
0.15	177.52	35.504	73.688	26.31
0.075	21.23	4.246	77.934	22.07
Tray	110.33	22.07	99.76	0.2
Total	500			

APPENDIX B

Compaction Test

Table B1: Dry Unit Weight Result and Moisture Content Results for Sample A

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m^3)	(kg)	(kg)	(kg)	(kN/m^3)	(%)	(kN/m^3)
4	0.001	4	5.6	1.6	15.70	5.10	14.93
8	0.001	4	5.75	1.75	17.17	8.14	15.88
12	0.001	4	5.85	1.85	18.15	12.08	16.19
16	0.001	4	5.8	1.8	17.66	13.37	15.86
20	0.001	4	5.7	1.7	16.68	15.20	14.48

Table B2: Dry Unit Weight Result for Sample B

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m3)	(kg)	(kg)	(kg)	(kN/m3)	(%)	(kN/m3)
4	0.001	4	5.9	1.9	18.639	5.45511	17.6748186
8	0.001	4	6.1	2.1	20.601	9.36528	18.8368747
12	0.001	4	6.15	2.15	21.0915	12.5304	18.7429274
16	0.001	4	6.1	2.1	20.601	15.542	17.8298739
20	0.001	4	6	2	19.62	21.028	16.2111209

Table B3: Dry Unit Weight Result for Sample C

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m3)	(kg)	(kg)	(kg)	(kN/m3)	(%)	(kN/m3)
4	0.001	4	5.4	1.4	13.734	3.729072	14.77129
8	0.001	4	5.55	1.55	15.2055	6.083141	15.26633
12	0.001	4	5.65	1.65	16.1865	11.17344	17.29823
16	0.001	4	5.6	1.6	15.696	14.60562	16.4206
20	0.001	4	5.5	1.5	14.715	22.72806	14.94228

Table B4: Dry Unit Weight Result for Sample D

Percentages of Water	Vol of Mould	Wt of Mould	Wt of Mould + Wet Soil	Wt of Wet Soil	Bulk Density	Moisture Content	Dry Unit Weight
(%)	(m3)	(kg)	(kg)	(kg)	(kN/m3)	(%)	(kN/m3)
4	0.001	4	5.35	1.35	13.2435	7.817198	13.32167
8	0.001	4	5.5	1.5	14.715	10.45973	14.8196
12	0.001	4	5.6	1.6	15.696	14.20751	15.83808
16	0.001	4	5.55	1.55	15.2055	17.78138	15.38331
20	0.001	4	5.5	1.5	14.715	21.58048	14.9308

APPENDIX C

California Bearing Ratio Test

Table C1: Soaked California Bearing Ratio Test Result for Sample A

Penetration (mm)	Dial Reading Top	Top Force (kN)	Dial Reading (mm)	Bottom Force (kN)
0.5	5	0.15	3	0.1
1	12	0.4	8	0.21
1.5	14	0.41	10	0.3
2	17	0.5	13	0.4
2.5	19	0.6	15	0.44
3	22	0.6	17	0.51
3.5	24	0.71	19	0.61
4	27	0.8	22	0.65
4.5	30	0.9	24	0.71
5	32	0.94	26	0.8
5.5	33	1	27	0.8
6	34	1	28	0.8
6.5	35	1.03	29	0.9
7	36	1.1	30	0.9

Table C2: Soaked California Bearing Ratio Test Result for Sample B

Penetration (mm)	Dial Reading Top	Top Force (kN)	Dial Reading (mm)	Bottom Force (kN)
0.5	4	0.11	2	0.06
1	10	0.29	6	0.18
1.5	14	0.41	10	0.3
2	16	0.47	12	0.35
2.5	17	0.49	14	0.41
3	17	0.49	15	0.44
3.5	18	0.52	16	0.47
4	19	0.55	16	0.47
4.5	20	0.58	17	0.5
5	21	0.61	17	0.5
5.5	22	0.64	18	0.53
6	22	0.65	19	0.56
6.5	23	0.68	19	0.56
7	23	0.68	19	0.56

Table C3: Soaked California Bearing Ratio Test Result for Sample C

Penetration (mm)	Dial Reading Top	Top Force (kN)	Dial Reading (mm)	Bottom Force (kN)
0.5	10	0.03	6	0.18
1	16	0.5	10	0.3
1.5	22	0.65	17	0.51
2	26	0.76	20	0.61
2.5	29	0.85	24	0.71
3	32	0.94	27	0.8
3.5	35	1.03	28	0.82
4	38	1.12	30	0.9
4.5	41	1.21	32	0.94
5	44	1.3	34	1.11
5.5	46	1.35	36	1.11

6	48	1.41	38	1.12
6.5	50	1.5	40	1.21
7	51	1.51	41	1.21

Table C4: Soaked California Bearing Ratio Result for Sample D

Penetration (mm)	Dial Reading Top	Top Force (kN)	Dial Reading (mm)	Bottom Force (kN)
0.5	10	0.3	8	0.24
1	12	0.4	10	0.3
1.5	16	0.5	13	0.4
2	19	0.61	15	0.44
2.5	22	0.65	17	0.51
3	24	0.71	19	0.61
3.5	26	0.76	21	0.62
4	28	0.82	23	0.71
4.5	31	0.9	25	0.74
5	34	1.11	27	0.8
5.5	37	1.11	28	0.82
6	40	1.21	29	0.9
6.5	41	1.21	30	0.9
7	42	1.23	30	0.9