UNIVERSITY OF NAIROBI

Department of Civil and Construction Engineering

COST COMPARISON OF CONCRETE VERSUS FLEXIBLE PAVEMENT DESIGNS FOR STEEP TO ROLLING SECTIONS ALONG A104 ROAD (NAKURU – ELDORET)

BY

KIPYATOR FRANKLIN KIBUKWO

A thesis submitted in partial fulfillment for the Award of the Degree of Masters of Science in Civil Engineering, Department of Civil and Construction Engineering, University of Nairobi

July 2013

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Sign: ……………………………………….. Date: …………………

<u>Mr. Kipyator Franklin Kibukwo</u>

This thesis has been submitted for examination with our approval as university supervisors.

Signed: ……………………………………….. Date: ……..………………

<u>Prof. Sixtus K. Mwea</u>

Signed: ……………………………………….. Date: ……..……………….

<u>Prof. Francis J. Gichaga</u>

ABSTRACT

The thesis seeks to find out the better option between concrete and flexible pavement in cost savings and service provision over a design period of time for the steep to rolling sections of road A104 (Nakuru – Eldoret) at Timboroa. On the flat terrain section of the road, minimal or no failure is experienced, however on the steep and rolling sections, failure is evident through rutting, caking, cracking amongst others. Flexible pavement is currently the pavement used in the section. The problem therefore, that the thesis is focusing on is the considerable failure on the steep to rolling sections while on immediate flat sections, minimal or no failure is experienced. The failure is evident on both the ageing section and the freshly reconstructed section.

The thesis covers the design of both a concrete and flexible pavement and computation of respective costs over a study period of forty years for the section, to inform whether it will be cheaper to introduce concrete pavement on the steep to rolling section or retain the flexible pavement. The study appreciates that concrete pavement has not established roots in Kenyan roads and therefore an attempt to assess if it can be a better solution on the failed sections. The objectives of the study are to establish the axle loading from the vehicles and strength of insitu materials to be used for the design of the two pavements and computation of respective costs for comparison.

The methodology included the use of descriptive statistics which included tally sheets which were used for collection of data while inferential statistics was used for analysis and presentation of the results and included amongst others graphs and charts. Both primary and secondary data were collected; secondary data was obtained from journals, books and reports by various organizations. Primary data was obtained from traffic count, material sample picking and testing and site tests. The material and traffic data was used to come up with the pavement design details which included respective pavement layers, materials used and ultimately used for computation of unit costs for each pavement which was used for cost comparison.

From the data collected and analyzed, the road was established to be a high traffic volume and heavily loaded road. It was also established that the insitu materials were not strong enough and therefore needed to be improved or strengthened. From the cost analysis, flexible pavement was cheaper in initial construction by about 79%, however, over the analysis period, a concrete pavement was 57.45% cheaper than a flexible pavement. It is therefore recommended that in the steep to rolling sections of the road, it would be preferably cheaper to use concrete pavement.

DEDICATION

To my parents, brothers, sisters and Karen, you are wonderful to me. This is for you

ACKNOWLEDGEMENT

I acknowledge a number of people for the outstanding support they rendered in the production of this thesis. First, I would like to thank **Prof S. K. Mwea** and **Prof. F. J. Gichaga** my supervisors for their unwavering support and invaluable advice throughout the thesis period. Further, I appreciate all the material support and encouragement given to me by **Eng. Isaac G. Wanjohi**, **Eng. I. K. W. Mutonyi**, **Eng. John Ndemi** and my family. I, above all, give thanks to **God** who held my hand all along and gave me wisdom, knowledge, good health and protection to undertake the assignment.

God bless you all.

TABLE OF CONTENTS

LIST OF FIGURES AND CHARTS

LIST OF TABLES

LIST OF ABBREVIATIONS

AASHO	American Association of State Highway Officials, which became AASHTO
AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ACV	Aggregate Crushing Value
ADT	Average Daily Traffic
ALD	Axle Load Distribution
BoQ	Bill of Quantities
BST	Bituminous Surface Treatment
CBR	California Bearing Ratio
COMESA	Common Market for East and South Africa
CRCP	Continuously Reinforced Concrete Pavement
CSA	Cumulative Standard Axles
ESA	Equivalent Standard Axle
FI	Flakiness Index
HGV	Heavy Goods Vehicle
HMA	Hot Mix Asphalt
IMF	International Monetary Fund
LAA	Los Angeles Abrasion
LCCA	Life Cycle Cost Analysis
LL	Liquid Limit
LGV	Light Goods Vehicle
JRCP	Jointed Reinforced Concrete Pavement
JUCP	Jointed Unreinforced Concrete Pavement
MGV	Medium Goods Vehicle
MPa	Mega Pascals
ISO	International Standard Organization
MSA	Million Standard Axles
MC	Moisture Content
MDD	Maximum Dry Density
MoR	Ministry of Roads
MoR&PW	Ministry of Roads and Public Works
OMC	Optimum Moisture Content
PCC	Portland Cement Concrete

PL	Plastic Limit
PI	Plasticity Index
PM	Plasticity Modulus = (PI * % passing 0.425mm sieve)
PVI	Pavement-Vehicle Interaction
SS	Standard Specification for Road Construction
TRRL	Transport Road Research Laboratory
UCS	Unconfined Compressive Strength
UK	United Kingdom

CHAPTER ONE

1.0 Introduction

This study seeks to carry out both a comparative design and costs for a concrete and flexible pavement with a focus on steep to rolling sections after observations indicated that the steep to rolling sections deteriorate faster than the sections on flat terrains. The study considered the northern corridor A104 highway at Timboroa, Kenya as a case study.

Road A104 with a total length of 648 km is partially part of the Northern Corridor and runs from Uganda border at Malaba through Eldoret,Nakuru, Nairobi, Athi River and finally ends at Tanzanian border at Namanga. It has a prominent international connecting function at present with the existing pavement on the road being of the flexible type. The section of A104 under study lies between Nakuru and Eldoret where the road exhibits uneven deterioration with varying terrains; specific reference point being Timboroa due to the varying terrain and climatic conditions.

Flexible pavements are dominant in Kenyan roads making up more than 97% of the paved roads while concrete roads make up a minor percentage, most of which are on weighbridges, some steep sections in certain counties and recently Mbagathi Road, Nairobi. The study is exploring the cost of the two pavements at steep and rolling terrain sections; sections observed to deteriorate faster than on flat terrain on the majority flexible pavements on the Kenyan roads.

The study is in five chapters with the first chapter introducing and giving a background into the study, the second chapter reviews existing literature on similar studies and reviews existing theory on the study. The third chapter covers the methodology used in acquisition of data and data collected while chapter four discusses and analyzes results of the study. The final chapter gives conclusion and recommendations on the study. Other information on the study are the references and appendices which form part of the thesis.

1.1 Background Information

The study section of the Northern Corridor at Timboroa is located in a place characterized by low temperatures averaging 18^0C with a terrain that varies from steep to rolling and flat. The altitude ranges between 1850m above sea level at Nakuru to 2100m above sea level at Eldoret. It has a substantial volume of heavy truck traffic amongst others moving goods from the Port City of Mombasa to the landlocked countries of Eastern and Central Africa (Uganda, Burundi, Rwanda and Eastern Democratic Republic of Congo). Due to the poor/slow services by the Rift Valley Railways (rail service provider in Kenya) and the improved road conditions, the truck volumes have been continuously growing and most of these trucks carry substantial load volumes along the road. Figure 1.1 below gives the map of the study area. The study section starts at Nakuru coordinates 0.2833° S, 36.0667° E and ends Eldoret coordinates 0.5167° N, 35.2833° E along road A104.

Figure 1.1 The study area map

No similar studies have been undertaken on the road section to assess or compare the performance of concrete or flexible pavement with varying terrains. Feasibility studies have in the past been carried out by the Ministry of Roads on the existing flexible pavement, so is the northern corridor phase rehabilitation programme studies that ended in 2007.

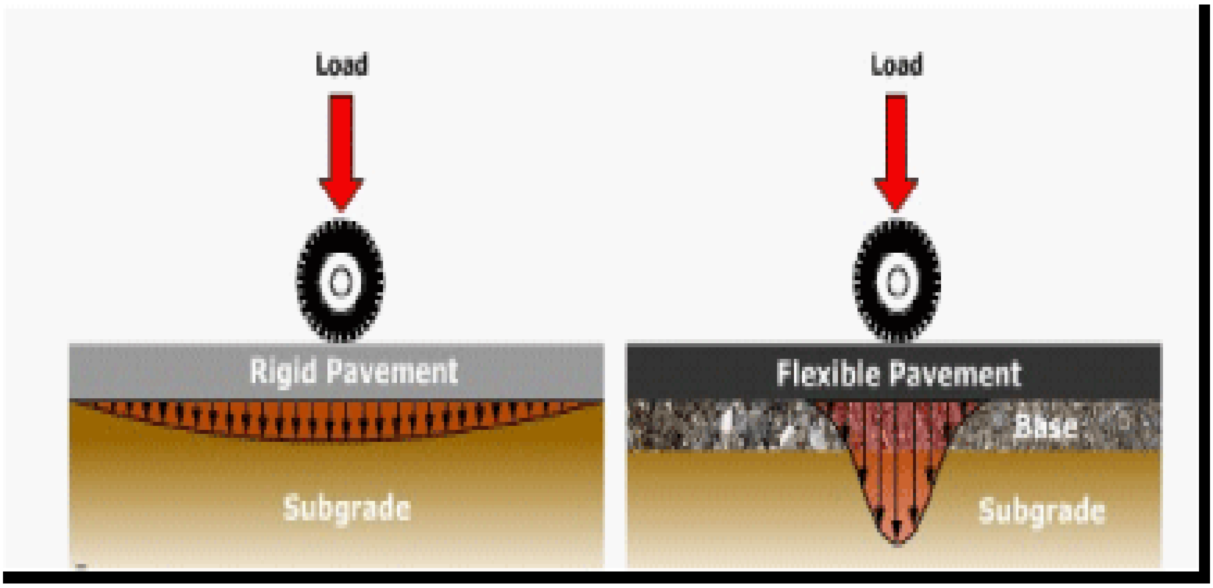
Kenyan roads are largely dominated by flexible pavements, including the road under study and has been performing poorly consistently, thus calling for a lot of both periodic and routine maintenance funds, making the overall pavement costs substantially high and thus posing the possible challenge not giving returns on investment by the end of the design period.

Therefore the study is focused on reviewing the existing pavements and their performance on the study road under the prevailing conditions and eventually forming an opinion on the best suited pavement for the road. Both flexible and rigid/concrete are the two commonly used pavements globally, and thus the study is focusing on the design of the two pavements for the section and deriving the unit cost for each for a comparative cost analysis and design aimed at arriving at conclusive findings.

Anon (1991) defines a road surface or pavement as a durable surface material laid down on an area intended to sustain vehicular or foot traffic, such as a road or walkway. He states that in the past cobblestones and granite sets were extensively used, but these surfaces have mostly been replaced by asphalt or concrete. Such surfaces are frequently marked to guide traffic. He further states that permeable paving methods are beginning to be used for low-impact roadways and walkways.

Uhlmeyer et al (2000) indicates that all hard surfaced pavement types can be categorized into two major groups, flexible and rigid. Flexible pavements are those which are surfaced with bituminous or asphalt materials. These can be either in the form of pavement surface treatments such as a bituminous surface treatment (BST) generally found on lower volume roads or, hot mix asphalt (HMA) surface courses generally used on higher volume roads such as the interstate highway network. These types of 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 materials which can accommodate the flexing.

On the other hand, rigid pavements are composed of a concrete surface course. Such pavements are substantially stiffer than flexible pavements due to the high modulus of elasticity of the concrete material. Further, these pavements can have reinforcing steel, which is generally used to reduce or eliminate joints. Each of these pavement types distributes load over the sub grade in a different fashion. Rigid pavement, because of concrete's high elastic modulus stiffness, tends to distribute the load over a relatively wide area of subgrade. The concrete slab itself supplies most of a rigid pavement's structural capacity. Flexible pavement uses more flexible surface course and distributes loads over a smaller area. It relies on a combination of layers for transmitting load to the subgrade (Uhlmeyer et al, 2000). Figure 1.2 below indicates the variation in load transfer for the two pavements.



Source: Tiwari, 2005

Figure 1.2 Rigid and flexible pavement load distribution

Uhlmeyer et al, (2000) states that flexible pavements generally require reconstruction or rehabilitation every 10 to 15 years. Rigid pavements, on the other hand, has a design life of between 20 and 45 years with little maintenance or rehabilitation. Thus, it should come as no surprise that rigid pavements are often used in urban, high traffic areas. But, naturally, there are trade-offs. For example, when a flexible pavement requires major rehabilitation, the options are generally less expensive and quicker to perform than for rigid pavements.

As a result of the above explanations on the roads/ pavements it is the essence of the study to carry out a comparative analysis on design and cost of concrete pavement as compared to flexible on sections with steep to rolling terrain.

1.2 Problem Statement

There is a faster deterioration of the road under study particularly on the sections with steep and rolling terrains as compared to the flat sections. This is despite consistent maintenance of the existing flexible pavement. The road experiences high traffic volumes which calls for minimal interruption of flow and most important to note is the utility of the road by heavy goods vehicles ferrying goods to neighboring countries. These heavy goods vehicles from observation, move at maximum speeds on the flat terrains on the study road thus imparting minimal damage, whereas on the steep to rolling terrain sections, they move at minimal speeds, thus imparting maximum damages on the road as depicted on figures 1.3 and 1.4 below. Since from previous studies, concrete pavements are known to be more durable than flexible pavements, a design of both pavements and cost analysis need to be done to ascertain precisely which kind of pavement is best steep for the steep to rolling sections.

A detailed visual inspection of the existing road and shoulders was undertaken by means of on-site observations and measurements. Surface distress along the road was noticeably variable, the principle forms of distress noted and recorded being: Surface distress and defects which included bleeding, ravelling or stripping (aggregate loss), crocodile and block cracks; longitudinal and transverse cracks and disintegration; deformations which included rutting without cracking, shoving and corrugations; structural distresses which included alligator (fatigue) cracking, depressions or settlements, rutting with cracking and non-load associated cracking; edge breaks and shoulder wear. The above observations are more critical on the steep to rolling sections as compared to the sections with a flat terrain. The road has a high traffic volume thus offers an ideal scenario for the study. Figures: 1.3 and 1.4 below illustrate the problem that the study seeks to address.

Figure 1.3: A section of the worn-out road shoulder of Northern Corridor (A104, Timboroa)

Figure 1.4: A flat section of the road just before the start of the worn out climbing section above

The road was reconstructed / overlaid less than five years ago (MoR&PW), but so far it is severely damaged. This work sought to find a solution to the problem that exists only on some sections of the road with an objective of maintaining an affordable cost on the greater section of the road and durability on the vulnerable rolling and steep section.
Figure 1.5 gives pictorial presentation of the effects of the damaged road sections and the road high traffic volumes experienced on the road.

	
Poor pavement conditions on the section has been a key cause of accidents.	Common traffic volumes on the section

Persistent rains in the study area makes the defects on the road worse

Figure 1.5: Sections of the damaged road defining the problem

1.3 Objectives of the Study

The objectives were key in the giving the study a guide. In general, the objectives broadly aimed at carrying out data collection and analysis; designing of both pavements in the study; developing bills of quantities (BoQs) for unit length of both pavements with a view to costing both pavements for ultimate comparison and this informed the conclusions and recommendations. The specific objectives were as follows:-

i. To establish the axle loading from the vehicles;
ii. To identify the pavement pertinent material properties;
iii. Design of an ideal concrete and flexible pavement for the road section;
iv. Establish the cheaper pavement through cost comparison of the two road designs.

1.4 Justification of the Study

Most of the roads in Kenya are of flexible pavement type which is estimated at approximately 11,000km as compared to concrete pavement which is well less than 100km. The flexible pavement has in most instances been found to deteriorate in some road sections in a manner that they do not offer the expected service to the end of the design period. Concrete pavement is yet to find its niche in Kenyan roads although it is widely used in a sizeable number of countries, therefore the study seeks to design, evaluate and assess the suitability cost wise of the two pavements in Kenyan roads, particularly in the sections where the flexible pavement has performed poorly.

1.5 Scope

The scope of works was limited to A104 road due to the high heavy goods traffic prevalence and a further limitation to steep to rolling sections as initial trial sections due to economic factors in Kenya, the study Country. A combination of both primary and secondary data was utilized in the study. A unit length (km) of the road for both pavements was sampled for both costing and comparison. Geometrics were not considered as both pavements are assumed to take the same alignment, so are the climatic/weather conditions.

1.6 Challenges faced during the study

There were various challenges experienced during the study which included the following:-

i. Erratic growth rates that hampered projection of data;

ii. Inadequate data on the case study road over a reasonable period of time into the past.

1.7 Types of Pavements

There are four common types of pavements available namely:-

1.7.1 Flexible Pavement;

A flexible pavement is one with low flexural strength, thus the external load is largely transmitted to the subgrade by the lateral distribution with increasing depth. Because of the low flexural strength, the pavement deflects if the subgrade deflects. Flexible pavement is the most preferred pavement type in Kenya currently.

1.7.2 Rigid Pavement;

As the name indicates, rigid pavement does not flex under load. Rigid pavement derives its capacity to withstand loads from the flexural strength or beam strength, permitting the slab to bridge over minor irregularities in the subgrade or subbase upon which it rests. In rigid pavement, the concrete slab is the main load bearing layer, therefore the performance of the pavement is more of a factor of the concrete slab rather than the subgrade.

1.7.3 Semi-rigid Pavement;

Semi-rigid pavement represents an intermediate state between flexible and rigid pavement. It has a much lower flexural strength as compared to concrete slabs, but it also derives support by the lateral distribution of loads through the pavement depth. Typical examples of a semi-rigid pavements are the lean concrete base, soil cement and lime-pozzolana concrete construction.

1.7.4 Composite Pavement.

A composite pavement comprises of multiple, structurally significant layer of different – sometimes heterogeneous composition. A typical example is the brick-sandwiched concrete pavement. It consists of a top and bottom layers of cement concrete which sandwich a brick layer in the neutral axis.

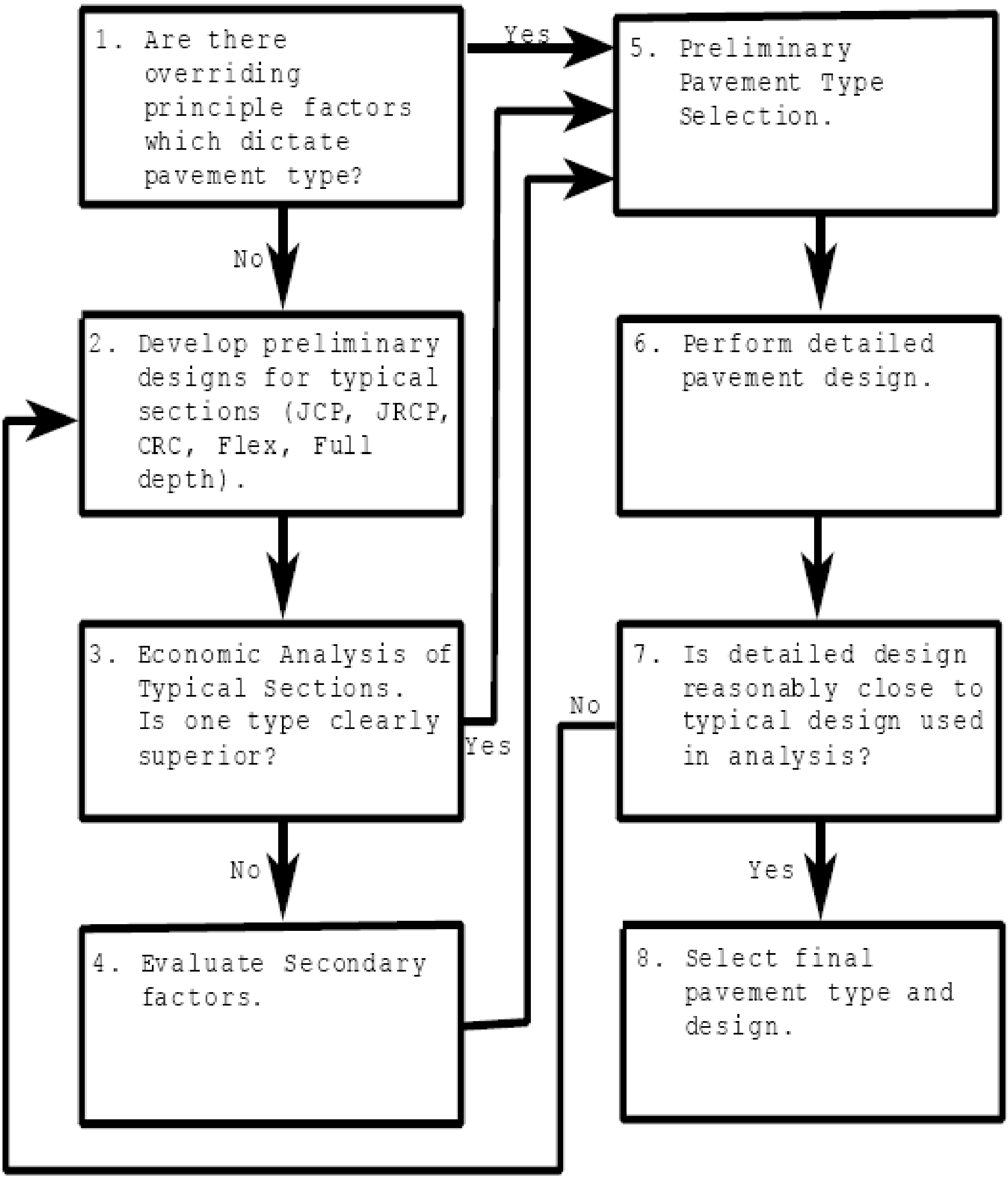
1.8 Pavement Type Selection Guidelines

1.8.1 General

The selection of pavement type should be an integral part of any pavement management program. The selection of pavement type is not an exact science, but one in which the highway engineer or administrator must make a judgment on many varying factors such as traffic, soils, weather, materials, construction, maintenance, and environment. The pavement type selection may be dictated by an overriding consideration for one or more of these factors. The selection process may be facilitated by comparison of alternate structural designs for one or more pavement types using theoretical or empirically derived methods. However, such methods are not so precise as to guarantee a certain level of performance from any one alternate or comparable service for all alternates.

Also, comparative cost estimates can be applied to alternate pavement designs to aid in the decision making process. The cost for the service of the pavement would include not only the initial cost but also subsequent cost to maintain the service level desired. It should be recognized that such procedures are not precise since reliable data for maintenance, subsequent stages for construction, or corrective work and salvage value are not always available, and it is usually necessary to project costs to some future point in time. Also, economic analyses generally do not consider the present or future financial capabilities of the contracting agency. Even if structural design and cost comparative procedures were perfected, they would not by their nature encompass all factors which should be considered in pavement type determination. Such a determination should properly be one of professional engineering judgment based on the consideration and evaluation of all factors applicable to a given highway section. The factors which may have some influence in the decision making process are discussed below. They are generally applicable to both new and reconstructed pavements. One group includes those factors which may have major influence and may dictate the pavement type in some instances. Some of the major factors are also incorporated in the basic design procedures and influence the structural requirements of the pavement design or subgrade and embankment treatments. In such cases they are assigned an economic value for comparative purposes.

The second group includes those factors which have a lesser influence and are usually taken into account when there are no overriding considerations or one type is not clearly superior from an economic standpoint. A flow chart of pavement selection procedure incorporating the major and secondary factors is shown in Figure 1.6 below



Source: Department of Transportation, Florida (2008)

Figure 1.6: Pavement selection criteria

1.8.2 Principal Factors

Traffic

While the total volume of traffic affects the geometric requirements of the highway, the percentage of commercial traffic and frequency of heavy load applications generally have the major effect on the structural design of the pavement. Traffic forecasts for design purposes have generally projected normal growth in the immediate corridor with an appropriate allowance for changes in land use and potential commercial and industrial development.

Soils Characteristics

The load-carrying capability of a native soil, which forms the subgrade for the pavement structure, is of paramount importance in pavement performance. Even in given limited areas the inherent qualities of such native soils are far from uniform, and they are further subjected to variations by the influence of weather. The characteristics of native soils not only directly affect the pavement structure design but may, in certain cases, dictate the type of pavement economically justified for a given location. As an example, problem soils that change volume with time frequently require stage construction to provide an acceptable riding surface.

Other principal factors include: Weather/Climatic Conditions; Construction Considerations which include speed of construction, passage of traffic during construction, ease of replacement, anticipated future widening amongst others; recycling of construction materials and cost Comparison

1.8.3 Secondary Factors

These include: Performance of similar pavements in the area; adjacent existing pavements; conservation of materials and energy; availability of local materials or contractor capabilities; traffic safety; and incorporation of experimental features.

CHAPTER TWO

2.0 Literature Review and Theoretical Background

2.1 Introduction

This chapter highlights the relevant literature and other studies carried out in the area including academic papers, theses, dissertations, books, journals and credible internet information by various institutions and personalities. It evaluates and correlates their findings which could be useful for further study on the same topic. The study was triggered by the desire to carry out an analysis on design and economic value of concrete pavement as compared to flexible pavement on sections with steep to rolling terrain.

2.2 Forms of Pavements

Literature is reviewed for the following two types of pavements under study:-

- Asphalt /Flexible Pavement;
- Concrete /Rigid Pavement.

Literature on similar studies is reviewed for the pavements and theoretical background for both is also discussed.

2.3 Similar studies and Researches Carried Out

Gidyelew and Chandra (2009) state that to compare the cost of two types of pavements, it is necessary to ensure that they are designed for the same traffic loading. Therefore the study was done to convert the traffic load given in million standard axles (MSA) into Axle Load Distribution (ALD) and vice-versa. Mathematical models were developed to estimate the ALD from individual vehicle counts. A total of 90 flexible pavements and 63 rigid pavements were designed and their costs computed. The costs include the construction cost and a fixed maintenance cost. Mathematical expressions were developed to relate the cost of pavements with soil CBR and traffic in MSA. The initial aim of the study was to determine the threshold values of CBR and MSA beyond which one of the pavements becomes economical in its combined construction and maintenance cost. The points of equal cost on the CBR versus MSA graph were determined using equations. The study summarized findings mathematically using the following equations:

- If MSA $<12.48+6.05 \times$ CBR, flexible pavement will be economical;
- If MSA $>12.48+6.05 \times$ CBR, rigid pavement will be economical;
- If MSA $=12.48+6.05 \times$ CBR, both pavements will have the same cost.

Asta (2011) describe a life cycle cost analysis (LCCA) for road pavements and evaluates its impact on pavement type choice. Working from literature, historical data and interviews, the LCCA technique was described. The LCCA methodology developed in the study was tested on a hypothetical project (road section in Reykjavík, Iceland). The purpose of the project was to develop a calculation model based on LCCA methodology. LCCA was tested for six traffic groups: 2,500, 5,000, 7,500, 10,000, 12,500, and 15.000 veh/day/lane. The tests were carried out on a flexible pavement and on one with concrete pavement. An analysis period of 40 years was chosen for the project; thus the cost for asphalt and concrete pavements are evaluated for this analysis period. Construction, rehabilitation and user costs were included in the model. A 6% discount rate was used for the base case scenario, and the allowed rut depth is 3.5 cm. From the results, a flexible pavement was more suitable for lower volumes of traffic and with increased traffic, concrete pavements are more competitive. Test results showed that when traffic is around 14000veh/day/lane, asphalt and concrete are competitive. Above 14000veh/day/lane, concrete pavement is favourable while below 14000veh/day/lane, flexible pavement is more favourable.

Mehdi (2012) state that improving sustainability of road network necessitates a fundamental understanding of pavements and their interaction with the users, vehicle fuel consumption required to overcome resisting forces due to pavement-vehicle interaction (PVI) is an essential part of life-cycle assessment (LCA) of pavement systems. These PVIs are intimately related to pavement structure and material properties. While various experimental investigations have revealed potential fuel consumption differences between flexible and rigid pavements, there is high uncertainty and high variability in the evaluated impact of pavement deflection on vehicle fuel consumption.

The research adopted the perspective that a mechanistic model which links pavement structural and material properties to fuel consumption can contribute to closing the knowledge gap of PVI in pavement LCA. With this goal in mind a first-order mechanistic pavement model is considered; a Bernoulli-Euler beam on viscoelastic foundation subjected to a moving load. Based on the model, scaling relationships are developed between the input parameters of top layer and subgrade moduli, pavement thickness, and loading conditions, with their impact on PVI and vehicle fuel consumption. The strength of these scaling relationships and their ability to guide pavement design are presented. Main findings from the Monte-Carlo simulations show that rigid pavements within the Network behave better than flexible ones in regard to PVI due to higher stiffness.

The paper by Gichaga (1983) emphasizes the need to facilitate proper planning of expenditure on roadbuilding, maintenance and reconstruction by carrying out field studies to establish longterm structural behaviour of road pavements. It further stresses the need to carry out regular evaluation of the state of roads in developing countries. Gichaga (1983) states that experience from some sampled completed roads shows that road pavements have at times failed prematurely thereby leading to unplanned expenditure in the exercise of rehabilitating them. The paper outlines results of studies carried out to establish long-term behaviour of road pavements under tropical climatic conditions. The studies involved measurements of elastic deflections, pavement distortion and rutting, cracking as well as establishing traffic loading patterns for typical high standard trunk roads of varying design in Kenya. The results of the studies show that while pavements are weakened by repeated wheel load applications, pavements also tend to develop strength with age.

The results further showed that for a pavement approaching failure, elastic deflections are a function of cracking and rutting and that higher elastic deflections are obtained during the months of high rainfall and high temperatures. The paper recommends that there is need for Road Authorities to regularly monitor factors that relate to road pavement performance such as traffic loading, pavement condition etc. In order to help in the financial planning for pavement strengthening and maintenance works, the necessary funds should be set aside in the budget. In order to ensure that road maintenance works are planned properly and pavement strengthening policies effectively formulated, it recommends that road authorities should monitor factors that relate road performance to such factors as traffic loading, pavement conditions etc on regular basis. In order to achieve the above recommendation, it is necessary that Road Authorities should institute systems of monitoring road pavement conditions. Such systems should be accompanied by catalogues specifying corrective measures corresponding to various distress features so that acceptable standards of road serviceability are maintained. In order to ensure effective implementation of the above recommendations it is necessary for a Road Authority to set aside necessary funds in the budget.

Holt et al (2011) highlights that both rigid and flexible pavements are commonly used in Ontario for both provincial highways and municipal roads. Each pavement type is designed and constructed based on local traffic and site conditions. Evaluation included an analysis of pavement life cycle strategies including initial and future costs for construction and maintenance activities. The results of this study showed an increase in life-cycle cost for flexible pavements as traffic levels increase, particularly with low strength subgrade soils. This trend is typical because with increasing traffic loads, the thickness of the granular base/subbase and asphalt concrete layers required to support the traffic were proportionally higher than the increase in concrete thickness required. The study further recommended alternate bidding for the varying pavement sections of the roads.

Embacher (2001) state that the costs of pavement construction, maintenance, and rehabilitation are primary factors considered by most local agencies in the selection of pavement type [hot-mix asphalt concrete (HMAC) or Portland cement concrete (PCC)] for new construction according to Embacher (2001). The optimal use of agency funds for any given project can be determined only through an economic analysis of all associated agency costs and the performance of the pavement.

Life-cycle cost analyses were performed on HMAC and PCC highway pavements in Olmsted and Waseca Counties, Minnesota. Heavy Construction Historical Cost Index and the Minnesota Department of Transportation Surfacing Indices were used to convert all expenditures over time into equivalent constant-dollar values. Direct comparisons were made on roadway sections with similar traffic volumes, ages, and environmental conditions. For Olmsted County, the favoured pavement type depended somewhat on the cost index values that were used in the analysis; however, index selection had no effect on the outcome for the Waseca County comparisons. When the results were normalized for traffic volumes (i.e., cost per lane mile per million vehicles carried), PCC pavements were clearly more cost-effective in all Olmsted County cases and all but one Waseca County case, regardless of the cost index value used. PCC pavements generally incurred significantly lower maintenance and rehabilitation costs than HMAC roadways in both counties.

2.4 Traffic and Materials

Theoretical background is covered under the two pavements and key inputs of traffic and material investigations are discussed below.

2.4.0 Traffic

2.4.1 General

Deterioration in paved roads caused by traffic is a function of the magnitude of the individual wheel loads and the frequency with which they are applied (Kadiyali, 1989). For pavement design purposes, therefore, it was necessary to know not only the total number of vehicles using the road but also the axle loads. Traffic loading is normally expressed in terms of 'equivalent standard axles. An axle carrying 80kN was arbitrarily defined as a 'standard axle', to which axles of different weights were correlated to derive equivalence factors, thereby obtaining an expression of the damaging effect. In the case study therefore, the ESA is considered the same while the deterioration is assumed to be caused by the slow speeds of traffic on the section. Thus:

$$ESA = \left(L/80 \right)^{4.5}$$

Where ESA is the equivalent standard axle, L is the axle load in kN divided by the standard 80kN axle, and 4.5 the exponent representing the relative damage. This equation was derived by Liddle (1962) for the test conditions at the time. Although Liddles' formula is safe only up to axle weights of 130kN (13 tonnes), nevertheless, in the absence of anything better, current practice is still to use this equation for greater axle weights. A more secure practice would be to determine the proportion of axle weights greater than 130kN and then to adjust the traffic category accordingly.

The ultimate objective in design was thus to determine the cumulative number of ESA in the design period. This is achieved in a number of operations:

i. the axle load distribution of the traffic is evaluated

ii. the axle loads converted into ESA
iii. the initial daily number of ESA calculated, and
iv. an annual growth rate over the design period selected.

Table 2.0 gives the allowable load limits for the vehicles using the road, sourced from Kenya National Highways Authority (KeNHA), Axle Load Section.

Table 2.0: Maximum permissible gross vehicle weights

Vehicle Type	Legal Limit (tonnes)
Vehicle with two axles	18
Vehicle with three axles	24
Vehicle & semi-trailer with total of three axles	28
Vehicle & semi-trailer with total of four axles	34
Vehicle & drawbar trailer with total of four axles	36
Vehicle & semi-trailer with total of five axles	42
Vehicle & drawbar trailer with total of five axles	42
Vehicle & semi-trailer with total of six axles	48
Vehicle & drawbar trailer with total of six axles	48

No vehicle with more than six axles is permitted unless special exemption is granted; however, debates are ongoing on the possibility of increasing the maximum vehicle load to 52 or 56 tonnes for a seven axle vehicle.

2.4.2 Evaluation of Traffic for Design Purposes

Traffic Counts

The loads imposed by private cars and light goods vehicles with axle weights less than 1.5tonnes do not contribute significantly to the structural damage of a paved road and thus, for design purposes they are ignored (MoR Design manual, 1987). However, for economic and future traffic volume forecasting, the total traffic is determined and routine traffic counts are carried out annually by the relevant authority a number of census points. They distinguish between cars, light goods, buses, medium goods and heavy goods vehicles. Where such results are available, the initial daily traffic can be estimated by extrapolation.

Where traffic census data is not available or is insufficient, specific traffic counts are required at key points and axle load surveys carried out to determine the initial daily traffic and possible seasonal variations. The recommended survey period is one week, for 24 hours at least on two days to determine the night time flows (MoR Design Manual, 1987), and the counts are classified into traffic classes. The times when there are especially increased or decreased traffic flows should be avoided. Automatic counters can be used for greater accuracy because the survey can be conducted over a longer period and detect seasonal variations. A standard type of vehicle classification scheme is presented in Table 2.1 as sourced from the Ministry of Roads.

Table 2.1 : Vehicle classification scheme

Category	**Type**	**Description**
1 Light vehicles		
i	Passenger cars	Cars seating up to nine passengers
ii	Small buses	Matatus, minibuses seating up to 30 passengers
iii	Light Goods	Pick ups
2 Medium and heavy vehicles		
i	Large buses	Buses and coaches seating more than 30 passengers
ii	Medium goods	2 axles, twin tyres on rear axle, >1.5 tonnes unladen weight, <8.5 tonnes gross vehicle weight
iii	Heavy goods	3 axles
iv	Heavy goods	4 axles or more, trailers included, >3 tonnes unladed weight or >8.5 tonnes gross vehicle weight
3 Others		Tractors, road rollers, or vehicles with 5 or more axles depending on survey requirements

2.4.3 Axle Load Surveys

Axle load surveys are required to estimate the equivalent standard axles (ESA) (Liddle 1962). Most of the ESA will be carried by the medium and heavy vehicles. The most common method of carrying out an axle load survey is to weigh a sample of vehicles at the roadside using portable weighpads. It is possible to weigh about 60 vehicles per hour using this method. If the traffic flow is too high a sample should be selected for weighing. On many roads it will be necessary to consider whether the axle load distribution of the traffic in both directions is the same and significant differences can occur for example on roads connecting docks, quarries, heavy industrial works and mining areas. In Kenya the Mombasa-Nairobi-Uganda highway is a good example. Survey results from the more heavily trafficked direction is used for pavement design purposes.

Evaluation of Axle Loads

According to the Ministry of Roads Design Manual, the axle loading is obtained by multiplying the average daily number of commercial vehicles by the appropriate equivalence factors and then summing the ESA for all the vehicle types.

Estimating the Cumulative Number of Standard Axles

To estimate the total number of ESA for the pavement design, it is necessary to forecast the annual traffic growth rate and the traffic expected on the road, as described below:-

2.4.4 Forecasting the Traffic Growth

Projection for future traffic is important and it is done over the design period of the pavement. The total traffic considered for projection are those expected to be attracted to the improved road. This is done by consideration of normal, diverted and generated traffic as indicated below (MoR Design Manual, 1987):

Normal Traffic: Traffic which would pass along the existing road in ordinary circumstances whose growth could be based on national historical trends, fuel sales or any other specific local circumstances.

Diverted Traffic: Traffic that changes from another route but still retains the same origin and destination

Generated Traffic: Additional traffic that is generated in response to the improvement of a road. Guidance can be obtained from the following factors: historical growth, economic trends, geometric capacity of the road, increases in vehicle numbers and loading and social realities. Typical growth rates range from 2 to 15% per annum, averaging about 5% per annum. (HydroArch S.R.L/Republic of Kenya (May 2007)

Length of Design Period

At the end of the design period, the road pavement will not be completely worn out or have deteriorated to the point that re-construction is needed but only require to be strengthened to carry traffic for a further period. During the design period, it is accepted that routine maintenance (e.g shoulders and drainage system maintenance, vegetation control, patching and sealing) and periodic maintenance (surface dressing, asphalt overlays, slurry seals) will be carried out. The aim is to minimize the total expenditure on the pavement, including the initial construction cost and subsequent maintenance or strengthening costs discounted to the present day value.

Stage construction offers economic advantages and initial design periods should be approximately 15 years, even if longer overall lives are anticipated. It also provides an opportunity to choose the structural characteristics of the second stage in the light of actual conditions, which may differ substantially from the original conditions.

According to MoR design manual, the cumulative number of ESA, T, for the chosen design period, N (in years), is then obtained from the following:

$$T = 365t_1 \frac{(1+i)^N - 1}{i}$$

Where:

t_1 is the average daily number of standard axles in the first year after opening, and

i is the annual growth rate expressed as a decimal fraction

2.4.5 Pavement Materials

According to Charles (1997), pavement materials which include the alignment soils and borrow materials for the subgrade and other materials for the overlying layers should be assessed both for quality and quantity. Other factors such as haulage distance need to be considered too. Materials that do not meet the required specifications are either removed from site or improved using materials such as cement or lime that reduces plasticity and/or increases strength.

Gichaga and Parker (1988) state that the main objective of road construction material selection is to ensure overall economy of the road project by selecting materials that will require minimum haul and that will preferably require no treatment to improve their strengths. Thus ideally, the most economical road material would be that which lies along the proposed road alignment or adjacent to it.

2.5 The Mbagathi Way Concrete Overlay Project

2.5.1 Background Information

a) General

Mbagathi Way is a two-lane dual carriageway connecting Ngong Road to Lang'ata Road in Nairobi, measuring a total of 6 km. The project was a culmination of sustained lobbying by cement makers, under the umbrella East Africa Cement Producers Association, to have Kenya use concrete in its road building against the present dominance of asphalt roads.

In the year 2001, stakeholders in the roads sector passed a resolution and the government stated that each road being constructed from the following year would have a trial section of concrete. A steering committee on concrete pavements, composed of professional engineers in the public and private sectors, under the chairmanship of the Engineer-in-Chief, Ministry of Roads and Public Works (MOR&PW), was subsequently constituted in 2001. The committee was mandated with the task of incorporating a Concrete Roads Chapter in the existing Road Design Manuals and specifications and providing leadership in the task of adopting concrete roads in Kenya. The committee identified Mbagathi Way as a suitable trial section for rehabilitation using cement concrete.

The government of Kenya at a cost of Kshs. 445 million ($6.05Million) funded the project. This included substantial ancillary works incorporating a new footbridge, drainage etc. The concrete works for the pavement cost Ksh. 150 million ($2.04Million) for the 6 km section.

The road was initially designed as a flexible pavement in the early 70s, but in 2004 when the road was to be improved, cement manufacturing companies were trying to market their products. They gave the government free cement to construct concrete pavement on the road, of which the the government agreed and provided expertise and supervision to carry out works.

The three cement producers in Kenya i.e. Bamburi Cement Limited, Athi River Mining and East African Portland Cement, committed to donate 3,400 tons of cement towards the project as per market share (57% of which was Bamburi's quota). In addition, they procured and provided for professional and experienced consultants to assist in design review and construction of the pavement.

The Mbagathi Way Road Rehabilitation project was intended to demonstrate the labour intensive construction methodology and performance of concrete pavements as an option to the more conventional asphaltic roads constructed in Kenya.

b) Location

Mbagathi Way is located a few kilometres from the Central Business District of Nairobi City. It is a dual carriageway road, which runs in a westerly direction from Lang'ata Road (C58) roundabout to Ngong Road (C60) roundabout at the city mortuary. It has a length of approximately 6km of 2 lanes.

c) Construction History

Mbagathi Way was first constructed in the early seventies (1972/1974). The surfacing thickness of the existing carriageway varies significantly from one section to another and varies between 20 and 115 mm (Asphalt Concrete). The subbase is made of gravel 50 mm and the base of the road is of hand packed stone (HPS) 300 mm thick. Analysis of Benkelman Beam measurements done on the road yielded a combined equivalent support stiffness of between 800 and 1200 Kg/M^2.

d) Description and Scope of Mbagathi Way Project

The works executed under the contract comprised mainly of but not limited to: Trimming of potholes and milling of surface to spoil; restoration of spalled edges and resealing of cracks; construction of access and cross culverts; patching of surface and failed areas with asphaltic concrete; provision of an overlay of 205 mm thick dowel jointed concrete base on the dual carriageway and roundabout at city mortuary; construction of a new footbridge; construction of footpaths in concrete block paving and provision of street lights.

2.5.2 Design of the Pavement

The concrete overlay was initially designed as a 220 mm thick dowel jointed pavement using the American Concrete Pavement Association whitetopping practice and Benkelman Beam deflection analysis. The design was subsequently reviewed and optimised to 205 mm thickness after running it through the South African CnCPave modeling**.** The CnCPave program is a mechanistic risk based design method, which does not rely on single absolute numbers for design and is particularly suited for Kenya due to the similarity with South Africa in climatic, weather and soil conditions.

The designed pavement structure is a 205 mm thick dowel jointed pavement, with transverse contraction joints at 4 m spacing. Load transfer at the joints is to be effected by means of mild steel R25 steel bars, 450 mm debonded on one side, spaced at 300 mm and placed at mid depth. The adjoining lanes are to be tied together at longitudinal joints by means of 750 mm long Y12 bars at 400 mm spacing. The pavement was being widened to mitigate against the effects of edge loading. Kerbstones were placed on top of the pavement to ensure the outer 300 mm will not undergo traffic loading especially by heavy trucks.

The parameters used in the design were as follows:

a. Daily truck traffic 400 trucks per day per lane
b. 10 million equivalent standard axles (T3) over 20 years
c. Existing pavement layers

i.	AC wearing course	20-115 mm
ii.	Gravel sub base	50 mm
iii.	Hand packed stone base	300 mm

2.5.3 Concrete Mix Design

The mix design was conducted by the contractor through Geoff Griffith Independent Testing laboratories and reconfirmed by the Ministry of Roads and Public Works.

The concrete was designed for a:

a.	Minimum flexural strength	4.2 Mpa
b.	Minimum compressive strength	35 Mpa
c.	Slump requirement:	80 mm at batching plant
		50 mm on site

The concrete was designed bearing in mind the haulage distance from the batching plant to the site, a total distance of 16 km. A retarding plasticiser was incorporated into the mix with the dual role of increasing workability at a low w/c ratio and retarding the initial set of cement to cater for the transit distance

The designed concrete mix proportions are as follows:

i.	Cement-CEM I 42.5	400 kg
ii.	20mm aggregates	800 kg
iii.	10mm aggregates	530 kg
iv.	River Sand	450 kg
v.	CRP4 admixture	1.45 litres
vi.	Water/cement ratio	0.422

The two stone sizes are used to improve strength and lower cost.

2.5.4 Materials Testing and Specifications

a) General

Raw materials intended for use in the production of concrete were at all times analyzed to establish compliance or otherwise, with the specification for the Works and BS 882. Tests on aggregates and sand were conducted at the Ministry of Roads and Public Works (Materials Department) whereas tests on cement are done at the Kenya Bureau of Standards.

b) Aggregates

The aggregates (fine and coarse) used in the project were supplied by Aristocrats Concrete Co. Ltd and are at all times required to comply with the requirements of BS 882. Various tests are carried out on the aggregates to establish their quality. These are:

i. Particle size analyses done in accordance with BS 812: Part 103: 1985 edition
ii. Flakiness Index in accordance with BS 812: Part 105-1: 1989 edition
iii. Aggregate Crushing Value in accordance with BS 812: Part 110: 1990 edition
iv. Aggregate Impact Value (AIV) in accordance with BS 812: Part 112: 1990 edition
v. Los Angeles Abrasion Value (LAA) in accordance with AASHTO T.96 (ASTM C.131)
vi. Sodium Sulphate Soundness (SSS) in accordance with BS 812: Part 121: 1989 edition
vii. Fineness Modulus of Fine Aggregate in accordance with BS 812: Part 103: 1985 edition
viii. Organic Content of Fine Aggregate in accordance with BS 812: Part 122: 1999 edition

c) Cement

The cement used at the project was required to comply with the requirements of the Kenyan Standard KS 1725, which has now been harmonised regionally to KS EAS 18.

d) Admixtures

The admixture in use is CRP4, a retarding plasticiser from Sika South Africa (pty) Ltd, with the dual role of retarding the initial set of cement and increasing workability at a low w/c ratio.

e) Water

Clean potable water was used for the concrete.

2.5.5 Construction of the Concrete Overlay

a) Introduction

The construction of the Mbagathi concrete pavement was labour based as opposed to the mechanised process whereby paving trains comprising pavers, curing and texturing machines are used. Labour based construction methods aim at utilizing simple construction equipment and exploiting local resources comprising of semiskilled and unskilled labour. This results in their gainful employment and improved livelihoods. This technology therefore made an incentive to counteract rising unemployment levels – a prevalent problem in Kenya today.

Labour-based contractors can be trained and contracted in the pavement construction process, after which, they would have acquired and developed adequate skills that would increase the capacity of the country to undertake future road works with minimal skilled manpower. The Mbagathi Road rehabilitation project employed 5 manual labourers to place the concrete, 3 labourers for the compaction and leveling of the ground, 2 labourers for the finishing and texturing and another 2 for the curing process. The only construction equipment used was the vibrating beam and the poker vibrator.

b) Preparation of the Surface to receive Concrete

The general procedure for the preparation of the surface to receive concrete was generally as follows:

i. The carriageway was widened from a width of 3.5 m to 3.9 m lane width. This was to cater for the placing of kerbstones on the edge of the pavement keeping in mind that the kerbstones were to be placed on the concrete pavement.
ii. Incase of any potholes in the existing roadway, they were repaired using hot mix asphalt.
iii. A survey team with the aid of a total station then placed pins on the sides of the lanes to indicate the extent and depth to be achieved when placing the concrete.
iv. Erection of metal formwork followed, using the surveyors' pins as guides.
v. Dowel cages were then assembled onto the existing asphalt surface to specified orientation and the tie bars fixed to the formwork
vi. The surface was swept to remove dust, leaves and other foreign materials that would hinder adherence of the concrete to the asphalt surface.

vii. Immediately before placing of concrete, the asphalt surface is sprayed with water to prevent it from absorbing moisture from the concrete mix.

c) Finishing and Texturing

After placing and compaction of concrete, the concrete surface is given a light broom finish in the transverse direction. It was observed that consistent concrete mixes gave rise to better and more consistent texture with an improvement in the riding quality. The timing of the texturing operation is important. If done too early or too late, the desired skid resistance is not obtained. The best time for texturing is just after the water sheen has disappeared and just before the concrete becomes non-plastic. Experience on site established that dry mixes produce better texture than wet mixes.

d) Curing

Curing is done immediately after texturing with Masterkure 194W, a resin based curing compound. This is applied after a thin spray of water is applied onto the surface to cater for any rapid loss of moisture from the concrete surface. The curing compound is applied at a rate of 0.35 l/m^2. The curing process is to prevent rapid water loss, thereby permitting cement hydration and controlling temperature. Additionally, curing ensures proper strength gain and durability.

2.5.6 Joint Construction

a) Introduction

Weakened plane joints are used to control the dry shrinkage cracking in a concrete pavement. The slow strength gain of concrete resulting from the hydration process of the cement and water causes a volumetric change to take place and the concrete shrinks. The net effect of this shrinkage is that tensile forces are set up in the concrete and when these forces exceed the tensile strength, a crack, which relieves these forces, forms in the concrete.

To prevent random occurrence of these cracks, grooves 50 mm in depth, are cut into the pavement surface at a spacing of 4 m thus reducing the tensile strength of the pavement and inducing cracking at these locations. As these joints take up all expansion and contraction movement of the pavement, it is important that the dowels are placed parallel to each other and the longitudinal centreline and should be at the same depth to avoid any locking up of the joint.

b) Joint Sawing

Sawing of joints is done within 4 to 6 hours of placing of concrete. The initial saw is cut 3 mm wide and 50 mm deep. The grooves are then washed out, using a pump that releases water at high pressure, removing particles clogging the joint that would otherwise cause stresses within the joint. Stresses within joints can cause spalling of the joint edges.

Cracking at the weakened plane joints indicates that they are functioning correctly and the expansion and contraction of the concrete is being taken up at these locations. Surveys done on site, from 19-06-06 to 19-07-06, indicated that 2 to 3 joints crack within 12 hours, every second to third joint cracks between 20 and 30 days and finally all the joints or in some instances every second joint cracks after 30 to 40 days.

c) Sealing of Joints

Reaming and air blowing of joints is done prior to sealing. The reaming is done to a width and depth of 6 mm and 30 mm respectively. It is delayed for at least 7 days to allow cracking to take place at the location of the joint. This is mainly to increase the width of the joint so it can accommodate the backing rod. The joints are left to dry for a minimum period of seven days. Incase of a downpour during the period, an additional seven days of drying is required before sealing.

2.5.7 Proposal for the Repair of Cracked Concrete Panels

Dry and plastic shrinkage cracks have occurred on several panels of the concrete pavement constructed. Late cutting and poor curing, respectively, have generally propagated the cracks, which have propagated to a degree that compromises the structural integrity of the pavement. A concrete consultant hired by the East Africa Cement Producers Association (EACPA) to oversee the Mbagathi Way Road Rehabilitation Project advised on the most effective approach to the problem. Consequently, a proposal was drawn to the same effect and presented to the contractor. The proposal highlighted the following measures to be taken:

a. For the panels whereby the plastic shrinkage cracks do not run full length across the slab, the write-up proposed the repair of these cracks with a proprietary low viscosity epoxy resin, Sikadur 52, from Sika South Africa (pty) Ltd.
b. For the cracks running across the width of the pavement lane, the write-up proposed the partial removal of concrete sections of the affected panels and reinstatement with reinforced concrete.

2.5.8 Quality Control

A high degree of quality control was exercised in the project. This was to ensure the success of the project and the durability of the concrete pavement. Concrete cubes were cast at the batching plant for strength tests. At the beginning of the project, accelerated concrete cube specimens used to be prepared for 24 hour compressive strength testing but due to shortage of the moulds and the consistency of the results, this was stopped. The other concrete cubes were tested for their 7 and 28 days compressive strengths and the concrete beams were tested for their 28 days flexural strengths.

2.6 Asphalt Concrete/ Flexible Pavements

2.6.1 General

Asphalt has been widely used since 1920 among the developing and developed nations. The viscous nature of the bitumen binder allows asphalt to sustain significant plastic deformation, although fatigue from repeated loading over time is the most common failure mechanism. Most asphalt surfaces are built on bases and subbases of various materials; although some 'full depth' asphalt surfaces are built directly on the native subgrade. In areas with very soft or expansive subgrades such as clay or peat, thick gravel bases or stabilization of the subgrade with Portland cement or lime may be required. (Anon, 1991)

Gransberg, (2005) states that depending on the temperature at which it is applied, asphalt is categorized as hot mix asphalt (HMA), warm mix asphalt, or cold mix asphalt. Hot mix asphalt is applied at temperatures over 300 degrees F with a free floating screed. Warm mix asphalt is applied at temperatures of 200 to 250 degrees F, resulting in reduced energy usage and emissions of volatile organic compounds. Cold mix asphalt is often used on lower volume rural roads, where hot mix asphalt would cool too much on the long trip from the asphalt plant to the construction site.

Anon (1991) states that concrete surface will generally be constructed for high volume primary highways having an Average Annual Daily Traffic load higher than 1200 vehicles per day. Advantages of asphaltic roadways include relatively low noise, relatively low initial cost compared with other paving methods, and perceived ease of repair. Disadvantages include less durability than other paving methods, less tensile strength than concrete, the tendency to become slick and soft in hot weather and a certain amount of hydrocarbon pollution to soil and ground water or waterways.

Gichaga and Parker (1988) highlights several methods for design of flexible pavement. These can be categorized into empirical, semi-empirical and analytical methods as discussed below:-

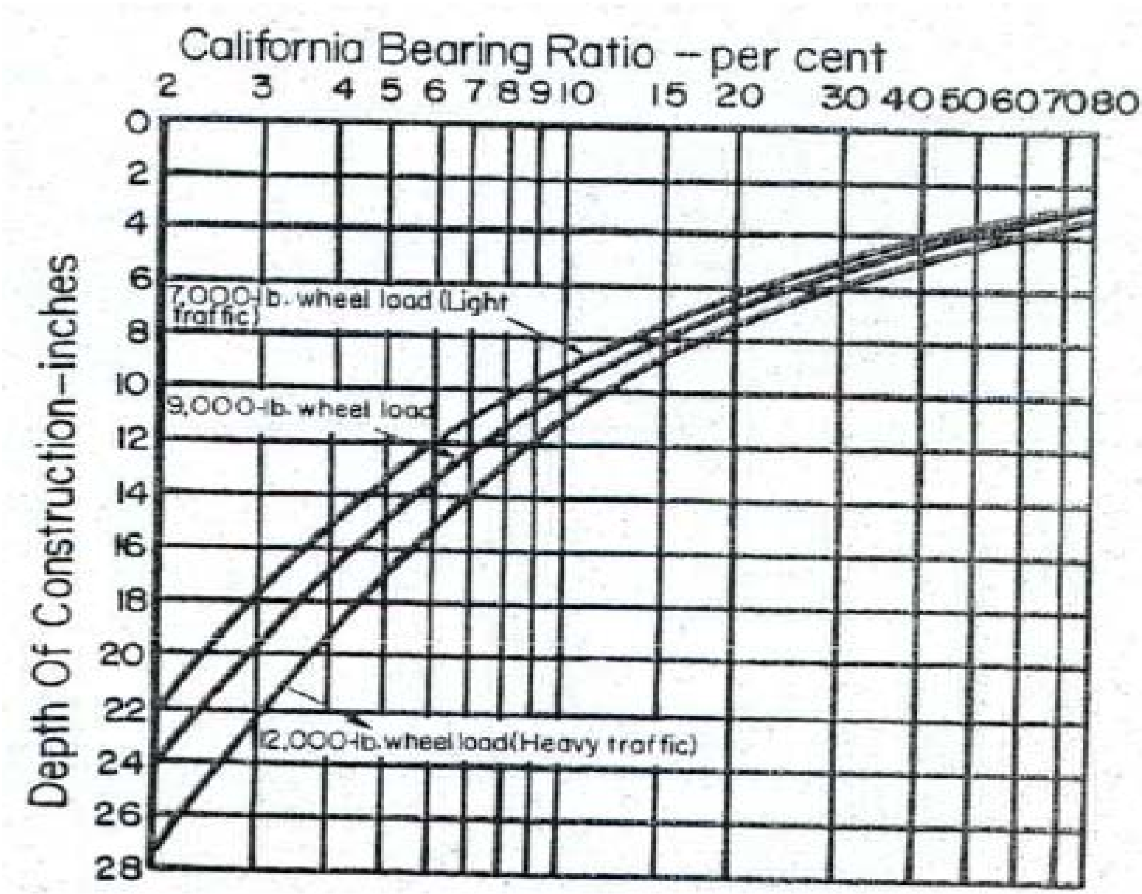
2.6.2 Ministry of Roads Design Manual (Kenya) Method

This is the most commonly used design method of roads in Kenya. Part III of the manual is specific to pavements. After consideration of the traffic loading and the alignment material strengths, the most appropriate pavement type and materials is selected from a set of charts. The method is specific to prevailing conditions in Kenya and therefore best suited for the design.

2.6.3 C.B.R Design Method

The CBR design method involves the determination of the CBR value of the subgrade as well as that of the subbase and base materials. Pavement layer thicknesses are then selected from CBR design curves, figure

2.1 below, on the basis of the relevant design wheel load. The method has been modified to accommodate varying traffic load patterns, as well as different environmental conditions.



Source: Highway Capacity Manual (1985)

Figure 2.1: Design curve for the CBR method
(Gichaga and Parker, 1988)

2.6.4 Road Note 31

This is a guide that provides structural design of bitumen surfaced roads in developing countries since its designs are economy based. The guide considers the traffic loading in terms of the cumulative number of standard axles on the basis of which the type of surfacing, and the thickness of base and subbase are selected from figure 2.2. Selection of the subbase thickness is also based on the bearing strength of the subgrade.

KEY TO STRUCTURAL CATALOGUE

Traffic classes
(10^6 esa)

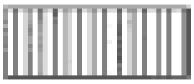
T1 = < 0.3
T2 = 0.3 - 0.7
T3 = 0.7 - 1.5
T4 = 1.5 - 3.0
T5 = 3.0 - 6.0
T6 = 6.0 - 10
T7 = 10 - 17
T8 = 17 - 30

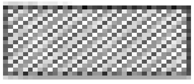
Subgrade strength classes
(CBR%)

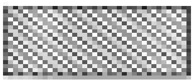
S1 = 2
S2 = 3 , 4
S3 = 5 - 7
S4 = 8 - 14
S5 = 15 - 29
S6 = 30+

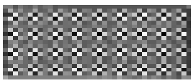
Material Definitions

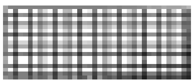

Double surface dressing


Flexible bituminous surface

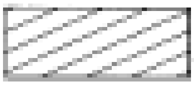

Bituminous surface
(Usually a wearing course, WC, and a basecourse, BC)


Bituminous roadbase, RB

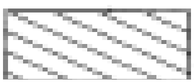

Granular roadbase, GB1 - GB3

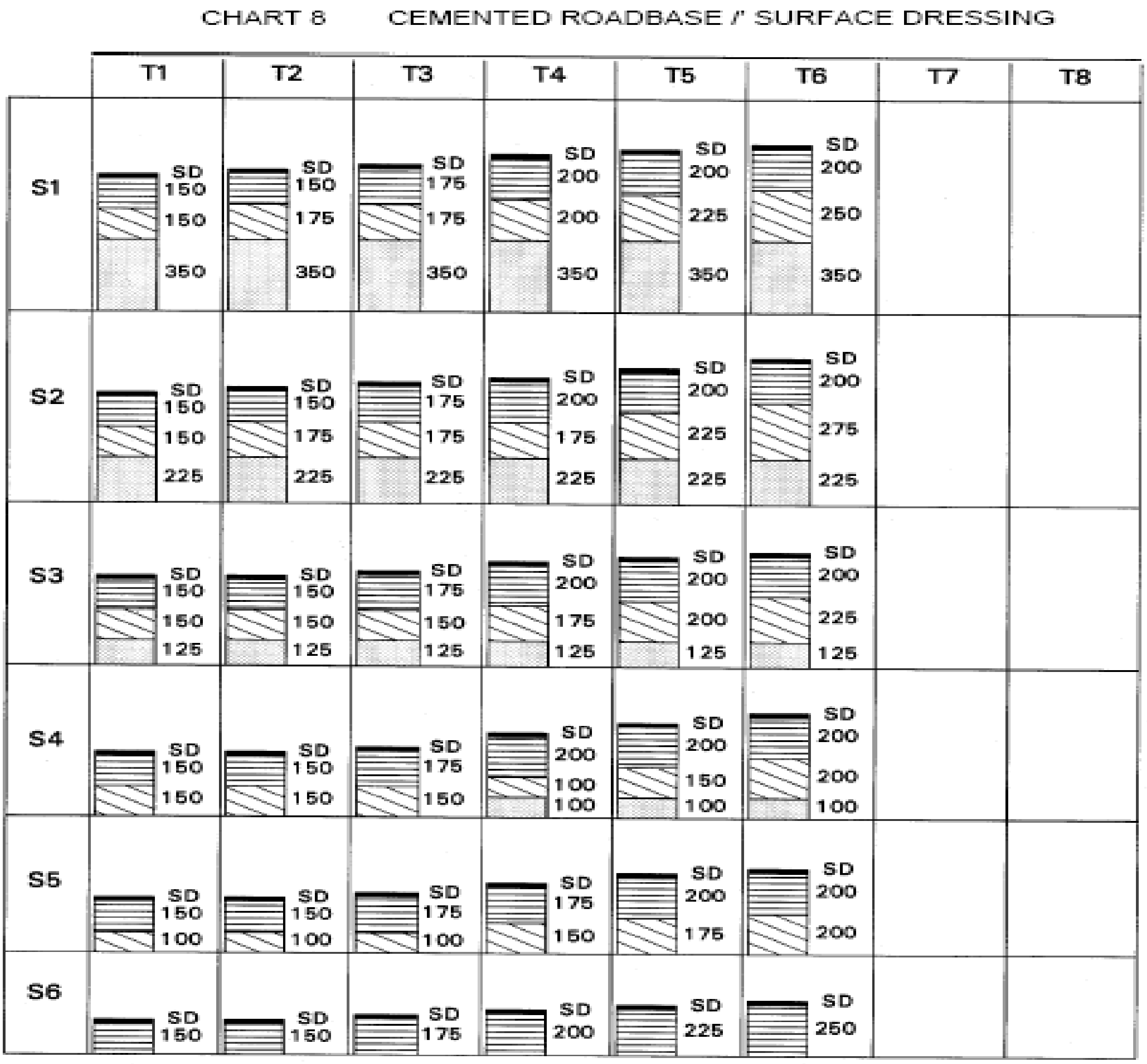

Granular sub-base, GS


Granular capping layer or selected subgrade fill, GC


Cement or lime-stabilised roadbase 1 , CB1


Cement or lime-stabilised roadbase 2, CB2


Cement or lime-stabilised sub-base, CS



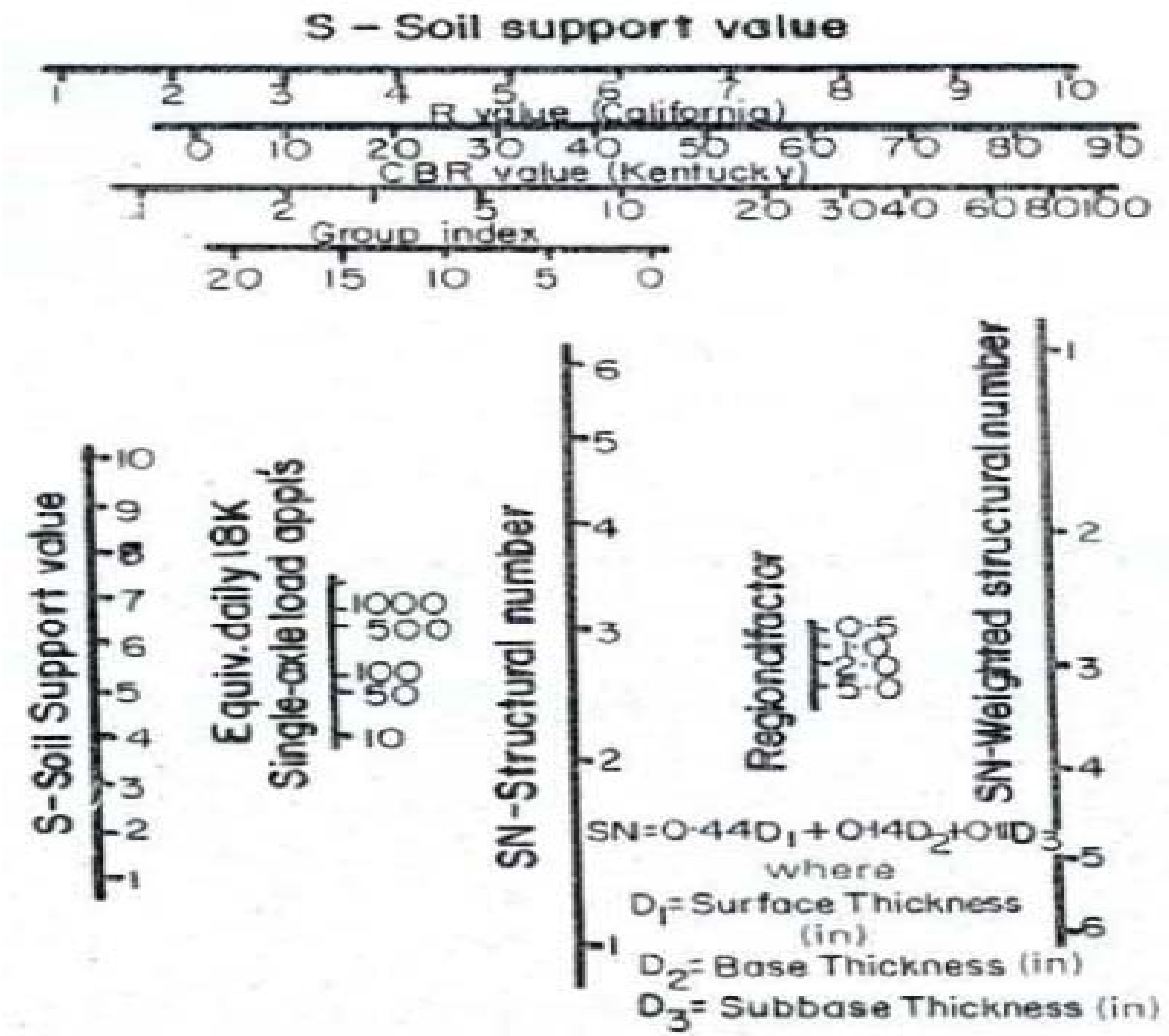
Note: A granular sub-base may also be used.

Source: RN31, TRRL (1993)

Figure 2.2: Design catalogue for Road Note 31

2.6.5 AASHTO Design Guide

This guide was developed from the results of the AASHO Road Test. It has been used widely in the tropical countries. Subgrade strength is defined in terms of the soil support value, while pavement thickness is expressed in terms of the Structural Number (SN) m 1.0 to 6.0. Traffic loading is expressed in terms of cumulative standard axles during the design life of the pavement, or in terms of daily axle applications. AASHTO Design Charts are given as figure 2.3.



Source: TRRL(1977) (Gichaga F.J and Parker N.A 1988)

Figure 2.3: AASHTO design chart

2.6.6 Other Empirical Methods

There are other methods which can be considered in the empirical and semi-empirical methods. These include the following:-

1. Group Index Method;
2. Road Note 29 Design Guide;
3. CEBTP Pavement Design Method for Tropical Countries;
4. Shell Pavement Design Method;
5. Hveem Stabilometer Design Method

2.6.7 Analytical Methods

Gichaga and Parker (1988) further state that analytical pavement design method involves the assumption of a pavement structure system. The strength characteristics (in terms of the modulus and poisson's ratio) for each layer maybe established or assumed. Traffic loading is then introduced and structural analysis carried out to determine the stresses and strains at critical points in the structure. The value of stresses and strains obtained from the analysis are compared with the maximum allowable values to design the adequacy of the design.

2.7 Flexible Pavement Design (Ministry of Roads Design Method)

2.7.1 General

Ministry of Roads Design Manual part III deals both with the pavement and respective materials. The manual has developed different crossections and defined various components of a paved road. Figures 2.4 and 2.5 show the terms used in describing the principal pavement and cross section components.

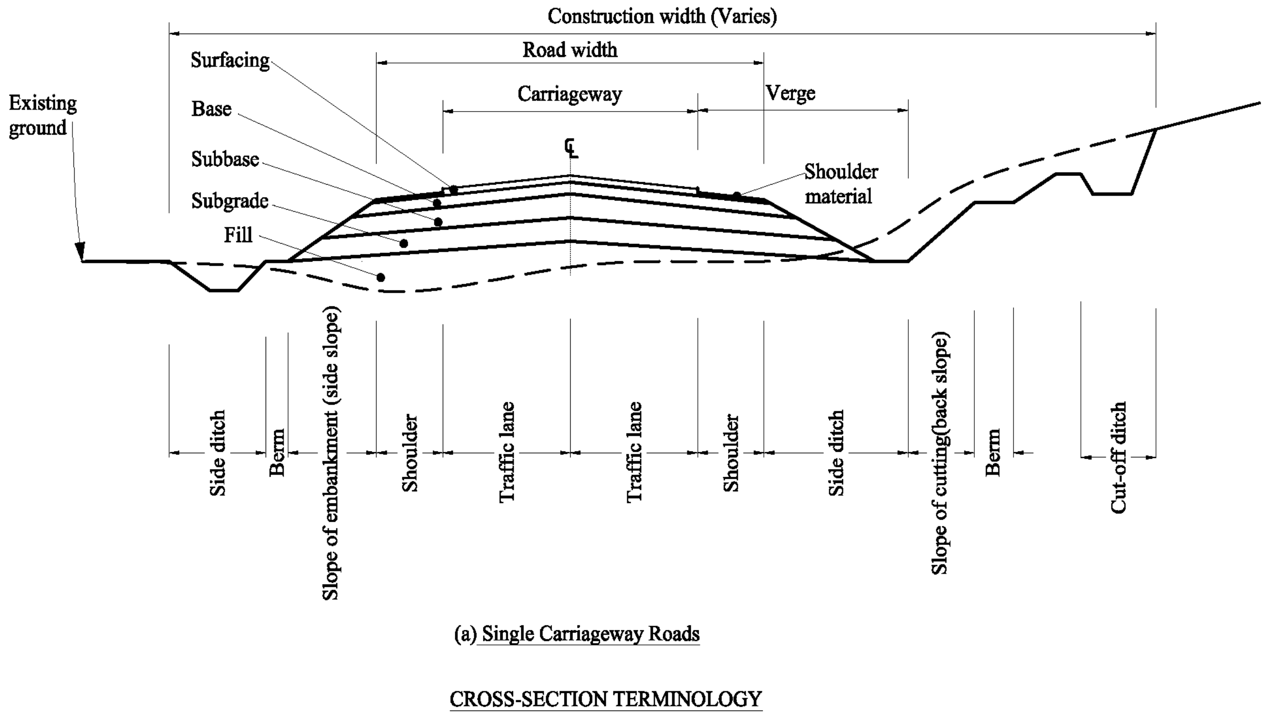
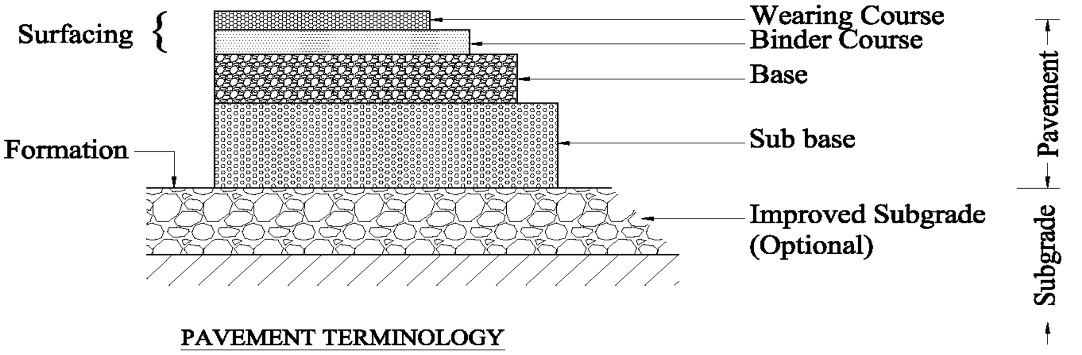


Figure 2.4: Single carriageway cross-section



Source: MoR design manual (1987);

Figure 2.5: Road pavement terminology

2.7.2 Sub-grade

Kadiyali (1989) gives specifications for processing subgrade while MoR Design Manual Part III (1987), gives the detailed procedures and material specifications for the subgrade. According to the MoR design Manual, the pavement should be designed to cope with the lowest measured CBR. Any sub-grade with a CBR of 5% or less will require a capping layer, sometimes known as a sub-grade improvement layer. This is constructed from approved granular or cement-bound material, laid and compacted in layers not greater than 200mm thick. A sub-grade with a CBR of 2% or less should have a 600mm thick capping layer; a sub-grade with a CBR of 2-5% should have a capping layer 350mm thick.

The aim of the design process is to protect the bearing capacity of the in situ subgrade material in order that the road pavement will be able to fulfill its service objective over the design period. The bearing capacity and quality of the subgrade (or roadbed or fill) is of prime importance in the selection of pavement type and is improved by overlaying it with layers of material to achieve an integrated and structurally balanced system.

Determining the Subgrade Strength

The strength of the subgrade depends on the type of material, its density and the prevailing moisture content. For each type of material, it is therefore necessary to determine the relative compaction that could be obtained in-situ and the maximum moisture content likely to occur in the subgrade.

In order to obtain a complete knowledge of the relationship between density, moisture content and CBR, a “3 point” CBR test should be carried out on a representative sample of each type of subgrade material to be utilized. The tests are conducted in the following way:

The samples shall be prepared at the moisture content expected at the time of field compaction. At each level of compaction, one CBR shall also be measured on one soaked specimen. The time of soaking will depend on the anticipated wettest conditions. The amount of water absorbed during soaking and the eventual swell shall also be measured.

The above method enables an estimate to be made of the subgrade CBR at different densities and thus helps in determining the relative compaction required. It also indicates the loss of strength which soaking may cause. A full particle size analysis should also be done on each representative sample.

Improved Subgrade

Placing an improved subgrade not only increases the bearing strength of the pavement support but also:

- protects the upper layers of earthworks against adverse weather conditions (protection against soaking and shrinkage),
- facilitates the movement of construction traffic,
- permits more effective compaction of the pavement layers,
- reduces the variation in the subgrade bearing strength, and
- prevents pollution of open-textured sub-bases by plastic fines from the natural subgrade.

Gichaga and Parker (1988) states that during construction, it is important to check that the specifications for preparing the subgrade are met. Common methods of checking the subgrade preparation involves checking the levels of formation, checking the horizontal alignment, and checking the degree of compaction.

2.7.3 Subbase

MoR design manual states that the next stage of the design process considers the usage of the pavement, and first specifies a thickness for the sub-base before determining the type of road base that will be required.

To determine sub-base thickness, it is necessary to know the subgrade CBR and the traffic volume in equivalent standard axles. The functions of the subbase are to act as a construction platform for the upper pavement layers and as a separation layer between the subgrade and the roadbase. In certain circumstances it may also act as a drainage layer, especially in concrete roads. The selection of a suitable subbase material will, therefore, depend on the design function of the layer and the anticipated moisture conditions, both at construction and in service.

Kadiyali (1989) gives various functions of the subbase which includes firm pavement support, prevent mud-pumping, reduce frost action, to act as capillary cut-off, and to provide a leveling course on distorted or undulating subgrade.

Subbase Materials

Natural Materials are commonly used for subbases can be lateritic, quartzitic or calcareous gravels, some forms of soft stone, coralstone (on the coast), clayey and silty sands, and conglomerate. When used as subbase they shall invariably have low plasticity. Other materials includes but not limited to graded crushed stone, stabilized natural materials, cement bound granular subbases. MoR Manual Part III (1987) gives the detailed procedures and material specifications for the subgrade.

Gichaga F.J and Parker N.A (1988) give the material specifications for the subbase. It gives the specification for three commonly used materials, that is gravel materials, stabilized gravel materials and graded crushed stone.

2.7.4 Road Base

Gichaga F.J and Parker N.A (1988) give the tests that should be carried out on the base materials. The base materials can either be gravel materials, stabilized gravel materials, graded crushed stone or lean concrete. The key tests that can be carried out on base material include, CBR, Los Angels abrasion tests, Aggregate Crushing Value, atterberg limits among other tests.

MoR design manual (1987) states that provision of a roadbase is dependent upon the cumulative number of standard axles anticipated over the design life of the pavement. A road base is defined as a layer or layers of bound material intended to give structural strength to a pavement. The main function of the base is to act as the load-spreading layer of the road pavement. Therefore, only strong materials will be suitable. Bases fall into two categories: unbound and bound. Unbound bases, such as natural gravels and crushed stone, rely on their intrinsic internal friction to develop the necessary bearing capacity. Bound bases have a binder, either bitumen or cement or lime, which is used to strengthen them and enhance their ability to reduce the traffic stresses on the layers below.

Base Materials

MoR Design Manual (1987) indicates that base materials includes but not limited to the following:-

a) Natural gravel

b) Graded Crushed Stone

c) Stabilized materials

d) Lean Concrete

e) Sand Bitumen Mixes

f) Dense Bitumen Macadam

g) Aggregates

h) Dense Emulsion Macadam

Kadiyali L. R (1989) indicates that the base is the main load bearing layer in a flexible pavement and gives two key functions of the road base: To act as the structural portion of the pavement and thus distribute the loads and also to prevent intrusion of subbase soils into the surfacing.

2.7.5 Surfacing

Gichaga F.J and Parker N.A (1988), state that the most commonly used surfacing material in construction of a flexible pavement are bituminous materials which are normally applied in thin layers ranging from 25mm to 100mm. Such materials include asphaltic concrete, gap-graded asphalt, sand asphalt, emulsion slurry seal and surface dressing. It further gives the key tests that should be done on surfacing materials which include Los Angels Abrasion tests, Aggregate Crushing Value, Flakiness Index, Sulphate Content, grading amongst other tests. MoR Design Manual (1987), defines two surfacing coats as follows:-

Prime Coat

A prime coat is an application of low viscosity bituminous binder to an unbound surface, usually an unbound or a cement/lime-bound surface, in order to promote and maintain adhesion between the road base and a bituminous surfacing. MC 30 and MC 70 are the most suitable binders. MC 30 can be used for practically all types of materials. MC 70 is suitable only for open textured materials, such as graded crushed stone. The depth of penetration should be between 3 and 10mm and the quantity sprayed should be dry within two days. The rate of application will depend on the texture and density of the material to be primed. It is usually between 0.8 and 1.2litre/m^2. It is good practice to dampen the surface to be primed as this facilitates the penetration of the binder. Priming a cement-treated layer with cut-back can cause slight surface disintegration, because of interference with the cement hydration. If difficulties arise, priming should be replaced with a bitumen emulsion tack coat, although the absorbance of an emulsion is not as good as cutback bitumen.

If the prime coat has to be trafficked before the surfacing is placed, it should be blinded with clean, non-plastic natural sand, crusher dust or fine aggregate.

Tack Coat

The prime function of a tack coat is to glue a new bituminous surface to an underlying bituminous surface. Tack coats should be very thin, otherwise they will act as a lubricant rather than a glue (especially in hot climates) and unnecessarily increase the bitumen proportion in the overlying asphalt. It is best to use a bitumen emulsion, spread thin to approximately 0.2 to 0.8 l/m^2. All tack coats is applied to a cleaned surface shortly before laying the next bituminous layer but allowing sufficient time for evaporation of cutter or run-off of emulsion water. Rapid curing cut-backs (RC 250, 800 or 300); medium curing cut-backs (MC 250, 800 or 3000); quick-breaking emulsions (Al or Kl-70); or A3 Anionic emulsion diluted with water l:l. MC 30 & MC 70 prime cut-backs are not suitable for tack coats.

2.7.6 Asphalt Concrete

General

According to the MoR Design Manual (1987), the road user mainly requires an asphalt concrete premix surfacing to provide a satisfactory riding quality and impart a sufficient skid resistance under all weather conditions. A premix surfacing required to protect the underlying pavement layers from ingress of water and the abrasive and disruptive actions of traffic and have a maximum maintenance-free life.

There are two generic types of asphalt premix surfacing:

- Interlocked aggregate mixes, such as asphaltic concrete, which derive stability from the aggregate interlock, obtained by careful adjustment of the mix grading, and from the cohesion provided by the bitumen, and
- Mortar type mixes, such as gap-graded asphalt or sand asphalt, which derive stability from the cohesion of the fines-filler-bitumen mortar.

Asphalt concrete is the bituminous surfacing of choice in Kenya. There is some doubt concerning the stability of gap-graded asphalts in hot climates, and even in temperate climates their use is declining in favor of alternative premixes, such as thin surfacing that is more durable and resistant to deformation.

Design

The design of asphaltic concrete mixtures assumes that the particle size distribution (grading) of the aggregate should produce the highest possible density in the aggregate fraction of the mixture.

Asphalt types include the following:-

a) Gap-graded Asphalt

b) Sand Asphalt

c) Reclaimed Asphalt Pavement (RAP)

MoR Design Manual Part III, gives design charts for picking the appropriate thicknesses of asphaltic concrete.

2.7.7 Flexible Pavement Design Procedure:-

The design of flexible pavement as per Ministry of Roads design manuals Part III involves the estimation of traffic loads and volumes and the pertinent projections; assessment of slab support conditions and eventually selection of an appropriate pavement type and materials from the design charts and tables. Kadiyali L. R

(1989) gives the minimum thicknesses for different pavement layers that is base, subbase and surfacing by considering the cumulative standard axles:-

2.7.8 Pavement Shoulders and Drainage

Kadiyali (1989) states that there are three factors for getting a good road: drainage, drainage and more drainage. It acknowledges that the main cause of a failed pavement is poor drainage. It also states that if water passes through a road and fill the native soil whatever maybe its thickness loses its support and goes to pieces.

Shoulders

According to MoR Design Manual (1987), deterioration of paved roads often begins with edge-fretting, especially if the shoulders are unsealed; the repair of such damaged roads is then difficult to carry out effectively. Thus, the pavement shoulders should be considered as a fundamental part of the pavement which functions are to:

i. Improve road safety by providing better visibility and convenient hard standing for temporarily disabled vehicles and police roadblocks
ii. Give added width to the carriageway for emergency use
iii. Provide lateral support to the pavement layers, especially if granular materials are used for the base
iv. Facilitate removal of surface water from the road and,
v. Protect the edges of the subgrade against soaking and facilitate the internal drainage of pavement layers.

Shoulders should therefore have sufficient strength to carry occasional traffic, be impervious to surface water, be properly shaped so as to shed water completely and be erosion resistant. It is always preferable to construct the base and subbase materials right across the shoulders to the drainage ditches. This provides lateral support to a granular base and simplifies the construction.

a) Bearing Capacity of the Shoulders

Use of the same pavement structure for the shoulders as for the carriageway simplifies construction and ensures that the bearing capacity of the shoulders will be adequate for the design life of the road. If this is not the case, site conditions will determine the strength required for the pavement depending mainly on the likelihood of heavy traffic using the shoulder.

Generally shoulders to bituminous roads should be constructed at least with material of gravel wearing course quality, which is to a minimum strength of CBR 30%. For the heaviest traffic, higher strengths are required, and in this case the shoulders should definitely be constructed to the same standard as the carriageway. For lightly trafficked roads (Classes T4 and T5), where no suitable gravel is available, material with a minimum soaked CBR of 15% at 95% MDD can be used. In arid areas the soaked condition may be relaxed to CBR of 15% at 95% MDD, at OMC.

b) Surfacing of Shoulders

MoR manual indicates that a waterproof and durable bituminous surfacing must be used for roads where the shoulders are paved. Prime coats alone are inadequate. If the shoulder base material is a non-cohesive material such as graded crushed stone or non-plastic gravel, the shoulders must be primed and sealed. The type of seal may be either a single or double surface dressing. It is preferable, however, that all shoulders should be sealed because, in addition to increasing their longevity, sealing prevents the ingress of surface water at carriageway edges.

Drainage

a) Drainage on the Road Surface and Shoulders

Rain falling on the road surface and shoulders must be conveyed rapidly to the side ditches. For this purpose, road and shoulder surfaces are given a crossfall, the value of which depends on the nature or the surface. The following crossfalls are recommended (MoR, 1987):

- Bituminous and concrete road surfacing : 2.5%
- Earth and gravel road surfaces :3 to 4%
- Gravel shoulders : 4%
- Primed or cement treated shoulders : 6%

b) Drainage of the Pavement Layers

Effective drainage of granular pavement layers is essential for their good performance and is ensured by attention to cross section details. In particular, 'boxed-in' pavements, where water could be trapped in the pavement layers, must not be used. Measures to ensure proper drainage of the pavement layers must be included in the design, particularly where internal drainage could be impaired.

c) Drainage of the Subgrade

MoR design manual requires indicates that sufficient deep open side drains or alternatively special facilities such as sub-surface drains will ensure proper drainage of the subgrade. Particular attention to design and construction details is required where rock occurs, which could trap water in the subgrade.

- In soils, open side drains shall not be less than 0.5m deep, measured from the drain bottom to formation level.
- In cuttings in soils open side drains shall not be less than 1m deep, measured from the drain bottom to formation level. This depth can be reduced to 0.5m if the subgrade is cement or lime modified.
- In cuttings in solid rock the required drainage measures depend on site conditions and shall be decided in individual cases.

The need for sub-surface drains as alternatives to open drains depends on site conditions, requiring careful consideration owing to their high cost.

2.7.9 Advantages and Disadvantages of Flexible Pavement

a) Advantages

i. Low initial construction cost;
ii. Less traffic noise compared to rigid pavement.
iii. Ease of construction technology;
iv. Ease of maintenance technology;

b) Disadvantages

i. Prone to damage;
ii. Short life span;
iii. Interruptive of traffic flow due to routine maintenance and reconstruction;
iv. Has high heat absorption rate.

2.8 Concrete Pavements

2.8.1 Introduction

Concrete surfaces are created using a concrete mix of cement, gravel, sand and water. The material is applied in freshly-mixed slurry, and worked mechanically to compact the interior and force some of the thinner cement slurry to the surface to produce a smoother, denser surface free from honeycombing. The water allows the mix to combine molecularly in a chemical action called hydration (Gerbrandt, 2004).
Kadiyali L. R (1989) states that the design of a rigid pavement is governed by a number of factors which include loading, properties of subgrade, properties of concrete, external conditions such as temperature &friction, joints and reinforcement.

2.8.2 Types of concrete pavements.

South African Manual M10 (2005) defined concrete surfaces into three common types: jointed plain (JPCP) jointed reinforced (JRCP) and continuously reinforced (CRCP). The one item that distinguishes each type is the jointing system used to control crack development.

a) Jointed plain concrete pavements (JPCP).

These are short jointed pavements that contain no reinforcing steel distributed throughout the slab. Transverse joints generally spaced at less than 5m. Jointed Plain Concrete Pavements (JPCP) contains enough joints to control the location of all the expected natural cracks. The concrete cracks at the joints and not elsewhere in the slabs. Jointed plain pavements do not contain any steel reinforcement. However, there may be smooth steel bars at transverse joints and deformed steel bars at longitudinal joints. The spacing between transverse joints is typically about 4.5m for slabs 175–300mm thick.

b) Jointed reinforced concrete pavements (JRCP).

Since the 1940s the jointed reinforced concrete pavement has been by far the most commonly used concrete pavement, though recent decades have seen unreinforced and continuously reinforced concrete pavements dominate on major highways. Transverse contraction control joint spacing is usually in the range 10 to 15m based on both technical and economic factors. They contain steel reinforcement. The steel reinforcement is either welded wire fabric or deformed steel bars comprising about 0.15-0.25% of the cross sectional area. The steel reinforcement is distributed through the slab. Jointed Reinforced Concrete Pavements (JRCP) contains steel mesh reinforcement (sometimes called distributed steel). In jointed reinforced concrete pavements, designers increase the joint spacing purposely, and include reinforcing steel to hold together intermediate cracks in each slab. The spacing between transverse joints is typically 10m or more

c) Continuously reinforced concrete pavement (CRCP).

It has no regularly spaced transverse joints but contain a significant amount of longitudinal steel. Reinforcement typically 0.6-0.8% of the cross sectional area. The principal benefit of this pavement type is the elimination of transverse contraction joints and their associated maintenance. Disruption costs attributable to maintenance operations are therefore minimized. For heavily trafficked, limited access roads this can be an important factor in pavement type selection as one of the reasons for having to close a trafficked lane, even if temporarily, is eliminated.

d) Prestressed concrete pavements.

By prestressing, such compressive stresses are introduced that the stresses due to shrinkage, temperature and traffic loadings stay within acceptable limits. Prestressed pavements are such a specialized and costly type of concrete pavement structure, that they are only applied at some airport-platforms where zero maintenance is very important.

CRCP pavements are designed with enough steel, 0.6–0.7% by cross-sectional area, so that cracks are held together tightly. Determining an appropriate spacing between the cracks is part of the design process for this type of pavement. Continuously reinforced designs generally cost more than jointed reinforced or jointed plain designs initially due to increased quantities of steel. However, they can demonstrate superior long-term performance and cost-effectiveness.

Houben (2006) states that there are several concrete pavement design methods which can either be empirical or analytical as discussed below:-

I. **Empirical design methods.**

Empirical methods are based on the analysis of the actual long term behavior of in service concrete pavements. This implies that an empirical design method can only be developed in regions/countries where concrete pavement structures are already used, during a long time and on a large scale. Examples of empirical concrete pavement design methods are:

i. The AASHTO-method (USA)
ii. The PCA-method (USA)
iii. The BDS-method (Britain)
iv. The BRD-method (Germany)

II. **Analytical design methods.**

The main design criterion in analytical design methods for (un)reinforced concrete pavement structures is checking cracking within the concrete top layer. Therefore in these design methods emphasis is laid on the calculation of the fatigue damage due to traffic and temperature loadings in the critical locations of the concrete layer. In some analytical design methods the traffic loading is expressed as a predicted number of equivalent standard axle load repetitions, by means of an AASHTO-like load equivalence factors

i. Dutch analytical (VNC) method
ii. The British design standards (BDS)-method

2.8.3 South African Design Manual, M10

This method requires the input of traffic loading and alignment soils characteristics charts. It employs charts to determine the various components of the pavement. The method has been used in the design of the concrete pavement for the case study.

2.8.4 The AASHTO-method

The AASHTO-method for the design of concrete pavement structures is based on the results of the AASHTO Road Test. The design criterion is serviceability (ridability), which is mainly determined by the pavement's longitudinal (un)evenness. The input parameters for application of this design method for both plain and reinforced concrete pavements are:

Traffic

i. The reliability factor (R)
ii. The overall standard deviation (So)
iii. The cumulative number of equivalent 80 kN single axle loads and the design traffic lane during the design life

Concrete slab

i. The mean flexural tensile strength of the concrete, determined after 28 days by means of a 4-point bending test (S'_c)
ii. The (mean) Young's modulus of elasticity of the concrete (E_c)
iii. The load transfer (J), dependent on the type of concrete pavement structure, the type of joint construction (whether or not dowel bars), the type of reinforcement, the slab thickness and the modulus of substructure reaction.

Substructure

i. The drainage coefficient
ii. The effective modulus of substructure reaction (k), where the seasonal variation (for instance due to frost/thaw- action) of the resilient modulus of the substructure layers and the potential loss of support of the concrete slab are taken into account.

2.8.5 The PCA-method

The PCA-method is mainly based on the AASHTO Road Test, and additional finite element calculations and tests. The design criterion is the cumulative 'internal damage' due to concrete fatigue and pavement erosion. The input parameters for application of this design method for both plain and reinforced concrete pavements are:

Traffic

i. For every axle load class the number of load repetitions (both for single and dual and tridem axles) on the design traffic lane during the design life
ii. The load safety factor (LSF)

Concrete slab

i. The type of concrete slab (plain/reinforced, whether or not dowel bars, type of reinforcement, etc.)
ii. The length of the concrete slab
iii. The mean flexural tensile strength of the concrete, determined after 28 days by means of a 4-point bending test and expressed as resilient modulus.

Substructure

The mean modulus of substructure reaction (k).

2.8.6 The BRD-method

The German design method for plain concrete pavement structures is a catalogue with a limited number of standard structures, mainly determined on the basis of a very extensive experience with concrete pavement structures.

Applicability of empirical design methods

It has to be emphasized that one has to be very careful with the application of empirical design methods. They only can be applied with confidence in those areas where all relevant local circumstances (such as climate, type of traffic, axle loadings, material properties, construction details, drainage measures, construction techniques and equipment, etc,) are (nearly) the same as those in the areas/countries for which the method was developed. This means for instance that in developing countries the above described Northern-American and Western-European empirical design methods can only be used for a first global design, and certainly not for the final design of a concrete pavement structure.

2.8.7 Dutch analytical (VNC) method

Two design criteria are used in the structural design of a plain concrete pavement: strength criterion, that is , preventing the concrete pavement for cracking; the required thickness of the concrete pavement is found from a strength criterion which on one hand is determined by the occurring flexural tensile stresses under traffic and temperature gradient loadings and on the other hand by the fatigue strength of the concrete, i.e. stiffness criterion : preventing the development of longitudinal unevenness at the transverse joints (so-called joint-faulting); the required thickness of the concrete pavement is found from a stiffness criterion which on one hand is determined by the occurring deflection at the transverse joints under traffic loading and on the other hand by the allowable deflection. initially, concrete pavement structure has to be assumed, which means that the length, width and thickness of the concrete slabs, the concrete quality, the type of joints, the thickness and modulus of elasticity of the base and sub-base, the modulus of subgrade reaction etc. have to be chosen. If it appears after the calculation that the assumed pavement structure does not fulfilled the technical and/or economical requirements, men the analysis has to be repeated for a modified pavement structure.

2.8.8 The British design standards (BDS)-method

The British design method is an empirical method for both plain and reinforced concrete pavements and is mainly based on the behavior of test pavements. The **Traffic, concrete slab width,** the **capping layer** and the **CBR – Value of the subgrade** are the key parameters assessed.

2.9 Design procedures

2.9.1 General

The design procedure consists of the following basic steps:

i. Estimating of traffic loads and volumes

ii. Determination of equivalent stiffness

iii. Slab thickness

iv. Joint and dowel design

v. Tie bar design

vi. Load transfer at joints

vii. Effects of different load transfer devices.

Houben (2005) states that the concrete slab is the main load carrying element. Because concrete slab has high elastic modulus, small depressions in the subgrade are easily bridged over, but if the depressions in the subgrade are large, the slab may crack. The loading due to traffic is considered in terms of magnitude and more significantly in terms of repetitions. Thus in design, we consider loading in terms of repeated equivalent standard axles during the design life of the pavement. Concrete pavements consist of a concrete slab, subbase and subgrade as shown in figure 2.6:-

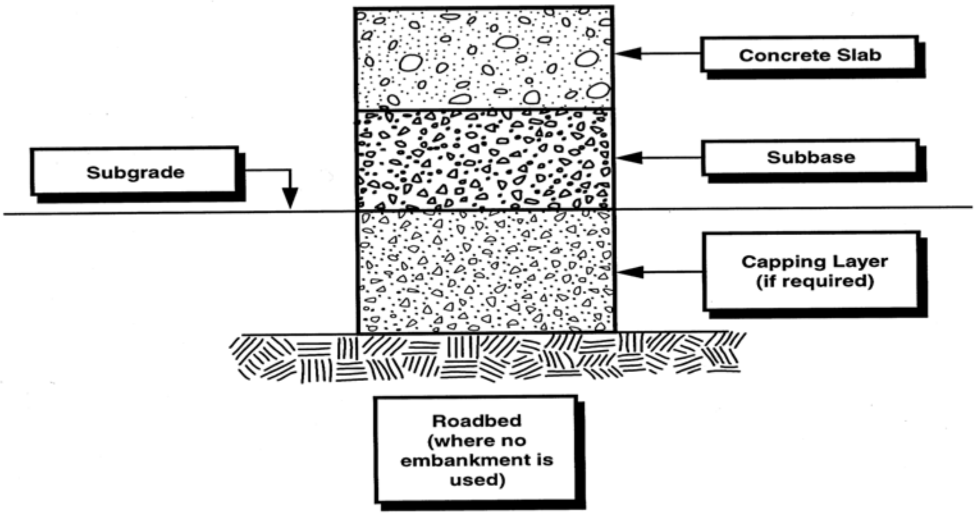
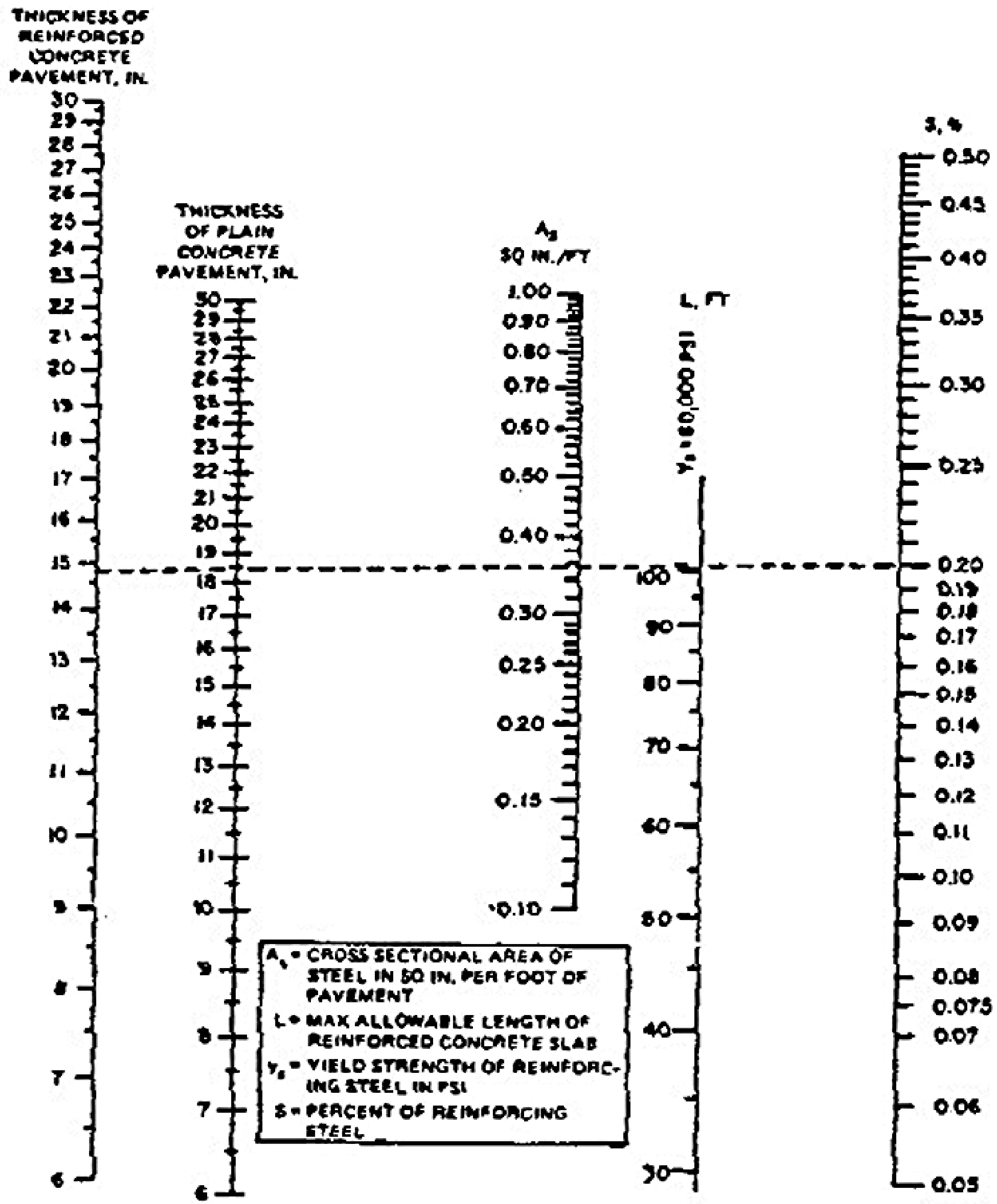


Figure 2.6: Structure of concrete pavement

Guyer (2009) highlights that the design procedure for reinforced concrete pavements uses the principle of allowing a reduction in the required thickness of plain concrete pavement due to the presence of the steel reinforcement. The design procedure has been developed empirically from a limited number of prototype test pavements subjected to accelerated traffic testing. Although some cracking will occur in the pavement under the design traffic loadings, the steel reinforcing will hold the cracks tightly closed. The reinforcing will prevent spalling or faulting at the cracks and provide a serviceable pavement during the anticipated design life. Essentially, the design method consists of determining the percentage of steel required, the thickness of the reinforced concrete pavement, and the minimum allowable length of the slabs. Figure 2.7 presents a graphic solution for the design of reinforced concrete pavements. Since the thickness of a reinforced concrete pavement is a function of the percentage of steel reinforcing, the designer may determine either the required percentage of steel for a predetermined thickness of pavement or the required thickness of pavement for a predetermined percentage of steel



Source: Guyer 2009

Figure 2.7: Guyer's reinforced rigid pavement design chart

2.9.2 Step by step design of the pavement

South African Manual, M10 (June 1995), gives the procedural design of a concrete pavement as shown below:-

Slab support

In order to determine the degree of support that the subgrade will provide to the pavement, the first step is to determine the stiffness of the subgrade expressed in terms of the stiffness modulus. The stiffness modulus is determined in the laboratory by doing triaxial or similar tests under repeated loading and the result is expressed in terms of a resilient modulus. The stiffness values in the design graphs, as used in table 2.2 below, are based on the resilient modulus values of the material tests, such as the mini plate bearing test, can also be used to evaluate the stiffness of material. The material description is equated to subgrade classes as per the first and last column in table 2.2.

Table 2.2: Showing stiffness modulus (Mr) for different subgrade materials

Suggested Mr range (Mpa)

Material description	Suggested Mr range(mpa)	Suggested Mr value	Subgrade class
G4	140-300	150	S6
G5	100-250	130	S5
G6	70-200	110	*
G7	50-160	90	S4
G8	40-120	70	S3
G9	30-80	50	S2
G10	15-50	30	SI

*can be adopted for either class S4 or S5

Determination of equivalent stiffness

After finding the subgrade and subbase stiffness and the subbase thickness, the equivalent stiffness is determined using the figure 2.8.

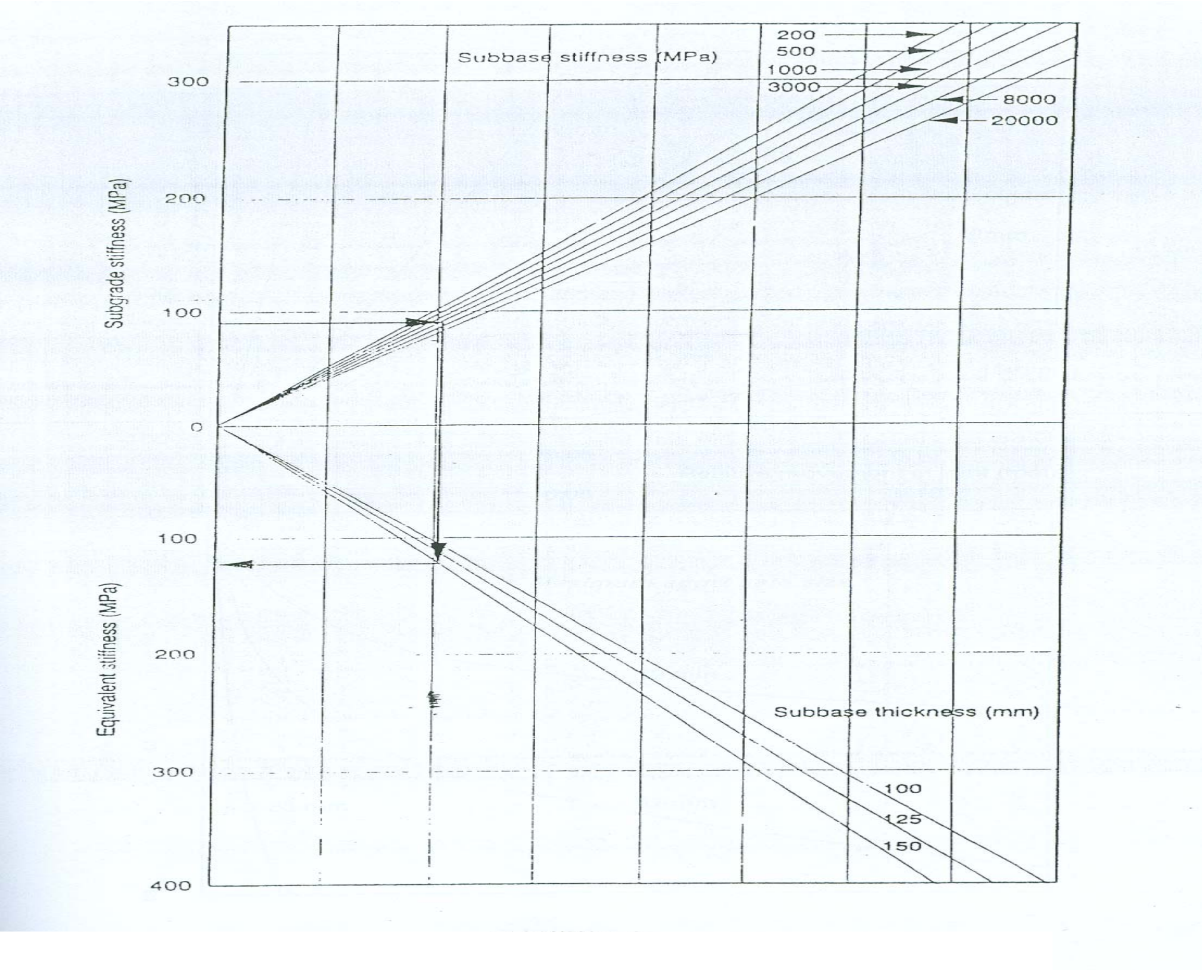


Figure 2.8: Chart for determining equivalent stiffness

Slab thickness

The concrete pavement thickness is determined from figure 2.9. Using the equivalent subgrade stiffness, the design traffic-in terms of equivalent E80 single axle loads the design concrete flexural strength as specified in the standard specifications and type of load transfer being used. Under certain conditions relatively thin pavements are arrived at, however judgment should be exercised not to construct impractically thin pavements since constructability constraints and the associated increased risk of failures should be taken into account.

The input into the design curve is traffic loading in terms of equivalent 80 kN single axle loads. The appropriate slab support stiffness derived in step two is subsequently intersected with the axles. The curves of equivalent slab support stiffness have been adjusted for a certain amount of erosion settlement as well as curling and, subsequently, a loss of support over a length of 600 mm is accounted for. Next, a line from the above-mentioned intersection is constructed to intersect with the curves ' indicating concrete flexural strength at age 28 days.

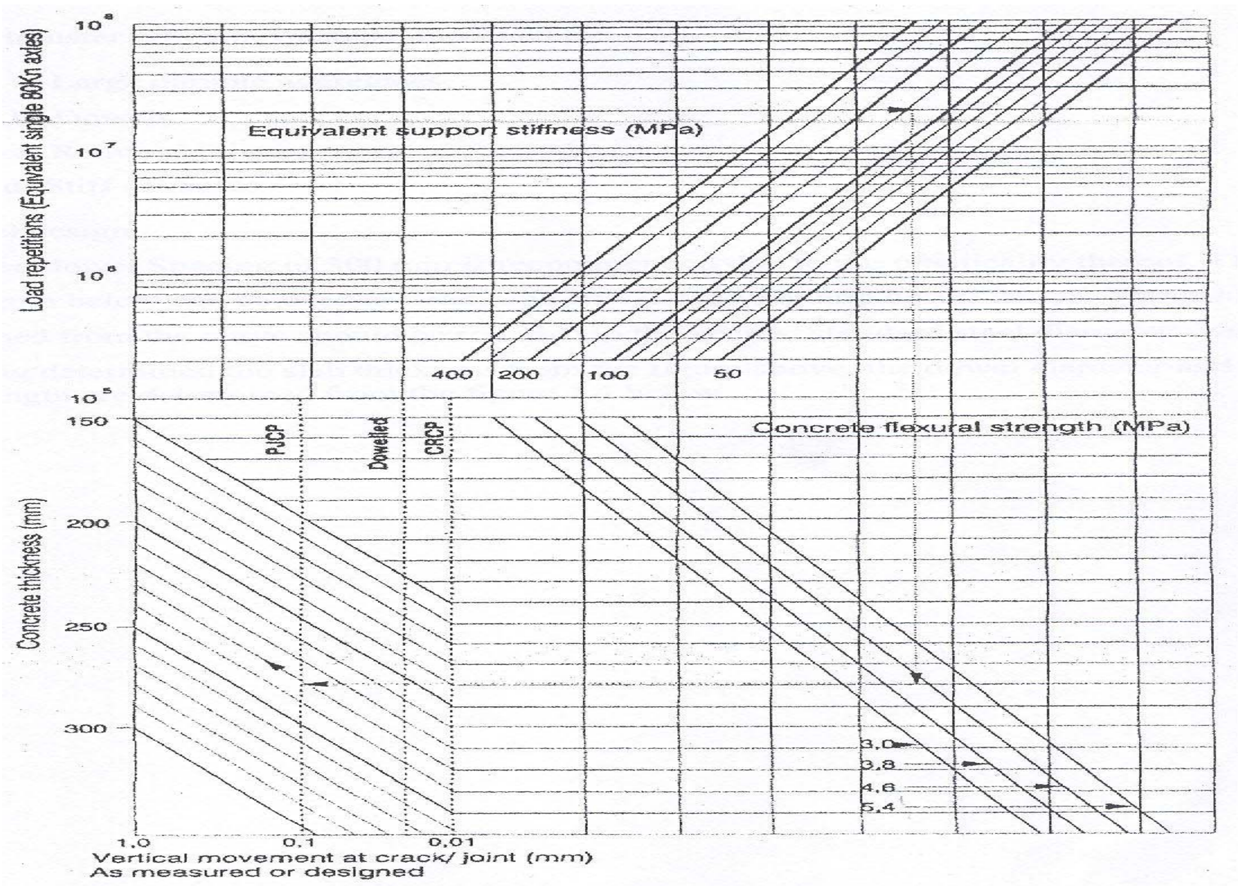


Figure 2.9: Chart for determination of concrete slab thickness

Joint and dowel design

The most often encountered and by far the most dramatic failure of concrete roads occur at the transverse joints. It is thus necessary that adequate load transfer across joints limits slab deflections to reduce faulting, spalling and corner breaks.

Load transfer efficiency can be improved by:

a) Large durable aggregates
b) Dowels
c) Reduced joint opening
d) Stiff subbases

Dowel design

A fixed dowel Spacing of 300 mm is recommended due to the practicality thereof. The curve in Figure 2.10 can be used to determine dowel diameter and dowel length. The value obtained from the curve should be rounded to the nearest standard steel diameter available.

Having determined the slab thickness from the figure above, the dowel diameter and dowel bar length are determined from the figure 2.10

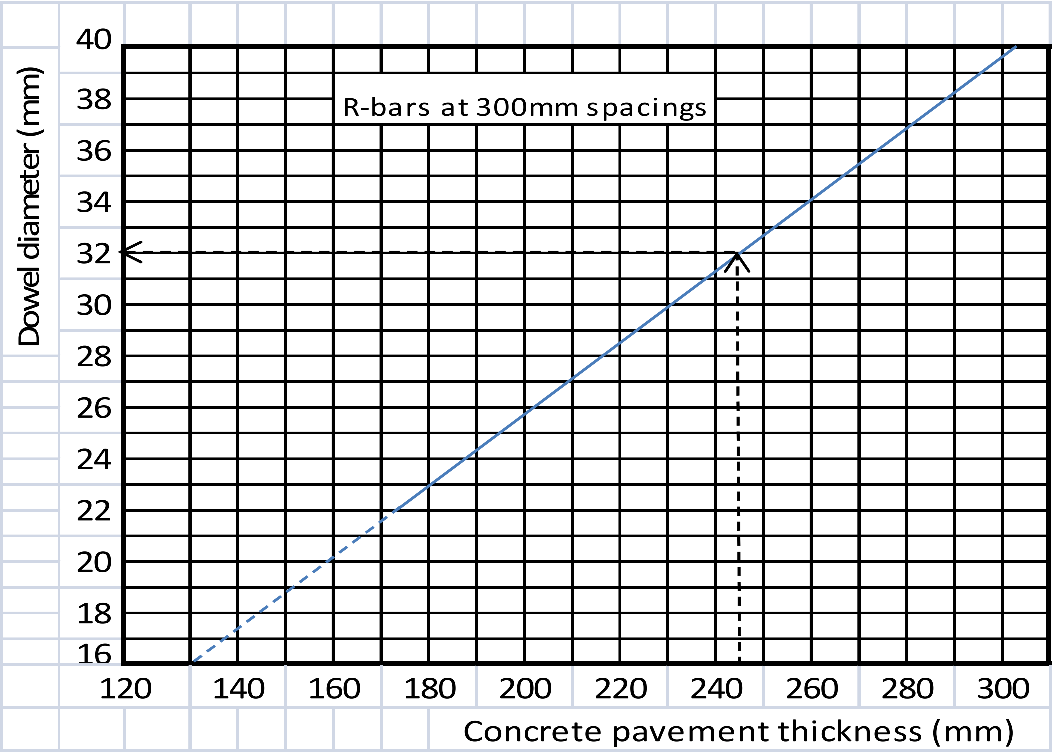


Figure 2.10: Showing relationship between slab thickness and dowel bar diameter

To allow slabs to move horizontally relative to each other, at least two thirds of the length of the dowel should be coated-with a bond breaking compound. The figure below is used to determine the length of the of the dowel bars basing on the pavement thickness derived from Fig. 2.11.

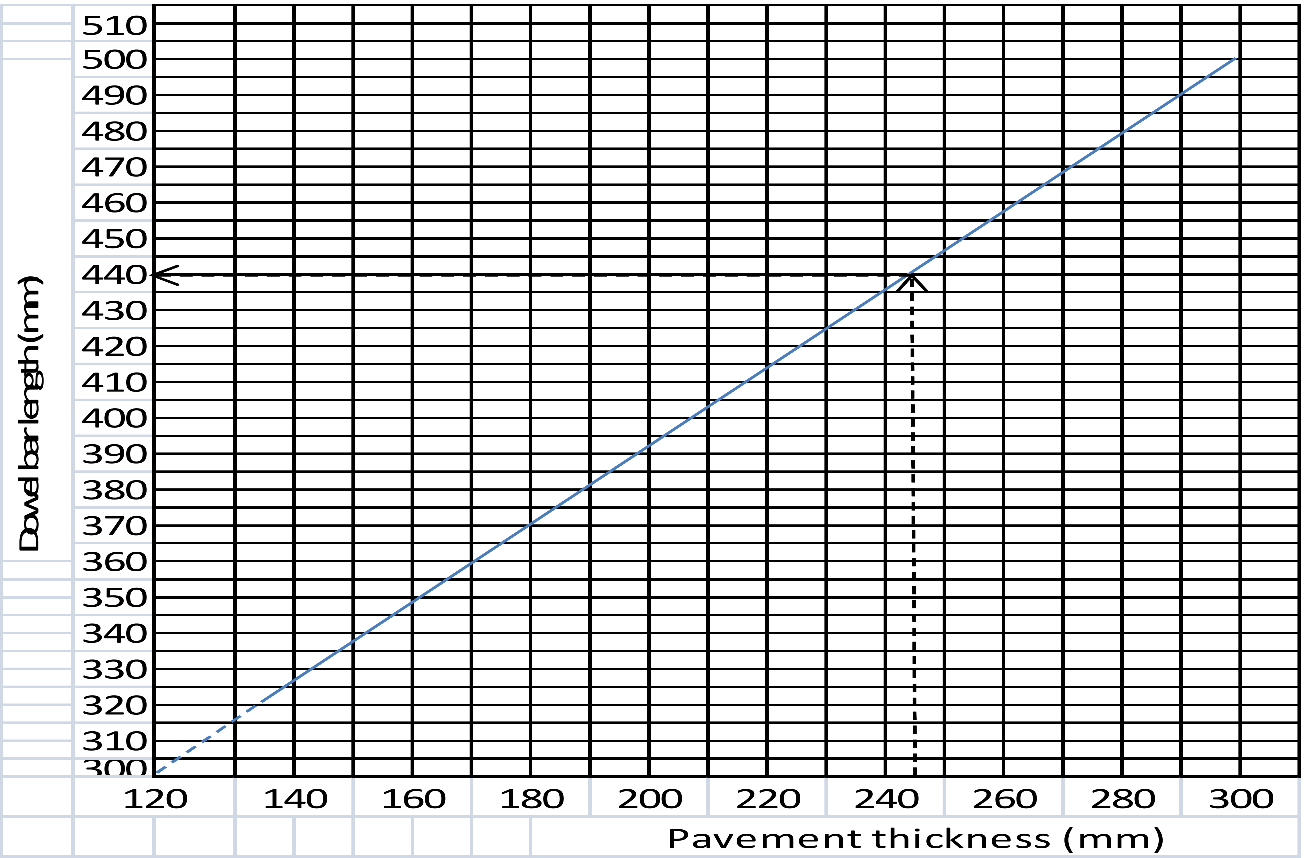


Figure 2.11: Determination of dowel length

Tie bar design

If the width of the pavement to be paved in one operation is wider than 4.5m hinge joints should be provided by sawing the concrete to a depth of 0.3 x concrete thickness. These joints should be sealed. Joints should be tied by inserting uncoated deformed steel tie-bars at a depth of two thirds pavement thickness into the slab.(For slabs less than 200 mm thick, the tie-bar should be inserted at mid depth in the pavement).

Tie-bars should, in all instances, be 750 mm long and the spacing should be calculated using the equation

$S=15.4x_r^2/Fe \times D$ ————————————————————(1.2)

Where:-

S	=	Dowel Spacing
r	=	radius of tie-bar (diameter/2) (mm)
Fe	=	distance from the edge of the pavement (m)
D	=	concrete thickness (mm)

Load transfer at joints

Figure 2.12 indicates the effect of different load transfer devices on relative movement. The top part of the figure shows the relative effect of dowel bars and the bottom part the relative effect of aggregate size and crack/joint spacing on relative vertical movement. Figure below may be used to determine the influence on load transfer caused by changes in bar spacing, bar size, aggregate size and joint spacing. In the event that both steel bars and aggregate interlock are considered to have an influence on pavement performance such as in the case of continuously reinforced concrete pavement {CRCP}, the most effective device is to be considered in the design. For normal concrete pavements variables such as slab length, the distance between joints, aggregate size, dowel spacing, etc. are usually specified. These normally are 4.5 m, 37.5 mm maximum, 22 mm bars spaced at 600 mm respectively.

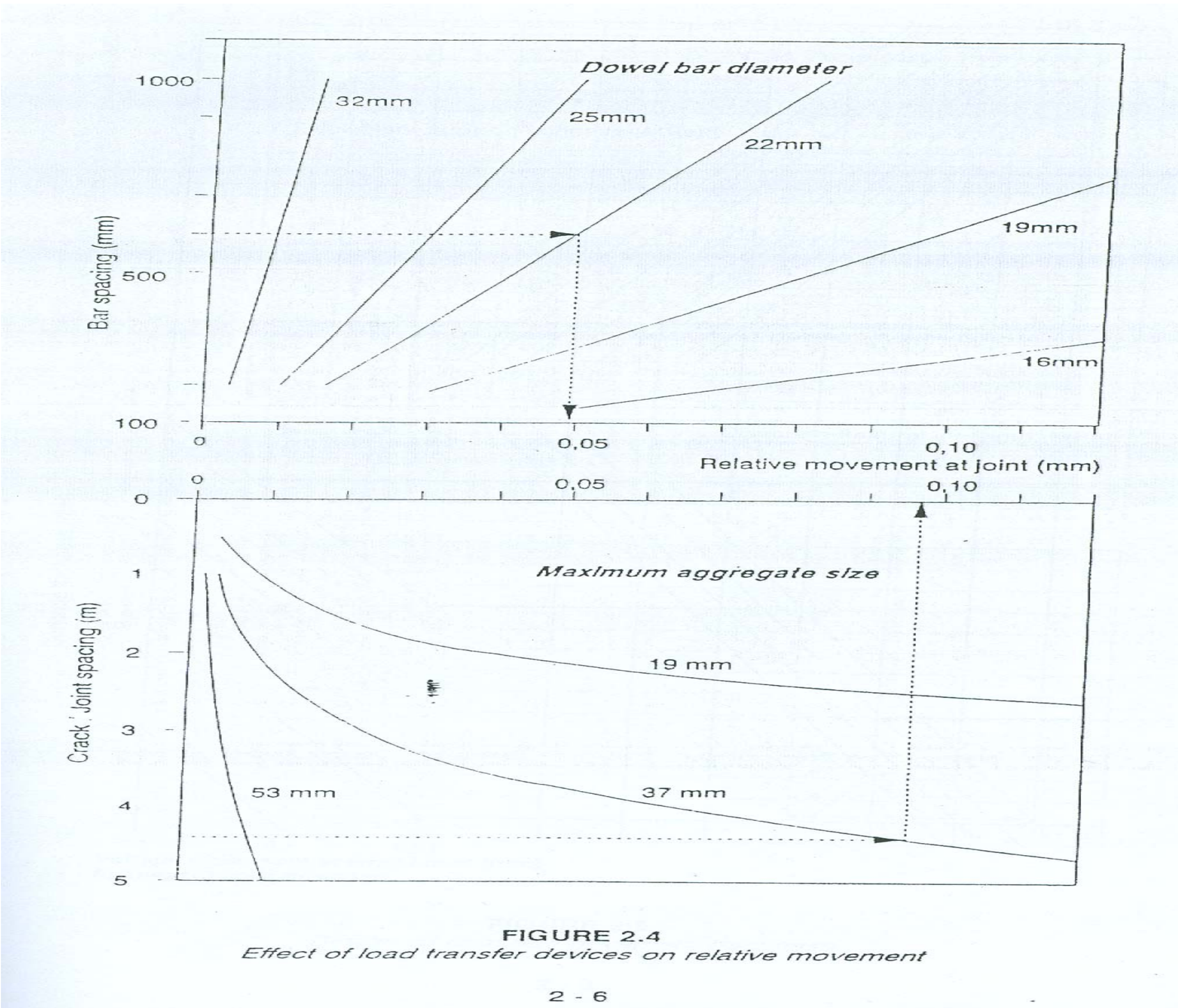


Figure 2.12: Effects of different load transfer devices.

2.9.2 Concrete Pavement Components and Functions

a) Subgrade and Subbase

The main requirement of the subgrade is to provide a foundation for the overlying layers as well as for operation by construction traffic. Subgrades with CBR >30 are suitable, except they should be free draining because eventually water will enter the pavement through the joints; when it does it must be able to drain away, otherwise ‘mud-pumping’ will occur as heavy vehicles pass from one slab to the next. If a subbase is laid, it must also be free-draining and should continue through the road shoulder. In the case study, it is likely that concrete roads will be constructed on old, probably reconstituted, asphalt pavements: obviously, in this situation subgrade strength will be > 30% CBR but attention should be given to the drainage condition.

Concrete pavements generally consist of a subbase and slab constructed on the subgrade, or foundation. The foundation consists of the roadbed and, if the roadbed is weak (CBR < 15), a capping layer comprising selected fill is required which serves to protect the subgrade.

Guyer (2009) indicates that soils not suitable for subgrade use should be removed and replaced or covered with soils which are suitable. The depth to which such adverse soils should be removed or covered depends on the soil type, drainage conditions etc and should be determined by the engineer on the basis of judgment and previous experience, with due consideration of the traffic to be served and the costs involved. In some instances, unsuitable or adverse soils may be improved economically by stabilization with such materials as cement, flyash, lime, or certain chemical additives, whereby the characteristics of the composite material become suitable for subgrade purposes. However, subgrade stabilization should not be attempted unless the costs reflect corresponding savings in base-course, pavement, or drainage facilities construction.

Prevention of subgrade pumping

South African manual M10 defines pumping *as* the ejection of fine particles in suspension along, or through, transverse or longitudinal joints, or cracks, caused by the downward slab movement actuated by the passage of heavy axle loads over the pavement after the accumulation of free water under the concrete slab. Pumping can occur when concrete pavements are placed directly on fine-grained plastic soils and are subjected to certain load conditions. Pumping does not occur immediately after a pavement is placed in service, but rather after an extended period during which repetitive heavy loads" are applied. Continued and uncontrolled pumping eventually leads to the displacement of enough soil for uniformity of support to be lost and slab ends left unsupported.

b) Capping Layer and Subbase

A capping layer is required only if CBR of the subgrade is less than 15%. The capping layer material shall have a minimum CBR value of 15% at 95% MDD. A subbase layer is required when the subgrade CBR is less than 30%. Generally, the thickness of the subbase provided will be 150 mm and it can consist of cement-stabilized material. The subbase shall have a minimum CBR value of 30% at 95% of MDD. For subgrade CBR values less than 2%, the roadbed material needs to be treated either by replacement or in-situ stabilization. A separation membrane (such as a polythene sheet) is required between subbase and concrete slab, mainly in order to reduce the friction between the slab and the subbase in JUCP and JRCP pavements, thus inhibiting the formation of mid-slab cracks. The minimum thickness of the polythene sheet shall be 2.6 mm. It also reduces the loss of water from the fresh concrete. For CRCP pavements, a bituminous spray should be used on the subbase, instead of polythene, because a degree of restraint is required. The primary Load supporting element in a concrete pavement comprises a rigid layer/slab constructed from Portland cement concrete. This layer may be reinforced with steel to control shrinkage cracking. Transverse joints can be provided with or without dowels to prevent uncontrolled cracking, or the slab can be prestressed to reduce critical tensile stresses in the concrete. The concrete surface should be durable and should provide a functionally acceptable running surface for the traffic it intends to carry over its life time.

The layers supporting the concrete slabs should:

i. provide uniform support over the design life of the pavement
ii. be resistant to hydraulic erosion
iii. not exhibit any significant permanent deformation under normal strain levels,

c) Slab support

Houben (2006) states that in order to determine the degree of support that the subgrade will provide to the pavement, the first step is to determine the stiffness of the subgrade expressed in terms of the stiffness modulus. The stiffness modulus is determined in the laboratory by doing triaxial or similar tests under repeated loading and the result is expressed in terms of a resilient modulus. Other tests such as the mini plate bearing test, can also be used to evaluate the stiffness of material.

d) Concrete Slab

The slab consists of Portland cement concrete, reinforcing steel (optionally), load transfer devices (dowels), tie bars and joint sealants.

i. **Portland Cement Concrete**

The main influences on the structural performance of concrete in roads are the strength of the concrete and its coefficient of thermal expansion. For concrete to harden satisfactorily the cement must be sound, the mixture of cement and aggregate properly designed, the water: cement ratio carefully controlled, and the concrete well compacted and kept moist during the curing period. The initial setting of the concrete is accelerated at high temperatures and this requires that particular care is necessary in tropical climates to compact the concrete before initial setting has occurred and keep it moist during curing. In drier climates, special measures are required to protect the concrete for at least 7 days after placing (M10 Manaual).

ii. **Cement**

The cement should conform to KS EAS 18-1. In addition, unless cement is properly stored and used in a fresh condition, the concrete quality will be substantially reduced. Cement that has lost strength due to hydration before use is characterized by the formation of lumps.

iii. **Water**

The water used for concrete preparation should be potable and should ideally conform to the requirements of BS EN 1008.

iv. **Aggregate**

KS 95 2003 specifies the quality and grading requirements for aggregates suitable for concrete production. It is an advantage to use aggregates with low coefficient of thermal expansion.

e) **Reinforcing Steel**

Guyer (2009) highlights that the reinforcing steel may be either deformed bars or welded wire fabric. The reinforcing steel will be placed at a depth of 31.25mm from the surface of the reinforced slab. This will place the steel above the neutral axis of the slab and will allow clearance for dowel bars. The wire or bar sizes and spacing should be selected to give, as nearly as possible, the required percentage of steel square metre width or length. Two layers of wire fabric or bar mat, one placed directly on top of the other, may be used to obtain the required percent of steel; however, this should only be done when it is impracticable to provide the required steel in one layer. If two layers of steel are used, the layers must be fastened together (either wired or clipped) to prevent excessive separation during concrete placement. When the reinforcement is installed and concrete is to be placed through the mat or fabric, the minimum clear spacing between bars or wires will be 1½ times the maximum size of aggregate. Maximum bar or wire spacing or slab thickness shall not exceed 12 inches. The bar mat or wire fabric will be securely anchored to prevent forward creep of the steel mats during concrete placement and finishing operations. The reinforcement shall be fabricated and placed in such a manner that the spacing between the longitudinal wire or bar and the longitudinal joint, or between the transverse wire or bar and the transverse joint, will not exceed 3 inches or one-half of the wire or bar spacing in the fabric or mat.

Cracks in Reinforced Concrete

According to the M10 manual, cracks in concrete develop by:

- temperature and/or moisture-related contractions and expansions, and
- frictional resistance between the slab base and underlying layer

Tensile stresses result, maximising at mid-slab, and if they exceed the tensile strength of the concrete, it cracks transversally and the stress is transferred to the reinforcing steel if present. The purpose of the (longitudinal) reinforcing steel is to control concrete cracking and hold the cracks tightly closed, maintaining the pavement as an integral unit. In general the amount of steel is small, and is insufficient to add to the flexural strength of the concrete slab and thus the structural strength of the pavement. Transverse reinforcing steel is used to ensure that the longitudinal reinforcing steel remains in the correct position during slab construction and also mitigates any longitudinal cracking that could eventually occur.

The selection of JUCP, JRCP or CRCP is a function of the pavement slab length. For joint spacing less than 5 meters, transverse cracking is not expected and reinforcement normally not required, therefore JUCP pavements are appropriate. For joint spacing between 5 and 15 meters, reinforcement is required, increasing in amount in proportion to the slab length, although the increasing cost of reinforcement is offset by a decreasing amount of joint dowells and sealants. The upper limit of 15m also allows slab and joint movements to be restricted and riding quality optimised. Beyond 15m CRCP pavements are recommended, with no joints but a considerably greater amount of reinforcing steel than JRCP. The choice between the different concrete pavement types is fundamentally an economic one and a balance of traffic levels, construction cost and maintenance interventions.

Dowell Bars

The most common failures of concrete roads occur at the transverse joints and it is imperative that adequate load transfer support is provided to minimize cracking, spalling and corner breaks. Load transfer support across the slabs is provided by dowels and enhanced by: Stiff subbases, large sized coarse aggregate (>25mm), small joint openings, and dowels.

Dowels are normally 20mm diameter, 400mm long and fitted at about 300mm spacings. Since they are load transfer devices they must be strong and robust and closely spaced to resist bending and shear of the concrete. To allow slabs to move horizontally relative to one another, at least 65% of the dowell must be coated with a bond-breaking compound, eg bitumen. Dowel's must not 'lock' the joint where they are placed, otherwise an uncontrolled crack may occur close to the joint.

End dowells should be at least 200mm distant from the slab edge. It is very important that dowells are aligned parallel with the pavement direction, otherwise strains will be generated that will be cracking and early deterioration of the concrete. Where joint openings are less than 1mm, dowels need not be utilized. For dowelled joints the joint opening should be 6mm or less. Short-slabed pavements thus do not need dowels but it is common practice to use dowells regardless of joint opening. On roads carrying heavy vehicles it is essential to provide dowels across joints to limit the vertical movement between slabs as vehicles pass over. It is also desirable to use dowels in roads over unconsolidated soils to prevent differential settlements between adjacent slabs. In transverse joints dowels are bonded into the concrete on one side of the joint. Bonding on the other side is prevented, usually by coating the dowels with bitumen and, for expansion joints, by providing a loose end-cap. It is particularly important that they are accurately aligned perpendicular to the face of transverse joints or parallel to the road if the joints are skewed.

Tie Bars

In contrast to dowells, tie bars are not load-transfer devices but fixing devices whose function is to tie two slabs together. Thus, whereas dowells must be smooth and lubricated on one end to maintain freedom of movement, tie bars must be deformed or hooked and firmly anchored in the slab to function properly. Typically they are used to prevent separation at longitudinal joints but at the same time allowing some warping to occur. They hold the joints together so that load transfer is achieved by aggregate interlock in the concrete. Tie bars are generally 12mm diameter, 750mm long and spaced at intervals of 600mm. When the width of the pavement in construction is greater than 4.5m, hinge joints are made. The concrete is sawed to a third of its thickness; the joint is sealed and then tied by inserting tie bars at two thirds slab thickness into the slab. Construction break joints are made by using long (at least 750mm) tie bars to join the old and new concrete. Reference is made to the South African M10 manual which contains details on the length and width of dowells and tie bars. The figure 2.13 below gives a definition of the bars.

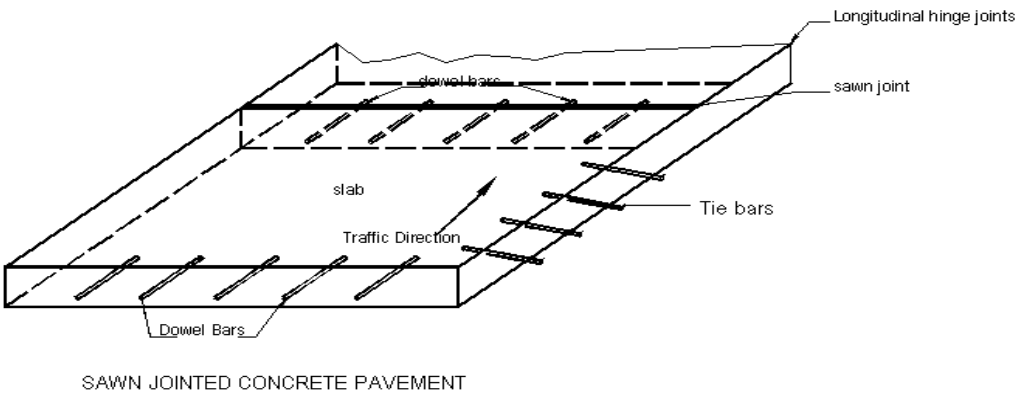


Figure 2.13: Definition of dowell and tie bars

2.9.3 Joints

Location and design of joints are related to the need to control stresses and the resulting strains induced by various causes such as traffic loading and environmental changes within the pavement. There are two basic types of stresses which may be present in a concrete road pavement:

i. Stresses induced by externally applied loads resulting from traffic using the pavement
ii. Stresses within the pavement resulting from contraction and expansion movements, and differential moisture and temperature changes within the depth of the pavement.

a) Purpose of joints

Joints in concrete road pavements are provided for the following reasons:

i. To divide the pavement into suitable lengths and widths for construction purposes.
ii. To control transverse and longitudinal cracking due to restrained contraction and the combined effects of restrained warping and traffic loads.
iii. To provide for differential movement.

b) Joint types

Kadiyali (1989) states that joints in reinforced concrete slab ensure that stresses developing due to expansion, contraction and warping within the slab are within reasonable limits. Concrete pavement joints fall within two general categories, transverse and longitudinal. They can be further subdivided into contraction, construction, warping and expansion joints. Figure 2.14 illustrates the different joint types.

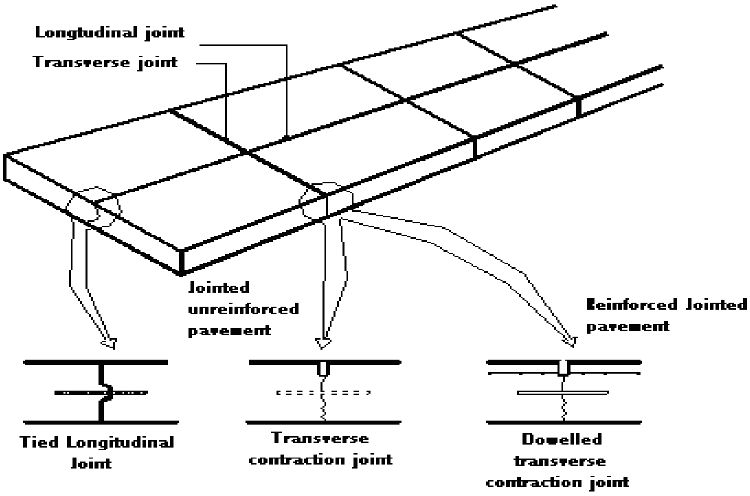


Figure 2.14: Types of concrete joints

c) Joint sealants for concrete road pavements

Jointing systems in concrete road pavements are designed to ensure both the structural integrity and riding quality of the pavement at the lowest possible annual cost over the life of the pavement. Joint sealants are designed to bond to the concrete within the joint opening. To accommodate the sealant, joints must be done in two stages. The first cut is deeper which induces the necessary crack; the second widened cut forms a groove for the sealant

Joint sealants are usually divided into two categories:

i. Field-Molded sealants which are poured or gunned into the joint;
ii. Factory-Molded sealants which are preformed compressed and inserted into the sealant reservoir of the plastic or hardened concrete.

The type of sealant and the dimensions of the joint should be designed to correspond to the expected movement in the pavement. Sealant failures can generally be attributed not to deficiencies in the seal material, but to poor joint design

2.9.4 Mix proportions

The objective of mix design is to obtain a concrete that will have the desired or the specified properties both in the fresh and hardened states. A concrete mix for pavements (M10 Manual) should be proportioned so that:

i. It has the lowest slump consistent with efficient placing and compaction to provide a homogeneous mass;
ii. It has the maximum size of aggregate economically available and consistent with proper placing;

iii. It has the strength required to withstand the loads to be imposed;
iv. It has adequate durability to withstand satisfactorily its service environment.

The steps involved in mix design as given in the Design of Normal Concrete Mixes are:

i. Determination of target mean strength, allowing for some variability of manufactured concrete, which leads to the selection of water/cement ratio
ii. Slump value accompanied by information on type of aggregate and its maximum size, which leads to the free water content
iii. Determination of cement content from above, which should satisfy durability requirements
iv. Determination of the total aggregate contents
v. Selection of the fine and coarse aggregate contents.

Table 2.3 indicates the typical components of a mix design

Table 2.3: A typical mix design is shown in table below

Constituent	Quantity
Portland Cement Type	320kg/m^3
20mm Aggregate	880kg/m^3
10mm Aggregate	240kg/m^3
Coarse Sand	490kg/ m^3
Fine Sand	180kg/m^3
Water Reducing Agent	2.5 1/m^3
Maximum Allowable Slump	60 mm
28 day Cone compressive strength	30Mpa

Source : Republic of South Africa, M10 Manual

2.9.5 Handling, placing and compaction

Concrete should be placed well so as to avoid segregation. Moving the concrete horizontally along the forms, or allowing it to fall for long distances should not be permitted. The objective of compaction is to expel entrapped air and consolidate the concrete. Full compaction of concrete is essential to ensure durability; proper vibration is a most effective method. Re-vibration of concrete is beneficial as long as an immersion vibrator can sink into the concrete under its own weight. Re-vibration then helps to eliminate air and water trapped under aggregate or reinforcement and to remove ‘early’ plastic cracking. Thus, strength, bond and impermeability are improved.

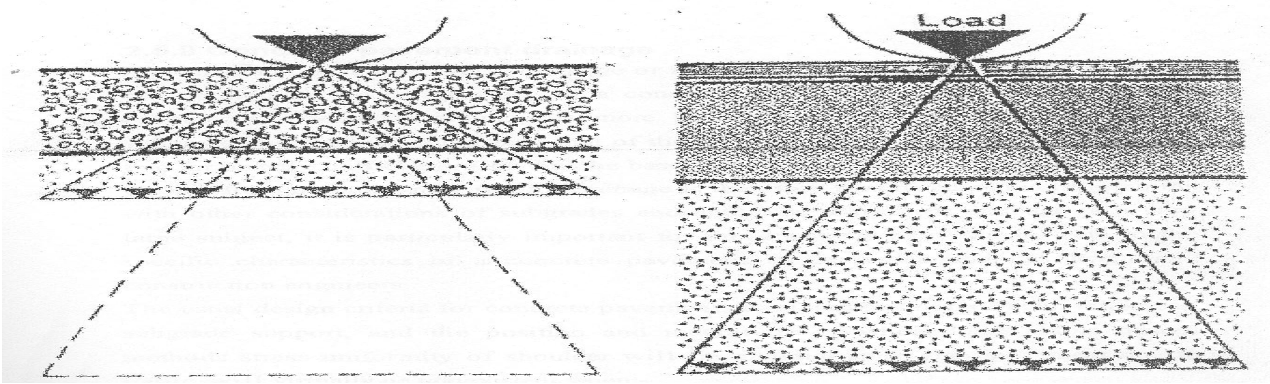
2.9.6 Curing of concrete

The purpose of curing is to maintain a maximum rate of hydration of the cement which governs the increase in strength and durability of the concrete. Good curing techniques ensure the presence of moisture and favorable temperature during the period immediately following placement so that hydration of the cement may continue until the desired properties are developed. Concrete pavements are relatively thin and have a high surface/volume ratio. Under the site conditions in which pavements are likely to be constructed the potential for moisture loss from the concrete immediately after placing is quite high.

2.9.7 Load transfer

Research has been undertaken on the effectiveness of cement-treated and unbound subbases on the transfer of loads across undowelled joints in jointed unreinforced concrete pavements, for a range of applications of a 4 tonne wheel load across a joint which had an opening of 0.9mm (M10 manual). This value approximates conditions which could be expected to occur in a typical, jointed unreinforced pavement with slab lengths of 5m or less. As load applications increased, the effectiveness of the unbound subbase decreased until it reached zero after one million load repetitions. Figure 2.15 shows load transfer in both a concrete and flexible pavement. On the cement treated subbase, the loss of effectiveness decreased slowly, at one million load repetitions, effectiveness remained at a level in excess of 50 on the carriageway for one or more of the following reasons:

i. To provide firm support for the pavement edges and for fixed forms or slip form pavers -improved support for paving plant will result in a smoother riding pavement
ii. To help control differential movement of soils near the pavement edge
iii. To provide a sub base for paved shoulders.



Concrete Pavement Flexible pavement *Source: M10 Manual*

Figure 2.15: Shows load transfer in both concrete and flexible pavement

2.9.8 Concrete pavement drainage

Like all other pavement types, drainage or the lack of drainage makes a considerable contribution to the performance of a concrete pavement. In the case of concrete pavements, inadequate drainage is more likely to affect the performance of the subgrade and subbase rather than that of the concrete base. However, it is important that for heavily trafficked roads, the base/subbase area is drained otherwise severe erosion from pumping may result.

Advantages of Concrete Pavements

i. Concrete is safer than asphalt roads because it increases visibility, especially at night.
ii. They reflect heat energy better than asphalt, which will be beneficial to the passage of vehicles in hot climates.
iii. Less energy for propulsion than asphalt. Fuel savings between 10-20% are indicated.

Disadvantages

i. High initial construction cost;
ii. traffic noise;
iii. Requires advanced technology in both construction and maintenance;

2.10 Summary Comparison of Flexible and Concrete Pavements

Tiwari (2005) summarizes comparison between concrete and flexible pavement as shown below:-

Flexible Pavement

1. Deformation in the sub grade is transferred to the upper layers
2. Design is based on load distributing characteristics of the component layers
3. Have low flexural strength
4. Load is transferred by grain to grain contact
5. Have low completion cost but repairing cost is high
6. Have low life span
7. Surfacing cannot be laid directly on the sub grade but a sub base is needed
8. No thermal stresses are induced as the pavement have the ability to contract and expand freely
9. Thats why expansion joints are not needed
10. Strength of the road is highly dependent on the strength of the sub grade
11. Rolling of the surfacing is needed
12. Road can be used for traffic within 24 hours
13. Force of friction is less
14. Deformation in the sub grade is not transferred to the upper layers.

Rigid Pavement

1. Deformation in the subgrade is not transferred to subsequent layers
2. Design is based on flexural strength or slab action
3. Have high flexural strength
4. No such phenomenon of grain to grain load transfer exists
5. Have low repairing cost but completion cost is high
6. Life span is more as compare to flexible
7. Surfacing can be directly laid on the sub grade
8. Thermal stresses are more vulnerable to be induced as the ability to contract and expand is very less in concrete
9. Thats why expansion joints are needed
10. Strength of the road is less dependent on the strength of the sub grade
11. Rolling of the surfacing in not needed
12. Road cannot be used until 14 days of curing
13. Force of friction is high

2.11 Bills of Quantities

Standard bills of quantities formats are employed and captures all the bills in the billing and evaluation/costing of a road project. Such templates shall be a good guide in computation of the bill of quantities for the pavements. It shall also assist in bill by bill comparison of the pavements. In addition to the computation and generation of the bills of quantities from first principles, the following key documents were utilized in the estimation of quantities:-

- Cost Estimates (Costes) estimates manual and software;
- Institute of Quantity Surveyors annual cost estimates manual;
- Realistic estimates from recently tendered projects were utilized in bills that cannot be expressly quantified.

CHAPTER THREE: METHODOLOGY AND DATA COLLECTION

3.0 Methodology

3.1 Introduction

This chapter details the mode of data collection and presents the various data collected to be analyzed. It summarizes the primary and secondary data collected for the study. The bulk data is presented in the appendices.

Some of the sources where data was acquired from included the following:-

- Ministry of Roads-Materials and Traffic Departments;
- University of Nairobi;
- Kenya National Highways Authority;
- Meteorological Department;
- Consultants.

3.2 Research Design

The research design employed both qualitative and quantitative methods that takes an indepth look rather than just examining surface features. The adoption of this research method is based on, William (2006) claim that qualitative methods can be used to better understand a problem. They can also be used to gain new perspective on things about how much is already known or to gain more in-depth information that might not be conveyed quantitatively.

3.3 Data Collection

Collection of both primary and secondary data was done. Primary data was collected through manual traffic counts and collection for lab testing of materials in addition to minor tests done on site; site visits were made to carry out visual inspection and judgment of the pavement. Secondary data was obtained from existing literature relevant to the study. Tally sheets were developed to facilitate the collection of the primary data. The key statistical method used is the descriptive statistics which includes the tally sheets for collection of data then converted to inferential statistical data such as charts, graphs etc which were used for analysis.

3.3.1 Traffic data

Prior to the undertaking of traffic counts, a review of available historical traffic data was done. This included data from historical records made available from the MoR&PW from counts undertaken in 2007 for the road section. A detailed analysis of these past traffic flows was undertaken in an attempt to gain an overall traffic growth pattern.

The traffic count was conducted for the following purposes:

i. To determine the traffic flow and future predictions;
ii. To determine design life;
iii. To determine vehicle carrying capacity/axle load;

a) Vehicle classification

Classifications are as follows:

Passenger cars	:	Passenger vehicles with less than 9 seats.
Light goods vehicles	:	Minibuses and goods vehicles of less than 1500kg unladen weight.
Medium goods vehicles:		Maximum gross weight 8500kg
Heavy goods vehicles	:	Gross vehicle weight 8500kg
Buses	:	All passenger vehicles larger than minibuses

b) Traffic Count Results; Historical Traffic Data

Prior to the undertaking of traffic counts, a review of historical traffic data was done. These included data from historical records made available from the Ministry of Roads (MoR). To this end, relevant traffic count data from counts undertaken by the Ministry of Roads and Public Works (MoR&PW) along the road in 2007 have been utilized. A detailed analysis of these past traffic flows was undertaken and projected in an attempt to gain an overall traffic volumes. This analysis revealed a marked increase in traffic flows over the years and, in particular, a tremendous growth of the various categories of vehicles.

c) Present Traffic Flows

Daily classified traffic counts were undertaken for a period of 7 days and 1 night from 06.00h to 18.00h for the day count and from 18.00h to 06.00h for the night count. Traffic counts were conducted on a normal week in the year, an upward factor was included to take care of the seasonal variation. These counts were carried out by trained enumerators. All traffic passing each of the count stations were recorded separately for each direction of travel for nine classes of vehicles distinguished. The data is given as table 3.1, 3.2 and 3.3

d) Traffic Growth Patterns

In an attempt to determine the likely future traffic growth rates for the project road, an analysis of the available historical traffic data and the recorded present traffic flows was undertaken. For the undertaking of this analysis, previous and current recorded traffic flows were tabulated and annual growth rates between these years derived for the corridor. This exercise was undertaken through comparison of, and growth changes for all vehicle classes. Whilst it was hoped that this exercise would present a somewhat definitive indication of traffic growth along the project road, such a pattern could not be gleaned from this exercise, it was also notable that when projections are made for the traffic counts undertaken in 1997, there was no match up with the volume of vehicles in 2007 and 2011 because of the erratics in the upward trend in economic growth from 2003. Given the erratic traffic growth pattern that has manifested itself along the road over the years, development of future growth rates on the basis of historical traffic growth was not deemed a reliable indicator.

e) Traffic Growth Rates

Given the erratic traffic growth patterns that have manifested itself along the road over the years, development of future growth rates on the basis of historical traffic growth was not deemed a reliable indicator. As such, the study has taken note of likely future traffic growth by taking estimates assumptions of regional and national economic growth indicators, taking into consideration likely future developments in the transport sector (e.g. more reliance and use of the oil pipeline) and the ability of the economy to sustain the upward growth trends. For the purpose of this evaluation the study appreciates that the determination of rates of growth for vehicle traffic adopts a common method of relating expected traffic growth to the growth of the economy as a whole by means of the following expression; the cross elasticity of demand for transport ($|e|^{AB}$).

$$\underline{\%\ \Delta\text{Fuel. X }\%\ \Delta\text{VehAB.}}$$
$$\%\ \Delta\text{GDP }\%\ \Delta\text{GDP}$$

where:

% ΔFuel. = Percentage change of Sale of petroleum products;

% ΔVehAB = Percentage change of (A) passenger and (B) freight traffic;

% ΔGDP = Percentage change of gross domestic product.

However, due to the erratics in the growth rates for vehicles and fuel, the study is adopting the common denominator of the GDP for purposes of the projection. Table 3.0 below gives the GDP for the period 2001-2011. This is for computation of the average traffic growth rates and for traffic volume projections.

Table 3.0: Kenyan GDP growth rates

2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
4.726	0.299	2.785	4.616	5.981	6.326	6.993	1.528	2.645	5.552	4.4

Source: IMF 2011

From Ttable 3.0, an average growth rate of 4.17% is achieved, therefore for purposes of this study, an estimated growth rate of **5%** is utilized.

f) Primary data

Table 3.1 gives the primary traffic data counts done at Timboroa Junction. The counts were done between 6am and 6pm for day counts while for night counts, it was done between 6pm and 6am. The data were utilized in computation of axle loads by applying equivalence factors. Table 2.0 of this study gives the legal axle load limits

Table 3.1: Primary traffic count

Northbound (to Eldoret)

Name of the Road: A104, Timboroa					Date: March 13, 2011 to March 19, 2011								
Traffic	Motocycle	Motorbike/ Tuktuk	Cars	Nissans	MGV (2Axle)	MGV (3Axle)	HGV 4axle	HGV 5Axle	HGV 6Axle	HGV Above 6Axles	Buses (MGV)	Others	**Total**
Mar-13	17	71	470	373	64	179	8	28	642	2	46	2	**1902**
Mar-14	30	8	305	311	87	107	7	33	337	0	30	2	**1257**
Mar-15	8	15	334	348	99	202	5	9	446	2	39	0	**1507**
Mar-16	2	26	326	358	108	195	5	45	454	6	47	3	**1575**
Mar-17 Day	5	14	286	263	109	195	2	13	432	0	35	4	**1358**
Night	13	14	334	289	92	199	2	15	270	0	44	3	**1275**
Mar-18	4	18	437	359	107	210	4	6	635	0	37	4	**1821**
Mar-19	2	12	489	364	108	192	3	9	424	0	29	1	**1633**
Total	**81**	**178**	**2981**	**2665**	**774**	**1479**	**36**	**158**	**3640**	**10**	**307**	**19**	
Average	**10**	**22**	**373**	**333**	**97**	**185**	**5**	**20**	**455**	**1**	**38**	**2**	
Less Night	**68**	**164**	**2647**	**2376**	**682**	**1280**	**34**	**143**	**3370**	**10**	**263**	**16**	

South Bound (to Nakuru)

Traffic	Motorcycle	Motorbike/ Tuktuk	Cars	Nissans	MGV (2Axle)	MGV (3Axle)	HGV 4axle	HGV 5Axle	HGV 6Axle	HGV 6Axles & Above	Buses	Others	**Total**
Mar-13	39	7	617	466	114	67	45	25	432	0	64	3	**1879**
Mar-14	20	20	342	343	98	113	26	49	263	53	22	3	**1352**
Mar-15	11	52	251	244	68	118	18	30	269	27	58	4	**1150**
Mar-16	3	22	195	242	89	141	25	2	340	18	24	3	**1104**
Mar-17 Day	7	11	275	322	118	179	1	35	423	0	39	1	**1411**
Night	6	18	331	232	82	206	10	46	296	0	63	0	**1290**
Mar-18	5	39	438	381	97	150	7	45	412	5	64	1	**1644**
Mar-19	17	15	445	301	120	139	1	26	307	0	36	1	**1408**
Total	**108**	**184**	**2894**	**2531**	**786**	**1113**	**133**	**258**	**2742**	**103**	**370**	**16**	
Average	**14**	**23**	**362**	**316**	**98**	**139**	**17**	**32**	**343**	**13**	**46**	**2**	
Less Night	**102**	**166**	**2563**	**2299**	**704**	**907**	**123**	**212**	**2446**	**103**	**307**	**16**	

g) Axle Load Data

Table 3.2 shows the HGV axle load data as collected from Gilgil Weighbridge. Since all the trucks had permits indicating the origin and destination, only vehicles using the study road were considered. The vehicles were on average overloaded by 20%.

Table 3.2: Axle load data summary

March 2011	Axle Load (Kg)	Overload (Kg)	Total (Kg)
13th	11154000	169150	11323150
14th	11714000	161240	11875240
15th	12048000	120630	12168630
16th	14126000	157400	14283400
17th Day	15324000	202170	15526170
Night	12540000	130100	12670100
18th Day	13332000	52070	13384070
Night	9230000	79380	9309380
19th	7556000	42730	7598730
Total	**85254000**	**905390**	**86159390**
Total ESA per day		**114**	**5385**

Source: Axle load department, KeNHA

h) Secondary Traffic Data Analysis

The data in table 3.3 was extracted from the Ministry of Roads for the 2007 traffic count (Ministry of Roads). The data were used for comparison with primary and axle load data.

Table 3.3: Secondary data

MoR Data-2007										
RD NO.	**Census Point**	**Cars**	**LGV**		**MGV**		**HGV**		**Buses**	**Total**
			M	O	T	O	T	O		
A104/21	N.W of Jn with C53 Burnt Forest	375	559	4	158	63	1091	226	161	2637
A104/22	S.E of Jn with C53Burnt Forest	345	653	242	4	226	48	749	172	2439
A104/23	South of Junction with C36 Nabkoi	312	553	251	7	160	46	704	182	2215
A104/24	South of Timboroa	345	478	289	14	240	43	709	145	2263
Total		**1377**	**2243**	**786**	**183**	**689**	**1228**	**2388**	**660**	**9554**
Average		**344**	**561**	**197**	**46**	**172**	**307**	**597**	**165**	**2389**

Source: MoR&PW

Key:

Light Goods	M:	Matatu
	O:	Others (Pickups, Land Rovers etc)
Medium Goods	T:	Tankers with 2 Axles
	O:	Other Medium Vehicles with 2 Axles
Heavy Goods	T:	Tankers with more than 2 Axles
	O:	Other Heavy Vehicles with more than 2 Axles

3.3.2 Materials Investigation

General

Material investigations undertaken for this research involved the determination of the physical and structural characteristics of the existing road pavement and subgrade. A summary of the field activities undertaken, the results of laboratory testing and the final recommendations with respect to materials utilisation are highlighted in this section.

The general environmental conditions of the area are as follows:-

- Red clay soils
- Maximum annual temperature 28^0C
- Minimum annual temperature 8^0C
- Annual average temperature 18^0C
- Annual average rainfall 1100mm
- Altitude 1850 - 2250m asl

The general soil conditions were as follows:

For the red soils,

- the unconfined compression strength at maximum thy unit weight and optimum moisture content (7 days curing) with 4% cement content stabilization is 2940 KN/M^2
- the corresponding CBR value is 18 which falls in CBR class S5
- liquid limit (%) 53
- plastic limit (%) 35.8
- plasticity index (%) 17.2

Subgrade data was achieved by collecting alignment soil samples and carrying out the necessary tests; existing data on the corridor from previous designs were also utilized. These included data from the Ministry of Roads; materials branch, Consultants and Contractors. Table 3.4 gives a summary of the materials data for the various tests carried out.

Table 3.4: Summary of material test results

		A104 Road, Timboroa										
Chainage		0+000	0+100	0+200	0+300	0+400	0+500	0+600	0+700	0+800	0+900	**Average**
CBR after Improvement		33	39	36	37	35	34	26	31	24	39	**33.4**
Neat CBR at 100% MDD		7	13	9	10	10	8	5	6	4	12	**8.4**
Initial Consumption Level (ICL)		3.2	3.3	3.3	3.3	3.4	3.4	3.7	3.5	3.8	3.2	**4%**
compaction	MDD (Kg/m3)	1141	1324	1142	1299	1277	1286	1228	1246	1086	1289	**1231.8**
	OMC(%)	31.6	35	36.3	34.4	35.2	36.2	33.8	35.4	25.6	34	
ATTERBERG LIMITS	LL	87	81	70	82	86	87	78	88	85	79	
	PL	53	51	42	51	52	56	50	53	51	50	
	PI	34	30	28	31	34	31	28	35	34	29	
	LS	17	15	14	16	17	15	14	18	17	14	
	PM	3162	2790	2744	3069	3298	3038	2744	3395	3332	2871	
GRADING % PASSING	50mm	100	100	100	100	100	100	100	100	100	100	
	37.5mm	100	100	100	100	100	100	100	100	100	100	
	20mm	100	100	100	100	100	100	100	100	100	100	
	10mm	99	98	100	100	100	100	100	100	100	100	
	5mm	97	97	100	100	100	100	100	99	100	100	
	2mm	95	96	100	100	99	100	100	99	99	100	
	1.18mm	95	95	99	100	98	99	99	99	99	99	
	0.6mm	94	94	99	99	98	99	98	98	99	99	
	0.425mm	93	93	98	99	97	98	98	97	98	99	
	0.212mm	89	91	97	98	97	98	96	96	98	98	
	0.15mm	88	90	96	97	96	97	95	94	97	97	
	0.075mm	86	89	94	96	96	96	94	93	96	96	
	SWELL %	1.22	0.65	0.76	0.61	0.51	1	1.01	1.34	1.25	0.47	
						SUMMARY OF ALIGNMENT SOILS TEST RESULTS					July 15, 2011	

From the above data neat CBR is 8.4% which indicates a need for improvement to well over the minimal 15% required.

3.3.3 Cost Data

Table 3.5 below gives data on concrete pavement contract data, the case of Mbagathi Way, while table 3.6 gives variation of prices for key materials of concrete pavement between 2005 and 2011.

a) Concrete pavement

Table 3.5: Concrete pavement contract data, Mbagathi Way

S/N	Item	Description
1	Date of Award	26th April 2005
2	Tender Sum	Ksh 445,363,927.20
3	Length of dual carriage road	2.85 x 2 km
4	Thickness of pavement	205 mm
5	Contractor	Kabuito Contractors Ltd
6	As built Carriageway width	7.6 m
7	Cost per Km	Ksh. 78,134,022.32

Source: MoR,2007

Table 3.6: Variation of price table

Item	Cost in 2005 (Ksh.)	Cost in 2011(Ksh.)	Variation of Price
Cement/50kg bag	600	900	50%
Steel (Y12-1 piece)	550	870	40%
		Average variation of Price	**45%**

Source: Bamburi Cement & Steel Structures respectively, 2011

b) Flexible Pavement

Table 3.7 below gives a sample flexible pavement projects/tenders awarded by KeNHA in the year 2011, the same year when the study and costs were based. These were used to ascertain the competitiveness of the designed road costs.

Table 3.7: Flexible pavement contracts

S/No.	Road No. & Name		Award Price	Length (Km)	Year Awarded	Works/KM (Ksh.)
1	C31	Ejinja - Bumala Road	1,730,000,000.00	37	2011	**46,756,757**
2	B4	Loruk - Barpelo	5,700,000,000.00	62	2011	**91,935,484**
3	C15	Sotik - Ndanai	1,500,000,000.00	28.7	2011	**52,264,808**
4	C92	Chiakariga – Mitunguu - Meru	4,677,635,582.82	55	2011	**85,047,920**
5	C81	Modika – Nuno Road	1,090,191,399.75 less 120m for other works in the contract	12	2011	**80,849,283**
6	A2	Turbi- Moyale Road	12,061,534,909.00	122	2011	**98,865,040**

Source: KeNHA, 2011

3.3.4 Pictorial presentation of data collection

Figure 3.1 below shows data collection clips

Digging of borrow pits

Full depth borrow pit

Sample collection

Traffic counts

Figure 3.1 Traffic data collection picking of alignment soil samples

Figure 3.2 shows pictorial presentation of a concrete pavement (Mbagathi Way)

Concrete pavement at Mbagathi Way, Kenya

Drainage works

Typical tranverse joint on the road

Typical longitudinal joint

Figure 3.2: Concrete pavement clips, Mbagathi Way, Kenya

CHAPTER FOUR: DISCUSSION AND ANALYSIS OF RESULTS

4.1 Introduction

The collected data are analyzed in this chapter and the necessary designs carried out after verification for completeness and consistency. The analysis was done using quantitative research technique involving the use of descriptive statistics in response to the research objectives. Both the primary and secondary data have been presented as tables or charts. The key statistical method used is the descriptive statistics which includes the tally sheets for collection of data then converted to inferential data for analysis and presentation. It is also worth noting that financial analysis compares benefits and costs to the unit project/the specific road section, while the economic cost analysis compares the benefits and costs to the whole economy. It is therefore to be noted that the study seeks to undertake cost analysis of the study with minimal reference to the benefits accruing from the cost invested.

4.2 Determination of design life

In view of the problems involved in achieving a major extension of life of a concrete road and the comparatively modest increase in initial slab thickness necessary to ensure a long service period, the design life used for concrete is normally greater than for a flexible pavement. This is because a flexible pavement has a shorter life. A design life of 15 years was used (design life as per KeNHA) for the flexible pavement while for the rigid pavement a design life of 40 years was used (as per the design life of Mbagathi Way). The design life for concrete pavement according to M10 Manual is between 20 to 45 years depending on workmanship, materials quality and maintenance. Therefore since the road is expected to receive timely quality maintenance and proper construction, a forty year life is assumed. For the flexible pavement, a design life of 15years is done for all the roads in Kenya, therefore it was adopted.

4.3 Traffic Data Analysis

4.3.1 Primary Traffic Analysis

The summary of daily traffic counts are presented in table 4.1 and analyzed in figure 4.1:-

Table 4.1: Primary traffic data analysis (Daily)

Vehicle Type	Northbound (to Eldoret)	South Bound (to Nakuru)	Total
Cars	2647	2563	**5210**
Light Goods Vehicle	2376	2299	**4675**
Medium Goods vehicle	1962	1611	**3573**
Heavy goods Vehicle	3557	2884	**6441**
Buses	263	307	**570**
Tractors	16	16	**32**

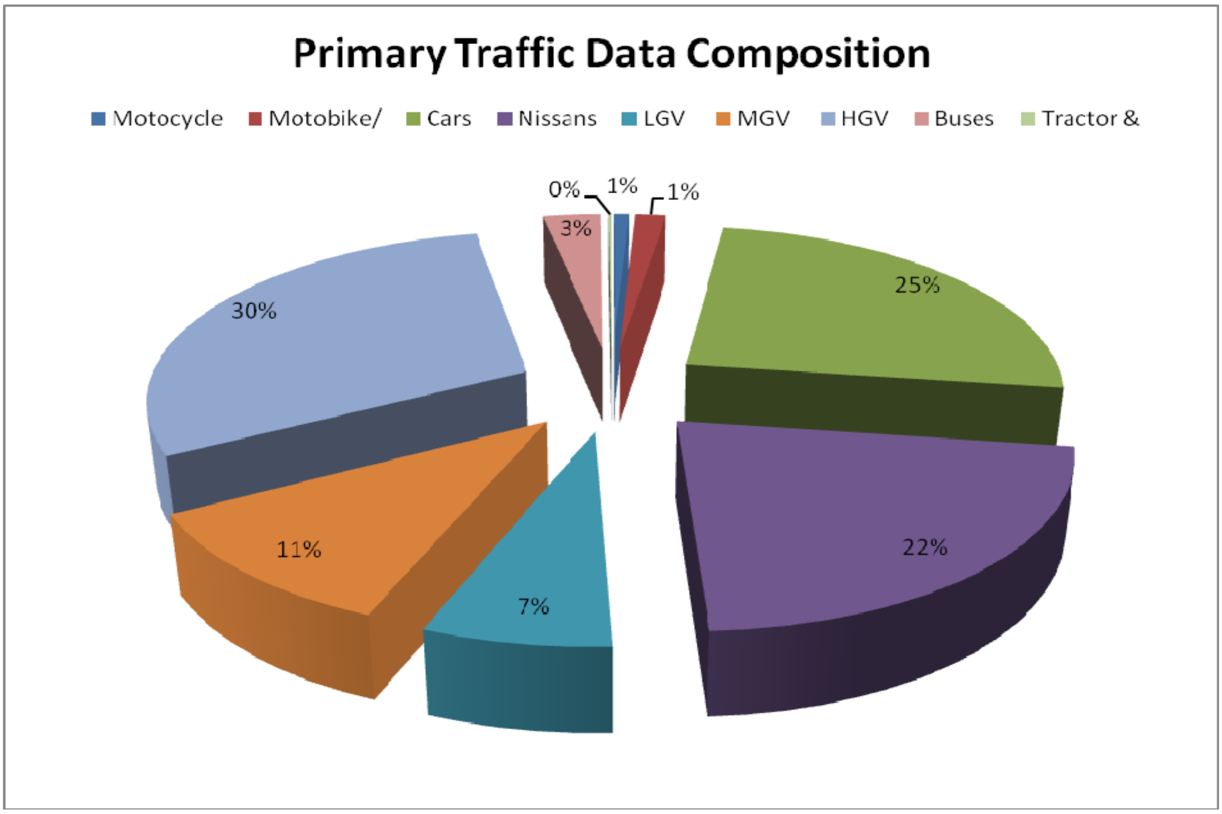


Figure 4.1: Traffic composition chart

From Axle load data collected at the same week at the Gilgil weighbridge (presented in table 3.2), the HGV weighed were overloaded on average by 20%, therefore the overload can be converted proportionately into vehicle numbers by factoring upwards the above HGVs and MGVs by 20%, thus new factored vehicle numbers are as below.

Table 4.2: Daily traffic counts

Vehicle Type	**Northbound (To Eldoret)**	**South Bound (To Nakuru)**	**Total**	**Average Design Data**
Cars	2647	2563	5210	**2647**
Light Goods Vehicle	2376	2299	4675	**2376**
Medium Goods vehicle	2355	1934	4289	**2355**
Heavy Goods Vehicle	4269	3461	7730	**4269**
Buses	263	307	570	**307**
Tractors	16	16	32	**16**

4.3.2 Secondary Traffic Data Analysis

The data from the Ministry of Roads for the 2007 traffic count are presented in table 4.3 below, projected as per table 4.4 and analyzed in figure 4.2.

Table 4.3: Secondary traffic data (daily)

MoR Data-2007										
RD NO.	**Census Point**	**Cars**	**LGV**		**MGV**		**HGV**		**Buses**	**TOTAL**
			M	O	T	O	T	O		
A104/21	N.W of Jn with C53 Burnt Forest	375	559	4	158	63	1091	226	161	2637
A104/22	S.E of Jn with C53Burnt Forest	345	653	242	4	226	48	749	172	2439
A104/23	South of Junction with C36 Nabkoi	312	553	251	7	160	46	704	182	2215
A104/24	South of Timboroa	345	478	289	14	240	43	709	145	2263
Total		**1377**	**2243**	**786**	**183**	**689**	**1228**	**2388**	**660**	**9554**
Average		**344**	**561**	**197**	**46**	**172**	**307**	**597**	**165**	**2389**

Key:

Light Goods	M:	Matatu
	O:	Others (Pickups, Land Rovers etc)
Medium Goods	T:	Tankers with 2 Axles
	O:	Other Medium Vehicles with 2 Axles
Heavy Goods	T:	Tankers with more than 2 Axles
	O:	Other Heavy Vehicles with more than 2 Axles

Projection of the above secondary data

Table 4.4: Projections of secondary traffic data (No.)

Growth rate assumed as 5% as per IMF average GDP for Kenya (2011)

MoR Data-2011										
RD NO.	**Census Point**	**Cars**	**LGV**		**MGV**		**HGV**		**Buses**	**Total**
			M	O	T	O	T	O		
A104/21	N.W of Jn with C53 Burnt Forest	456	679	5	192	77	1326	275	196	**3205**
A104/22	S.E of Jn with C53Burnt Forest	419	794	294	5	275	58	910	209	**2965**
A104/23	South of Junction with C36 Nabkoi	379	672	305	9	194	56	856	221	**2692**
A104/24	South of Timboroa	419	581	351	17	292	52	862	176	**2751**
Total		**1674**	**2726**	**955**	**222**	**837**	**1493**	**2903**	**802**	**11613**
Average		**418**	**682**	**239**	**56**	**209**	**373**	**726**	**201**	**2903**

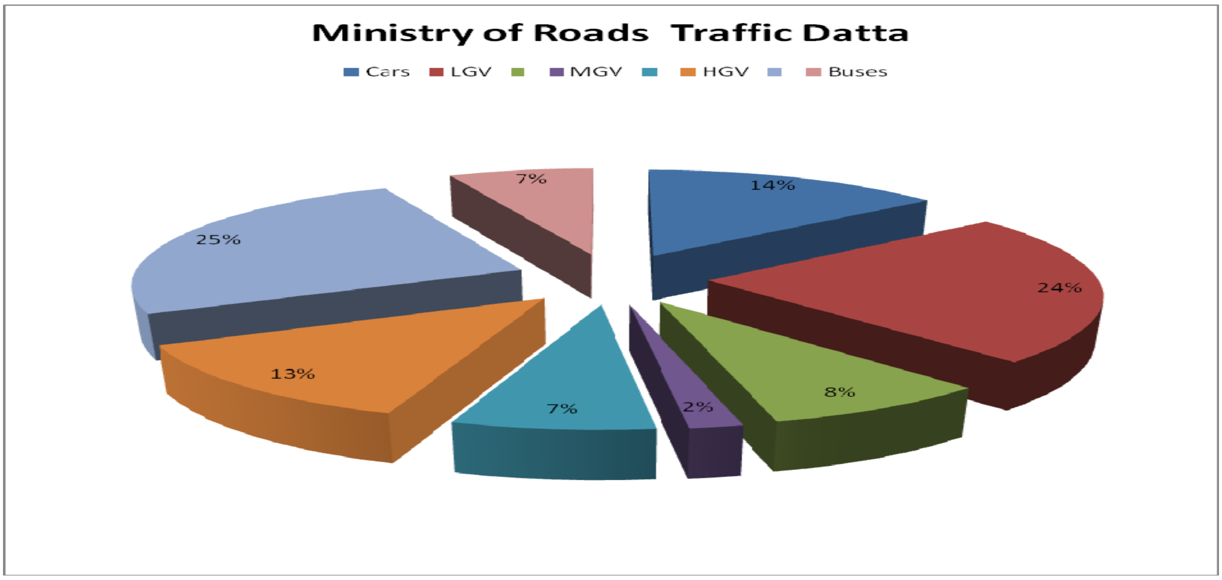


Figure 4.2: Showing composition of secondary traffic data

From the above chart compared to the primary data (figure 4.1), there is a slight variation in percentage of vehicle classes particularly the HGV of 30% against 25% which is comparable, thus the collected data can be used for design purposes.

A comparison of the axle load data (presented in table 3.2) with the HGV of the primary data (table 4.2) is presented as per figure 4.3.

Total load = 86159390kg = 861593900N = 86159.390 KN

Daily ESA = 86159.390/80 = 10769.92 / 2 (for one way) = 5385

5385 – (114/2) = **5328** verses **4269** for the HGV as noted from the primary tally

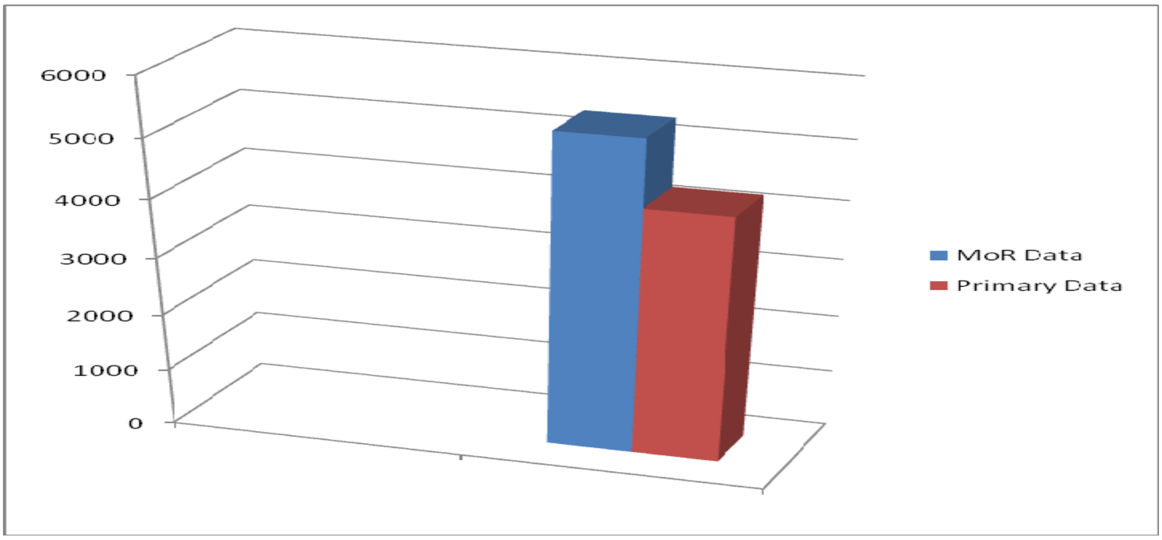


Figure 4.3: Comparison of the above primary HGV and axle load data

4.4 Pavement Design Parameters

When designing the pavements both mix design and structural design, two fundamental external design parameters were considered: the characteristics of the subgrade upon which the pavement is placed and the applied loads. First, the subgrade upon which the pavement is placed will have a large impact on structural design. Subgrade stiffness and drainage characteristics help determine pavement layer thickness, the number of layers, seasonal load restrictions and any possible improvements to subgrade stiffness and drainage itself. Second, the expected traffic loading is a primary design input (both in mix design and structural design). Traffic loads are used to determine pavement composition, layer type and thickness, all of which affect pavement life.

4.4.1 Equivalence factors

In order to determine the traffic loading to be inflicted on the new pavement by the various vehicle categories. Their axle loads were converted to numbers of equivalent single standard axles (ESA) by determining axle equivalence factors for each group. These equivalence factors were calculated based on Liddle's formula as shown below:

$EF = (L/80)^{4.5}$ where: 'L' is the load of a single axle in KN.

The actual equivalence factors thus derived for the various vehicle categories are presented in Table 4.5:

Table 4.5: Vehicle equivalent standard axles

Vehicle Type	Average Axle load(KN)	Equivalent Standard Axles
Light Goods Vehicle	20	0.002
Medium Goods Vehicle	60	0.274
Heavy Goods Vehicle	80	1
Buses	40	0.0442
Tractors	30	0.012

The above equivalence factors are used to compute the respective equivalent standard axles and ultimately the cumulative standard axles as shown in table 4.6 below.

Table 4.6: Calculation of total standard axles

Vehicle type	No.	EF	ESA one way/day	Total std axles per day
Cars	2647	0	-	-
Light Goods Vehicle	2376	0.002	4.752	**1734.48**
Medium Goods vehicle	2355	0.274	645.27	**235523.6**
Heavy goods Vehicle	4269	1	4269	**1558185**
Buses	307	0.0442	13.5694	**4952.831**
Tractors	16	0.012	0.192	**70.08**
Total				**1,800,466**

4.4.2 Evaluation of cumulative standard axles and Traffic Classes

$$\textbf{CSA} = \mathbf{365t}\left\{ \{(1+r)^n - 1\}/r \right\}$$

CSA– Cumulative standard axles

t - total standard axles in a day

r – traffic growth rate (taken as 5%, derived from the current growth rate of Gross Domestic Product (GDP)

n – design life cumulative equivalent standard axles

For Concrete pavement, a design life of **40 years** is adopted while for flexible pavement, a design life of **15 years** is adopted.

Case I: Concrete Pavement

CSA = 1800,466 x $[(1+0.05)^{40} -1] /0.05$

217,495,879 = $\mathbf{217.5 \times 10^6}$

Design life - 40years

Case II: Flexible Pavement

CSA = 1800,466 x $[(1+0.05)^{15} -1] /0.05$

= 38,851,469 = $\mathbf{38.85 \times 10^6}$

Traffic Class T1 (i.e. T1 falls between 25 and 60) as per table 4.7 below

Design life - 15years.

Table 4.7: Traffic classes and the corresponding cumulative standard axles

Traffic class	Cumulative number of standard axles ($x10^6$)
T1	25 - 60
T2	10 - 25
T3	3 - 10
T4	1 - 3
T5	0.25- 1

Ministry of Roads Manual (1987)

Traffic axles of **38.85 x10^{6}** and falls in traffic class T1

Table 4.8 below was used to select the subgrade class to be used for the design.

Table 4.8: Subgrade soil classes and the corresponding CBR ranges

Subgrade soil class	CBR range (%)
S1	2-5
S2	5 - 10
S3	7-13
S4	10-18
S5	15-30

Ministry of Roads Manual (1987)

The 45 cement/lime improved alignment soils has a CBR of average **33.4**, with a number of points lying below 30 and for safety in design, the minimum of **24** was used for the design, therefore in subgrade **class S5**

Figure 4.4 below shows a comparison of the material CBR before and after improvement.

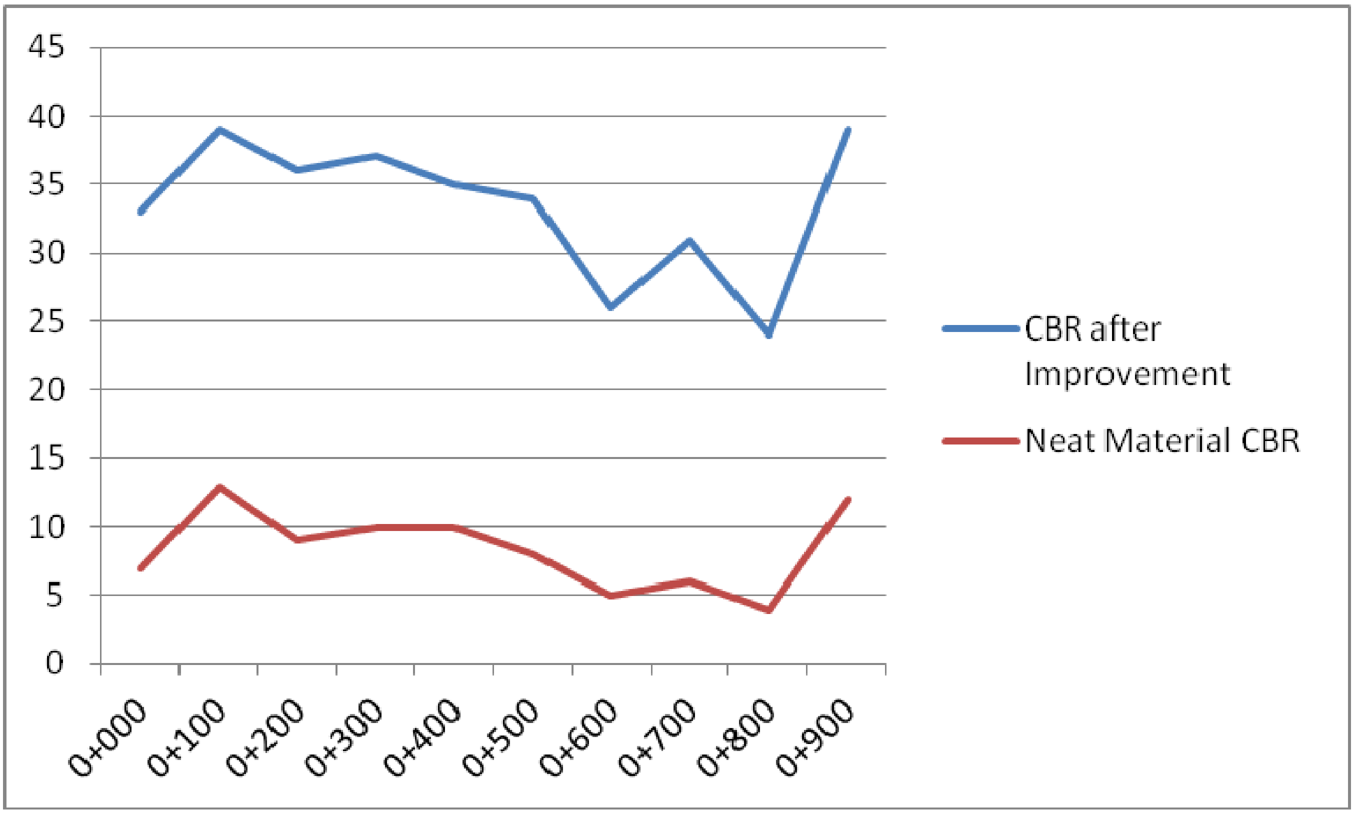


Figure 4.4: Summary of CBR of the neat and improved material

4.5 Design of Pavement Structures

4.5.1 Design influences

Traffic loading and materials are the key factors that influenced the design. It entailed determination of traffic class and characteristics of alignment soils.

4.5.2 Concrete Pavement Design (As per M10 Design Manual, South African)

The design of concrete pavement has been done as per the guidelines and procedures of the South African M10 Manual. The Kenyan manual is yet to be gazetted, therefore M10 offered a more standard approach and has been developed and used in relatively comparable conditions as the case study.

Step 1: Design traffic

The Cumulative Standard Axles (CSA) from chapter three was found out to be equal to 217500000

CSA = **2.175×10^{8}**

= **217.5×10^{6}**

Step 2: Slab support

Using the subgrade class S5, derived above, the resilient modulus (Mr) range is selected from the table 4.9 below

Table 4.9: Suggested resilient modulus for different subgrade materials

Material description (Equivalence of subgrade classes)	Suggested Mr range (mpa)	Suggested Mr value	Subgrade class
G4	140-300	150	S6
G5	100-250	130	S5
G6	70-200	110	*
G7	50-160	90	S4
G8	40-120	70	S3
G9	30-80	50	S2
G10	15-50	30	S1

*can be adopted for either class S4 or S5 *Source: South African M10 Manual*

From the table above, the Resilient Modulus (Mr) which expresses the subgrade stiffness is determined. The subgrade of the road is S5 therefore, Resilient Modulus (Mr) = **130MPa**

Step3: Determination of stiffness modulus of upper layer (subbase)

– The unconfined compressive strength of the subgrade soil of the road as indicated in chapter three is =**2940KN/M^2**

– Subgrade CBR = 33.4%, no capping layer required, subbase adopted = 150mm

– From figure 4.5, the stiffness values of the top layer is determined

– From the chart, the subbase stiffness modulus = **4400 Mpa**

Step4: determination of equivalent stiffness

After finding the subgrade and subbase stiffness, the equivalent stiffness was determined using figure 4.5

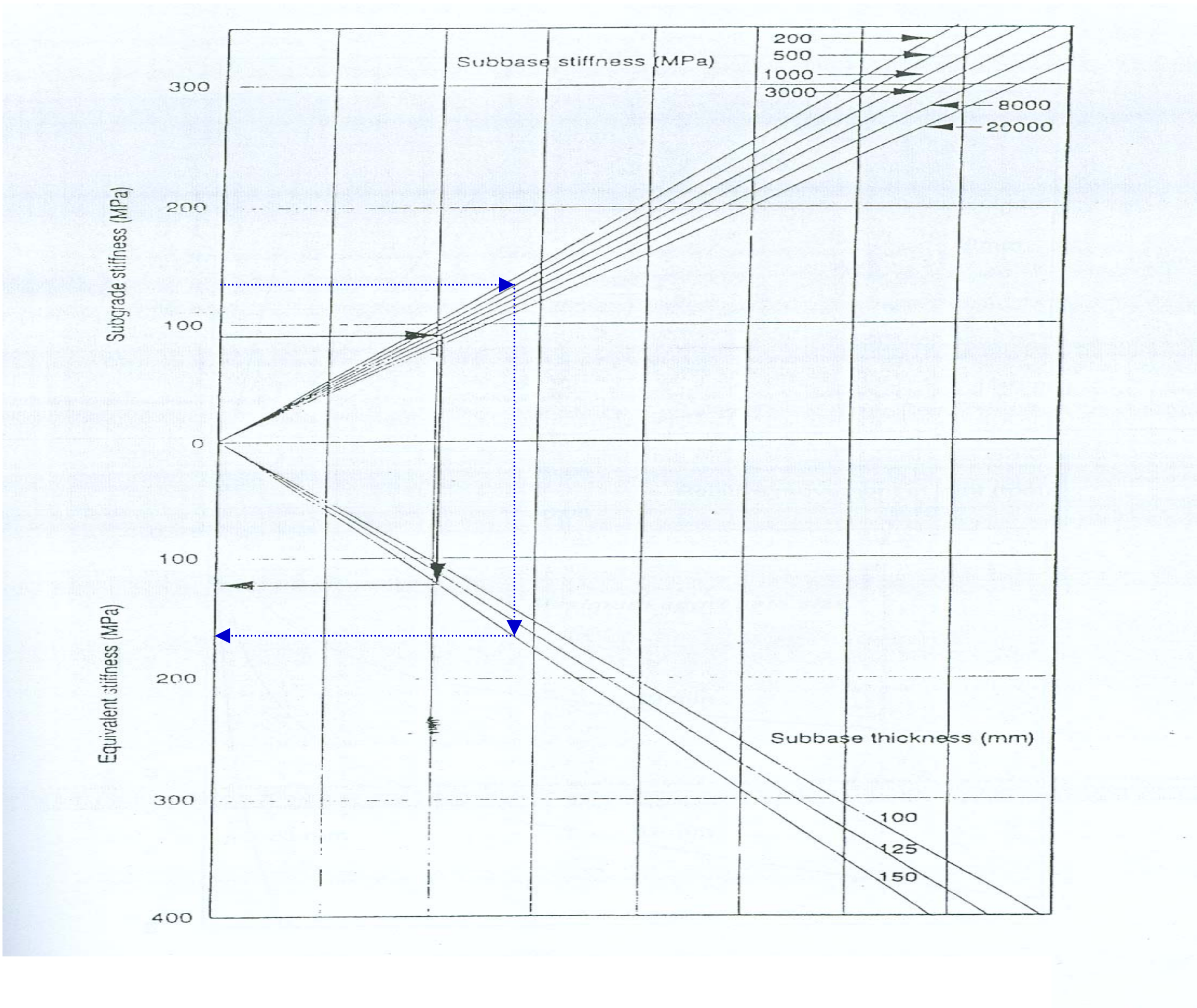


Figure 4.5: Determination of equivalent slab support stiffness.

From the figure 4.5 above, the equivalent stiffness = **165MPa**

Step 5: Slab thickness

The concrete pavement thickness was determined from the figure 4.6 below

The inputs into the design chart were:-

- traffic loading = 2.17 x 10^8 std axles
- equivalent support stiffness —165MPa
- concrete flexural strength = 4.6 MPa

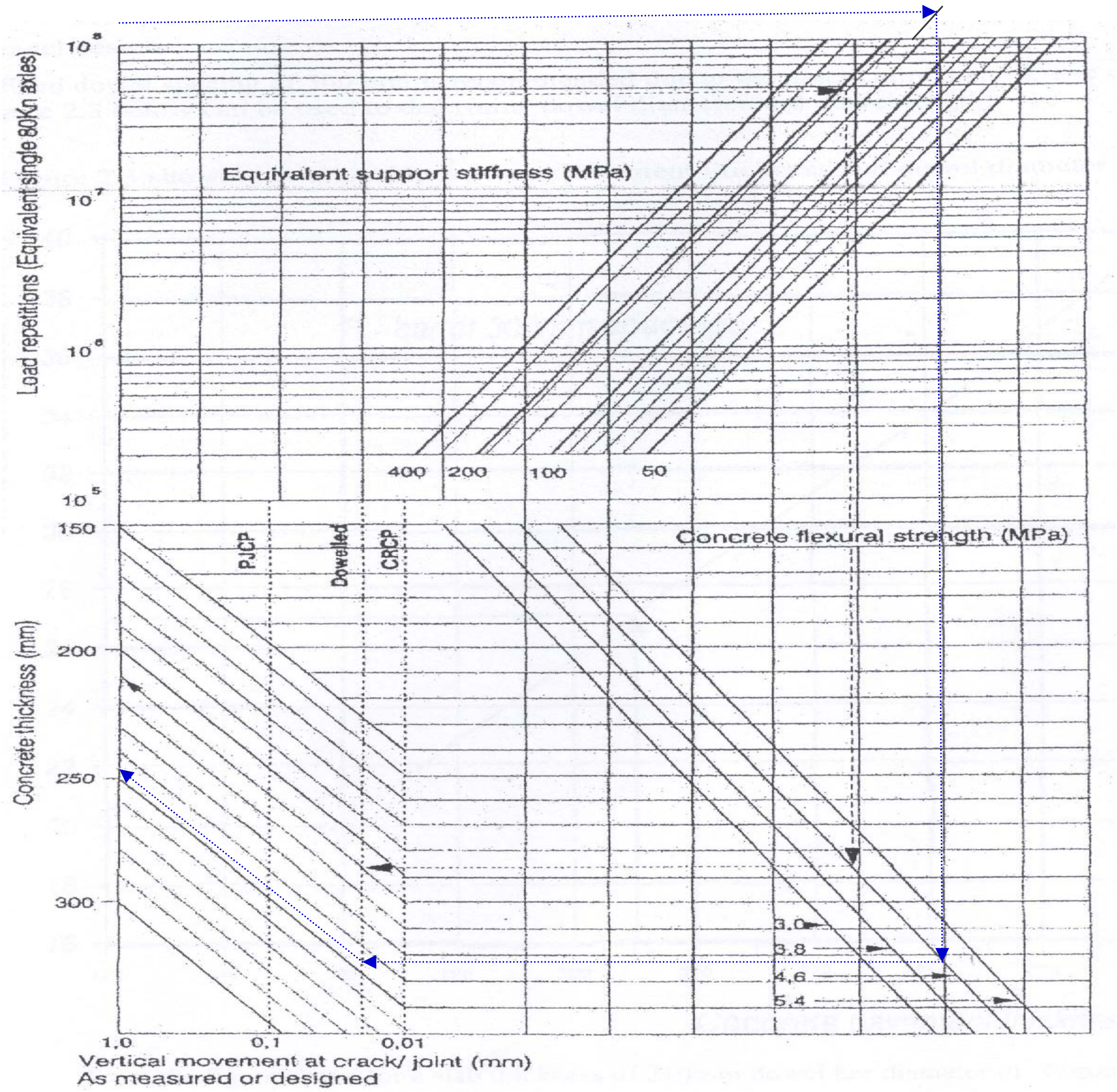


Figure 4.6: Determination of slab thickness.

From the figure 4.6 above, the concrete slab thickness = **245mm**

Step 6: Joint and dowel design

Dowel design

A fixed dowel spacing of 300mm is recommended due to the practicality thereof. The curves in Figure 4.7 and 4.8 are used to determine dowel diameter and dowel length respectively.

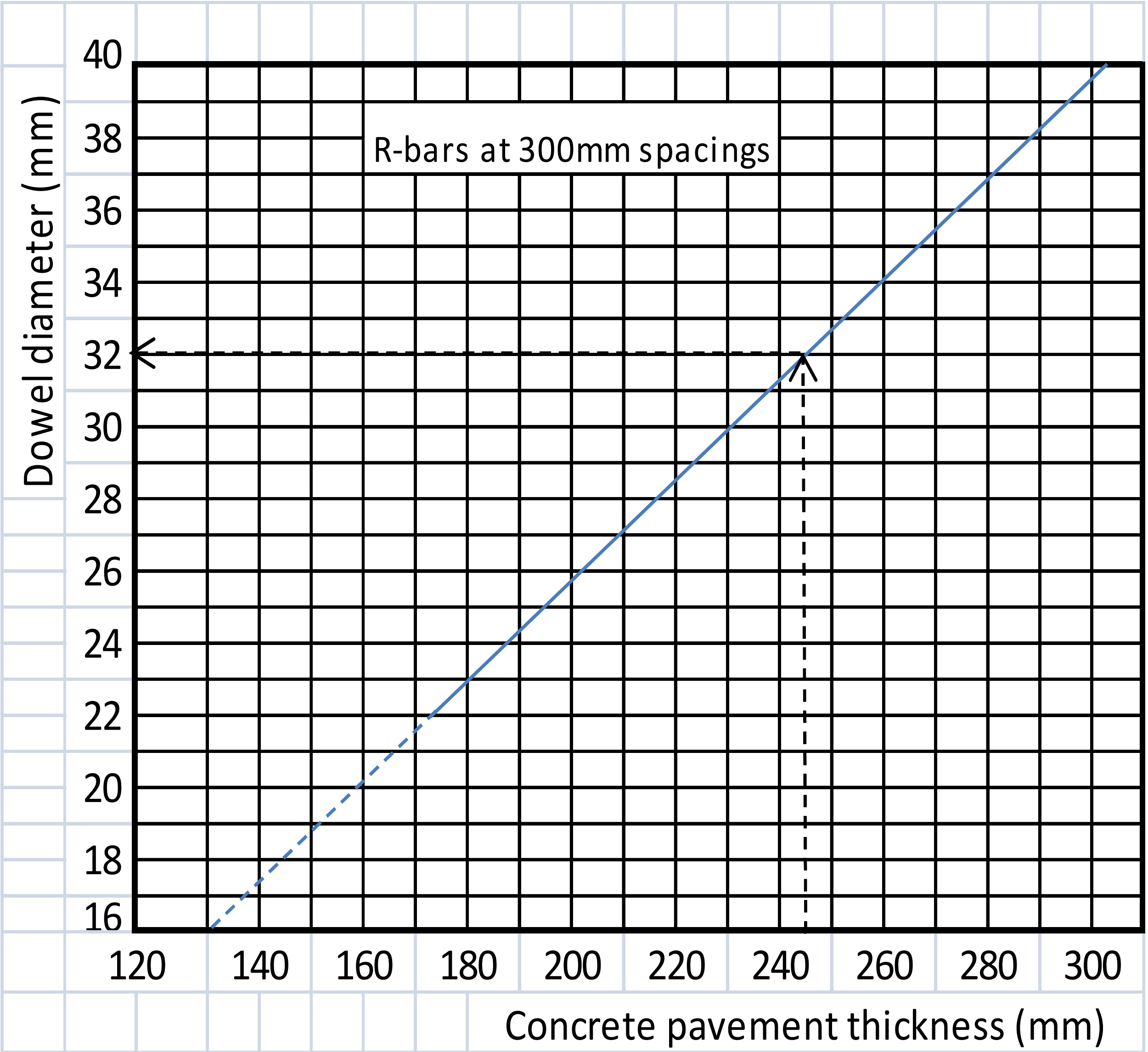


Figure 4.7: Dowel diameter determination chart

From the figure 4.7 above, for a slab thickness of 245mm, a dowel bar diameter of **32mm** obtained

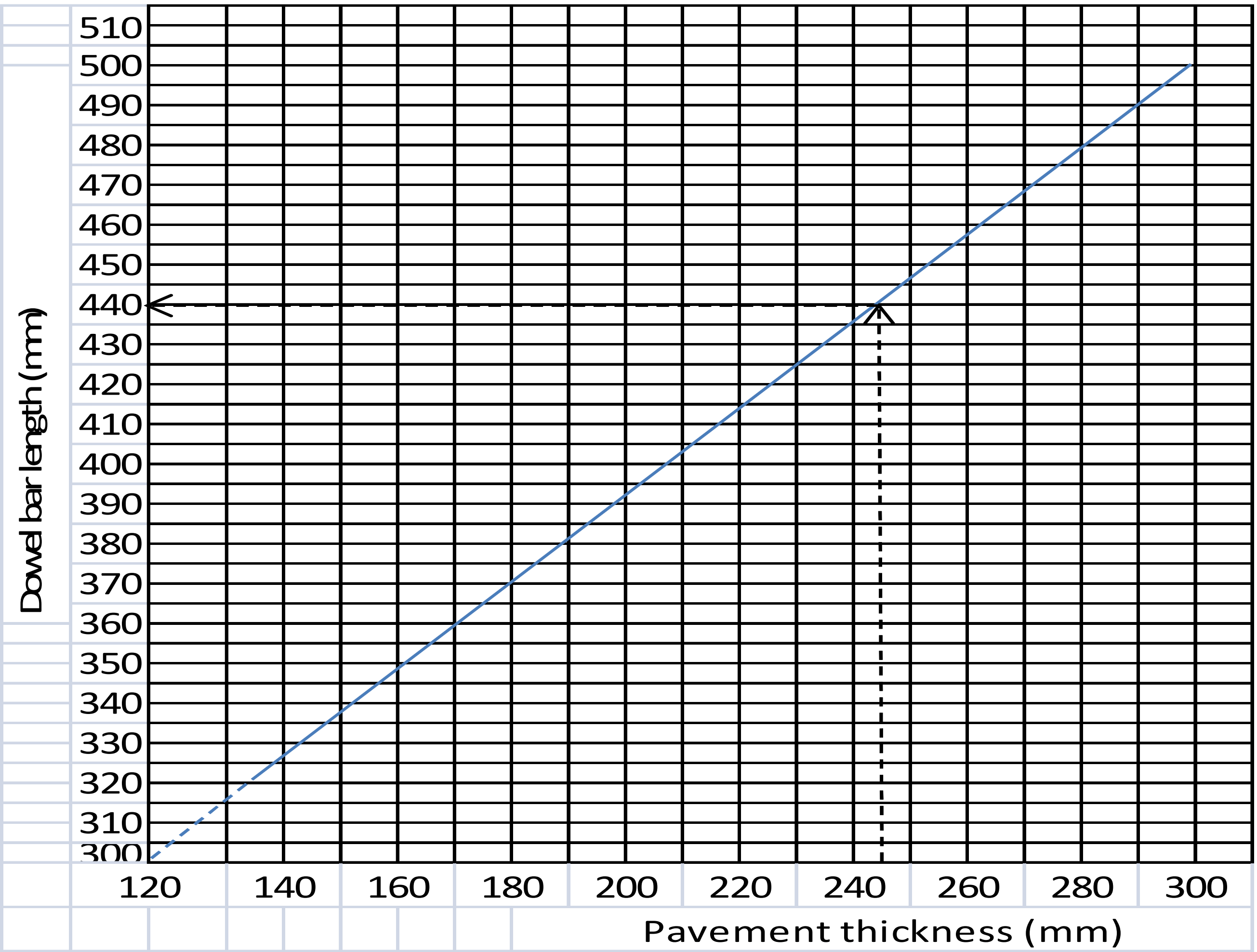


Figure 4.8: Dowel length determination chart

From the figure 4.8, for pavement thickness of 245 mm dowel bar length of **440mm** is obtained

Step 7: Tie bar design

Tie-bars should, in all instances, be 750 mm long and the spacing should be calculated using the equation:-

S=15.4 x **r^2/(Fe** x **D)…………………………………………..**

Where:-

S = Spacing of the tie bars

r = radius of tie bar (diameter/2)(usually taken as 12mm)

Fe = distance from the edge of the pavement (m) (lane width)

D = Concrete thickness (mm)

S = 15.4 x6^2/(3.5 x 245) = **0.647M =647MM**

Load transfer at joints

From the figure 4.9 below, the following parameters are arrived at;

– distance between joints = 2.2m

-aggregate size = 37.5mm

–dowel bars adopted = 32mm

-relative movement at joints = 0.01mm

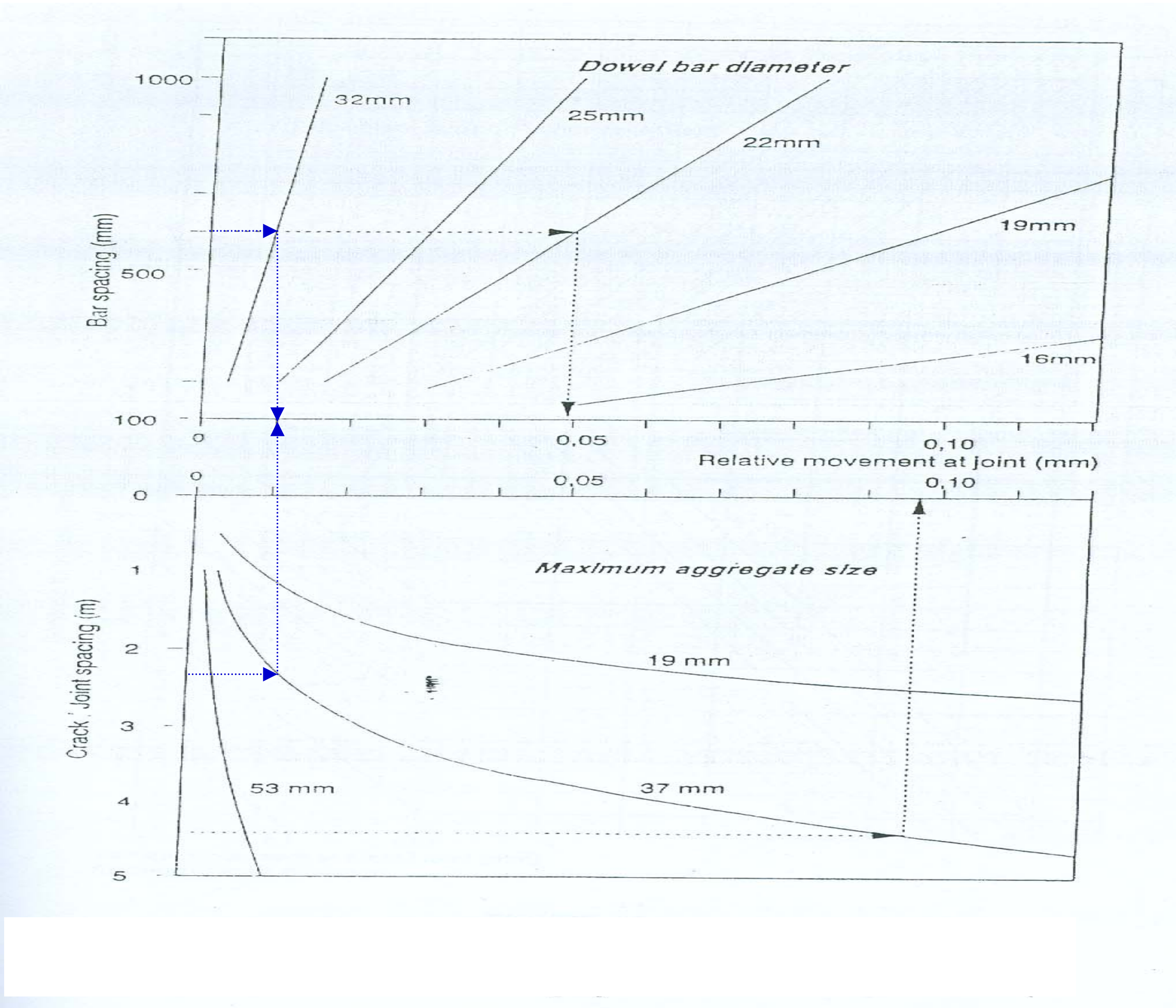


Figure 4.9: Chart for determination of other parameters

Figure 4.10 shows the designed concrete pavement for the case study

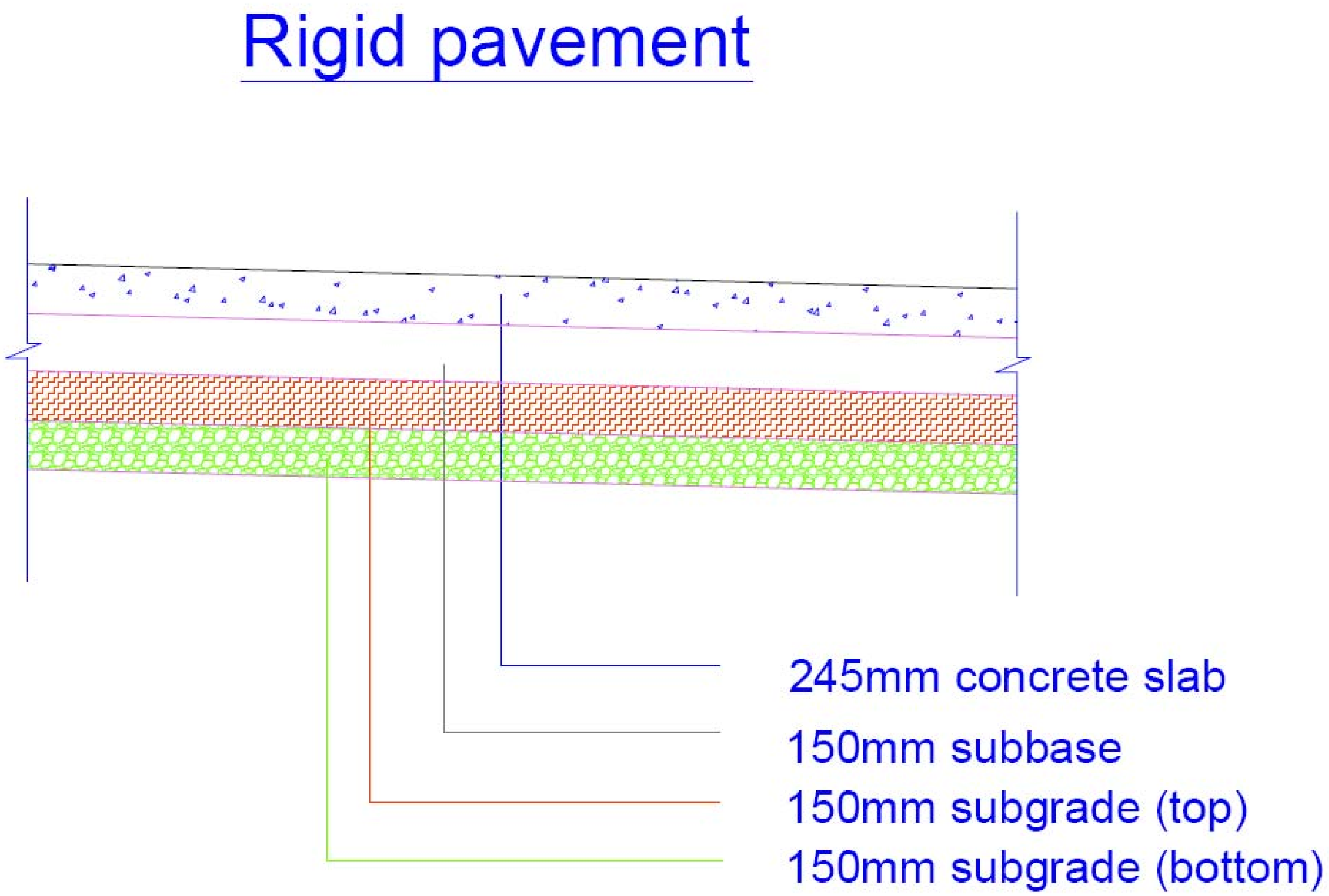
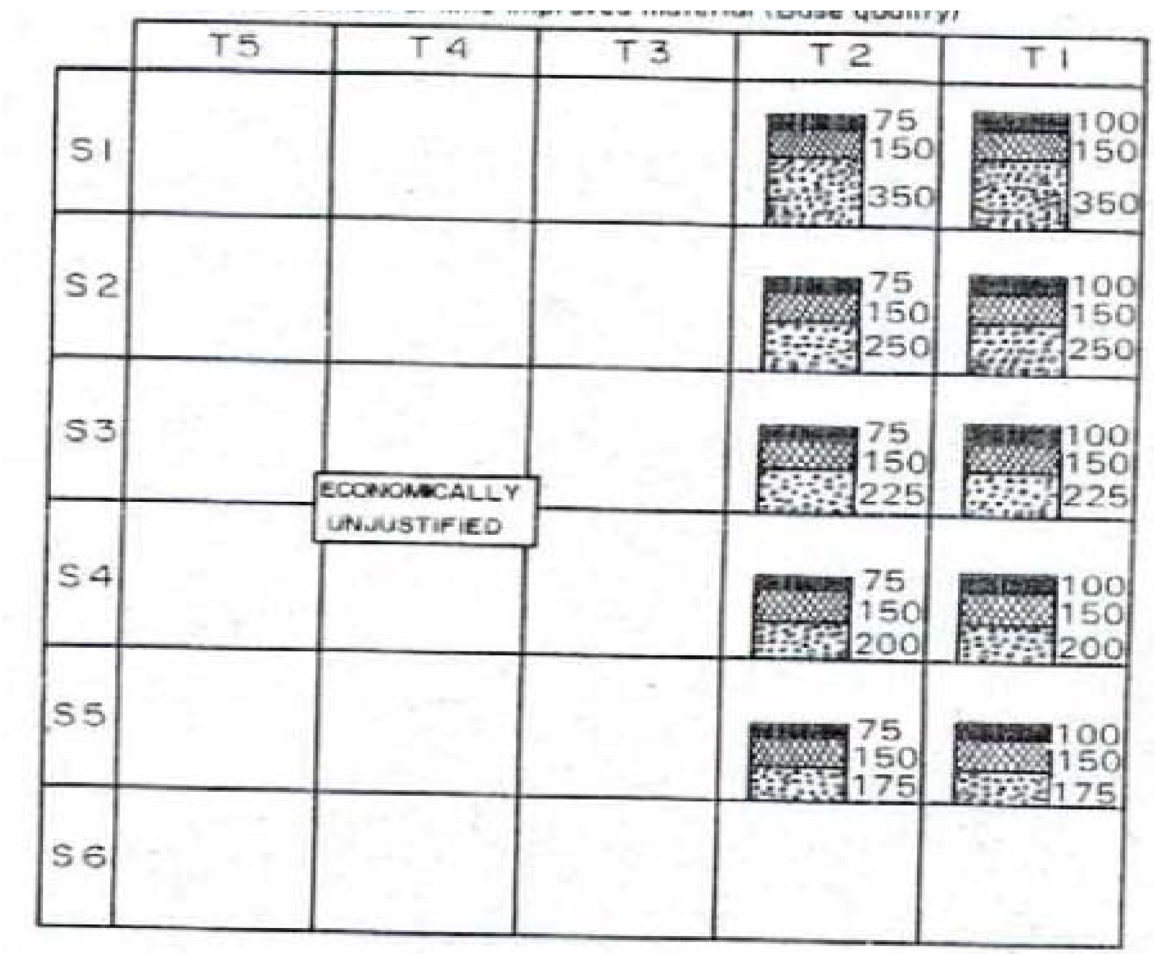


Figure 4.10: The designed concrete pavement

4.5.3 Flexible Pavement Design (MoR Design charts Method)

For the design of a flexible pavement using the MoR design manual, it is necessary to quantify the value of two variables namely; the CBR (California Bearing Ratio) of the sub-grade and the expected traffic volumes in terms of cumulative standard axles. Figure 4.11 below is used to deduce the pavement materials. From the materials investigation and traffic counts, the following values were respectively achieved for the two variables:-

- CBR = 24% - S5
- Traffic loading = 38.85 x 10^6 —T1



Base: Cement Stabilized gravel
Subbase: Cement or lime improved material

Figure 4.11: Chart for determining structural layers thicknesses

From figure 4.11 above, for a traffic of class T_1 and subgrade class S5, a pavement of the following characteristics is arrived at;

Subbase

Materials: cement or lime improved material (base quality) preferably graded crushed stone.

Thickness: 175mm

Base

Materials: Cement stabilized gravel; thickness: 150mm

surfacing

Thickness: 100mm Surfacing

A summary of the above design is presented in figure 4.12 below

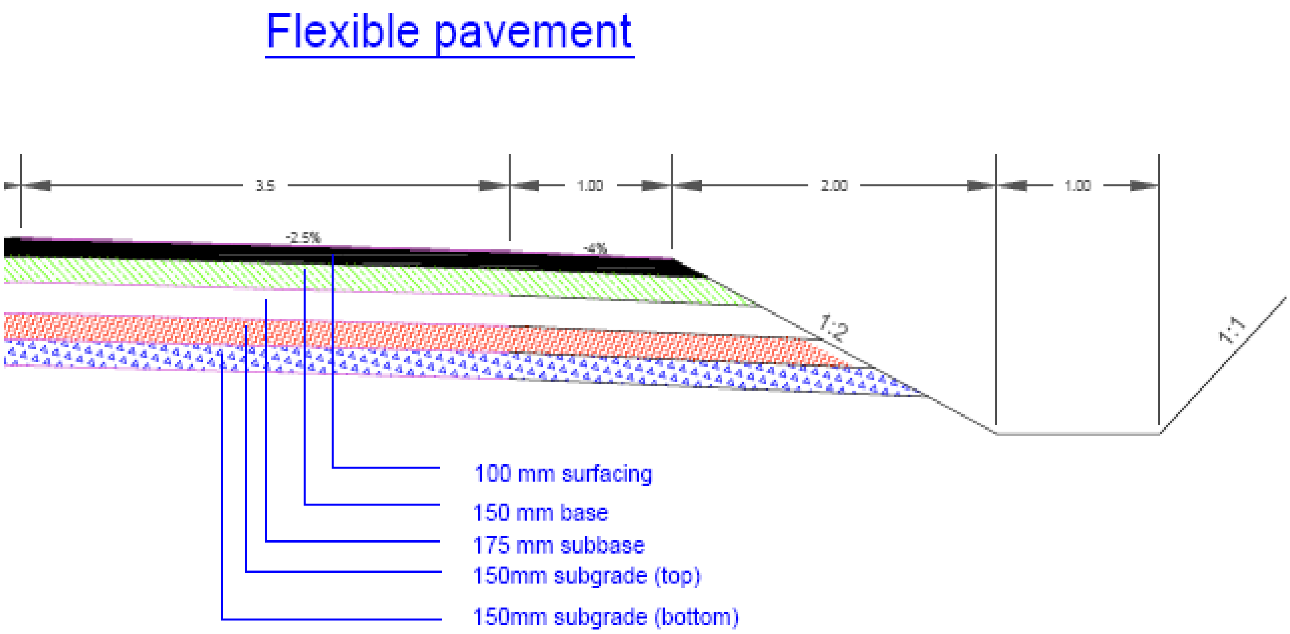


Figure 4.12: The designed flexible pavement

4.6 Quantities and Cost Estimates

The bills of quantities for the two pavements used in this study are meant to cover a 1km road length. It should also be clearly noted that the study is based on sections with steep to rolling terrain, therefore a 3.5M wide climbing lane over the 1km study length has been considered.

4.6.1 Determination of Quantities

Works quantities and the resultant costs were estimated for the full inclusive works, as

designed and discussed herein, for the 1 km of both the concrete and flexible pavements. The design consideration a 15-year design life for flexible pavement and 40-year design life for rigid pavement. The quantities have been calculated based on final design proposals as determined from the various site investigations and studies undertaken. In determining quantities for the work items, the following key bills have been considered for purposes of overall costing and comparison:

It is expected that the different bill items for the two pavements would be invariable except for the following bills:-

i. Bill No.12 – cement and lime treatment
ii. Bill No.14 – natural material subbase and base
iii. Bill No.15– bituminous surface treatment and surfacing
iv. Bill No.16 – bituminous mixes
v. Bill No.17 – concrete for pavement works.

4.6.2 Bill of Quantities

The quantities are for 1km unit road length and inclusive of a 3.5m wide climbing lane since the study is based on sections with steep to rolling terrain. The full Bill of Quantities are given as appendix I. The rates were derived from the harmonization of the Engineer's Estimates and three contractors namely H Young, Kabuito Contractors and Intex Construction Company who bid for a section of the Northern Corridor in 2011 between Eldoret and Malaba that was tendered and awarded. (*Courtesy of Kenya National Highways Authority)*. A maximum margin of error of 10% is assumed. The summarized bill of quantities is given as table 4.10 below:-

Table 4.10: Summary bill of quantities for the two pavements

SUMMARY OF BILLS OF QUANTITIES			
Bill No.	**DESCRIPTION**	**Flexible Pavement**	**Concrete Pavement**
1	PRELIMINARY AND SUPERVISORY/SUPPORT SERVICES	**4,630,000.00**	**4,630,000.00**
4	SITE CLEARANCE AND TOPSOIL STRIPPING	**285,000.00**	**285,000.00**
5	EARTHWORKS	**7,407,500.00**	**7,407,500.00**
7	EXCAVATION AND FILLING FOR STRUCTURES	**2,884,000.00**	**2,884,000.00**
8	CULVERTS AND DRAINAGE WORKS	**9,889,400.00**	**9,889,400.00**
9	PASSAGE OF TRAFFIC	**1,025,500.00**	**1,025,500.00**
12	NATURAL MATERIAL SUBBASE AND BASE	**8,100,000.00**	**4,050,000.00**
14	CEMENT AND LIME TREATMENT	**4,980,120.00**	**1,660,040.00**
15	BITUMINOUS SURFACE TREATMENT AND SURFACE DRESSING	**7,966,979.10**	-
16	BITUMINOUS MIXES	**7,793,100.00**	-
17 A	CONCRETE FOR PAVEMENT WORKS	-	**73,950,702.00**
17 B	OTHER CONCRETE WORKS	**3,229,770.00**	-
20	ROAD FURNITURE	**2,000,000.00**	**2,000,000.00**
22	DAYWORKS	**1,000,000.00**	**1,000,000.00**
25	HIV/AIDS AWARENESS AND EDUCATION	**250,000.00**	**250,000.00**
1	**SUB TOTAL (1)**	**61,441,369.10**	**109,032,142.00**
	Add 15% of Sub-Total 1 of Bills as Provisional Sums for Variation of Price and Contingencies	9,216,205.37	16,354,821.30
2	**SUB-TOTAL (2)**	*70,657,574.47*	*125,386,963.30*
3	**Add 16% of Sub-Total (2) for V.A.T. - (3)**	*11,305,211.91*	*20,061,914.13*
	GRAND TOTAL	**81,962,786.38**	**145,448,877.43**

4.7 Analysis and comparison of costs

a) Concrete Pavement

Analysis of Mbagathi Way Data and the Designed Road Data

From the data given in Chapter 3 as table 3.5;

The cost/km of the designed pavement in 2011 = **Ksh.145, 448,877.43** (table 4.10)

The cost/km of Mbagathi way in 2005 = **Ksh. 78,134,022.32**

The dimensions of the two pavements are respectively:-

- The designed pavement = **10.5m** width by **245mm** thickness
- Mbagathi Way = **7.6m** width by **205mm** thickness

Therefore the unit costs of the two pavements are equated as follows:-
Unit cost of Mbagathi Way with the dimensions of the designed road

= {(10.5 x 245) / (7.6 x 205)} x 78134022.32 = **Ksh. 129, 011, 407.20**

From table 3.6, the average variation of prices achieved between 2005 and 2011 was 45%

Therefore cost of the pavement (2011) = 129, 011, 407.2 + (0.45x129011407.2)

= Ksh **187,066,540.00**

Figure 4.13 below gives a graphical comparison of Mbagathi Way and the designed concrete pavement costs in the year 2011:-

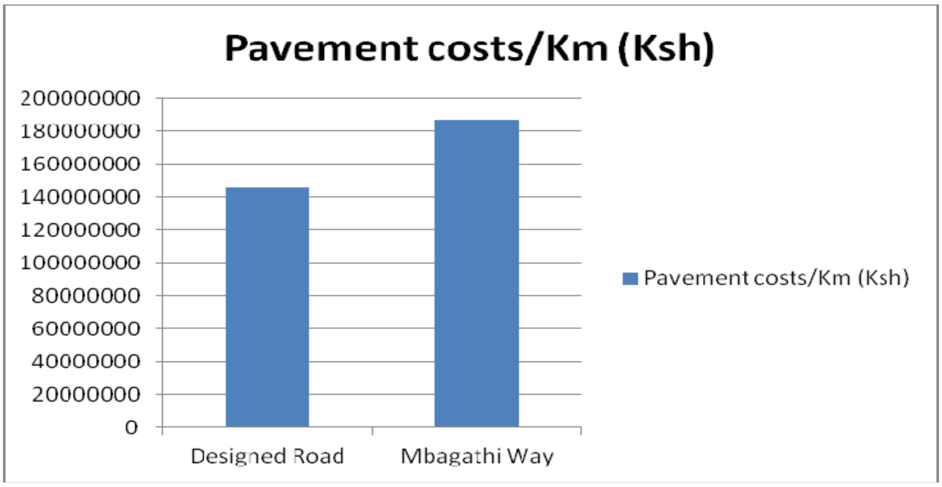


Figure 4.13: Graphical comparison of the designed concrete pavement and Mbagathi Way

From figure 4.13 above, there is reasonable variation in costs of initial construction of the two pavements. This can be attributed to the fact that for Mbagathi Way, the high initial cost of the concrete base, the key pavement layer which ensures durability is incurred.

b) Flexible Pavement

Table 4.11 below gives computed costs of 1km road length for the sample flexible pavement contracts awarded in 2011 and compared to the designed flexible pavement.

Table 4.11: Unit length cost for various sample projects

S/No.	Road No. & Name		Award Price	Length (Km)	Cost/KM (Ksh.)
1	A104	Design Road			**81,962,786.38**
2	C31	Ejinja - Bumala Road	1,730,000,000.00	37	**46,756,757**
3	B4	Loruk - Barpelo	5,700,000,000.00	62	**91,935,484**
4	C15	Sotik - Ndanai	1,500,000,000.00	28.7	**52,264,808**
5	C92	Chiakariga – Mitunguu -	4,677,635,582.82	55	**85,047,920**
6	C81	Modika – Nuno Road	970,191,399.75	12	**80,849,283**
7	A2	Turbi- Moyale Road	12,061,534,909.00	122	**98,865,040**

Figure 4.14 below gives a comparison of various flexible pavements as sampled from projects awarded in 2011 in tandem with the design year of the road.

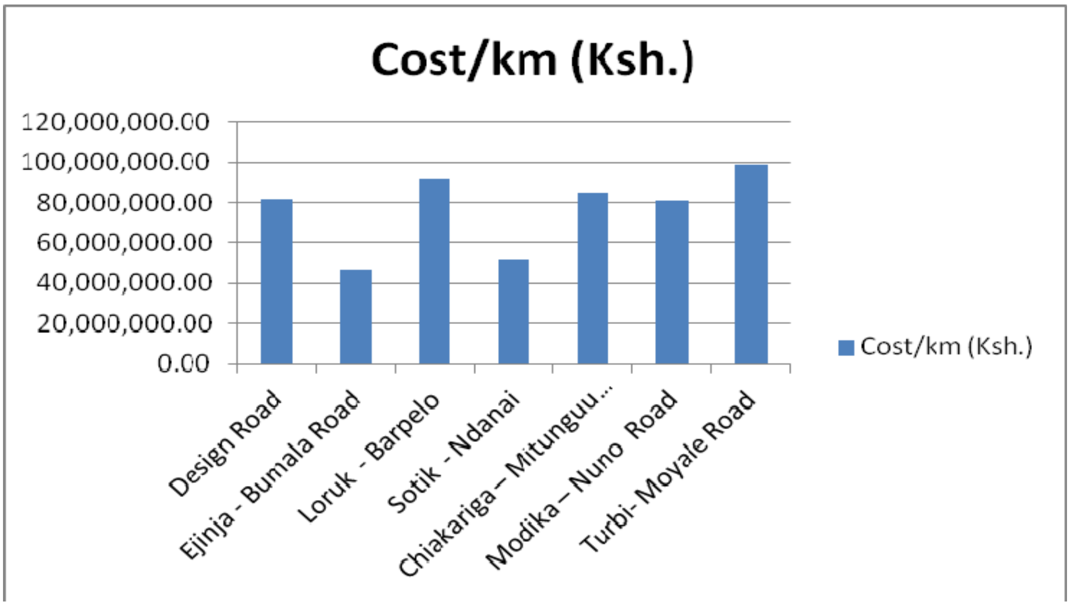


Figure 4.14: Unit length comparison of selected flexible pavements and the designed road.

From figure 4.14 above, the following can deduced:-

i. The unit length cost of the design road is comparable to 67% of the sampled roads;
ii. The low cost of unit length in other roads is attributed to competitive bidding;
iii. The high cost per unit length in Turbi – Moyale is mainly due to the high haulage distance for key construction materials;
iv. That the unit cost of the design road is an acceptable approximation.

4.7.1 Pavement Construction Costs

The figure 4.15 below gives the bill by bill comparison for the two designed pavements (KSh.)

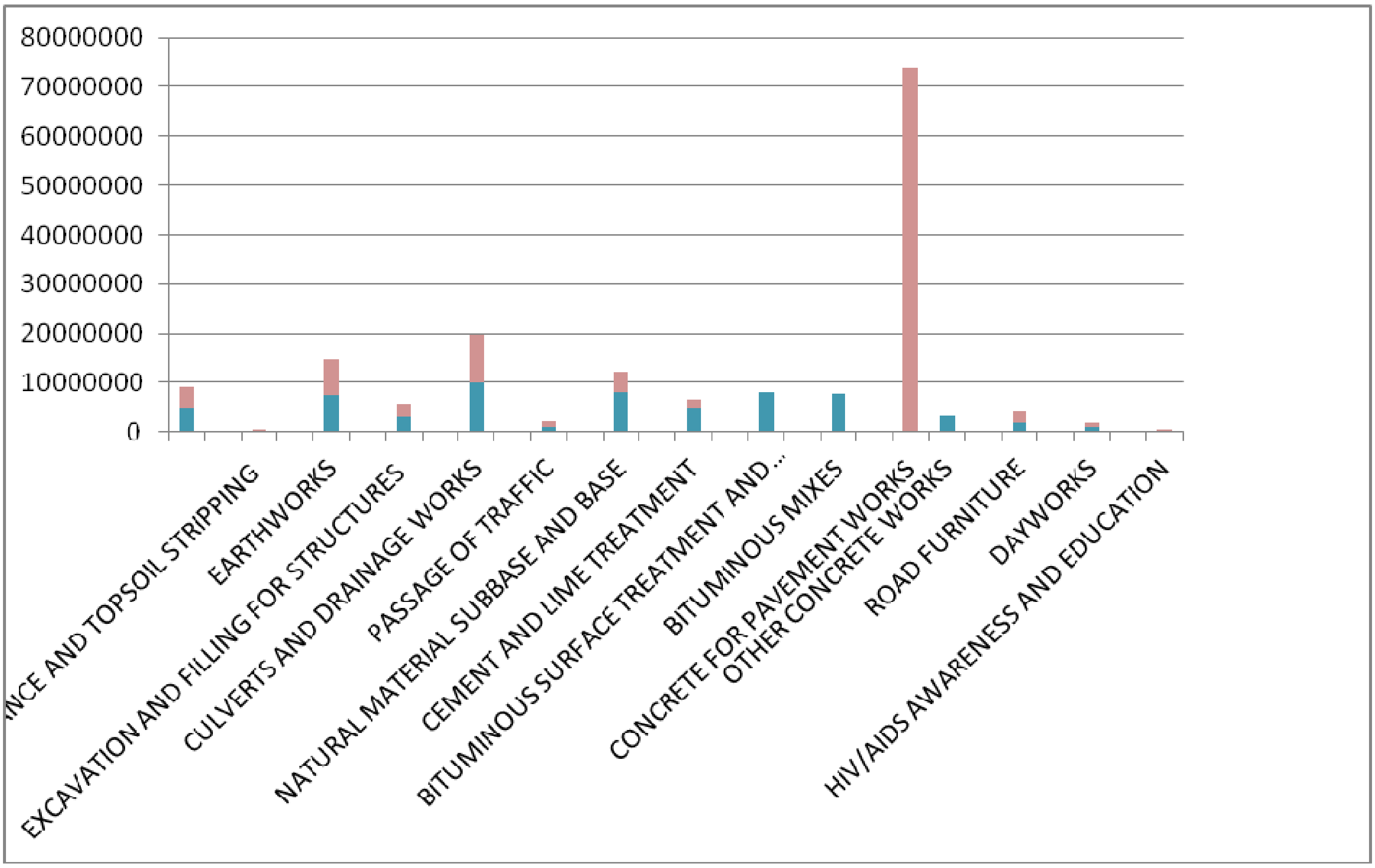


Figure 4.15: Bill by bill comparison of the different pavements

From the figure 4.15 above, it is seen that:-

- The two pavements share a number of bills that is from the bill on preliminaries to the bill on drainage works and HIV/AIDS awareness;
- The substantial difference in the cost of the two pavements is contributed by the concrete for pavement works which costs Ksh. 73 million out of the Ksh. 110 million quantity costs for the pavement ;
- The concrete works in the concrete pavement constitute over 60% of the cost of doing the works;

Figure 4.16 and 4.17 respectively give a comparison of Initial construction costs per km and the design lives (years) for the two pavements.

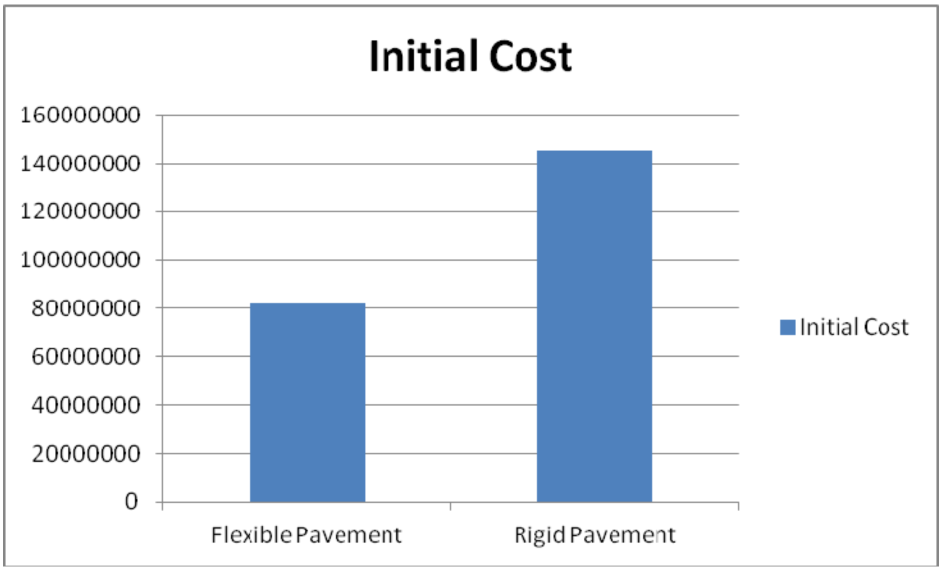


Figure 4.16: Initial cost comparison

From figure 4.16 above, the initial construction costs of a flexible pavement are substantially less than for a concrete pavement. Figure 4.17 however gives the expected design life (years) of the pavements.

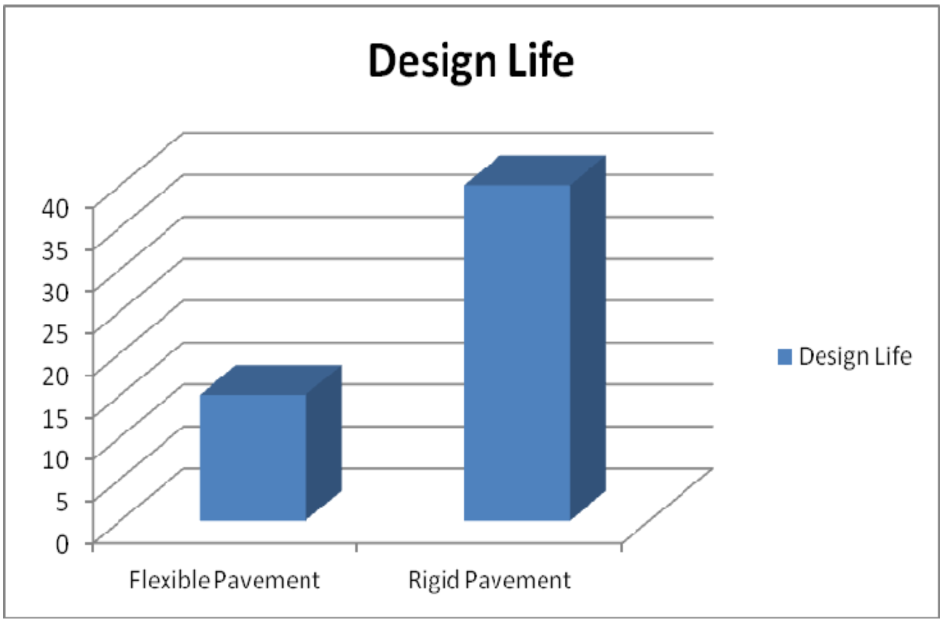


Figure 4.17: Expected design life comparison

From figure 4.17, with both pavements receiving the requisite maintenance, concrete pavement is expected to give more than double the service life as compared to flexible pavement.

4.7.2 Design and Maintenance Costs Analysis

Routine maintenance and periodic maintenance rates are derived from Kenya National Highways Authority (KeNHA) recently tendered (March 2012) performance based contracts where contractors were required to give monthly costs of maintenance (routine and periodic) of a unit length of selected twelve (12) road projects in Kenya. Table 4.12 below gives the annual maintenance costs for the pavements over the analysis period.

Table 4.12: **Cost comparison (Ksh.)**

Summary of Analysis					
Year	Activity/Cost	Concrete Pavement	Cumulative Concrete Costs	Flexible Pavement	Cumulative Flexible Costs
2011	Fresh Construction	145,448,877.43	145,448,877.43	81,962,786.38	81,962,786.38
2012	Routine Maintenace	350,000.00	145,798,877.43	500,000.00	82,462,786.38
2013	Routine Maintenace	357,000.00	146,155,877.43	525,000.00	82,987,786.38
2014	Routine Maintenace	364,140.00	146,520,017.43	551,250.00	83,539,036.38
2015	Routine Maintenace	371,422.80	146,891,440.23	578,812.50	84,117,848.88
2016	**Routine/Periodic Maintenance**	378,851.26	147,270,291.48	2,000,000.00	86,117,848.88
2017	Routine Maintenace	386,428.28	147,656,719.77	500,000.00	86,617,848.88
2018	Routine Maintenace	394,156.85	148,050,876.61	525,000.00	87,142,848.88
2019	Routine Maintenace	402,039.98	148,452,916.60	551,250.00	87,694,098.88
2020	Routine Maintenace	410,080.78	148,862,997.38	578,812.50	88,272,911.38
2021	**Routine/Periodic Maintenance**	5,000,000.00	153,862,997.38	2,500,000.00	90,772,911.38
2022	Routine Maintenace	350,000.00	154,212,997.38	500,000.00	91,272,911.38
2023	Routine Maintenace	357,000.00	154,569,997.38	525,000.00	91,797,911.38
2024	Routine Maintenace	364,140.00	154,934,137.38	551,250.00	92,349,161.38
2025	Routine Maintenace	371,422.80	155,305,560.18	578,812.50	92,927,973.88
	Residual Value			16,392,557.28	76,535,416.60

2026	**Reconstruction (from the base)**	378,851.26	155,684,411.43	57,373,950.47	133,909,367.07
2026	**Traffic interuption costs**			5,000,000.00	138,909,367.07
2027	Routine Maintenace	386,428.28	156,070,839.72	500,000.00	139,409,367.07
2028	Routine Maintenace	394,156.85	156,464,996.56	525,000.00	139,934,367.07
2029	Routine Maintenace	402,039.98	156,867,036.55	551,250.00	140,485,617.07
2030	Routine Maintenace	410,080.78	157,277,117.33	578,812.50	141,064,429.57
2031	**Periodic Maintenance**	10,000,000.00	167,277,117.33	2,000,000.00	143,064,429.57
2032	Routine Maintenace	350,000.00	167,627,117.33	500,000.00	143,564,429.57
2033	Routine Maintenace	357,000.00	167,984,117.33	525,000.00	144,089,429.57
2034	Routine Maintenace	364,140.00	168,348,257.33	551,250.00	144,640,679.57
2035	Routine Maintenace	371,422.80	168,719,680.13	578,812.50	145,219,492.07
2036	**Routine/Periodic Maintenance**	378,851.26	169,098,531.39	2,500,000.00	147,719,492.07
2037	Routine Maintenace	386,428.28	169,484,959.67	500,000.00	148,219,492.07
2038	Routine Maintenace	394,156.85	169,879,116.51	525,000.00	148,744,492.07
2039	Routine Maintenace	402,039.98	170,281,156.50	551,250.00	149,295,742.07
2040	Routine Maintenace	410,080.78	170,691,237.28	578,812.50	149,874,554.57
	Residual Value			22,949,580.19	126,924,974.38
2041	**Periodic/Reconstruction of Flexible**	15,000,000.00	185,691,237.28	160,647,061.30	287,572,035.69
2041	**Traffic interuption costs**			6,250,000.00	293,822,035.69
2042	Routine Maintenace	350,000.00	186,041,237.28	500,000.00	294,322,035.69
2043	Routine Maintenace	357,000.00	186,398,237.28	525,000.00	294,847,035.69
2044	Routine Maintenace	364,140.00	186,762,377.28	551,250.00	295,398,285.69
2045	Routine Maintenace	371,422.80	187,133,800.08	578,812.50	295,977,098.19
2046	**Periodic Maintenance**	378,851.26	187,512,651.34	2,000,000.00	297,977,098.19
2047	Routine Maintenace	386,428.28	187,899,079.62	500,000.00	298,477,098.19
2048	Routine Maintenace	394,156.85	188,293,236.46	525,000.00	299,002,098.19
2049	Routine Maintenace	402,039.98	188,695,276.45	551,250.00	299,553,348.19
2050	Routine Maintenace	410,080.78	189,105,357.23	578,812.50	300,132,160.69
	Residual Value	29,089,775.49	160,015,581.75	48,194,118.39	251,938,042.30

	Summary of Costs			
		Concrete Pavement		**Flexible Pavement**
	Construction Costs	145,448,877.43		299,983,798.15
	Periodic Maintenace	30,000,000.00		11,000,000.00
	Routine Maintenance	13,656,479.80		17,240,500.00
	Traffic Interuption costs			11,250,000.00
	Residual Value	29,089,775.49		87,536,255.85
	Net Total	160,015,581.75		251,938,042.30
Assumptions				
That the annual inflation and variation in prices between reconstruction of pavements is estimated at 40%				
The cost of routine maintenance goes up by approximately 10% after every periodic maintenance				
The residual value of a pavement after the design Life is 20%				
There is no maintenance during the reconstruction year				

4.7.3 Discussion of Cost Comparison Costs

Figures 4.18 and 4.19 analyze the economic cost analysis data above

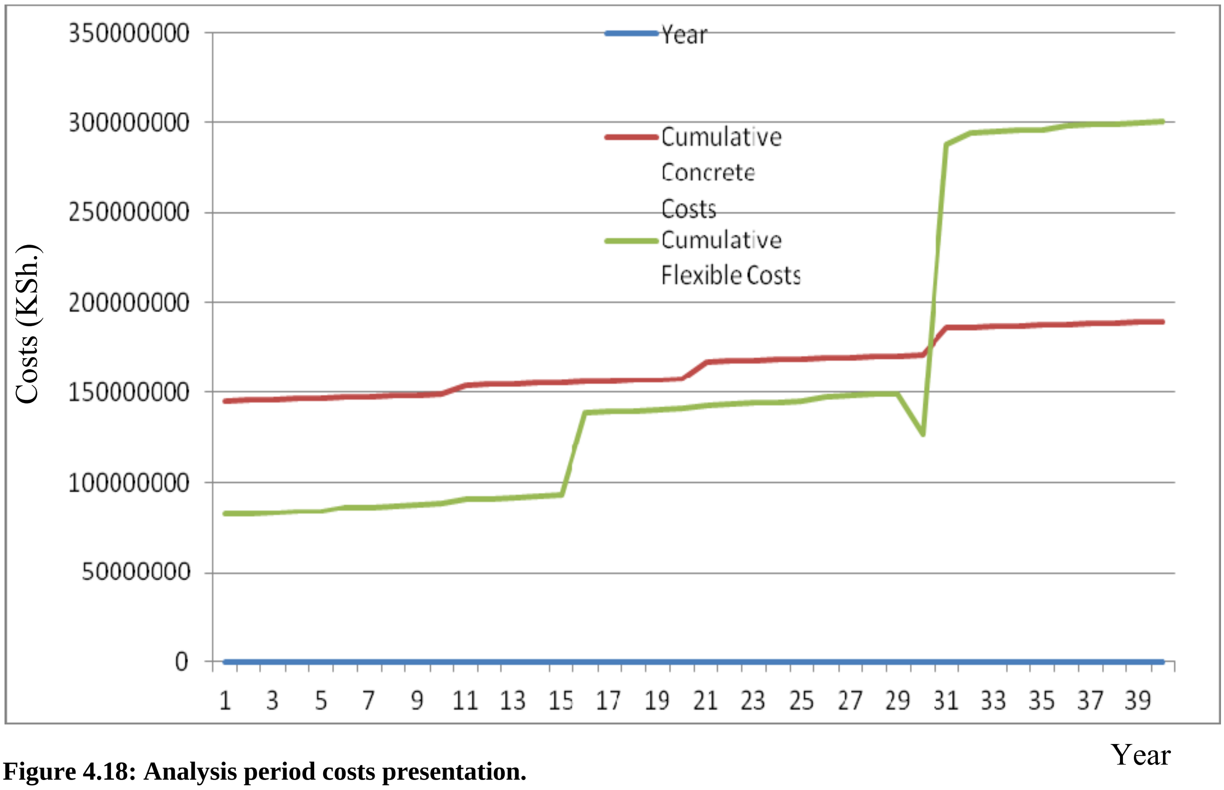


Figure 4.18: Analysis period costs presentation.

From figure 4.18:-

i. The cumulative costs of a flexible pavement exceeds those of a concrete pavement over the analysis period of forty years;

ii. A flexible pavement is cheaper than a concrete pavement upto the period of the second reconstruction (30th year);

iii. After the second reconstruction, the flexible pavement becomes substantially more costly than a concrete pavement.

Figure 4.19 below gives the comparison of various components of the two pavements.

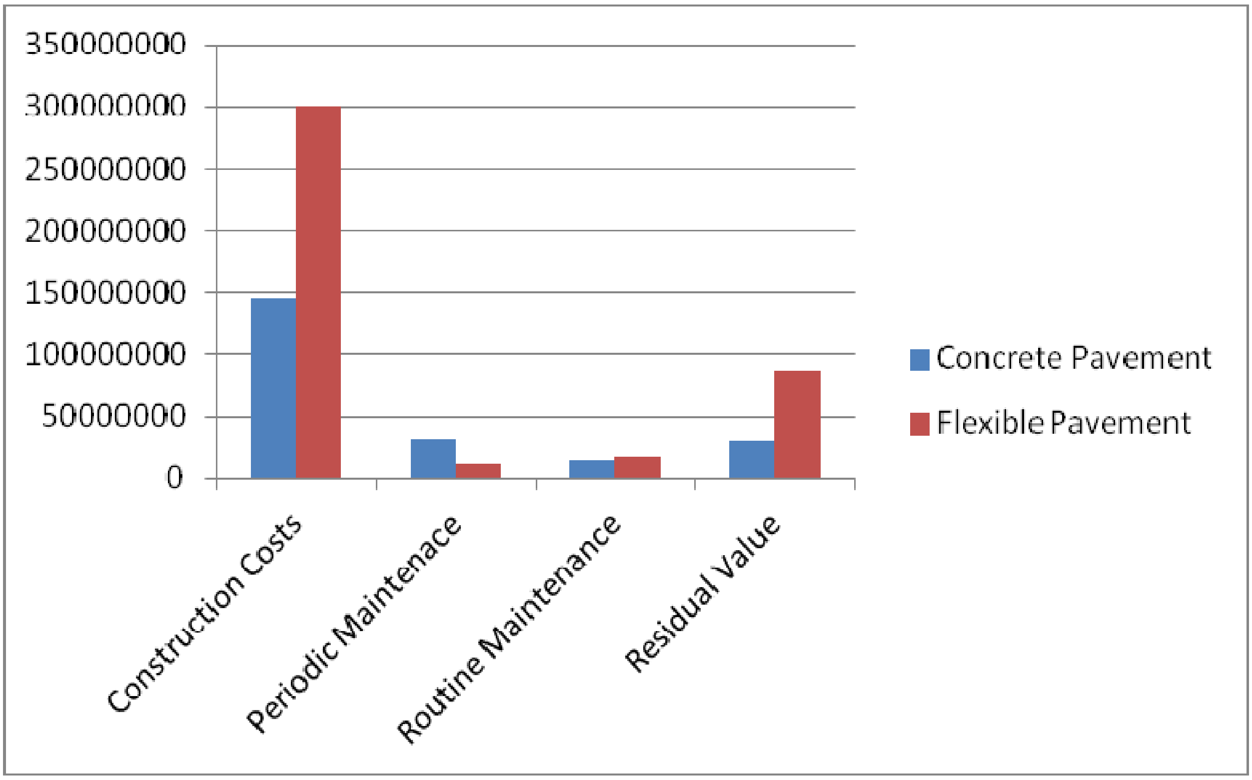


Figure 4.19: Comparison of various components of the costs (Ksh) for the two pavements

From figure 4.19 above, it can be adduced that:-

i. The initial construction costs of a concrete pavement is higher but the cumulative construction/reconstruction costs of a flexible pavement over the analysis period exceeds the concrete pavement's;

ii. The reconstruction of flexible pavement more than once over the analysis period raises its overall costs substantially;

iii. Inflation and variation of prices makes the net value of flexible pavement more costly due to reconstruction;

iv. The concrete pavement is less advantageous in residual/salvage value than a flexible pavement. These includes the pavement materials reuse or reduced processing of layers during construction/reconstruction.

4.7.4 Net Unit Costs

Figure 4.20 below conclusively compares the cumulative net costs for the two pavements over the design period, with a consideration of the residual value of both pavements.

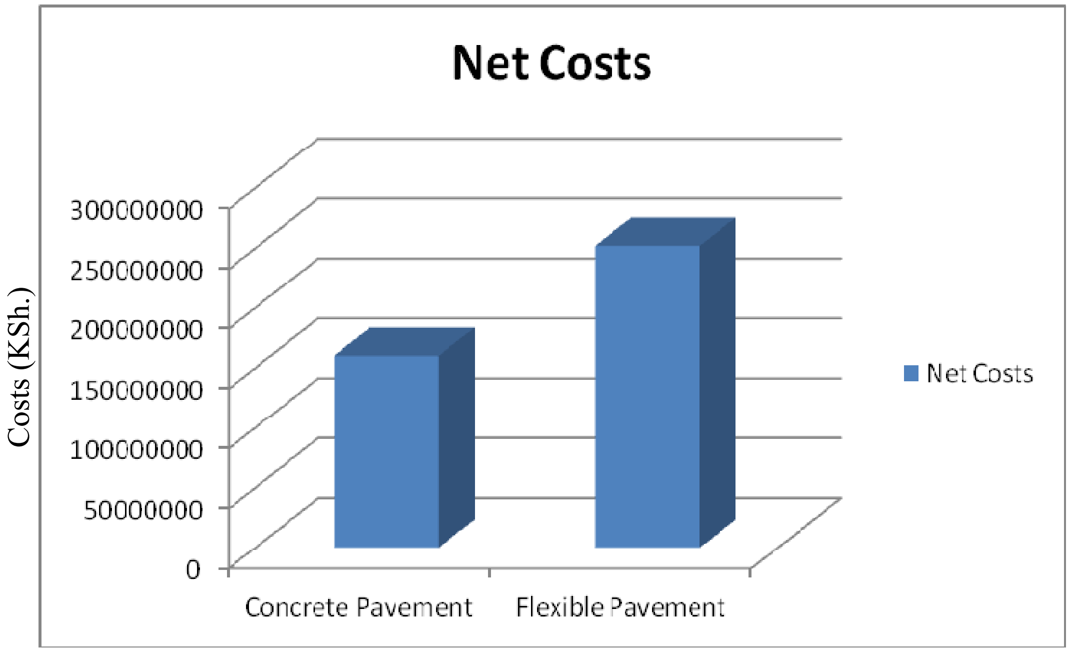


Figure 4.20: Unit cost comparison

From the above figure 4.20, it can be observed that the net cost of a concrete pavement is cheaper than a flexible pavement. This is despite other factors such interruption of traffic, costs of advertisement for works due to the recurrent reconstruction of flexible pavement and continued reduced level of service due to fast deterioration. Further to that, the cost of importation of fuel and fuel products makes the flexible pavement more expensive as compared to the locally available materials for making cement and the production processes.

From figure 4.20 above, the findings of the study can therefore be summarized as follows:

Net cost of flexible pavement = **Ksh. 251,938,042.30**

Net cost of concrete pavement = **Ksh. 160,015,581.70**

Difference in cost = **Ksh. 91,922,460.55**

It can then be concluded that from the analysis, the net cost of a flexible pavement is **57.45%** more expensive than the cost of a concrete pavement.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The concrete pavement chosen for the road is jointed (dowel) reinforced concrete pavement because the road was found to have a high traffic volume after traffic count data was analyzed. JRCP is best suited for high volume roads.

Cost comparison of using concrete or flexible pavement showed that in terms of lifecycle cost, use of concrete pavement is cheaper while in terms of initial construction costs, a bituminous pavement is cheaper. Feasibility of an investment is judged by calculating the life cycle cost as opposed to consideration of initial cost only, then concrete pavement is the better option to be adopted.

In summary it can therefore be concluded that:-

1. The road has a high traffic volume and axle loading with cases of overloading.
2. The alignment soils (subgrade material) materials have a low strength and thus improved to meet the threshold for the design.
3. Due to the high traffic volume and for purposes of economy, jointed reinforced concrete pavement (dowelled) is best suited for the road.
4. In terms of lifecycle cost, use of concrete pavement is cheaper while in terms of initial construction costs, a bituminous pavement is cheaper.
5. Flexible pavements are widely used due to its low initial construction costs;
6. Concrete slab in concrete pavement constitute over 60% of the costs of construction of a concrete pavement.
7. The high initial construction costs of a concrete pavement reduces its preference for use in the road section;
8. In general, other than the glaring noise problem, a concrete pavement is preferable to a flexible pavement in terms of durability and costs;

5.2 Recommendations

For the damaged road section, if reconstruction is to be undertaken, then concrete pavement should be adopted because of its lifecycle cost efficiency. It is ideal to develop design procedures for the concrete pavement to suit the local conditions, because current design methods are borrowed from other countries. In summary, it is therefore recommended that:-

1. For the damaged road section, if reconstruction is to be undertaken, then concrete pavement should be adopted;
2. During design, there is need to factor in for traffic overload;
3. There is need for more monitoring and evaluation to curb traffic overloading for realization of design life of the pavements. This can be done through mobile weighbridges;
4. Since concrete pavement is cheaper than flexible pavement on sections with steep to rolling, terrain, there is need for alternate bidding in procuring of construction services;
5. The use of concrete pavements on highways can be rolled out in phases in Kenya starting with the sections with steep to rolling terrain, as in the past such sections have failed even before attainment of the 15 year design life;
6. Road agencies should embrace the high initial investment costs for concrete pavement as its life cycle cost is cheaper;
7. There is need for sensitization of the stakeholders and the government on the preference of a concrete pavement to a flexible pavement;
8. Further studies should be undertaken to compare the life cycle costs and benefits for the two pavements;
9. Further studies should be undertaken to ascertain the key parameters that contribute to the magnified damage on road sections with steep to rolling terrain and compared to the sections on flat terrain;
10. Further studies should be carried out to ascertain the precise criteria for undertaking routine and periodic maintenance for both concrete and flexible pavement; both on timing and minimization of maintenance costs;
11. There is need to carry out further research on performance and financial implications of having reduced concrete pavement thickness with an asphaltic overlay ;
12. Further studies to develop a criteria for evaluating the residual value of both concrete and flexible pavements should be carried out;

REFERENCES

American Concrete Association, 1998. *Whitetopping-State of the Practice*:

Anon (1991), *Highway construction/Ground Insulation, Styropor: Technical Information, Retrieved 29 January 2010*

Asta Guciute Scheving (2011) *Life Cycle Cost Analysis of Asphalt and Concrete Pavements*, Master of Science Thesis, Reykjavík University, Iceland.

Barish, N (1978), *Economic Analysis in Engineering and Management Decision* (2nd Edition)

Cement & Concrete Association. Australia, Concrete Roads Manual 1997

Charles J. A (1997) *Selection and use of Engineering Materials* (3rd Edition), Butterworths Publishers, UK

Department of Transportation, State of Florida (2008). *Pavement Type Selection Manual,* Florida Department of Transportation Pavement Management Section Office of Roadway Design

Design Manual for Roads and Bridges (DMRB), Volume 7 (*Pavement Design*); *IAN 73/06 (Foundation Design*); HD29 (*Surveys & Investigations*); HD30 (*Maintenance Assessment Procedure*); HD32 (*Maintenance of Concrete Roads*)

Embacher, R A & Snyder, M. B (2001) *Life-Cycle Cost Comparison of Asphalt and Concrete Pavements on Low-Volume Roads: Case Study Comparisons*, Transportation Research Board, Paper No. 1749

Gerbrandt, R (2004), *Annual conference of the Transportation Association of Canada*, Montreal

Gichaga F. J. (1983), *Evaluation of flexible road pavements in Kenya. Highway Investment in Developing Countries,* Thomas Telford Ltd, London.

Gichaga F. J. and N. A Parker (1988); Essentials *of Highway Engineering with Reference to Warm Climates*, Macmillan Publishers.

Gidyelew A. B. & Satish Chandra (2009); *Comparative Study of Flexible and Rigid Pavements for Different Soil and Traffic Conditions*, Journal of the Indian Roads Congress, Paper No. 554

Gransberg, (2005*). National Cooperative Highway*, Transportation Research Board.

Grant E. (1990), *Principles of Engineering Economy (8th Edition)*

Guyer P. J. (2009). *An Introduction to Rigid Pavement Design*, Guyer Partners, CED Engineering, New York

Holt Anne, P.Eng., Sherry Sullivan and David K. Hein (2011), *Life Cycle Cost Analysis of Municipal Pavements in Southern and Eastern Ontario,* Edmonton, Alberta

Houben L. J. M. Ir. (2006), *Structural Design of Pavements (Part 6). Rigid Pavement Design.*

Huang Y H (2004), *Pavement Analysis and Design (2nd Edition)*

Kadiyali L. R, (1989) *Principles and practice of Highway Engineering, Khanna Tech Publications, Delhi*

International Monetary Fund, IMF (2011), EconStats : Kenya | IMF World Economic Outlook

Liddle Wallace J. (1962) *Application of AASHO Road Test Results to the Design of Flexible Pavement Structures,* U.S. Bureau of Public Roads. Manual of Contract Documents for Highway Works (MCHW), Volume 3.

Mehdi Akbarian (2012); *Model Based Pavement-Vehicle Interaction Simulation for Life Cycle Assessment of Pavements*, Cambridge MA

Millard, 1993, *Road Building in the Tropics: HMSO State of the Art Review 9.*

Ministry of Roads Design Manual (1987) : *Pavement Design, Part III.* The Republic of Kenya.

Pell P.S. (1978) *Development in Highway Pavement Engineering* (1st Edition), Applied Science Publications

Ministry of Roads (2011) Cost Estimation Manual for Road Maintenance Works, Republic of Kenya.

Republic of Kenya (May 2007), Ministry of Roads and Public Works, Roads Department, Northern Corridor Rehabilitation, Programme Phase III, *Formulation Study and Design for the Rehabilitation of the Eldoret - Turbo - Webuye Road (A104) Engineering Report*, Hydroarch S.R.L,

Republic of South Africa (June 1995), *Concrete Pavement Design Manual M10.*

Rodgers, M. (2002) *Highway Engineering* (Blackwell Science)

Sepulveda, J. A Schaums (1984), *Outline of theory and problems of Engineering Economics.*

Thomas Concrete Specialists (2007), *Why Concrete Paving Is Better Alternative Than Asphalt Paving.*

Tiwari, Devesh Dr. (2005). *Life-Cycle Cost Analysis of Cement Concrete Vis Flexible Pavement*, Central Road Research Institute New Delhi

Transport Research Board, *National Research Council. Highway Research Manual (1985). Special Report No. 209*

Transport and Road Research Laboratory, Department of Environment, Department of Transport (1977), *A guide to the Structural Design of Bitumen Surfaced Roads in Tropical and Subtropical and Subtropical Countries,* H.M.S.O

Transport and Road Research Laboratory *(1993)* Road Note 31, *A guide to the structural design of bitumen-syrfaced roads in Tropical and Sub-tropical Countries, Fourth Edition, Overseas Centre, TRL*

Uhlmeyer et al. (2000), *Top-Down Cracking in Washington State Asphalt Concrete Wearing Courses.* Transportation Research Record 1730. Transportation Research Board, National Research Council, Washington, D.C.

Ursich Clifford, P.E. (1995) *Economic Evaluation of Ohio's Flexible and Rigid Interstate Pavements*, Flexible Pavements, Inc.

Watson, J. (1994) *Highway Construction and Maintenance, Longman Publishers,UK*

Webster F. V and Cobble B. M. (1966), '*Traffic Signals' Road research Technical Paper No.56*, H.M.S.O

William M.K. (2006). *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*. Newbury Park, a Sage Publications Inc.

Yang N.C. (1973), *Design of Functional Pavements*, McGrawhill Book Company, New York

Yoder John E.I, (1975), *Principles of Pavement Design 2nd Edition, Wiley Publishers*

http://www.standardsforhighways.co.uk/dmrb/index.htm
http://www.standardsforhighways.co.uk/mchw/index.htm

APPENDICES

APPENDIX I – BILL OF QUANTITES FOR THE TWO PAVEMENTS

SUMMARY OF BILLS OF QUANTITIES			
Bill No.	**DESCRIPTION**	**Flexible Pavement**	**Concrete Pavement**
1	PRELIMINARY AND SUPERVISORY/SUPPORT SERVICES	**4,630,000.00**	**4,630,000.00**
4	SITE CLEARANCE AND TOPSOIL STRIPPING	**285,000.00**	**285,000.00**
5	EARTHWORKS	**7,407,500.00**	**7,407,500.00**
7	EXCAVATION AND FILLING FOR STRUCTURES	**2,884,000.00**	**2,884,000.00**
8	CULVERTS AND DRAINAGE WORKS	**9,889,400.00**	**9,889,400.00**
9	PASSAGE OF TRAFFIC	**1,025,500.00**	**1,025,500.00**
12	NATURAL MATERIAL SUBBASE AND BASE	**8,100,000.00**	**4,050,000.00**
14	CEMENT AND LIME TREATMENT	**4,980,120.00**	**1,660,040.00**
15	BITUMINOUS SURFACE TREATMENT AND SURFACE DRESSING	**7,966,979.10**	**-**
16	BITUMINOUS MIXES	**7,793,100.00**	**-**
17 A	CONCRETE FOR PAVEMENT WORKS	**-**	**73,950,702.00**
17 B	OTHER CONCRETE WORKS	**3,229,770.00**	**-**
20	ROAD FURNITURE	**2,000,000.00**	**2,000,000.00**
22	DAYWORKS	**1,000,000.00**	**1,000,000.00**
25	HIV/AIDS AWARENESS AND EDUCATION	**250,000.00**	**250,000.00**
1	**SUB TOTAL (1)**	**61,441,369.10**	**109,032,142.00**
	Add 15% of Sub-Total 1 of Bills as Provisional Sums for Variation of Price and Contingencies	9,216,205.37	16,354,821.30
2	**SUB-TOTAL (2)**	*70,657,574.47*	*125,386,963.30*
3	**Add 16% of Sub-Total (2) for V.A.T. - (3)**	*11,305,211.91*	*20,061,914.13*
	GRAND TOTAL	**81,962,786.38**	**145,448,877.43**

BILL NO. 1 : PRELIMINARY AND SUPERVISORY/SUPPORT SERVICES					
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**AMOUNT**	
				Flexible Pavement	**Rigid Pavement**
1.01	Provide, furnish and maintaining accommodation for Engineer's staff.				
	(a) Engineer's Senior Staff				
	(i) Type I	No	1	600,000.00	600,000.00
	(ii) Type II	No	2	900,000.00	900,000.00
	(b) Engineer's Junior Staff			-	-
	(i) Type III	No	2	600,000.00	600,000.00
	(ii) Type IV	No	2	300,000.00	300,000.00
				-	-
1.03	Provide, furnish and maintain Engineer's Representative's main office.	Item	1	50,000.00	50,000.00
1.04	Provide and maintain Laboratory for Engineer's representative and his staff.	Item	1	30,000.00	30,000.00
1.05	Provide laboratory equipment and reagents for use by the Engineer's representative for the entire duration of the contract as per the attached appendix to this item.	item	1	20,000.00	20,000.00
1.06	item deleted			-	-
1.07	Provide and maintain survey equipments for use by the Engineer's representative for the entire duration of the contract as per the attached appendix to this bill item.	item	1	80,000.00	80,000.00
				-	-
1.09	Provide, fuel and maintain with a driver two (2) new station wagon vehicle of engine capacity min. 3000cc diesel propelled fully loaded as per cl. 138 of special specs and approved by the Engineer, inclusive of the first 4000km per vehicle month.	V.mth	1	250,000.00	250,000.00
1.10	E.O Item 1.09 for mileages over 4000km per vehicle month.	Km	1,000	30,000.00	30,000.00
1.14	Allow Prime Cost (P.C.) sum of Kshs. 200000 for the Resident Engineer's Miscellaneous account to be spent in whole or part as directed by the Resident Engineer against receipts.	PC	1	200,000.00	200,000.00
1.15	E.O. item 1.14 for the contractor's overheads and profit.	%	10	20,000.00	20,000.00
1.16	Provide, erect and maintain publicity signs as directed by the Engineer.	No.	2	40,000.00	40,000.00
1.17	Allow Prime Cost (P.C.) sum of Kshs 100,000 for relocation of services.	PC Sum	1	100,000.00	100,000.00
1.18	E.O. item 1.17 for the contractor's overheads and profit.	%	10	10,000.00	10,000.00
1.19	Allow a prime cost (P.C) sum of Kshs 500000 for the R.E attendance upon his staff including overtime in accordance with clause 137 of special specification.	PC	1	500,000.00	500,000.00
1.20	E.O. item 1.19 for the contractor's overheads and profit.	%	10	50,000.00	50,000.00
1.21	Allow for Prime Cost (P.C) Sum of KShs. 50000 for Resident Engineer and staff mobile phone airtime.	PC Sum	1	50,000.00	50,000.00
	Total Carried forward to next page			**3,830,000.00**	**3,830,000.00**

BILL NO. 1 : PRELIMINARY AND SUPERVISORY/SUPPORT SERVICES..Cntd					
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**AMOUNT**	
	Brought forward from previous page.			**3,830,000.00**	**3,830,000.00**
1.22	E.O. item 1.21 for the contractor's overheads and profit.	%	10	5,000.00	5,000.00
1.23	Allow a prime cost (P.C) sum of Kshs. 200000 for land acquisition as directed by the Engineer.	PC Sum	1	200,000.00	200,000.00
1.24	E.O. item 1.23 for the contractor's overheads and profit.	%	10	20,000.00	20,000.00
1.25	Allow a Prime Cost (P.C.) of KShs 100000 for off-road environmental mitigation measures to be used as directed by the Engineer.	PC Sum	1	100,000.00	100,000.00
1.26	E.O. item 1.25 for the contractor's overheads and profit.	%	10	10,000.00	10,000.00
1.27	Allow a Prime Cost (P.C) sum of KShs. 50000 for training of engineers, technicians and other support staff as maybe instructed by the Engineer.	PC Sum	1	50,000.00	50,000.00
1.28	E.O. item 1.27 for the contractor's overheads and profit.	%	10	5,000.00	5,000.00
1.30	Allow a Prime Cost (P.C) sum of KShs 100,000 for Environmental Impact Assesment Study and license.	PC	1	100,000.00	100,000.00
1.31	E.O. item 1.31 for the contractor's overheads and profit.	%	10	10,000.00	10,000.00
1.32	Provide and Maintain Office stationery and equipment which includes a laptop and desktop computers complete with software, photocopier and scanner to revert to the Engineer.	LS	1	300,000.00	300,000.00
	Total of Bill carried forward to summary			**4,630,000.00**	**4,630,000.00**

BILL NO. 4 : SITE CLEARANCE AND TOPSOIL STRIPPING					
ITEM	DESCRIPTION	UNIT	QUANTITY	AMOUNT	
				Flexible Pavement	Rigid Pavement
4.01	Clear site on road reserve and material sites including removal of trees, hedges, bushes and other vegetation or deterious organic material, grub up roots and back fill to 100% MDD (AASHTO T99) with approved material in accordance with the specification.	Ha	1	85,000.00	85,000.00
4.02	Strip topsoil 200mm deep or as may be directed by the Engineer.	m^3	500	100,000.00	100,000.00
4.03	Allow a Prime Cost (P.C) sum of KShs. 100,000 for the removal of structures on the road reserve. Measurement to be done on Dayworks basis	PC	1	100,000.00	100,000.00
	Total of Bill carried forward to summary			**285,000.00**	**285,000.00**

BILL NO. 5 : EARTHWORKS					
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**AMOUNT**	
				Flexible Pavement	**Rigid Pavement**
	No separate payment shall be made for the overhaul of material and the cost of such haulage shall be included in the rates and/or prices				
5.01	Fill in soft material to 95% MDD (AASHTO T99) in layers of 150mm each	m^3	2,400	1,440,000.00	1,440,000.00
5.02	As item 5.01 but in hard materials.	m^3	1,000	900,000.00	900,000.00
5.03	Cut to spoil in soft material	m^3	2,400	1,080,000.00	1,080,000.00
5.04	As item 5.03 but in hard materials.	m^3	1,140	712,500.00	712,500.00
5.05	Compaction of 150mm thick original ground under fills and in cuts below subgrade to 95% MDD.(AASHTO T99)	m^3	3,000	900,000.00	900,000.00
5.06	Extra over item 5.01 for compaction of top 300mm below formation level in cuts and fills (subgrade) to 100% MDD. (AASHTO T99)	m^3	2,200	440,000.00	440,000.00
5.07	Provide geotextile filter fabric to under, over or around rockfill as directed by the Engineer	m^2	1,000	500,000.00	500,000.00
5.08	Top soiling over side slopes, cuts and fills.	m^2	750	60,000.00	60,000.00
5.09	Grass over side slopes in fills and cuts.	m^2	750	75,000.00	75,000.00
5.10	Provide and place rockfill on swampy areas as directed by the Engineer	m^3	1,000	1,300,000.00	1,300,000.00
	Total of Bill carried forward to summary			**7,407,500.00**	**7,407,500.00**

BILL NO. 7: EXCAVATION AND FILLING FOR STRUCTURES					
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**AMOUNT**	
				Flexible Pavement	**Rigid Pavement**
7.01	Excavate for structures in soft material	m^3	500	250,000.00	250,000.00
7.02	As item 7.01 but in hard materials.	m^3	200	200,000.00	200,000.00
7.03	Excavate and backfill for gabions in soft material and compact the excavation to receive the gabion boxes and / or spoil the excavated material as directed by the Engineer	m^3	100	55,000.00	55,000.00
7.04	Provide and place macafferri or equivalent 2x1x1 m gabions or matresses as shown on the drawings or as directed by the Engineer.	m^2	660	594,000.00	594,000.00
7.05	Provide and place rock fill to gabion boxes.	m^3	200	260,000.00	260,000.00
7.06	Provide 1:3 cement mortar grouting to gabion faces as directed by the Engineer.	m^3	200	100,000.00	100,000.00
7.07	Provide, place and compact rock fill below structure.	m^3	500	600,000.00	600,000.00
7.08	Provide and place cement grouted stonepitching as directed by the Engineer	m^2	500	675,000.00	675,000.00
7.09	provide and compact porous fill material (6/10mm chippings or similar approved) behind structures	m^3	50	150,000.00	150,000.00
	Total of Bill carried forward to summary			**2,884,000.00**	**2,884,000.00**

BILL NO. 8 : CULVERTS AND DRAINAGE WORKS					
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**AMOUNT**	
				Flexible Pavement	**Rigid Pavement**
	Note: No separate payments shall be made for gravel for blinding or hauling to spoil unsuitable excavation materials and the cost of such shall be included in the rates and prices.				
8.01	Excavate in soft material for minor drainage structures, catchwater drains, concrete pipe culverts headwalls, wingwalls, apron, toe walls, drop inlets, and compact as specified or as directed by the Engineer.	m^3	450.00	202,500.00	202,500.00
8.02	As item 8.01 but in hard materials.	m^3	100	100,000.00	100,000.00
				-	-
8.03	Provide, lay and joint 600mm I.D precast concrete pipes culverts	m	36	360,000.00	360,000.00
				-	-
8.04	As for item 8.03 but 900mm I.D	m	120	2,160,000.00	2,160,000.00
				-	-
8.05	As for item 8.03 but 1200mm I.D	m	24	540,000.00	540,000.00
				-	-
8.06	Provide and place class 15/20 concrete to beds and surrounds.	m^3	144	2,162,400.00	2,162,400.00
				-	-
8.07	Provide and place class 25/20 concrete to head walls, wingwalls, aprons, toe walls, inlets and outlets to pipe culverts including formwork.	m^3	49	1,111,500.00	1,111,500.00
				-	-
8.08	Provide and place A142 fabric mesh reinforcement or equivalent for item 8.07	m^2	400	400,000.00	400,000.00
				-	-
8.09	Excavate in soft material for,mitre drains, cut off drains, and outfall drains to free flowing conditions	m^3	500	625,000.00	625,000.00
				-	-
8.10	As item 8.09 but in hard materials.	m^3	50	75,000.00	75,000.00
				-	-
8.11	Excavate, remove and dispose damaged pipe culverts including demolition of inlet and outlet structures.	m	100	75,000.00	75,000.00
				-	-
8.12	Excavate, remove and hand over to client ARMCO culverts including demolition of inlet and outlet structures	m	50	25,000.00	25,000.00
				-	-
8.13	Excavate in soft material, provide and joint 300mm half round concrete channels of equivalent approved including bedding and backfilling with selected material as directed.	m	100	210,000.00	210,000.00
				-	-
8.14	Provide and place 300mm Invert Block Drains with single side slabs.	m	40	140,000.00	140,000.00
				-	-
8.15	Provide and place 300mm Invert Block Drains with double side slabs.	m	30	120,000.00	120,000.00
8.16	Construct concrete scour checks as directed by the Engineer.	m^3	100	1,400,000.00	1,400,000.00
				-	-
8.17	Provide crushed rock backfill in subsoil drains	m^3	50	75,000.00	75,000.00
				-	-
8.18	Provide filter fabric to subsoil drains	m^2	100	108,000.00	108,000.00
	Total of Bill carried forward to summary			**9,889,400.00**	**9,889,400.00**

BILL NO. 9 : PASSAGE OF TRAFFIC					
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**AMOUNT**	
				Flexible Pavement	**Rigid Pavement**
9.01	Allow for the passage of traffic through the works	LS	1	100,000.00	100,000.00
9.02	Construct and maintain, including watering 6.5m wide deviations having a 150mm thick gravel wearing course of CBR greater than 20% including road signs.	km	2	750,000.00	750,000.00
9.03	Provide and compact natural gravel of CBR greater than 20% for maintanance of existing road ahead of works	m^3	135	175,500.00	175,500.00
	Total of Bill carried forward to summary			**1,025,500.00**	**1,025,500.00**

BILL NO. 12: NATURAL MATERIAL SUBBASE AND BASE					
ITEM	DESCRIPTION	UNIT	QUANTITY	AMOUNT	
				Flexible Pavement	Rigid Pavement
	No overhaul will be paid for seperately under this item				
	and the cost of hauling will be deemed to have been				
	included in the rates. The rates inserted shall include all items as listed in method-A of measurement in the standard specifications				
12.01	Provide, place, water, process and compact to 95% MDD (AASHTO T180) natural gravel for subbase	m^3	2,700	4,050,000.00	4,050,000.00
12.02	Provide, place, water, process and compact to 95% MDD (AASHTO T180) natural gravel for base	m^3	2,700	4,050,000.00	
	Total of Bill carried forward to summary			**8,100,000.00**	**4,050,000.00**

BILL NO. 14: CEMENT AND LIME TREATMENT					
ITEM	DESCRIPTION	UNIT	QUANTITY	AMOUNT	
	Flexible Pavement			**Flexible Pavement**	**Rigid Pavement**
14.01	Provide, transport to site and spread cement, as stabilising agent for the natural gravel subbase and base material as specified and as directed by the Engineer.	ton	92	2,108,160.00	
14.02	Provide, transport to site and spread Lime, as stabilising agent for the natural gravel subbase and base material as specified and as directed by the Engineer.	ton	62	1,416,960.00	
14.03	Allow for mixing in cement and/or lime into natural gravel	m^3	1,950	780,000.00	
14.04	Allow for curing and protection of the treated material as specified.	m^2	15,000	675,000.00	
	Rigid Pavement				
14.01	Provide, transport to site and spread cement, as stabilising agent for the natural gravel subbase material as specified and as directed by the Engineer.	ton	31		702,720.00
14.02	Provide, transport to site and spread Lime, as stabilising agent for the natural gravel subbase material as specified and as directed by the Engineer.	ton	21		472,320.00
14.03	Allow for mixing in cement and/or lime into natural gravel	m^3	650		260,000.00
14.04	Allow for curing and protection of the treated material as specified.	m^2	5,000		225,000.00
	Total of Bill carried forward to summary			**4,980,120.00**	**1,660,040.00**

BILL NO. 15: BITUMINOUS SURFACE TREATMENT AND SURFACE DRESSING					
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**AMOUNT**	
				Flexible Pavement	**Rigid Pavement**
15.01	Prepare surface of carriageway, junctions, accesses etc, provide and spray MC 30 cut-back bitumen as prime coat at a rate of 1.0-1.2 lt/m^2 or as directed by the Engineer	Litres	8,851	1,053,269.00	
				-	
15.02	Prepare primed surface, provide and spray MC3000 cutback Grade bitumen as binder for first seal on shoulders, junctions and accesses at a spray rate of 1.1-1.3 lts/m^2 or as directed by the Engineer	Litres	3,750	506,250.00	
				-	
15.03	Provide, spread and roll 14/20 mm precoated chippings as 1st seal on shoulders, junctions and accesses at a spread rate of 75 - 90 m^2/m^3 or as directed by the Engineer	m^3	188	1,941,000.00	
				-	
15.04	Prepare 1st seal surface, provide and spray MC3000 cutback bitumen as binder for second seal on shoulders, junctions and accesses at a spray rate of 0.9-1.1 lts/m^2 or as directed by the Engineer	Litres	3,750	506,250.00	
				-	
15.05	Provide, spread and roll 6/10 mm precoated chippings as 2nd seal on shoulders, junctions and accesses at a spread rate of 100 - 130 m^2/m^3 or as directed by the Engineer	m^3	20	188,618.40	
				-	
15.06	Prepare primed surface, provide and spray MC3000 cutback Grade bitumen as binder for single seal on Carriageway at a spray rate of 1.1-1.3 lts/m^2 or as directed by the Engineer	Litres	10,385	1,401,907.50	
				-	
15.07	Provide, spread and roll 10/14 mm precoated chippings as single seal at a spread rate of 75 - 90 m^2/m^3 or as directed by the Engineer	m^3	47	462,809.20	
				-	
15.08	Prepare surface, provide and spray K1-60 bitumen emulsion as tack coat at a rate of 0.5-0.8 lt/m^2 or as directed by the Engineer	Litres	16,875	1,906,875.00	
	Total of Bill carried forward to summary			**7,966,979.10**	**-**

BILL NO. 16: BITUMINOUS MIXES					
ITEM	DESCRIPTION	UNIT	QUANTITY	AMOUNT	
				Flexible Pavement	Rigid Pavement
16.01	Prepare surface, Provide, place and compact Asphalt concrete type I as directed by the Engineer	m^3	315	7,793,100.00	
	Total of Bill carried forward to summary			**7,793,100.00**	-

BILL NO. 17: CONCRETE WORKS					
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**Amount**	
				Flexible Pavement	**Rigid Pavement**
17A	**Concrete for Pavement Works**				
17.01	Structural Concrete				
	Providing, hauling all materials, preparation, handling, mixing, placing to class UF3 finishing and curing.				
	a) Concrete Class 25/20	m^3	17		385650
	b) Concrete Class 30/20	m^3	10		240000
17.02	Blinding Concrete				
	Providing, hauling all materials, preparation, handling, mixing, placing to class UF1 finishing and curing.				
	a) Concrete Class 15/20	m^3	7		126000
17.03	Formwork for formed surface finishes				
	Supply, erect and dismantle formwork for concrete of the following classes. The rates shall cover inclined formwork of all slopes and angles.				
	Supply, erect and dismantle formwork for concrete of the following classes. The rates shall cover inclined formwork of all slopes and angles.Class F3 finish	m^2	420		840000
17.04	Reinforcement for miscellaneous works				
	Providing, cutting, shaping and placing high yield, high bond strength bars.				
	a) Diameter equal or less than 16 mm.	tonnes	5		657655
	b) Diameter greater than 16 mm.	tonnes	8		1045170
17.05	Ditto but mild steel round bars				
	Diameter equal or less than 16 mm.	tonnes	5		657655
17.06	Provide,place and compact class 30/20 concrete for Slab (10.5mwide,250mm thick,1000m long)-includes a climbing lane	m^3	2,625		63000000
17.08	Joint Sealant for the pavement	m	3,000		3600000
17.04	Reinforcement for Pavement (Tie and Dowel Bars)				
	Providing, cutting, shaping and placing high yield, high bond strength bars.				
	a) Diameter equal or less than 16 mm.	tonnes	2		263062
	b) Diameter greater than 16 mm.	tonnes	23		3135510

17B	**Other Concrete Works**				
17.01	Structural Concrete				
	Providing, hauling all materials, preparation, handling, mixing, placing to class UF3 finishing and curing.				
	a) Concrete Class 25/20	m^3	17	385,650.00	
	b) Concrete Class 30/20	m^3	10	240,000.00	
17.02	Blinding Concrete				
	Providing, hauling all materials, preparation, handling, mixing, placing to class UF1 finishing and curing.				
	a) Concrete Class 15/20	m^3	7	126,000.00	
17.03	Formwork for formed surface finishes				
	Supply, erect and dismantle formwork for concrete of the following classes. The rates shall cover inclined formwork of all slopes and angles.				
	a) Class F3 finish	m^2	59	117,640.00	
17.04	Reinforcement				
	Providing, cutting, shaping and placing high yield, high bond strength bars.				
	a) Diameter equal or less than 16 mm.	tonnes	5	657,655.00	
	b) Diameter greater than 16 mm.	tonnes	8	1,045,170.00	
17.05	Ditto but mild steel round bars				
	Diameter equal or less than 16 mm.	tonnes	5	657,655.00	
	Total of Bill carried forward to summary			**3,229,770.00**	**73,950,702.00**

BILL NO. 20: ROAD FURNITURE					
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**AMOUNT**	
				Flexible Pavement	**Rigid Pavement**
20.00	Provide a lumpsum amount for road furniture	No.	1	2,000,000.00	2,000,000.00
				-	
	Total of Bill carried forward Summary			**2,000,000.00**	**2,000,000.00**

BILL NO .22: DAYWORKS					
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**AMOUNT**	
				Flexible Pavement	**Rigid Pavement**
	Plant/Equipment				
	Provide a lumpsum amount for dayworks to cover for Plant/Equipment, Labour and Materials.		1	1,000,000.00	1,000,000.00
	Total of Bill carried forward Summary			**1,000,000.00**	**1,000,000.00**

BILL NO. 25 : HIV/AIDS AWARENESS AND EDUCATION					
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**AMOUNT**	
				Flexible Pavement	**Rigid Pavement**
25.01	Instituting an HIV/AIDS awareness and prevention Campaign	Month	1	50,000.00	50,000.00
25.02	Allow PC sum of Kshs. 200000 for HIV/AIDS training	PC	1	200,000.00	200,000.00
	Total of Bill carried forward Summary			**250,000.00**	**250,000.00**

APPENDIX II – TRAFFIC TALLY SHEETS

A. Primary Traffic Count														
	Name of the Road: A104, Timboroa						Date: March 13, 2011 to March 19, 2011							Total
	Traffic	Motocycle	Motobike/ Tuktuk	Cars	Nissans	LGV (2Axle)	MGV (3Axle)	Transists 4axle	Transists 5Axle	Transists 6Axle	Other Transists	Buses	Tractor & Others	
	Direction													
	To Nakuru	39	7	617	466	114	67	45	25	432	0	64	3	1879
Mar-13	To Eldoret	17	71	470	373	64	179	8	28	642	2	46	2	1902
	To Nakuru	20	20	342	343	98	113	26	49	263	53	22	3	1352
Mar-14	To Eldoret	30	8	305	311	87	107	7	33	337	0	30	2	1257
	To Nakuru	11	52	251	244	68	118	18	30	269	27	58	4	1150
Mar-15	To Eldoret	8	15	334	348	99	202	5	9	446	2	39	0	1507
	To Nakuru	3	22	195	242	89	141	25	2	340	18	24	3	1104
Mar-16	To Eldoret	2	26	326	358	108	195	5	45	454	6	47	3	1575
Mar-17	To Nakuru	7	11	275	322	118	179	1	35	423	0	39	1	1411
Day	To Eldoret	5	14	286	263	109	195	2	13	432	0	35	4	1358
Mar-17	To Nakuru	6	18	331	232	82	206	10	46	296	0	63	0	1290
Night	To Eldoret	13	14	334	289	92	199	2	15	270	0	44	3	1275
	To Nakuru	5	39	438	381	97	150	7	45	412	5	64	1	1644
Mar-18	To Eldoret	4	18	437	359	107	210	4	6	635	0	37	4	1821
	To Nakuru	17	15	445	301	120	139	1	26	307	0	36	1	1408
Mar-19	To Eldoret	2	12	489	364	108	192	3	9	424	0	29	1	1633
Total		**189**	**362**	**5875**	**5196**	**1560**	**2592**	**169**	**416**	**6382**	**113**	**677**	**35**	
Average		**12**	**23**	**367**	**325**	**98**	**162**	**11**	**26**	**399**	**7**	**42**	**2**	

Directional Traffic

	Name of the Road: A104, Timboroa					Date: March 13, 2011 to March 19, 2011								Total
	Traffic	Motocycle	Motobike/ Tuktuk	Cars	Nissans	LGV (1Axle)	MGV (2Axle)	Transists 3axle	Transists 4Axle	Transists 5Axle	Transists 6Axle & Above	Buses	Tractor & Others	
	Direction													
Mar-13	To Eldoret	17	71	470	373	64	179	8	28	642	2	46	2	1902
Mar-14	To Eldoret	30	8	305	311	87	107	7	33	337	0	30	2	1257
Mar-15	To Eldoret	8	15	334	348	99	202	5	9	446	2	39	0	1507
Mar-16	To Eldoret	2	26	326	358	108	195	5	45	454	6	47	3	1575
Mar-17 Day	To Eldoret	5	14	286	263	109	195	2	13	432	0	35	4	1358
Night	To Eldoret	13	14	334	289	92	199	2	15	270	0	44	3	1275
Mar-18	To Eldoret	4	18	437	359	107	210	4	6	635	0	37	4	1821
Mar-19	To Eldoret	2	12	489	364	108	192	3	9	424	0	29	1	1633
Total		**81**	**178**	**2981**	**2665**	**774**	**1479**	**36**	**158**	**3640**	**10**	**307**	**19**	
Average		**10**	**22**	**373**	**333**	**97**	**185**	**5**	**20**	**455**	**1**	**38**	**2**	
Less night		68	164	2647	2376	682	1280	34	143	3370	10	263	16	

	Name of the Road: A104, Timboroa					Date: March 13, 2011 to March 19, 2011								Total
	Traffic	Motocycle	Motobike/ Tuktuk	Cars	Nissans	LGV (1Axle)	MGV (2Axle)	Transists 3axle	Transists 4Axle	Transists 5Axle	Transists 6Axle & Above	Buses	Tractor & Others	
	Direction													
Mar-13	To Nakuru	39	7	617	466	114	67	45	25	432	0	64	3	1879
Mar-14	To Nakuru	20	20	342	343	98	113	26	49	263	53	22	3	1352
Mar-15	To Nakuru	11	52	251	244	68	118	18	30	269	27	58	4	1150
Mar-16	To Nakuru	3	22	195	242	89	141	25	2	340	18	24	3	1104
Mar-17 Day	To Nakuru	7	11	275	322	118	179	1	35	423	0	39	1	1411
Night	To Nakuru	6	18	331	232	82	206	10	46	296	0	63	0	1290
Mar-18	To Nakuru	5	39	438	381	97	150	7	45	412	5	64	1	1644
Mar-19	To Nakuru	17	15	445	301	120	139	1	26	307	0	36	1	1408
Total		**108**	**184**	**2894**	**2531**	**786**	**1113**	**133**	**258**	**2742**	**103**	**370**	**16**	
Average		**14**	**23**	**362**	**316**	**98**	**139**	**17**	**32**	**343**	**13**	**46**	**2**	
Less Night		102	166	2563	2299	704	907	123	212	2446	103	307	16	

B. MoR Data										
RD NO.	Census Point	Cars	LGV		MGV		HGV		Buses	TOTAL
			M	O	T	O	T	O		
A104/21	N.W of Jn with C53 Burnt Forest	375	559	4	158	63	1091	226	161	2637
A104/22	S.E of Jn with C53Burnt Forest	345	653	242	4	226	48	749	172	2439
A104/23	South of Junction with C36 Nabkoi	312	553	251	7	160	46	704	182	2215
A104/24	South of Timboroa	345	478	289	14	240	43	709	145	2263
Total		**1377**	**2243**	**786**	**183**	**689**	**1228**	**2388**	**660**	**9554**
Average		**344**	**561**	**197**	**46**	**172**	**307**	**597**	**165**	**2389**

Key:

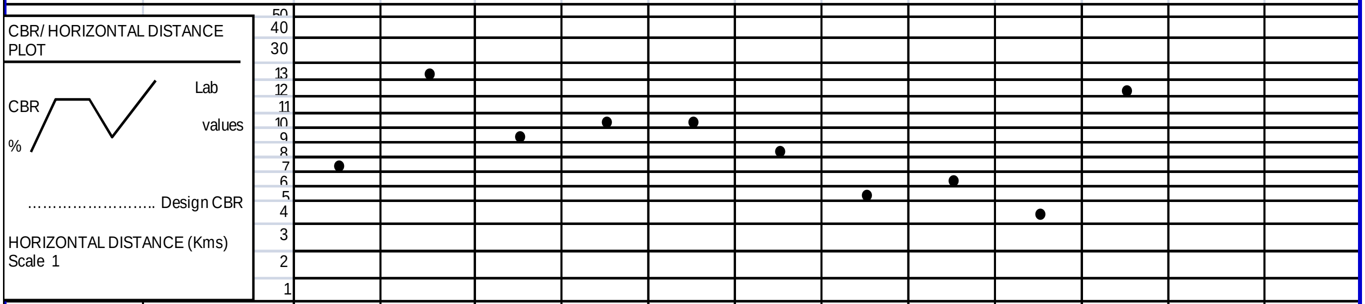
Light Goods	M:	Matatu
	O:	Others (Pickups,Land Rovers etc)
Medium Goods	T:	Tankers with 2 Axles
	O:	Other Medium Vehicles with 2 Axles
Heavy Goods	T:	Tankers with more than 2 Axles
	O:	Other Heavy Vehicles with more than 2 Axles

APPENDIX III – MATERIAL INVESTIGATIONS

MAIN TESTS MATERIAL SHEETS

- **California Bearing Ratio (CBR)**
- **Liquid Limit (LL)**
- **Plastic Limit (PL)**
- **Plasticity Index (PI)**
- **Initial Consumption Level (I.C.L) Test Sheets**

A104 Road, Timboroa Appendix III



chainage		0+000	0+100	0+200	0+300	0+400	0+500	0+600	0+700	0+800	0+900
4 days soaked CBR at 100% MDD		7	13	9	10	10	8	5	6	4	12
compaction	MDD (Kg/m3)	1141	1324	1142	1299	1277	1286	1228	1246	1086	1289
	OMC(%)	31.6	35	36.3	34.4	35.2	36.2	33.8	35.4	25.6	34
ATTERBERG LIMITS	LL	87	81	70	82	86	87	78	88	85	79
	PL	53	51	42	51	52	56	50	53	51	50
	PI	34	30	28	31	34	31	28	35	34	29
	LS	17	15	14	16	17	15	14	18	17	14
	PM	3162	2790	2744	3069	3298	3038	2744	3395	3332	2871
GRADING % PASSING	50	100	100	100	100	100	100	100	100	100	100
	37.5	100	100	100	100	100	100	100	100	100	100
	20	100	100	100	100	100	100	100	100	100	100
	10	99	98	100	100	100	100	100	100	100	100
	5	97	97	100	100	100	100	100	99	100	100
	2	95	96	100	100	99	100	100	99	99	100
	1.18	95	95	99	100	98	99	99	99	99	99
	0.6	94	94	99	99	98	99	98	98	99	99
	0.425	93	93	98	99	97	98	98	97	98	99
	0.212	89	91	97	98	97	98	96	96	98	98
	0.15	88	90	96	97	96	97	95	94	97	97
	0.075	86	89	94	96	96	96	94	93	96	96
	SWELL %	1.22	0.65	0.76	0.61	0.51	1	1.01	1.34	1.25	0.47

Done	**University of Nairobi**	**A104 Road**	**Done By:**
			F. K. Kipyator
	School of Engineering	SUMMARY OF ALIGNMENT SOILS TEST RESULTS	F56/76257/2009
	Department of Civil and Construction Engineering		**Supervised By:**
		Timboroa	Prof. S. K. Mwea
			Prof. F. J. Gichaga

APPENDIX IV - MATERIAL LOGS

Northern Corridor A104 Road, Timaboroa — APPENDIX IV — Jun-11

ALIGNMENT SOILS LOGGING

DEPTH	TRIAL STATION	DESCRIPTION
	KM 0+000	
0		
0.1		Overburden/Top Soil
0.2		
0.3		Black greyish Soils
0.4		
0.5		Dark Brown Soils
0.6		
0.7		
0.8		
0.9		
1.0		

DEPTH	TRIAL STATION	DESCRIPTION
	KM 0+100	
0		
0.1		Overburden/Top Soil
0.2		
0.3		Brown soil
0.4		
0.5		
0.6		Red friable Soils
0.7		
0.8		
0.9		
1.0		

DEPTH	TRIAL STATION	DESCRIPTION
	KM 0+200	
0		
0.1		Overburden/Top Soil
0.2		
0.3		
0.4		Red friable Soils
0.5		
0.6		
0.7		
0.8		
0.9		
1.0		

DEPTH	TRIAL STATION	DESCRIPTION
	KM 0+300	
0		
0.1		Overburden/Top Soil
0.2		
0.3		
0.4		Red friable Soils
0.5		
0.6		
0.7		
0.8		
0.9		
1.0		

DEPTH	TRIAL STATION	DESCRIPTION
	KM 0+400	
0		
0.1		Overburden/Top Soil
0.2		
0.3		Red friable Soils
0.4		
0.5		
0.6		
0.7		
0.8		
0.9		
1.0		

DEPTH	TRIAL STATION	DESCRIPTION
	KM 0+500	
0		
0.1		Overburden/Top Soil
0.2		
0.3		
0.4		
0.5		Red friable Soils
0.6		
0.7		
0.8		
0.9		
1.0		

University of Nairobi **School of Engineering** **Department of Civil and Construction Engineering**	**A104 Road** SUMMARY OF ALIGNMENT SOILS TEST RESULTS Timboroa	**Done By:** F. K. Kipyator F56/76257/2009 **Supervised By:** Prof. S. K. Mwea Prof. F. J. Gichaga

Northern Corridor A104 Road, Timaboroa

DEPTH	TRIAL STATION	DESCRIPTION
	KM 0+600	
0		
0.1		Overburden/Top Soil
0.2		
0.3		
0.4		Red friable Soils
0.5		
0.6		
0.7		
0.8		
0.9		
1.0		

DEPTH	TRIAL STATION	DESCRIPTION
	KM 0+700	
0		
0.1		Overburden/Top Soil
0.2		
0.3		
0.4		Red friable Soils
0.5		
0.6		
0.7		
0.8		
0.9		
1.0		

DEPTH	TRIAL STATION	DESCRIPTION
	KM 0+800	
0		
0.1		Overburden/Top Soil
0.2		
0.3		
0.4		Red friable Soils
0.5		
0.6		
0.7		
0.8		
0.9		
1.0		

DEPTH	TRIAL STATION	DESCRIPTION
	KM 0+900	
0		
0.1		Overburden/Top Soil
0.2		
0.3		
0.4		Red friable Soils
0.5		
0.6		
0.7		
0.8		
0.9		
1.0		

	A104 Road	**Done By:**
University of Nairobi		F. K. Kipyator
School of Engineering	SUMMARY OF ALIGNMENT SOILS TEST RESULTS	F56/76257/2009
Department of Civil and Construction Engineering		**Supervised By:**
	Timboroa	Prof. S. K. Mwea
		Prof. F. J. Gichaga

APPENDIX V: HEAVY VEHICLE (AXLE LOAD) CLASSIFICATION CHARTS

LOAD TYPE ____________

OWNER/S ....

ADDRESS ....

....

....

REPUBLIC OF KENYA

MINISTRY OF ROADS AND PUBLIC WORKS

AXLE LOAD ENFORCEMENT UNIT

AXLE LOAD SUMMARY SHEET

DATE: ....

NO.

VEHICLE REG No.	STATION/SITE	TIME
VEHICLE TYPE	VEHICLE INSPECTOR	PROHIBITION ORDER No.

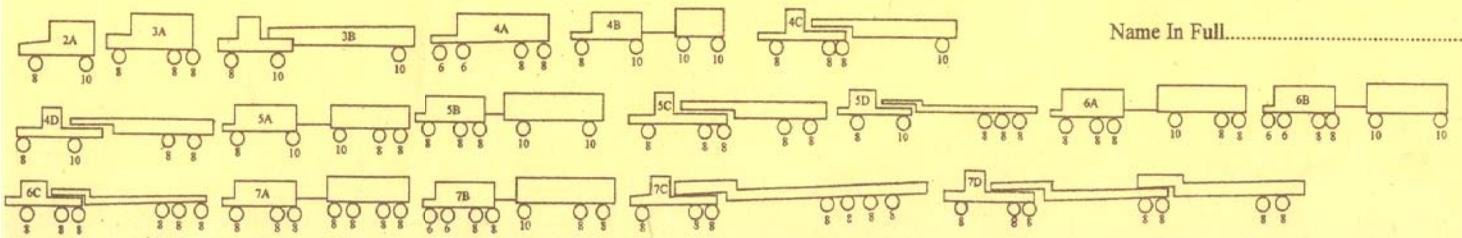
	SDTQ*	LOAD	LEGAL LIMIT	OVERLOAD
A1.				
A2.				
A3.				
A4.				
A5.				
A6.				
A7.				

*S=Single Axle D=Double Axle T=Triple Axle Q=Quadruplicate

I CERTIFY THAT THE VEHICLE WHOSE PARTICULARS ARE ENTERED ABOVE WAS FOUND TO BE OVERLOADED AS INDICATED. A PROHIBITION ORDER IN RESPECT OF THE VEHICLE HAS BEEN ISSUED.

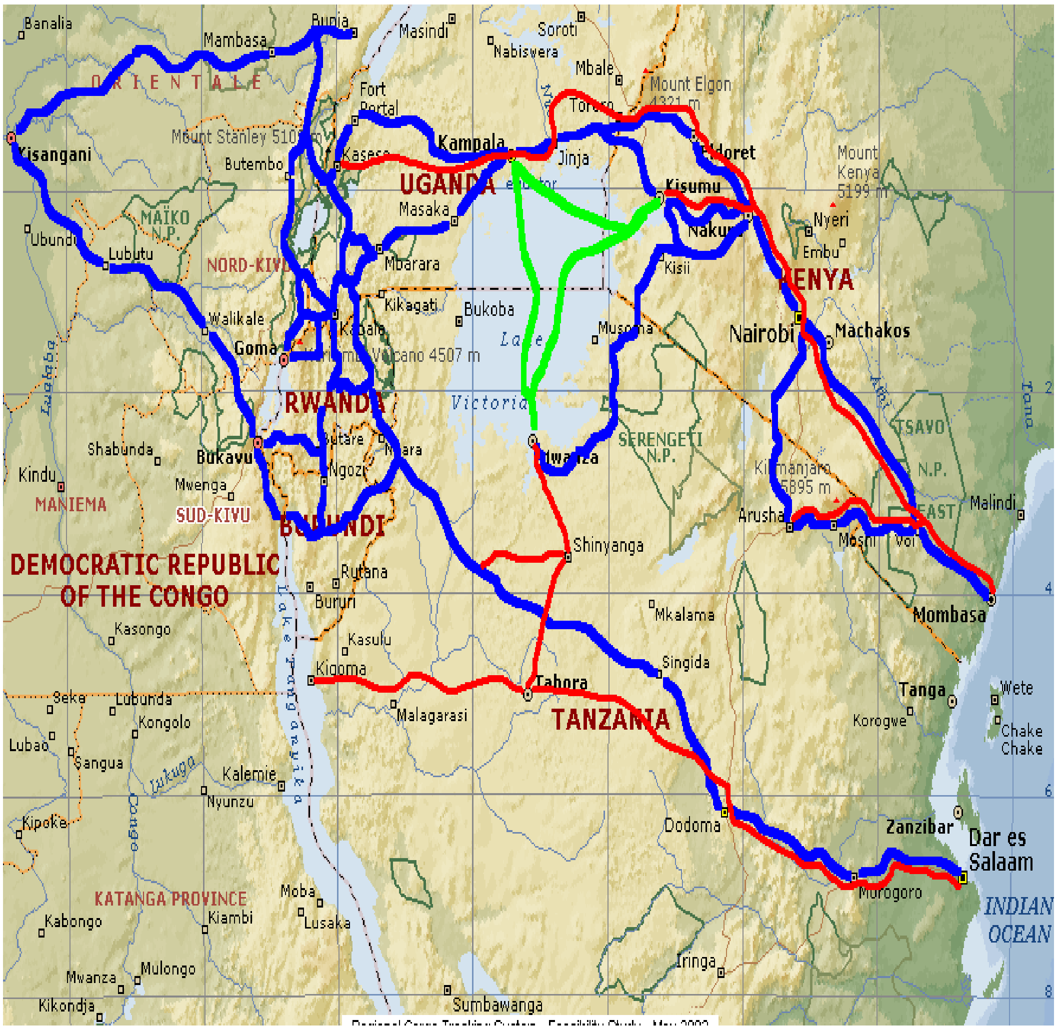
Signed..............................

Name In Full..............................



APPENDIX VI- THE CORRIDOR

A map indicating the corridor route and modes of transport



Northern (Mombasa Port) Corridor

Road
Rail Transport
Lake