بسم الله الرحمن الرحيم

Sudan University of Science and Technology

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Characterization, Parameters, and Correlation of Highway Pavement Construction Materials

توصيف ومعاملات مواد تشييد رصف طرق المرور السريع والارتباط بينـها

A Thesis Submitted in Partial Fulfillment for MSc Degree in Civil Engineering (Construction Engineering)

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الآية

بسم الله الرحمن الرحيم

قال تعالي:﴿وَلَا تَمْشِ فِي الْأَرْضِ مَرَحًا إِنَّكَ لَنْ تَخْرِقَ الْأَرْضَ وَلَنْ تَبْلُغَ الْجِبَالَ طُولًا (37) كُلُّ ذَلِكَ كَانَ سَيِّئُهُ عِنْدَ رَبِّكَ مَكْرُوهًا (38) ذَلِكَ مِمَّا أَوْحَى إِلَيْكَ رَبُّكَ مِنَ الْحِكْمَةِ وَلَا تَجْعَلْ مَعَ اللَّهِ إِلَهًا آخَرَ فَتُلْقَى فِي جَهَنَّمَ مَلُومًا مَدْحُورًا (39)﴾

صدق الله العظيم

سورة الإسراء الآيات (37-38-39)

Dedication

This thesis is dedicated to my parents, my husband, son and daughter for their love, endless support and encouragement.

Acknowledgment

In the name of Allah, the most merciful, the most compassionate all praise is to Allah, the lord of the worlds; prayers and peace be upon Mohammed his servant and messenger.

First and foremost, I must acknowledge my limitless thanks to Allah.

I would like to express my special appreciation and thanks to my supervisor **Prof Dr. Galal A. Ali Mohamed**, you have been tremendous mentor for me. I would like to thank you for encouraging my research.

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I also would like to express my wholehearted thanks to my family for their generous support they provided me through the process of pursuing the master degree. Because of their unconditional love and prayers, I have the chance to complete this thesis.

Abstract

These thesis studies highway pavement materials, types, flexible and rigid, characteristics and all tests related CBR, resilient modulus, modulus of sub grade reaction (k), design parameters, and correlation. The thesis includes study case for two roads, El Moneera – El Saffaya highway (Road 1) a national road way that made for the people who were affected by Alsteit, Atabara dams and section of Omdurman Ring Road (Road 2), samples were taken and tests were carried out to study soil type and properties of each to find out where its suitable for pavement construction or not.

Test results showed that (Road 1) soil is classified as black cotton soil; this type of soil is not suitable for pavement construction and needs improvement either by using stabilizers or soil replacement. Road 2 soil varies from sandy, silty and rocky soils. Initial test results show that it’s suitable for pavement construction after improving by compaction.

المستخلص

تدرس هذه الدراسة مواد رصف الطرق من التربه،الحجر بانواعه الطبيعي والمكسور،البيتومين وأنواعها وخصائصها وجميع الاختبارات ذات الصلة وانواع الطرق ومعايير التصميم وربط العلاقات المتبادلة. شملت الدراسة دراسة حالة لطريقين ، طريق المنيرة - السفايا السريع (الطريق 1),و قد تم انشاءه للمتضرررين من اقامة سدي الستيت وعطبره. وجزء من طريق أم درمان الدائري (الطريق 2) ، تم أخذ العينات وأجري لها اختبارات لدراسة نوع التربة بالموقع والمعمل وخصائص كل منها لمعرفة ما اذا كانت هذه التربة مناسبة لبناء الرصيف أم لا.

أظهرت نتائج الاختبار أن التربة (الطريق 1) تصنف على أنها تربة قطنية سوداء ، وهذا النوع من التربة لا يصلح مباشرة لانشاء الطريق و يحتاج إلى تحسين إما باستخدام المثبتات المختلفه أو استبدال التربة بشكل كامل. اما (الطريق 2) تتفاوت التربه بين التربة الرملية والطمية والصخرية. اظهرت نتائج الاختبار الأولية أنها وبعد المعالجه باستخدام الدمك يمكن انشاء الطريق عليها.

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List of Abbreviations and Symbols

RPs : Rigid (or Concrete) Pavements

PCC : Portland Cement Concrete

JPCP : Jointed Plain Concrete Pavement

JRCP : Jointed Reinforced Concrete Pavement

CRCP: Continuous Reinforced Concrete Pavement

PCP : Prestressed Concrete Pavement

AASHTO: American Association of State Highway and Transportation Officials

PCA: Portland Cement Association

AI: Asphalt Institute

CBR: California Bearing Ratio

$\mathbf{N_A}$: Number of Axles per Trucks Surveyed, say 100

ADT: Daily Traffic, veh. /day in both directions

D: Direction Split (the larger value is used in the design)

$\mathbf{P_T}$: % Trucks

r: Annual Traffic Growth Factor for Design Period n

L: The Lane Distribution Factor which varies with the volume of traffic and the number of lanes.

$\mathbf{w_{18}}$: The Number of 18-kip (80-kN) Single-axle load applications

$\mathbf{Z_R}$: Normal deviate for a given Reliability R

$\mathbf{S_O}$: Overall Standard Deviation

D: Slab Thickness in Inches

$\Delta\mathbf{PSI}$: Present serviceability index

$\mathbf{P_t}$: The Serviceability at time t

$\mathbf{S_c}$: Modulus of Rupture of Concrete

$\mathbf{C_d}$: Drainage Coefficient

J: Load Transfer Coefficient

$\mathbf{E_c}$: Elastic Modulus

K: Modulus of Subgrade Reaction

$\mathbf{A_s}$: is the Area of Steel required per unit width

$\boldsymbol{f_s}$: is the Allowable Stress in Steel.

CHAPTER ONE

CHAPTER 1

Introduction

1.1 Background

Highways appear to be one of the most important infrastructures that give sign of civilization, and spinning the development wheel. Pavements are designed and constructed to provide durable all-weather travelling surfaces for safe and convenient movement of people and goods with an acceptable level of comfort and service.

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil subgrade, whose primary function is to distribute applied vehicle loads to subgrade. Pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting characteristics, and low noise pollution. Ultimate aim is to ensure that transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the sub-grade.

There are two major types of pavements: flexible or asphalt pavements, rigid or concrete pavements.

Flexible pavement provides sufficient thickness for load distribution through a multilayer structure so that stresses and strains in the subgrade soil are within required limits. On the other hand, rigid pavements are constructed of Portland cement concrete (PCC) slab placed either directly on the prepared subgrade or on a single layer of granular or stabilized material.

Materials are commonly referred to as high-performance materials. Because more is known about the molecular structure of materials and because of continuous research efforts by scientists and engineers, new materials such as polymers, adhesives, composites, geotextiles, coatings, cold-formed metals, and various synthetic products are competing with traditional civil engineering materials. In addition, improvements have been made to existing materials by changing their molecular structures or including additives to improve quality, economy, and performance. For example, super-plasticizers have made a breakthrough in concrete industry, allowing production of much stronger concrete. Joints made of elastomeric materials have improved safety of high-rise structures in earthquake-active areas. Lightweight synthetic aggregates have decreased weight of concrete structures, allowing small cross-sectional areas of components. Polymers have been mixed with asphalt, allowing pavements to last longer under effect of vehicle loads and environmental conditions. The field of fiber composite materials has developed rapidly in the last 30 years. Many recent civil engineering projects have used fiber-reinforced polymer composites. These advanced composites compete with traditional materials due to their higher strength-to-weight ratio and their ability to overcome such shortcomings as corrosion. For example, fiber-reinforced concrete has much greater toughness than conventional Portland cement concrete. Composites can replace reinforcing steel in concrete structures. In fact, composites have allowed construction of structures that could not have been built in the past. Nature and behavior of civil engineering materials are as complicated as those of materials used in any other field of engineering. Due to high quantity of materials used in civil engineering projects, civil engineer frequently works with locally available materials that are not as highly refined as materials used in other engineering fields. As a result, civil engineering materials frequently have highly variable properties and characteristics.

1.2 Problem Statement and Significance

Selection of the most appropriate pavement materials must take into consideration a number of potentially conflicting issues, any of which may limit the range of options that can be considered. Main issue is the cost of investigation, design, construction, and future maintenance of pavement which must be determined in order that resources are not wasted on providing a costly, long life pavement when a less expensive, short term solution is required to allow the most desirable pavement material. Other issues that might control selection of pavement materials are the climate, geomorphology, land use, geometry, construction time, availability and quality of construction materials.

High performance quarried materials will likely be obtained from the nearest possible source in order to minimize transport costs. Often, however, imported material may not be sufficiently strong to satisfy pavement design requirements. In such cases, solution is found in design of either stronger pavement layers or a reduction in stress requirement for layer. One of the most cost effective ways to make pavement stronger is to modify or stabilize pavement material. As an alternative, it is possible to reduce stress requirement by stiffening the foundation. Again, this can be done by either modifying or stabilizing the foundation.

1.3 Research methodology

This research used, data from previous studies and laboratory, field sampling for the two case studies mentioned.

1.4 Objectives

1. To review pavement construction materials.
2. To investigate, properties and characteristics of highway pavement materials.

3. To study methods and types of materials properties correlations.
4. To study and determine design parameters correlations.

1.5 structure of thesis

The research consists of seven chapters organized as follows:

Chapter 1 (introduction): this chapter gives a general background about highway pavements, problem statement objectives.

Chapter 2(literature review): this chapter discusses highway pavement materials types, road planning, comparison between Marshall and Super-pave.

Chapter 3 (Highway pavement materials, tests and characterization, Design parameters and Correlation): this chapter reviews: soil, aggregate, bitumen, hot-mix asphalt concrete, base and sub-base materials, CBR test, plate bearing test, resilient modulus test, resilient modulus, modulus of sub-grade reaction, modulus of elasticity and modulus of rupture, layer coefficients, correlation equations for resilient modulus, Correlation between CBR and *k* value.

Chapter 4 (application of correlation to case study): this chapter illustrates, road projects for case studies, road 1 and road 2.

Chapter 5 (results and discussion): this chapter includes, comparison between study cases, discussion of results.

Chapter 6 (Conclusion): this chapter contains: summary, conclusion and recommendation for further studies, references.

CHAPTER TWO

CHAPTER 2

Literature Review

2.1 General

Materials used for roadway construction have progressed with time. This advancement in materials has been accompanied with corresponding advancements in methods with which these materials are characterized and applied to pavement structural design. Currently, there are two primary types of pavement surfaces — Portland cement concrete (PCC) and hot-mix asphalt concrete (HMAC). Below this wearing course are material layers that provide structural support for the pavement system. These may include either aggregate base with subbase layers, or treated base with subbase layers, and the underlying natural or treated subgrade. Treated layers may be cement-treated, asphalt-treated or lime-treated for additional structural support. There are various methods by which pavement layers are designed. HMAC may be designed using Marshall, or Super-pave mix design (R.A. Higginset al 2005).

First question that is asked when a road is built relates to the function that it is going to serve. At the lowest level, there is a local road that provides access to individual housing units in small residential neighborhood. Local roads feed into collector roads that link up multiple neighborhoods. Collector roads feed into the minor arterial roads, which in turn link to the major arterials that provide connections between large scale community networks. At the highest level, there are freeways and expressways that carry regional and intercity traffic. Size of roads in each road class depends on density of the activities, housing, industrial, office, or other activities, as this will have bearing on the volume of traffic generated.

Ultimate goal of road planning is to ensure safe and smooth flowing traffics conditions through the entire system of roads. While it is important that roadways must have sufficient capacity to accommodate the traffics demand, it is critical to recognize that road design and management should be under taken to ensure that available capacity is not unduly affected by creation of unnecessary bottlenecks and conflicts. Freeways and expressways are designed for maximum mobility with high speeds and capacities. If there are limited or no controls on access points to a major freeway or expressway, capacity, efficiency of travel, and safety levels of roadway may be compromised. This is why access to large regional highways needs to be strictly controlled to interchanges spaced many kilometers apart. On the other hand, Local Street, which has individual links to adjacent properties, cannot be expected to serve a long distance mobility function.

Functions of roads evolve over time. As a region becomes more intensively built-up, traffics volumes on a major arterial may increase and speeds maybe reduced. Building of a new freeway that bypasses these built-up areas to serve through flow traffics easing congestion may lead to arterial taking on more of an access function. Development of new major roadways requires a reexamination of classification system of the region's entire road network and some displacement of roads from their original classes may be necessary. Changes in the categorization of roads provide useful opportunities for redistribution of traffic so that functional integrity of entire road system is structurally sustained. Along term land-use transport plan should be developed to determine not only functional class of particular roadway but also to establish estimated life of that roadway within the class. An area may avoid expensive modifications of existing roadways to sustain its functional position within a particular class if it is clear from long-term plan that roadway may be displaced to an access function when a proposed new roadway is built later on.

Road and highway system is an important asset for circulation of people and goods, for sustaining economic and social life of a city or region. Roads are also expensive assets, and it is not prudent to simply add on new capacity in roadway system when it is not able to cope with the growing traffic volume. A more efficient and cost-effective solution would be to examine closely the structure and flows in existing roads and highways, and to evaluate possibility of easing or removing bottlenecks to smooth traffic flow.

Roads are considered having high construction cost comparing with other infrastructures which can make a great influence in decision making. Also global increment in materials and products and limitation of projects funding to fulfill the needs for sustainable development makes the planners search to minimize construction cost and maintain required quality to involve in many projects.

In Sudan, entire road network is constructed with flexible pavement. Only few concrete pavements were constructed manually by private sector, especially in oil production areas internal road networks, due to its high cost compared with asphalt pavements which can be constructed in lower prices.

Sudan moved to invest forward in cement production according to the studies that indicate availability of huge percent of lime stone the main cement's row material in country especially at state of Nile River. About eight factories are working in cement production industry now and many others are proposed and under establishment.

Aliand Akasha (2013) made comparative studies for rigid versus flexible pavements for Sudan highways under different soil strength and traffic conditions.

It was found that replacing flexible pavements with jointed plain concrete is more feasible and achieves long term good pavement performance.

Mix design for asphalt concrete surfacing materials in developing countries like Sudan is commonly based on the recommendations given in asphalt institute manual series, MS-2(1994) and is carried out using Marshall Test procedure. Basic requirement of the method is that level of Marshall Compaction used should produce a density in design mix which is equal to that which will be produced in the road after secondary compaction under traffic.

2.2Flexible pavements

Flexible pavement is surface constructed by bituminous (or asphalt) materials. These can be either in the form of pavement surface treatments such as a bituminous surface treatment generally found on lower volume roads and HMA, which were generally used on higher volume roads or high way network. Successful of HMA pavement requires good planning, design, construction (materials, subgrade, and workmanship) and planned future maintenance. Asphalt pavements are constructed of one or more course of HMA placed directly on the subgrade or on an aggregate base.

Flexible pavements are called “flexible” since the total pavement structure “bends” or “deflects” due to traffic loads. A flexible pavement structure is generally composed of several layers of material to accommodate this “flexing” effect. The purpose of pavement is use for load support where flexible pavement uses more flexible surface course and distributes loads over a smaller contributing area. It relies on a combination of layers for transmitting load to the sub grade Flexible pavement generally require some sort of maintenance or rehabilitation every 10 to 15 years. In order to take maximum advantage of this property, material layers are usually arranged in order of descending load bearing capacity with the highest load bearing capacity material (and most expensive) on the top and the lowest load bearing capacity material (and least expensive) on the bottom.

Typical flexible pavement structure consisting of:

-Surface course: The layer in contact with traffic loads. It provides characteristic such as friction, smoothness, noise control, rut resistance and drainage (figure 2.1).In addition, it prevents entrance of surface water into the underlying base, sub-base and subgrade. This is the top layer and the layer that is exposed to traffic. It may be composed of one or several different HMA sub layers.

-Base course: The layer immediately beneath the surface (figure 2.1), it Provides additional load distribution and contributed to drainage and frost resistance. This is the layer directly below HMA layer and generally consists of aggregate (either stabilized or unstabilized).

- Subbase course: This is the layer (or layers) under the base layer (figure 2.1), between base course and subgrade. Subbase generally consists of lower quality materials than base course but better than subgrade soils (Sreedevi B.G et. all.2014).

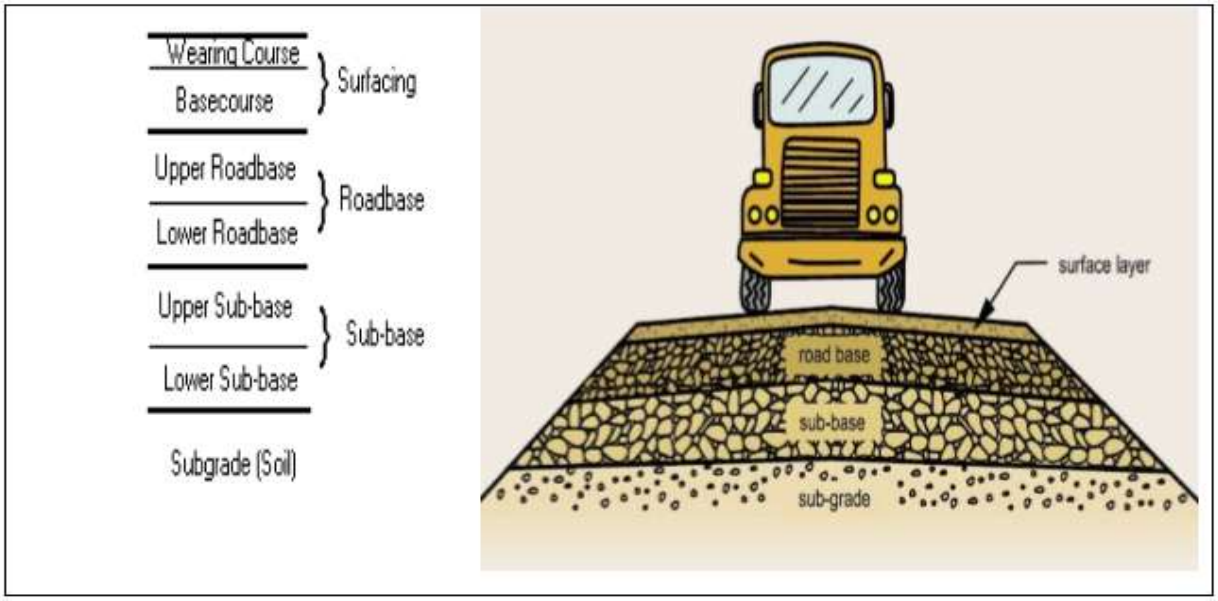

Figure 2.1: Pavement Structure Layers for Flexible Pavement

2.3 Rigid pavements

A rigid pavement is a structure comprising of Portland cement concrete layer (base) which is usually supported by a subbase layer on subgrade fig (2.2), rigid pavement has rigidity and high modulus of elasticity to distribute the load over a relatively wide area of soil.

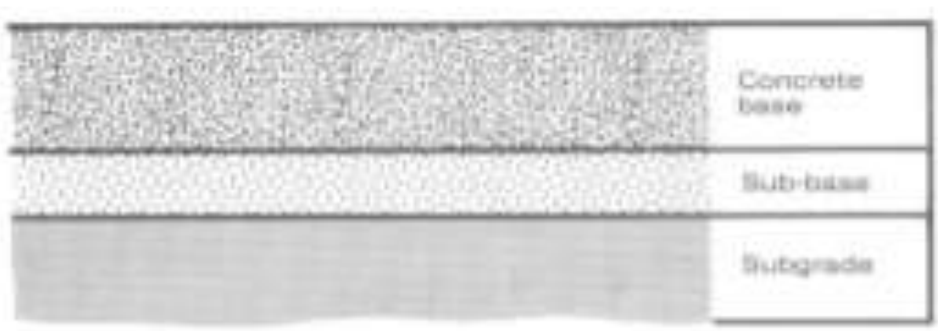

Figure (2.2): Rigid Pavement Structure

The high modulus of elasticity and rigidity of concrete compared to other road making materials provide a concrete pavement with a reasonable degree of flexural strength. This property leads to externally applied wheel loads being widely distributed. This in turn limits pressures applied to subgrade. The major portion of load carrying capacity of a concrete pavement is therefore provided by the concrete layer alone. Its thickness is primarily determined by flexural strength of concrete and by the magnitude of wheel or axle loads.

Subbases do not make a significant structural contribution to concrete pavements. The purpose of subbase is to provide uniform support to concrete base layer and to provide sufficient resistance to erosion of subbase material under traffic and environmental conditions.

-Types of rigid Pavements

-Jointed Plain (unreinforced) Concrete Pavement – PCP

-Jointed Reinforced Concrete Pavement – JRCP

-Continuously Reinforced Concrete Pavement – CRCP

-Steel Fiber Reinforced Concrete Pavement – SFCP

2.4 Comparison between Rigid and Flexible pavement

Rigid pavements	**Flexible pavements**
Deformation in subgrade is not transferred to subsequent layers Design is based on flexural strength or slab action	Deformation in subgrade is transferred to upper layers Design is based on load distributing characteristics of layers component.
Rigid pavement carries high flexural strength	Flexible pavement carries low flexural strength
No such phenomenon of grain to grain load transfer exists	Load is transferred by grain to grain contact
Have low repairing cost but completion cost is high	Have low completion cost but repairing cost is high

Life span is more as compare to flexible (Low Maintenance Cost)	Have low life span (High Maintenance Cost)
Surfacing can be directly laid on subgrade	Surfacing cannot be laid directly on subgrade but subbase is needed
Thermal stresses are more vulnerable to be induced as ability to contract and expand is very less in concrete	No thermal stresses are induced as pavement have ability to contract and expand freely
Expansion joints are needed	Expansion joints are not needed
Strength of road is less dependent on strength of the subgrade	Strength of road is highly dependent on strength of the subgrade
Rolling of surfacing in not needed	Rolling of surfacing is needed
Road cannot be used until 14 days of curing	Road can be used for traffic within 24 hours

2.5Comparisonof Marshall and Superpave (I.H. Hafez,M.W.witczak)

Mix design was conducted on 20 different mixtures categories as: conventional, wet process asphalt rubber (manufacturer pre-blended); dry process rubber asphalt, polymer modified mixes and wet process asphalt rubber (plant blended). These designs were developed using Marshall Procedure and super-pave gyratory level 1 procedure. Here is a comparison between design asphalts contents results obtained by two procedures. Superpave design were conducted at a traffic level compared to traffic of 75 blows of Marshall procedure and for three climatic regions representative of cool to warm conditions.

Major problems were encountered with superpave gyratory approach for five mixtures within the dry process level. These problems appear to be related to high resiliency of rubber aggregate during gyratory compaction process coupled with time dependent swell of these mixtures directly after compaction. It's concluded that superpave level 1 mix design approach is not applicable to those mixtures.

For other four groups of mixtures studies, differences between binder contents from Marshall and Superpave were found to be function of group type. Differences in design content obtained from Superpave gyratory were found to be about 1.0% more asphalt as the climatic regions went from warm to cool conditions. This finding was true for all types of mixtures studied.

In general, conventional mixtures and the manufacturer pre-blended rubber asphalts gave similar design values between Marshall and "warm" Superpave climatic region and contrast is true for plant blended rubber asphalt.

2.6 Materials stabilization

Stabilization may be defined as the alteration of the properties of an existing soil either by blending (mixing) two or more materials and improving particle size distribution or by the use of stabilizing additives to meet the specified engineering properties. Quite often soils are stabilized for road construction in most parts of the world for the following one or more objectives:

• Improve the strength (stability and bearing capacity) for subgrade, subbase, base, and low-cost road surfaces,

• Improve the volume stability – undesirable properties such as swelling, shrinkage, high plasticity characteristics, and difficulty in compaction, etc.

• Improve durability – increase the resistance to erosion, weathering or traffic.

• Improve high permeability, poor workability, dust nuisance, frost susceptibility, etc.

Basically four techniques of soil stabilization are commonly practiced in pavement construction:ƒ Mechanical stabilization, Cement stabilization, Lime stabilization, and Bitumen stabilization.

Materials that used for stabilization such as, cement, lime, bitumen.

CHAPTER THREE

CHAPTER 3

Highway Pavement Materials, Tests and Characterization, Design parameters and Correlation

3.1 General

Highway pavement is a structure consisting of superimposed layers of processed materials above natural soil sub-grade, whose primary function is to distribute applied vehicle loads to sub-grade. Pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting characteristics and low noise pollution. Ultimate aim is to ensure that transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of sub-grade.

3.2 Soil

Soil is defined as assemblage of mineral particles and organic matter in the form of a deposit. All types of soil derive from disintegration of rocks and decomposition of vegetation, combination (solid, liquid and air) gives soil its basic properties, which affect its mechanical behavior.

Some basic soil tests are: Particle size analysis, Liquid limit, plastic limit and plasticity index, Proctor compaction test and Moisture condition value test.

3.3 Aggregates

Aggregates used in construction can be crushed aggregates, natural aggregates, Slag, recycled materials, which meets the required mechanical, natural and chemical properties for layer to be used.

Some aggregate tests are: Sieve analysis, Flakiness index test, Shape Index test, Sand equivalent test, Aggregate abrasion value test, Determination of density of aggregate particles and Water content test.

3.4 Bitumen

According to CEN EN 12597 (2000), bitumen is virtually an in volatile, adhesive and waterproofing material derived from crude petroleum or present in natural asphalt, which is completely or almost completely soluble in toluene and very viscous or almost solid at ambient temperatures.

According to same specification, asphalt is a mixture of mineral aggregate and bituminous binder. In addition, bituminous is the adjective applicable to binders and mixtures of binders and aggregates containing bitumen. Hence, bituminous binder is adhesive material containing bitumen.

Furthermore, natural asphalt is relatively hard bitumen found in natural deposits, often mixed with fine or very fine mineral matter, which is virtually solid at 25°C.

3.5 Hot-Mix Asphalt Concrete (HMAC)

HMAC consists primarily of mineral aggregates, asphalt cement (or binder) and air. It is important to have suitable proportions of asphalt cement and aggregates in HMAC so as to develop mixtures that have desirable properties associated with good performance. These performance measures include resistance to the three primary HMAC distresses: permanent deformation, fatigue cracking and low temperature cracking. Permanent deformation refers to plastic deformation of HMAC under repeated loads. This permanent deformation can be in form of rutting (lateral plastic flow in the wheel paths) or consolidation (further compaction of the HMAC after construction). Aggregate interlock is the primary component that resists permanent deformation with asphalt cement playing only a minor role.

Angular, rough-textured aggregates will help reduce permanent deformation. Stiffer asphalt cement may also provide some minor benefit. Cracking can be subdivided into two broad categories: load associated cracking and non-load associated cracking.

Load associated cracking has traditionally been called fatigue cracking. Factors associated with the development of fatigue cracking include in-situ properties of the structural section, asphalt cement, temperature and traffic. Non-load associated cracking has traditionally been called low-temperature cracking.

Michael.s. Mamlouk, John.B. Zaniewsky, et al. (2016)

3.6 Base and Subbase Materials

Success or failure of a roadway section is often dependent upon underlying subgrade. Strength, stiffness, compressibility and moisture characteristics of the subgrade can have significant influences on pavement performance and long-term maintenance requirements. Subgrade must be strong enough to resist shear failure and have adequate stiffness to minimize vertical deflection. Stronger and stiffer materials provide more effective foundation for the riding surface and will be more resistant to stresses from repeated loadings and environmental conditions. Critical component of pavement design involves a thorough and reliable characterization of subgrade. A number of laboratory methods are available to characterize strength and stiffness of subgrade soils including Resistance value (R-value), California Bearing Ratio (CBR) and repeated load triaxial laboratory tests. In-situ tests to evaluate subgrade properties include, among others: falling weight deflectometer (FWD), in-situ CBR, plate load, miniature cone penetrometer and dynamic cone penetrometer tests. While HMAC and PCC are primarily used on the surface of pavements, there are several underlying layers that play a critical role in performance of a pavement. This includes bases, sub bases, and subgrade. These layers consist primarily of treated and untreated aggregates.

Granular materials for use in subbase courses shall be naturally occurring gravel, blended as necessary with fine or coarse material and screened to produce specified gradation. Crushing of natural granular material shall not normally be required, unless for meeting the grading requirements, producing a higher quality subbase with improved mechanical stability.

Aggregates for use in base course construction shall be either crushed stone or crushed gravel. Fine aggregate shall consist of screenings obtained from crushed stone and gravel or sand.

3.7 Highway Pavement Material Tests

3.7.1 CBR test

California bearing ratio (CBR) is a penetration test for evaluation of mechanical strength of road sub-grades and base-courses. It was developed by California department of transportation before World War 2.

Test is performed by measuring pressure required to penetrate a soil sample with a plunger of standard area. Measured pressure is then divided by the pressure required to achieve an equal penetration on standard crushed rock material Eq. (3.1).

CBR test is described in ASTM standards D1883-05(for laboratory prepared samples) and D4429 (for soil in place in field) and AASHTO T193. CBR test is fully described in BS1377: soils for civil engineering purposes: part4, compaction related tests.

CBR rating was developed for measuring load-bearing capacity of soils used for building roads. CBR can also be used for measuring load bearing capacity of unimproved airstrips and soil under paved airstrips.

$$CBR = P/Ps\ (\%) \qquad (3.1)$$

P=measured pressure for site soils (N/mm^2)

Ps=pressure to achieve equal penetration on standard soil (N/mm^2)

Prime objective of soil stabilization is to improve California bearing ratio of in-situ soils by 4 to 6 times. Other prime objective of soil stabilization is to create a solid and strong sub-base and base courses. In certain regions of the world, typically developing countries and now more frequently in developed countries, soil stabilization is being used to construct the entire road.

In the past, soil stabilization was done by utilizing binding properties of clay soils, cement-based products such as soil cement, utilizing the (rammed earth) technique (compaction) and lime.

Traditionally and widely accepted types of soil stabilization techniques use products such as bitumen emulsions which can be used as binding agents for producing a road base. However, bitumen is not environmentally friendly and becomes brittle when it dries out. Portland cement has been used as alternative to soil stabilization. However, this can often be expensive and is not a very good (green) alternative.

National society of professional engineers has explored some of newer types of soil stabilization technology specifically looking for alternatives.

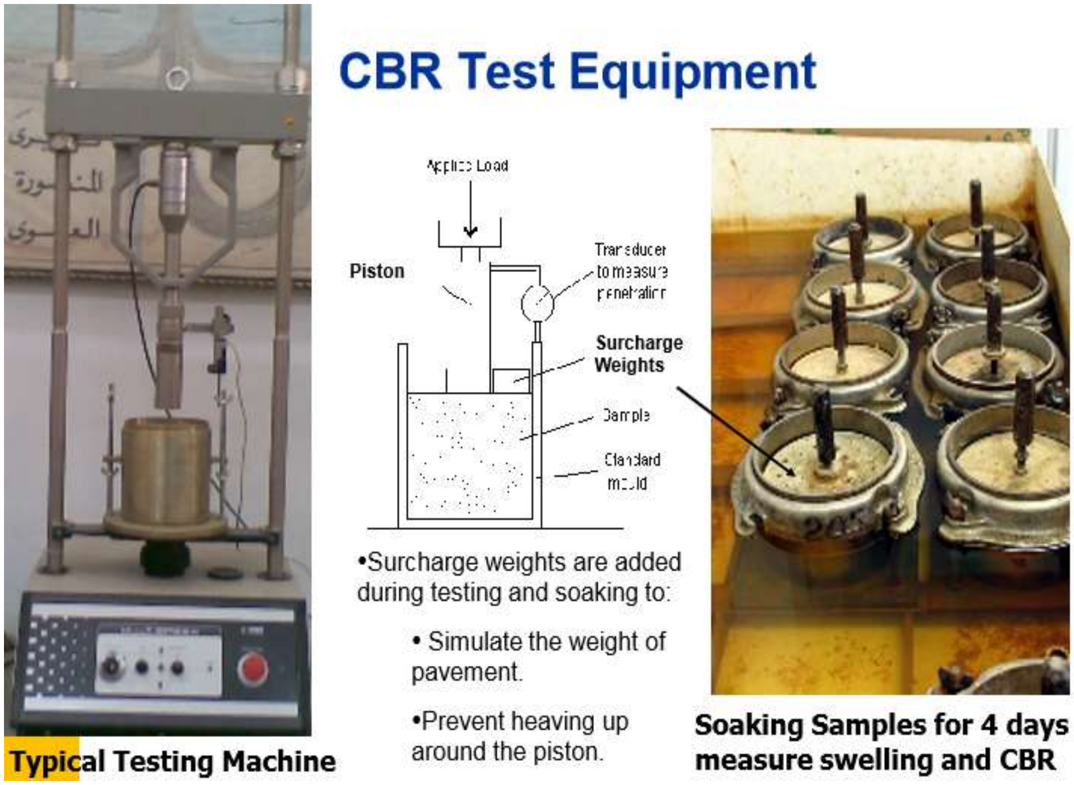

Figure (3.1): CBR test equipment

3.7.2 Plate bearing test (modulus of subgrade reaction *k*)

Plate bearing test is used for determination of soil bearing capacity with respect to the modulus of surface reaction (*k* value). Subgrade bearing capacity in terms of *k* value is used, mainly, in rigid pavement design methodologies.

Determination of modulus of reaction is based on Westergaard theory for stresses and deformations (deflections) for loading concrete plates, where subgrade elastic reaction in a vertically loaded plate with pressure (p) is considered to be vertical and proportional to the vertical deformation (deflection) of subgrade, at all levels of loading. Constant of proportionality between applied pressure (p) and respective deflection (δ_z) is defined as the modulus of subgrade reaction (*k*); that is,

$$p = k \times \delta_z \qquad (3.2)$$

Test is carried out on compacted material with certain moisture, using a steel circular plate and a load application system. Steel plate can be of various diameters, but the plate normally used has a 762 mm diameter. For increasing plate's rigidity, two additional circular plates of smaller diameter (approximately 650 and 550 mm) are placed on top of it. Load application is usually carried out with hydraulic jack assembly, which is properly adjusted to a fixed reaction beam of a load vehicle. Plate bearing test arrangement is shown in Figure 3.2.

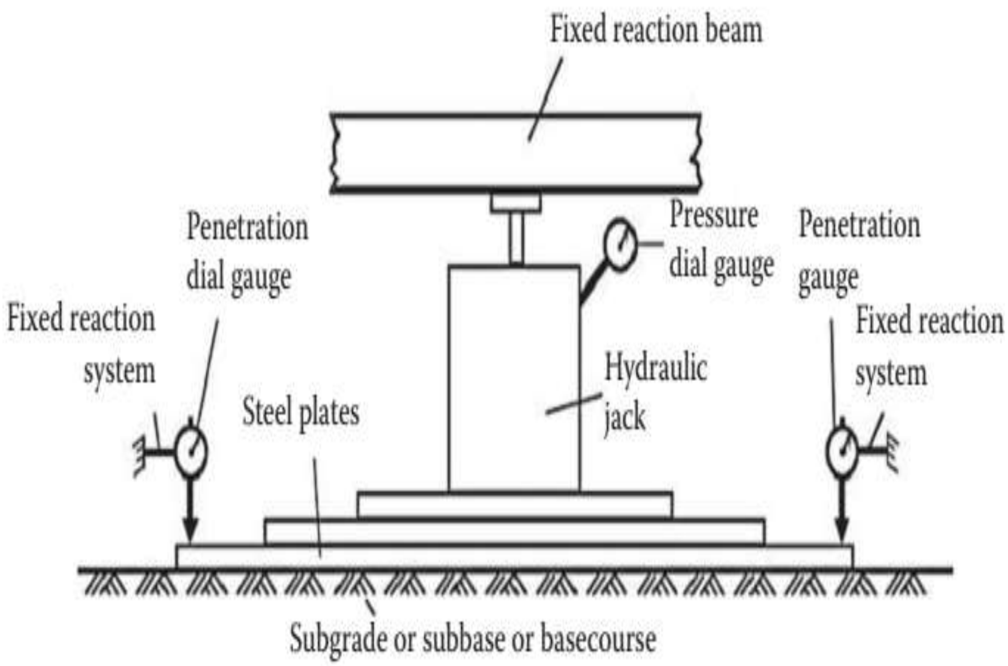

Figure 3.2 Schematic representation of the plate bearing test.

When the load is applied pressure induced on the layer's surface results in a corresponding deflection, which is measured by two, three or even four gages. The average value of deflection measured at different magnitudes of pressure determines pressure (kPa) versus deflection (mm) curve. Theoretically, the curve should be linear. However, this is not the case because of the non-elastic behavior of soil or unbound material. As a result, *k* value is determined from a point of the curve as defined by test procedure adopted. In most cases, either pressure corresponding to 1.25 mm deflection or deflection caused by 68.94 kPa pressure, using a 762 mm diameter plate.

Thus, the modulus of reaction (*k* value) is calculated with one of the following equations:

k_{762}= p/1.25 (kPa/mm) (3.3)

or

k_{762}= 68.94/δz (kPa/mm) (3.4)

Where k_{762} is the modulus of reaction using a 762 mm diameter plate is the applied pressure (kPa) and δ_z is the deflection (mm).

3.7.3 Repeated load triaxial test – resilient modulus test

Resilient modulus of granular materials and fine grained soil is determined using repeated triaxial test, by applying a repeated axial cyclic stress of fixed magnitude, load duration and cycle duration to a cylindrical specimen. While specimen is subjected to dynamic cyclic stress, it is also subjected to a static confining stress provided by a pressure chamber. Cyclic load application, though, is better to simulate the actual traffic loading.

Triaxial test under repeated axial loading is performed using a similar apparatus to the one used for typical triaxial test in which a static axial loading is used (ASTM D 2850 2007). Apparatus used for the determination of resilient modulus is as shown in Figure (3.3). Deviator stress σ_d ($=\sigma_1 - \sigma_2$) is repeated, at a fixed magnitude and frequency. Loading of soil specimen, under influence of deviator stress, results in a deformation, part of which is recoverable during stage of unloading. This recoverable strain along with deviator stress determines resilient modulus (M_R), or modulus of elasticity (E), of the material tested, using Eq. (3.5).

$$MR \text{ (or E)} = \sigma_d/\varepsilon_r \text{ (kPa)} \quad (3.5)$$

Where ε_r is the recoverable strain (mm/mm).

A detailed description of test procedure can be found in Asphalt Institute MS-10 and AASHTO T 307 (2007).

Compaction of soil specimens is carried out by either double plunger method or kneading compactor and specimen is tested at maximum density. The test can also be carried out in undisturbed specimens extracted from the site.

Dimensions of cylindrical specimens depend on maximum particle size. Length of the specimen should not be shorter than twice its diameter and its minimum diameter shall not be less than 71 mm or six times the maximum size particle. Cylindrical test samples are normally 100 mm in diameter by 200 mm in height.

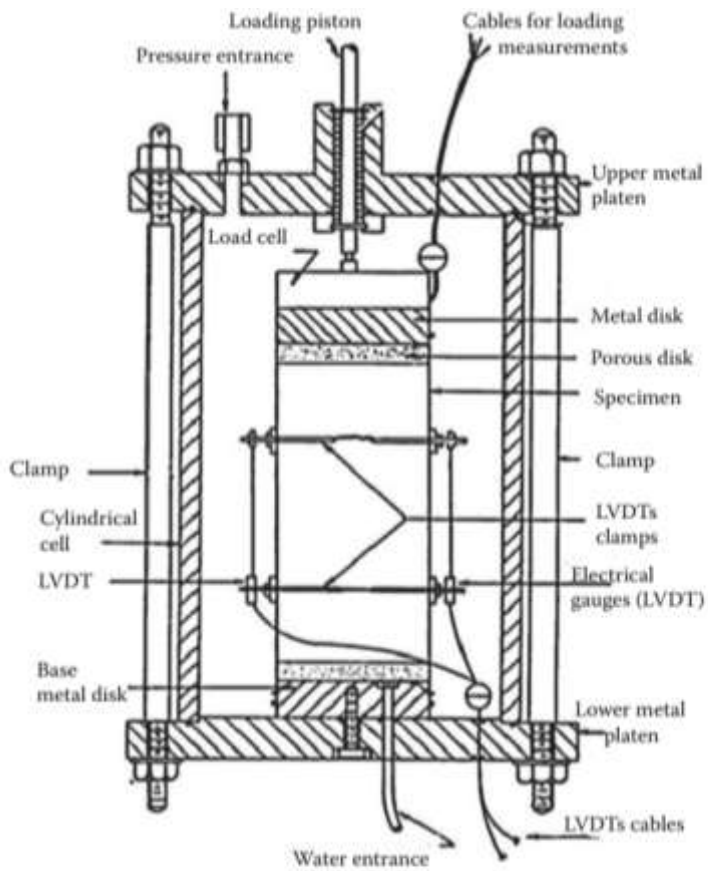

Fig (3.3) Triaxial Cell for Testing Cylindrical Specimens

3.8 Design parameters

3.8.1 Resilient modulus

Resilient modulus is the elastic modulus to be used with elastic theory. It is well known that most paving materials are not elastic, but experience some permanent deformation after each load application. However, if the load is small compared to strength of material and is repeated for large number of times, deformation under each load repetition is nearly completely recoverable (and proportional to the load) and can be considered elastic.

At initial stage of load applications, there is considerable permanent deformation, as indicated by plastic strain. As the number of repetition increases, plastic strain due to each load repletion decreases. After 100 to 200 repetitions, strain is practically all recoverable, as indicated by ε_r .

Elastic modulus based on recoverable strain under repeated loads is called resilient modulus M_R, defined as

$$\mathbf{M_R} = \boldsymbol{\sigma_d / \varepsilon_r} \qquad (3.6)$$

In which is deviator stress, which is the axial stress in an unconfined compression test or axial stress in excess of confining pressure in a triaxial compression test. Because applied load is usually small, resilient modulus test is nondestructive test, and the same sample can be used for many tests under different loading and environmental conditions.

3.8.2 Modulus of subgrade reaction (k)

For concrete pavements, the primary requirement of the subgrade is to be uniform, this is the fundamental reason for specifications on subgrade compaction, the strength of the soil is characterized by the modulus of subgrade reaction referred to *k*.

3.8.3 Modulus of Elasticity (Ec) and Modulus of Rupture (concrete properties)

Modulus of Rupture used in the AASHTO Design Guide equations is represented by the average flexural strength of the pavement determined at 28 days using third-point loading (ASTM C 78).

Modulus of Elasticity for concrete (Ec) depends largely on the strength of concrete. Typical values are from 2 to 6 million psi.

3.8.4 Layer Coefficients

Structural layer coefficients are required for flexible pavement design, a value for these coefficients is assigned to each layer material in pavement structure in order to convert actual layer thickness into the structural number (SN). These values have been used in the structural calculations. If specific elements, such as a Superpave mix or polymer modified mix are used, the designer should adjust these values to reflect differing quality of materials Huang, Y.H et al. (2011).

3.9Correlation

3.9.1Correlation equations for resilient modulus

Resilient modulus approach was first incorporated into pavement analysis and design in the 1980s after several decades of research. Since that time, there has been significant effort to relate resilient modulus to more readily measured soil parameters using index and strength tests. One noteworthy complication to such an evaluation is lack of a widely accepted test procedure to measure resilient modulus. Many laboratory and field approaches have been proposed; consequently, it is important to examine specific details of any study before applying a correlation equation in design or before incorporating a correlation equation into an agency-wide standard. Specific details that could significantly affect reliability of any correlation equation include resilient modulus test protocols as well as information on soil type and moisture conditions.

3.9.1.1 R-value Correlation Equations

Idaho Transportation Department (ITD) commissioned a study in the late 1970s to develop a correlation between resilient modulus and R-value (Buu 1980). RLT test was used to measure M_R and then correlated to R-value test result. RLT tests were conducted at University of Idaho using customized triaxial equipment and R-value tests were conducted at ITD headquarters in Boise, Idaho. Correlation equations are reported in Yeh & Su (1989) as:

$$M_R(ksi) = 1.455+0.057\times R \quad (3.7)$$

$$M_R(ksi) =1.66+038\times R \quad (3.8)$$

Correlations correspond to resilient modulus test conditions of σ_d = 6 psi and σ_3 = 2 psi. Where σ_d is the vertical deviator stress and σ_3 is the lateral confining pressure. Eq. (3.7) was developed from tests on 10 fine-grained soils with R-values between 46 and 68; Eq. (3.8) was developed from tests on 14 coarse-grained soils with R-values between 9 and 82 (Yeh and Su 1989, Sandefur 2003). Coefficient of determination (R_2 value) of a regression equation indicates the ability of equation to predict outcome of a given set of inputs. An R_2 value close to unity indicates the data fits the correlation equation very well. The R_2 values for Eq. (3.7) and (3.8) are 0.10 and 0.82, respectively (Yeh and Su 1989), indicating Eq. (3.8) is a better predictor of M_R for the soil samples considered in analysis.

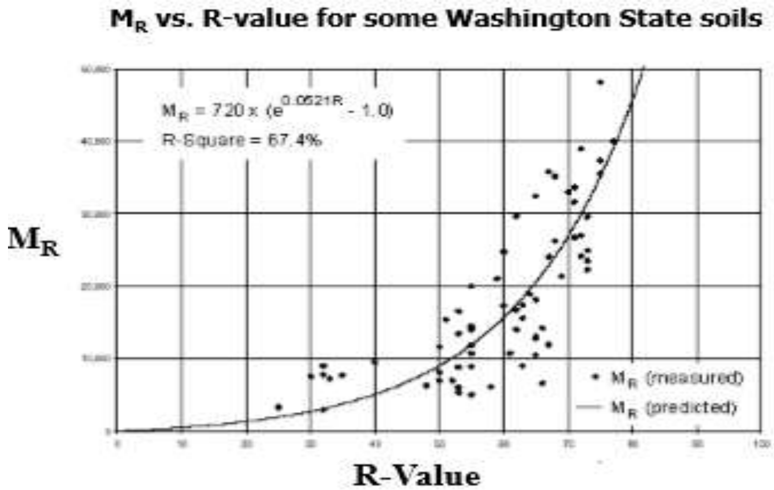

Fig (3.4) correlation between M_R and R-value

3.9.1.2CBR Correlation Equations

Heukelom and Klomp (1962) developed a commonly referenced CBR correlation based on dynamic modulus measurements and in-situ CBR tests. In-situ CBR test results were correlated with measurements obtained using an instrumented vibratory compactor in the field; not from RLT tests in a laboratory. Correlation was developed based on a combination of three sets of data:

1) Wave velocity data reported by Jones (1958) for CBR values between 2 and 20.

2) Wave velocity measurements conducted by Heukelom and Klomp (1962) for CBR values between 3 and 200.

3) Stiffness measurements conducted by Heukelom and Klomp (1962) for CBR values between 3 and 200.

Heukelom and Klomp (1962) used these three data sets to calculate a dynamic modulus from the wave velocity. Even though Heukelom and Klomp (1962) did not refer to the modulus as a resilient modulus, correlation equation (Eq. 3.9) is referenced in several sources; sometimes as Heukelom and Klomp (1962) and sometimes as the Shell Laboratory method (Asphalt Institute 1982, Drumm et al. 1990, Witczak et al. 1995, Sukumaran et al. 2002, Puppala 2008).

$$M_R(ksi)=1.42\times CBR \quad (3.9)$$

While the regression coefficient of 1.42 provides the best fit for 69 test results with CBR values ranging from 2 to 200, it could easily vary from 0.7 to 2.8 because of the large scatter in the data. Most references to Eq. (4.4) simply round the coefficient to 1.5, which is likely a result of this wide range.

3.9.1.3 Soil Property Correlation Equations

Jones &Witczak (1977) developed two correlation equations for A-7-6 subgrade soils in California. Resilient modulus RLT tests were performed at σ_d = 6, 12, and 18 psi and σ_3 = 2, 4, 6, 8, and 12 psi. The regression equations can be used to calculate M_R at specific stresses (σ_d = 6 psi and σ_3 = 2 psi) by inputting water content (w) and degree of saturation (S):

Eq. (3.10) is based on M_R results of 10 remolded soil samples compacted to modified Proctor density (R_2 = 0.94):

$$\text{Log } M_R\,(ksi) =-0.1328w+0.0134S+2.319 \quad (3.10)$$

Eq. (3.10) is based on M_R results of 97 undisturbed field samples (R_2 = 0.45):

$$\text{Log } M_R\,(ksi)=-0.1111w+0.0217S+1.179 \quad (3.11)$$

Where, w is the water content and S is the degree of saturation. Jones and Witczak (1977) postulated that one possible reason for the differences between Eq. (3.10) and (3.11) is that the remolded samples compacted wet of optimum may have had a dispersed structure; whereas, the undisturbed field samples most likely had a natural flocculated structure.

3.9.2Correlation between CBR and *k* value

Provided that composition and thickness uniformity of soil layer exists, it has been found that the following relationship between CBR and *k* stands:

$$CBR = 6.1 \times 10{-}8\times (k762)1.733(\%) \quad (3.12)$$

Where *k* 762is the modulus of reaction measured with a 762 mm diameter plate for plate penetration, which is usually 1.25 mm.

In case a smaller plate is used, k762can be calculated with the following relationship:

$$k762= F\times k\,mm \quad (3.13)$$

Where F is the coefficient calculated with the following relationship:

$$F= 0.00124D+ 0.0848 \quad (3.14)$$

Where D is the diameter of loading plate (mm), and *k* mm is the modulus of reaction determined by the plate bearing test, using a certain millimeter diameter plate.

Using the above relationships, the plate bearing test is used by some organizations, as well as for the estimation of CBR of soil layer, which contains a high percentage of coarse soils.

Table 3.1Subgrade soil types and range of approximate *k* values

Type of Soil	Support	*k* Values psi/in^3 (MPa/m)	CBR	R-Value
Fine-grained soils in which silt and clay-size particles predominate	Low	75 to 120 (20 to 34)	2.5 to 3.5	10 to 22
Sands and sand-gravel mixtures with moderate amounts of sand and clay	Medium	130 to 170 (35 to 49)	4.5 to 7.5	29 to 41
Sands and sand-gravel mixtures relatively free of plastic fines	High	180 to 220 (50 to 60)	8.5 to 12	45 to 52

CHAPTER FOUR

CHAPTER 4

Application of Correlations to Case Study

4.1 Road Projects for Case Studies

The study was conducted for El Moneera – El Saffaya highway (Road 1) which is part of the national road network.

The other case study was for (Road 2), the section of Omdurman Ring Road, representing a state road.

4.1.1 Road (1) Characteristics

El Moneera - El Saffaya road is one of projects associated to the re-residence of the effected peoples from construction of Seteit & Atbara dams.

Alignment is about 60 km starts from El Moneera passing through Wad Jabir and El Drabi cities towards El Saffaya at the northern east of country.

Roughly between latitude 15^0 and longitude 36^0 in Butana area see figure 4.1.

The whole road corridor passes through semi flat terrain with some hills up to El Saffaya. The type of soils along the alignment is clayey soils (expansive soil).

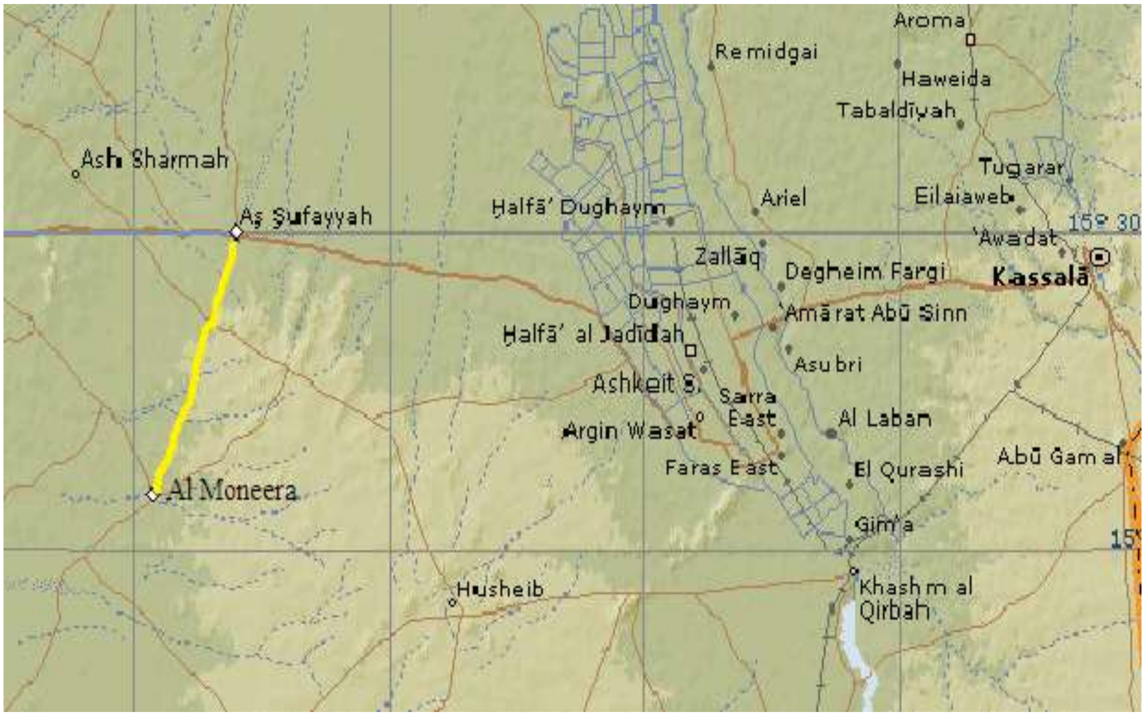

Figure 4.1: Road (1) Project Area Plan

Figure 4.2: Road (1) Project Site

Figure 4.3: Road (1) Alignment

Figure 4.4: Features of Road 1

The geometric design of the road consists of single carriageway with 3.65m single lane in each direction.

4.1.2 Road 2 Characteristics

About seven km of Omdurman ring road the section of Khartoum ring road project, which connecting the three parts of the capital area together (Khartoum, Omdurman and Bahry) was selected to perform the study. This section is now under construction and reaches to the crushed stone base works.

The alignment starts from Sheryan El Shmal Road, and ends in the intersection of Dar Elsalam Road with Qandahar. The corridor is crossing three small valleys (khours) discharging water to Abu Annja the main khour. There was a hill at the end of the alignment which had been crushed to maintain the required road level and to supply the base layer material.

The soil along the alignment varies from sandy, silty and rocky soils.

Figure 4.5: Road 2 Project Area Plan

Figure 4.6: Intersection of Omdurman Ring Road with Sheryan El Shemal Road

Figure 4.7: Road 2 Alignment

The geometric design of the road consists of double carriage way with three lanes on each direction; the lane width is 3.65 m.

4.2 Material Properties

4.2.1 Road 1 Sub-grade and Construction Materials Laboratory Testing Results

Along the proposed alignment, seventeen pits were dug, and samples were taken for approximately 60 cm depth to carry out the sub-grade soil laboratory testing. Thirteen samples had been taken from the proposed aggregate quarries which had been located at twelve villages within the project area near to beginning of the proposed road.

Results of sieve analysis, liquid limits, plasticity index, soil classification accordance to AASHTO M145 and the CBR values had been shown in Table D-1of Appendix D.

It's noticeable that the sub-grade soil all along the alignment falls under the group of A-7-6 which categorized as plastic clayey soil with high plasticity indexes ranging between 26.5% - 32.5% this type of soil is subject to extremely high volume change between wet and dry seasons.

The CBR values were taking range from 1% - to 3% at the seven samples which selected randomly. This type of soil is not suitable for pavement construction.

Improved sub-grade shall be required to be replaced after excavation and removing of 12 in (30 cm) of the existing sub-grade.

There are many quarries near the project area have got considerable amounts of soil with CBR greater than 10%, suitable for improved sub-grade construction.

The aggregate falls in group A-1-a witch including gravel and A-1-b which includes coarse sand. The plasticity indexes are ranging from non-plasticity to 11%. The CBR values obtained falls in rang of 40% - 100%.

Aggregate investigation clearly shows appropriate materials for construction of sub base and base layers tabulated in Table D-2 of Appendix D.

4.2.2 Road 2 Sub-grade Soil and Construction Material Laboratory Test Results

Through the samples which had been taken for soil analysis, the sub-grade soil encountered on the proposed alignment are vary from non to medium plastic soils (SM, SC, and CL) and classified as A-4, A-2-6, A-2-4 and A-6 according to AASHTO classification system.

The percentage of fine soil varies between 17.0 – 61.2%

The liquid limits have range between Non – 37.2

The plasticity index varies between Non -13.2

CBR values were measured for selected sub-grade and varies between 2.5 – 25 % with Swell varies between 0 – 30%. Table D-3 of Appendix D is shown the mentioned above results.

The exposed sub-grade soil generally is suitable to be used as embankment materials. The sub-grade shall be excavated to depth of 12 in (30 cm), and placed in layers with good compaction to perform the embankment.

The samples were taken from the nearby borrow pits proposed to supply the construction materials generally consist of Sandy Gravel with Silt, Gravely Sand with Silt, Sandy Silt with Gravel, Sand soils with Silty Gravel. There are classified in ASTEM system (SC, SM & CL). In AASHTO system they belong to A-2-4 & A-2-6.

The liquid limits have range of 19 – 26.

The plasticity index varies between 6.1 -10.7.

CBR values were measured for selected construction and varies between18 –43% with a swell varies between 0 - 0.02%

The construction material tests results were shown in Table D-3 of Appendix D. The construction materials meet the requirements of the design standard of sub base layers in one borrow pit only which shows CBR value of 43% and falls at coordination of E= 4412911, N= 1742193.

For construction of base there are many quarries for supplying of stones, which can be processed and crushed to prepare the required material.

4.3 Resilient Modulus M_R

The design CBR had been determined by using Asphalt Institute percentile value, as shown in table D-4 of Appendix D.

1. The percentile value opposite to Road 1 flexible pavement design traffic ESAL = 6.2×10^5 is 75%.

2. The percentile value opposite to Road 2 flexible pavement design traffic ESAL = 5.24×10^6 is 87.5%.

4.3.1 Road (1) Sub-grade Resilient Modulus M_R.

The CBR values of the seven samples had been arranged in ascending order in table 4.8 and analyzed to get the cumulative curve obtained in figure 4.1. By entering figure 5.1 with the design percentile value of 75% the design CBR value was found to be equal to 1.9%**.**

The sub-grade soil is not suitable for pavement construction. It is recommended to be cut and remove from site and replaced with selected material to work as improved sub-grade (capping) with CBR = 10%, this soil is available near the site

Table 4.1: Determination of Road (1) Sub-grade Design CBR

CBR values	No. of observations	No. of CBR values ≥ value shown	% CBR values ≥ value shown
1	2	7	100
2	1	5	71.43
2.2	2	4	57.14
2.8	1	2	28.57
3	1	1	14.29
Total	**7**		

4.3.1.1 Improved Sub-grade (capping) Resilient Modulus M_R.

The materials shall be selected for the improved sub-grade construction shall have a CBR value of 10%.

CBR = 10%

$M_R = 1500 \times 10 = 15{,}000$ psi

The design should be performed based on the improved sub-grade resilient modulus.

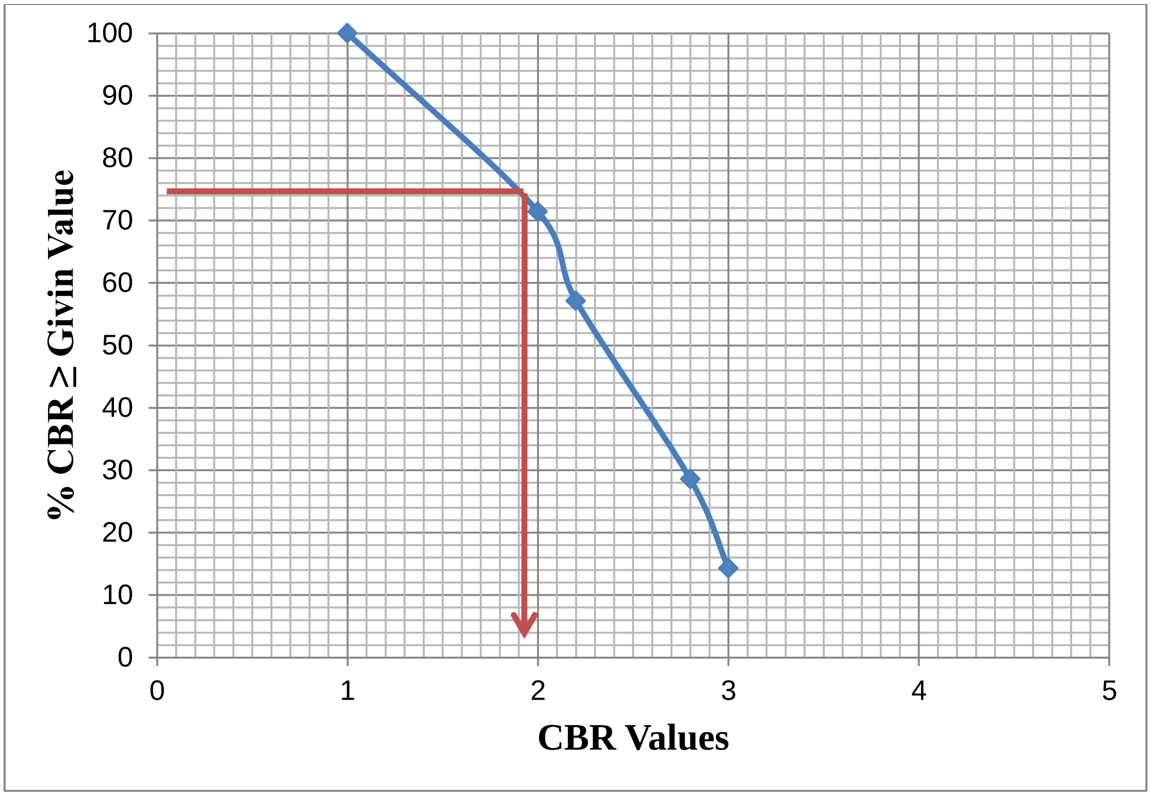

Figure 4.8: Road 1 Sub-grade Design CBR

4.3.2 Road 2 Sub-grade Resilient Modulus M_R

Fifteen CBR values had been analyzed adopting the above procedure in Table 4.7 the 87.5 percentile had been used to determine the design CBR value which is equal to 5 **%**from the cumulative curve in Figure 4.2

M_R (psi) = 1500×CBR

= 1500× 5

= 7,500 psi

4.3.2.1 Road 2 Improved Sub-Grade Resilient Modulus:

The sub-grade soil shall be processed through good compaction to achieve desirable strength, and perform embankment layer with CBR greater than the actual. For design purpose CBR = 8 is assumed.

M_R (psi) = 1500×CBR

= 1500 × 8

= 12,000 psi

Table 4.2: Determination of Road 2 Design CBR

CBR values	**No. of observations**	**No. of CBR values ≥ value shown**	**% CBR values ≥ value shown**
4.5	1	11	100.00
5	2	10	90.91
6	3	8	72.73
7	1	5	45.45
8	1	4	36.36
10	1	3	27.27
15	1	2	18.18
17	1	1	9.09
Total	**11**		

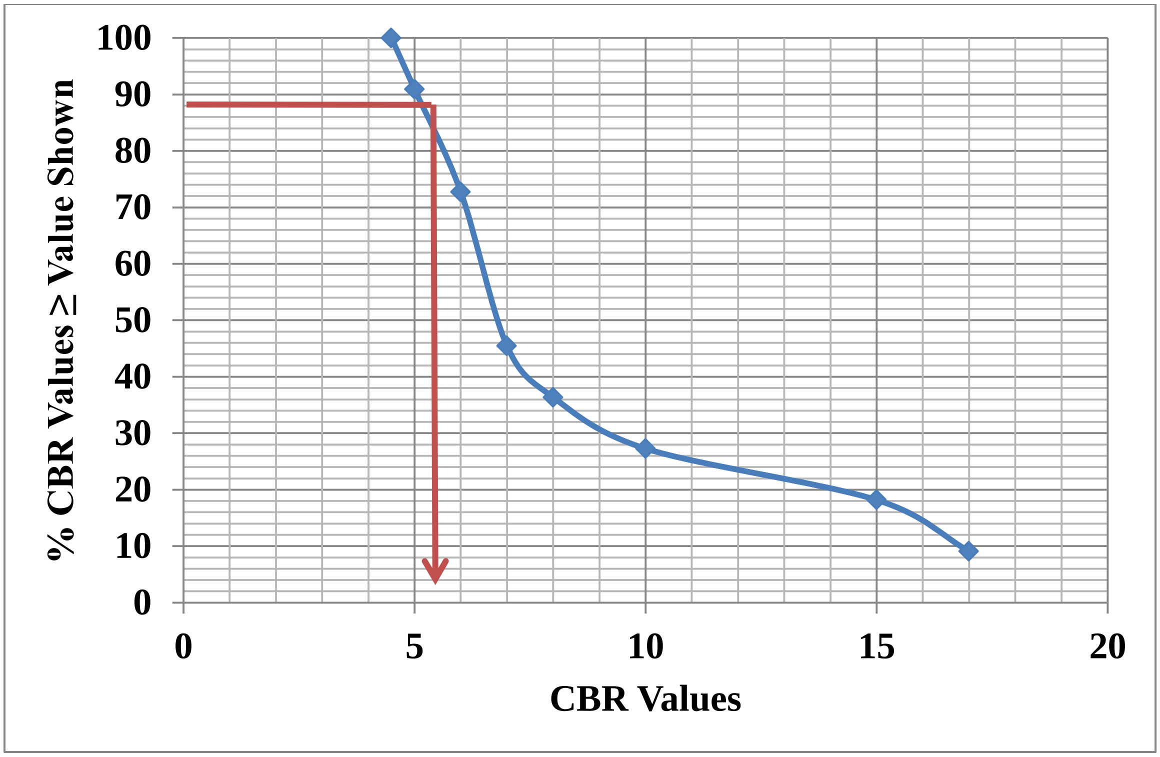

Figure 4.9: Road 2 Sub-grade Design CBR

4.3.3 Road 1 and 2Pavement Structure Resilient Modulus

1. Road 1 Sub-Base Resilient Modulus E_{SB}

Four CBR data were analyzed using the same procedure as indicated in Table 4.9.Figure 4.3 shows the cumulative curve was made by the analysis. Dropping line from the design percentile value of 75% to intersect the cumulative curve; then from the intersection point another line had been made to intersect the horizontal axis to obtain the design CBR which found to be equal to45%.

The suggested correlation to obtain the resilient modulus E_{SB} from CBR value:

E_{SB} (MPa) $= 10.342 \times CBR^{0.64}$

$= 10.342 \times 45^{0.64}$

$= 118 \text{ MPa} \times 145$

$= 17{,}110 \text{ psi} \supset 17{,}000 \text{ psi}$

Table 4.3: Determination of Road 1 Sub-Base Design CBR

CBR values	No. of observations	No. of CBR values ≥ value shown	% CBR values ≥ value shown
40	1	4	100
45	1	3	75.00
49	1	2	50.00
63	1	1	25.00
Total	**4**		

2. Road 2 Sub-Base Resilient Modulus E_{SB}

Hence there are one borrow bit meet the required design specification as mentioned above with CBR value equal to43% the correlated resilient modulus for this value can be determined as follows:

E_{SB} (MPa) $= 10.342 \times CBR^{0.64}$

$= 10.342 \times 43^{0.64}$

$= 114.8 \times 145$

$= 16{,}949 \text{ psi} \supset 17{,}000 \text{ psi}$

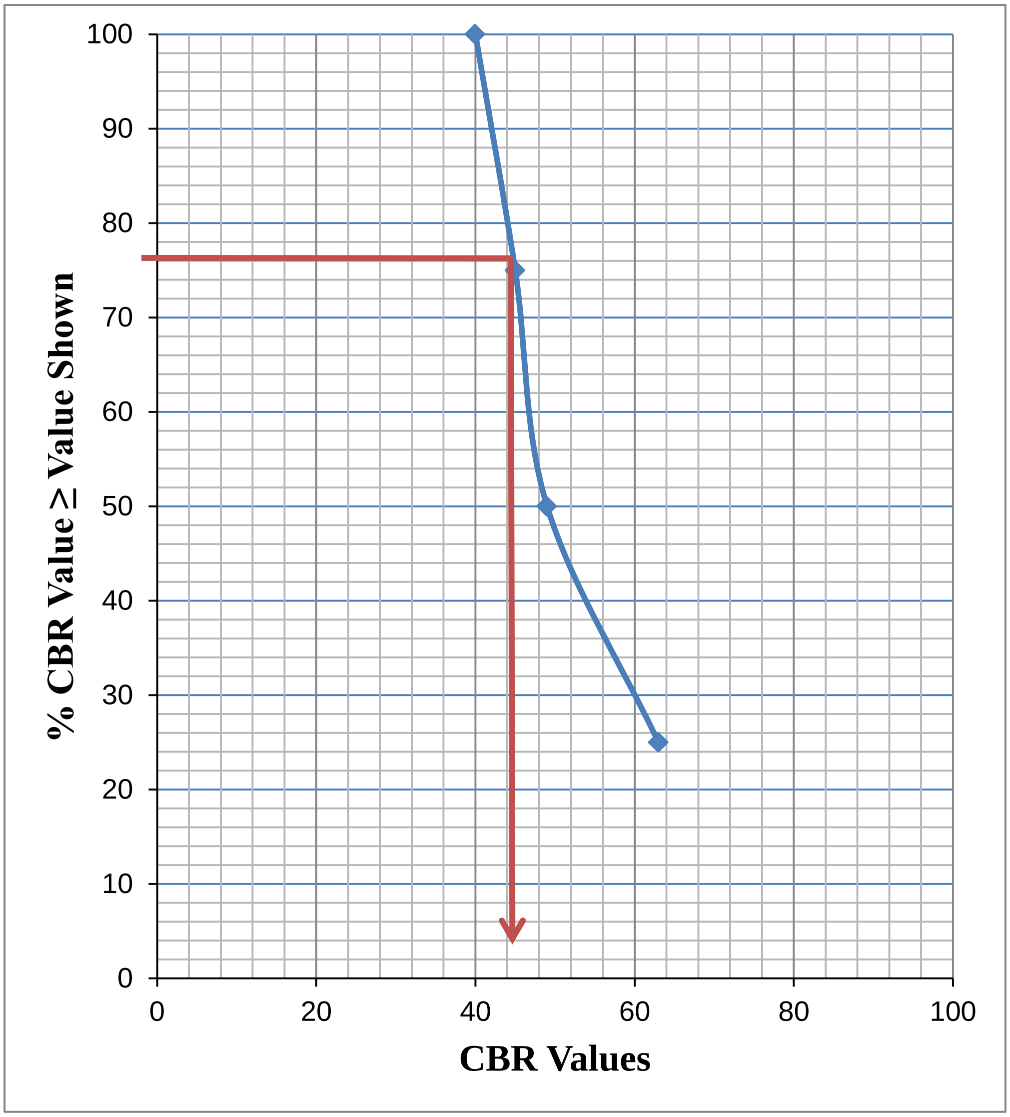

Figure 4.10: Road 1 Sub-base Design CBR

3. Road 1 Base Resilient Modulus E_{BS}

Seven out of nine samples of construction materials laboratory tests results show a CBR value of 100%. It is suggested to make this value the design value hence the design percentile 75% falls outside the curve range.

The suggested correlation to obtain the resilient modulus E_{BS} from CBR value:

E_{BS} (MPa) = $10.342 \times CBR^{0.64}$

$= 10.342 \times 100^{0.64}$

$= 197 \text{ MPa} \times 145$

$= 28{,}574 \text{ psi} \supset 28{,}600 \text{ psi}$

4. Road 2 Base Resilient Modulus E_{BS}

There are no suitable quarries found near the project area to supply the granular base material according to the soil investigation. There a hill cross the alignment will be excavated to maintain the road level and shall be crushed and graded for supplying of base material.CBR value of this material will exceed the 80**%.** For design purpose it will be taken as 80% the minimum design specification required for base material.

E_{BS} (MPa) $= 10.342 \times CBR^{0.64}$

$= 10.342 \times 80^{0.64}$

$= 171 \times 145$

$=24{,}795 \text{ psi} \supset 25{,}000 \text{ psi}$

CHAPTER FIVE

CHAPTER 5

Results and Discussion

5.1 Introduction

Characteristics for each road was determined and find out that road 1 initial test results show that it's not suitable for pavement construction and materials needs to be improved, so to avoid over budget we can study the option of concrete paving at that area. Road 2 initial test results shows that it's suitable for pavement construction also rigid pavement my cost less.

5.2 Results

From chapter (4) application of correlations to case study, material properties results for each road are summarized in table (5.1) and table (5.2).

Table (5.1) CBR values for road (1) and road (2)

Material Properties	Road 1	Road 2	Notes
CBR values sub-grade (%)	10	8	-Design CBR for road (1) was found to be 1.9% and was improved by selected material to 10%. -Design CBR for road (2) was found to be 5 % and improved by compaction to 8%.
CBR values sub-base (%)	45	43	-Road (1): four CBR data were analyzed, the design CBR was found to be equal to 45%. -Road (2): one borrow bit meet the required design specification with CBR 43%.

CBR values base (%)	100	80	-Road (1): Seven out of nine samples shows CBR of 100%. -Road (2): no suitable quarries near the area, for design purpose it will be taken as 80% the minimum design specification required for base material.

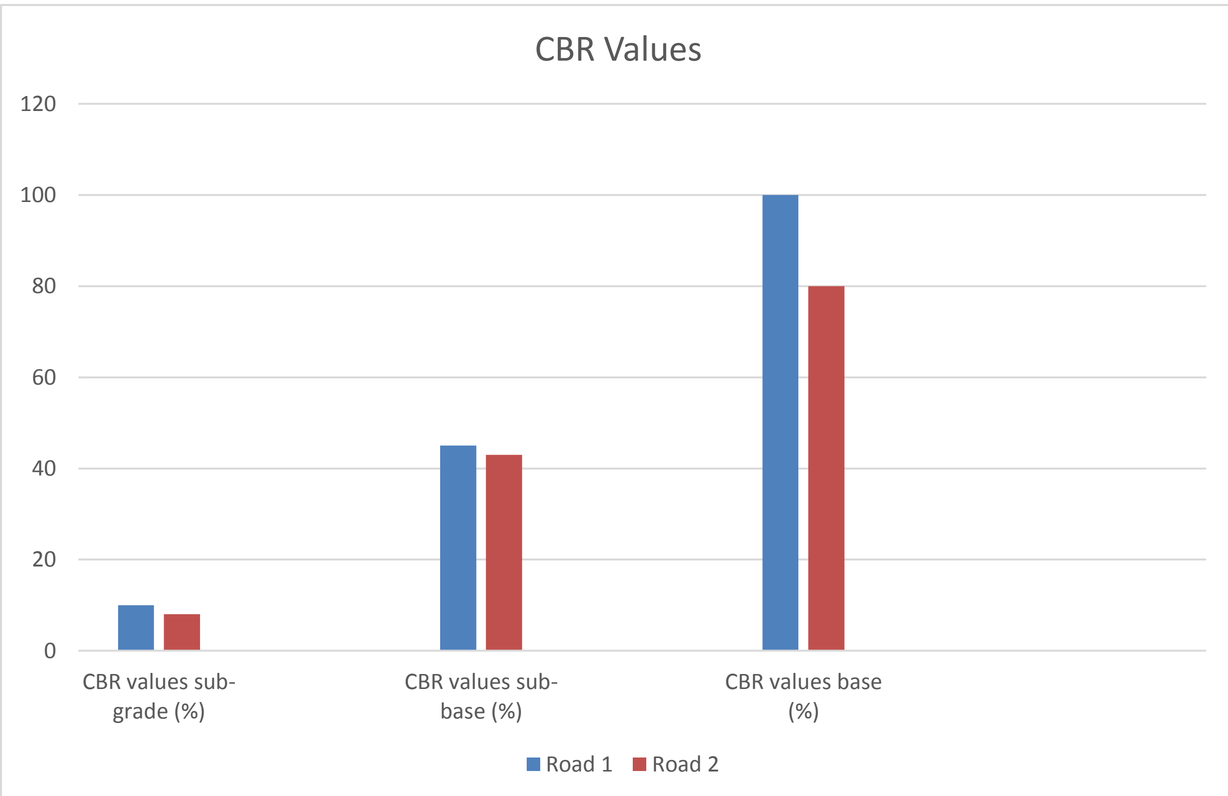

Figure (5.1) CBR values for road (1) and road (2)

Table (5.2) Resilient Modulus values for road (1) and road (2)

Material Properties	Road 1	Road 2	Notes
Sub-grade Resilient Modulus(psi)	15,000	12,000	For road (1) the design should be performed based on improved sub-grade resilient modulus, road (2) sub-grade soil shall be processed through good compaction to achieve desirable strength.
Sub-Base Resilient Modulus E_{SB}(psi)	17,000	17,000	For both road (1) and (2) the resilient modulus was obtained by correlation from CBR value.
Base Resilient Modulus E_{BS}(psi)	28,600	25,000	For both road (1) and (2) the resilient modulus was obtained by correlation from CBR value.

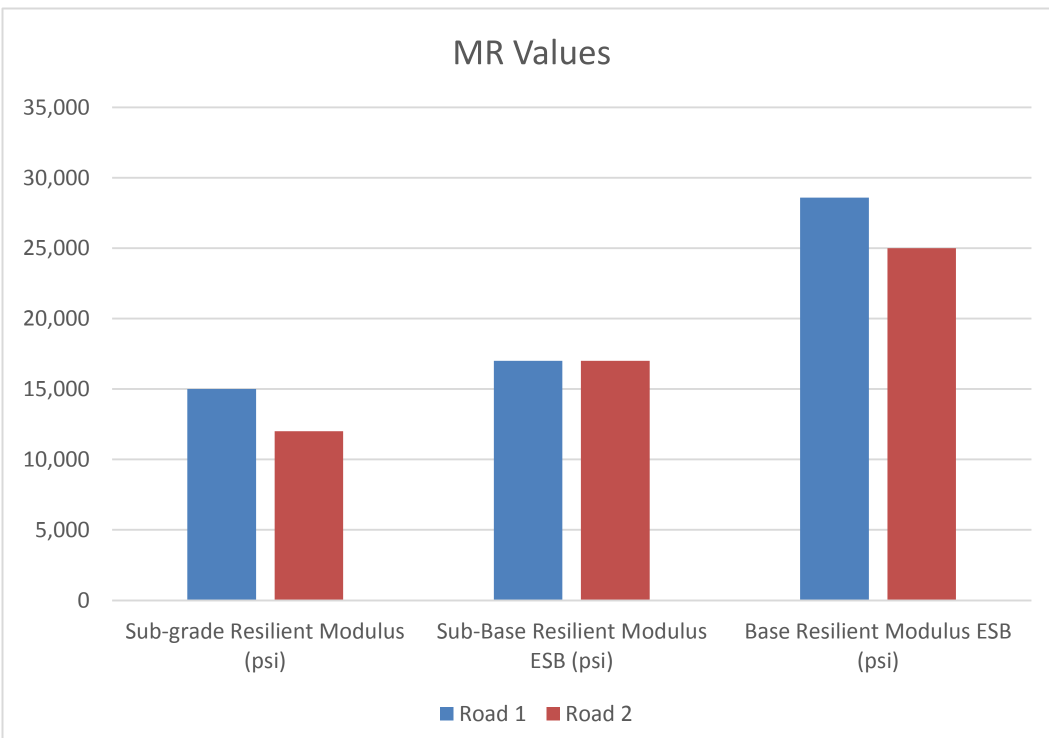

Figure (5.2) MR values for road (1) and road (2)

5.3 Discussion

In case of Road 1 due to type of soil which has been classified as black cotton soil as mentioned earlier. This type of soil needs either stabilization with appropriate stabilizer material such as lime or to be excavated and removed and replaced with capping layer in case of using flexible pavement. Since rigid pavement is not depending on sub-grade soil bearing capacity to sustain heavy traffic loads applied over it. It’s enough to construct concrete slab over one layer of sub base or base may be constructed of granular materials, cement treated materials, lean concrete or open graded, highly permeable materials, stabilized or unsterilized over native sub-grade.

CHAPTER Six

CHAPTER 6

Conclusion

6.1 Summary

This study reviewed, pavement construction materials, material characterization and all tests related to, properties of each material used, a case study for correlation between two roads, El Moneera – El Saffaya highway (Road 1) which is part of the national road network, and a section of Omdurman Ring Road, representing a state road (Road 2), laboratory tests and field tests was made for each road and comparison between properties of each was carried out to find that (Road 1)sub-grade soil all along the alignment categorized as plastic clayey soil, this type of soil is not suitable for pavement construction and improvement is required, (Road 2) soil encountered on the proposed alignment are vary from non to medium plastic soils, the sub-grade soil generally is suitable to be used as embankment materials, for construction of base there are many quarries for supplying of stones, which can be processed and crushed to prepare the required material.

6.2 Conclusions

Test results for two road shows that soil needs improvement or replacement to suit pavement construction, so because Subbases do not make a significant structural contribution to concrete pavements; the purpose of subbase is to provide uniform support to base concrete layer and to provide sufficient resistance to erosion of subbase material under traffic and environmental conditions. Both base and subbase layers in flexible pavements contribute significantly to structural properties of pavement. Compares large and very significant variations of elastic modulus between concrete and flexible pavement materials, for identical loading, it is obvious that performance of concrete pavements would be greatly superior. So in our cases here we can study the option of using concrete pavement as an alternative after cost comparison between two options.

6.3 Recommendations

6.3.1 Recommendations for the study

1. It is recommended to use different stabilization techniques with stabilizers that are available such as(lime, cement, bitumen) in areas with poor sub-grade consisting of black cotton soil, This kind of soil exists in the following country states (Kasala State, El Gadarif State, Blue Nile State, Sinar State, El Jazeera State, South Kurdufan State, South Darfur State, and South White Nile.

2. The availability of natural aggregate in many areas in Sudan will further reduce the pavement cost compared to flexible pavements due to their suitability for use in rigid pavement. On the other hand, for asphalt pavement which uses crushed aggregate, quarry must be sought for sources suitable for crushed stone production.

3. It is recommended to improve all laboratory equipment's regarding pavement materials testing.

6.3.2 Future recommendations

1. It is recommended to make more studies on material characteristics all around the country.

2. It is recommended to bring stabilization equipments so that using stabilization is more economical that constructing rigid pavements.

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