UNIVERSITY OF NAIROBI

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Department of Civil and Construction Engineering

PERFORMANCE OF LOW VOLUME SEALED ROAD PAVEMENTS: A CASE STUDY OF ROADS 2000 STRATEGY IN CENTRAL KENYA

BY

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A Thesis Submitted in Partial Fulfilment for the Award of the Doctor of Philosophy in Civil Engineering, Department of Civil and Construction Engineering, University of Nairobi.

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DECLARATION

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

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DEDICATION

To Shyrose.

Requiesce In Pace.

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First and foremost, I thank my parents, Mr. Zakaria Macharia Wainaina and Mrs. Teresia Nduta Macharia, for their unconditional love and unwavering support. Thank you both for your endearing sacrifice in taking me through school, and for giving me the strength to reach for the stars and pursue my dreams. I hope this achievement will complete the dream that you had for me all those many years ago when you chose to give me the best education you could.

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ABSTRACT

The road sector in Kenya is an integral part of its economy. The country has approximately 170,000 kilometres of road network, managed by the line ministry, through the Kenya Roads Board (KRB), Road Authorities and other Agencies. Insufficient financial resources, organizational and operational systems with inadequate investment in maintenance has led to the devaluation of the road network as an asset, as well as the aftermath effects of high vehicle operating costs which directly affects the economy negatively. The deplorable condition of these road assets led the Government of Kenya to shift its emphasis from the construction of new roads to the rehabilitation and maintenance of the existing road network using the maintenance strategy known as the Roads 2000 (R2000) Strategy. The strategy aimed to improve road maintenance and construction by introducing appropriate technology on a road network basis for the selective rehabilitation, spot improvement and maintenance of prioritised links. The strategic goal of the R2000 program was to bring the rural road network of Class D, E and Special Purpose roads including parts of the unclassified network to a maintainable standard and ensure that KRB Road Maintenance Levy Fund (RMLF) resources are used to maintain the maintainable and recently improved road network. This study aimed at evaluating the performance of the low volume pavements on completed roads, and assessing the impacts of the R2000 program in Central Kenya. Roads constructed under the three batches of phase two were investigated to establish the current condition of the roads. The present serviceability was assessed by taking and analysing roughness and rutting measurements, and in addition to visual assessments, a present serviceability rating was assigned. The level of investment by the authorities on maintenance was evaluated by analysing the prioritisation criteria towards fund allocation. Axle control by the authorities on the completed roads was examined by conducting axle loading and analysis of the present traffic loading. Further, the roads were assessed for climate resilience using visual methods, and whether the appropriate adaptation techniques are in place to improve the climate resilience of the infrastructure. All the data from these investigations were collected and analysed using the appropriate methods, standards and tools, and the results used to make valid conclusion on the performance of the completed low volume sealed roads. The major defects on the road were noted and examined closely to determine the extent and cause of the defect. Such defects included rut development, pothole formation, delamination of pavement layers, longitudinal, transverse and crocodile cracking, encroachment of vegetation onto the carriageway and stone loss. Each road had its own specific dominating defects, arising from different prevailing weather, traffic or material conditions and the road use. For the climate resilience, the roads exhibited issues that included erosion, problematic soils, road and wayside drainage problems, embankments and cuttings' instability, construction problems and maintenance glitches. Tests and measurements conducted on the pavements showed that the completed low volume sealed roads generally had a strong pavement that was adequate to support 15-year design traffic. Axle load surveys revealed that the 10 and 15-year design traffic classes for completed roads was still within the expected low volume sealed roads traffic classes. However, it was established that axle load control was not being undertaken and the capacity to do so was minimal on the regional bodies. The assessment conducted on the performance of the side drainage showed that majority of the roads had side drainage with inadequate depths. Shallow side drainages are not desirable as they allow water to ingress into the pavement through the edge of the pavement layers. The high roughness values obtained, which were deduced to be as result of distresses such as rutting and potholes, were concluded to be as a result of inadequate and untimely maintenance of the roads surface. The recommended maintenance approach should be such that interventions for the defects such as cracks, potholes, edge breaks among others are carried out as soon as they identified. It was observed that all the roads surveyed did not have adequate adaptability measures for climate resilience. It was recommended that the Annual Road Inventory and Conditional Survey (ARICS) incorporates collection of additional data in the assessment on issues that touch on climate resilience, and the assessment of which should inform the application of suitable adaptation techniques to improve the climate resilience of the completed roads, and more so the low volume sealed roads.

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AASHTO	American Association of State Highway and Transportation Officials
AADT	Annual Average Daily Traffic
AFD	Agence Française de Développement
ALC	Axle Load Control
APRP	Annual Public Roads Programme
ARWP	Annual Roads Work Programme
BESM	Bitumen Emulsion Stabilised Materials
CBR	California Bearing Ratio
CESA	Cumulative Equivalent Standard Axles
CRC	Constituency Roads Committee
DESA	Daily Equivalent Standard Axles
DCP-DN	Dynamic Cone Penetrometer- DCP Number
DF	Drainage Factor
DSC	Design and Supervision Consultant
EAC	East African Community
ESA	Equivalent Standard Axle
ESM	Emulsion Stabilised Materials
ETB	Emulsion Treated Base
IRI	International Roughness Indices
IWP	Inner Wheel Path
KeNHA	Kenya Highways Authority
KeRRA	Kenya Rural Roads Authority
KfW	Kreditanstalt für Weideraubau
KIHBT	Kenya Institute of Building and Highways Technology
KRB	Kenya Roads Board
KURA	Kenya Urban Roads Authority
KWS	Kenya Wildlife Service
LVSR	Low Volume Sealed Roads
MEPDG	Mechanistic Empirical Pavement Design Guide
MGV	Medium Goods Vehicles
MoR	Ministry of Roads

MoTIHUD	Ministry of Transport, Infrastructure Housing, Urban Development and Public Works
Mpa	Megapascal
MRP	Minor Roads Programme
MRPW	Ministry of Roads and Public Works
MSC	Management Supervision Consultant
MTRD	Materials Testing and Research Division
ORN-40	Overseas Road Note 40
OWP	Outer Wheel Path
PCI	Pavement Condition Index
PBRM	Performance Based Routine Maintenance
PSR	Present Serviceability Rating
RARP	Rural Access Roads Program
R2000	Roads 2000
RICS	Road Inventory Condition Survey
RMs	Regional Managers
RMLF	Road Maintenance Levy Fund
RSIP	Road Sector Investment Programme
SADC	Southern African Development Community
SIDA	Swedish International Development Cooperation Agency
SN	Structural Number
VEF	Vehicle Equivalent Factor
VLC	Vehicle Load Control
WIM	Weigh in Motion

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

The transportation sector is one of Kenya's major pillars of economic development contributing 10.7 per cent to the Gross Domestic Product (GDP) in the year 2022 (KRB, 2023). The performance of the transport sector improved in 2022, and road transport was the most predominant mode of transport in Kenya, accounting for over 90 per cent of all freight and passenger traffic (KNBS, 2023). Kenya's road assets are valued at over Kshs 3.5 trillion and therefore there is need to establish the road asset administration in the its development strategy, to facilitate road maintenance, rehabilitation and development in an effective manner (KRB, 2023).

At independence, in 1963, Kenya had approximately 45,000km of roads, of which only 2,000km were paved and the rest were earth and gravel roads which were subject to closure during the rainy season. The network had insufficient geographical reach for the attainment of the development objectives of the people of independent Kenya and had a focus on the transport interests of the settler community. In the 1960s, emphasis was laid on upgrading of the principal highway arteries in the trunk road system. This was followed by the improvement of the primary road network through selective paving of heavily trafficked segments. At the same time, feeder roads were constructed within the former settler areas (MoRPW, 2006).

Planned labour-based road works in Kenya started in the 1970's with the Rural Access Roads Program (RARP), executed between 1974 and 1986, where approximately 8,000 km of farm to marketplace access roads were constructed. The Minor Roads Program (MRP) was implemented next, between 1986 and 1996, where approximately 4,500 km of the classified Secondary (D), Minor (E) and Special Purpose roads were improved (MoR, 2013).

It was revealed, in the 1990's, that the road maintenance regimes in place were inadequate to maintain the high number of improved roads in good condition. In a bid to solve the problem, the government initiated the Roads 2000 (R2000) Strategy. The concept is a technique of road development and management that guarantees optimum utilization and development of locally available resources where technically and economically feasible. The strategy was to be initiated countrywide to cover the whole road network, founded on the lessons gained from the two-preceding labour-based programmes. The concept was anticipated to be complete by the year 2000, hence the term "Roads 2000" (MoR, 2013).

Nevertheless, owing to the numerous institutional and operational challenges, the concept was executed only in six districts by the year 2000 and its influence was limited. To increase the uptake of the strategy, the government established a R2000 Strategic Plan in 2004, for the period from 2005 to 2010. The plan was to offer a framework for the execution of the strategy. In 2010, when the plan was concluded, the strategy had been realised in numerous parts like Eastern, Nyanza, Central and Rift Valley. Approximately 8,000 km of roads were upgraded by the program, and about four million man-days of employment were created in the rural areas, where such openings were limited. In addition, the programme advocated for the incorporation of social and environmental matters into the road's sector (MoR, 2013).

Invigorated by the accomplishments of the 2004-2010 Strategic Plan, and the desire to increase the gains to people all over the country, the government developed the second R2000 Strategic Plan. The new plan was intended to address the difficulties met during the execution of the preceding R2000 programme, to additionally develop and roll out the R2000 strategy, and consolidate the achieved gains (MoR, 2013).

The Government of Kenya (GOK), in partnership with Agence Française de Développement (AFD), started the Road 2000 Projects to improve the roads that were in deplorable state in Central Region of Kenya. The program was rolled out in 2007 with projects under Phase 1 (Batches 1, 2 and 3). By the year 2022, projects under Phase 2 (Batch 3) were complete and commissioned.

Once the projects were completed, the plan was to place the roads under Performance Based Routine Maintenance (PBRM) Programme under Kenya Rural Roads Authority (KeRRA) (KeRRA, 2018).

Low volume roads are roads designed for a traffic loading not exceeding one million equivalent standard axles per lane over their design lives. These roads are constructed using locally available natural materials that may be improved to meet the provided standards (Otto et al, 2020). The performance of low volume sealed roads is determined by an appropriate and adequate drainage, a strong bituminous seal that is resealed in a timely manner, and an allowance for occasional overloaded axles (Rolt et al, 2022).

Road maintenance serves the purpose of preserving the road asset, and needs to be done regularly and timely to be effective. Road maintenance is classified as either emergency, routine or periodic. Routine maintenance includes limited works carried out frequently, aimed at ensuring that the usability and safety of the road in the short-run is guaranteed, and to avert early decline of the road condition (PIARC 1994). Frequency of activities varies but is generally once or more than a week or month. Characteristic activities usually comprise of bush clearance, desilting of culverts and drains, pothole patching and repair, and grading and gravelling of gravel roads (Sally et al, 2005).

Periodic maintenance is aimed at preserving the structural integrity of a road section, and the encompassed activities are large scale, thereby needful of specific equipment and skilled workers. This type is costly, as compared to routine maintenance. The activities require precise identification and planning for design and execution, and they are classified as either preventive, resurfacing, overlay or pavement reconstruction. Emergency works are carried out for maintenance that is unforeseen, and necessitates urgent action (Sally et al, 2005).

Maintenance of roads is carried by either using labour or machinery, dependent on the type, severity, and extent of road distresses. Equipment is preferred on heavy and extensive maintenance procedures, whereas labour is used on small scale works that incorporate simple hand tools and light machinery (Berhane, 2023). When roads are constructed and opened to traffic, they incur functional and structural decline necessitating maintenance, as a result of excessive traffic loading and environmental effects (Yonghong eta al, 2019). With an expanding network and limited available funds, appropriate maintenance is vital to keep good serviceability of the roads and curtail costs of operation (Simoes et al, 2017).

The current study concentrated on roads completed under the three batches of phase two in central Kenya, in areas of Kiambu and Murang'a. The roads were completed on different times from 2011 to as late as 2019.

1.2 Problem Statement

The Roads 2000 program under phase two, which started in March 2011, has taken up more than Kenya Shillings 6.4 billion, most of it being donor funded investment. The phase two project was modelled on the phase one project but with a wider coverage, a larger budget and also put more emphasis on quality control and maintenance (KeRRA, 2018).

The main outputs of the phase two project as formulated were training of routine maintenance, gravelling and Low Volume Seal Roads (LVSR) contractors; training of public and private sector contract managers and supervisors; capacity building of KeRRA at Regional and National level; rehabilitation of 1,100 km of gravel roads; construction of 165 km of low volume sealed roads; maintenance of all phase one and phase two improved roads, and Maintenance of 6,000 km of roads within Kiambu, Murang'a, Kirinyaga, Nyeri, Laikipia and Nyandarua regions (KeRRA, 2018).

By the start of 2019, the roads under Batch 3 of the phase two were completed and handed over to KeRRA and County Government for maintenance. A review of the earlier completed roads shows that the transition to maintenance was not successful and most of the roads currently are in urgent need of maintenance intervention.

The maintenance fund managed by KRB is insufficient. Notwithstanding its ostensible gains, the Roads 2000 concept is not fully incorporated in regular maintenance programmes and remains to be donor driven. The prioritisation criteria in regional bodies in charge of maintenance of the roads is such that the roads that require the most attention are allocated the available limited funds. The completed roads under the R2000 program are usually left out in preference to the authorities opening up new roads. This means that the roads end up neglected and deteriorate fast.

In the current Kenyan practise, for the purpose of road asset management, maintenance and rehabilitation planning, it has become routine to carry out visual condition assessments of the road network at specified frequencies. The valuations typically look at the condition of the roads, classifying deteriorations such as cracking, rutting and pothole failures by their levels and spread, in a bid to prioritise and allocate funds for subsequent actions. Normally, attention is only given to the road carriageway area for assessment. More often than not, assessments on climate resilience and the application of suitable adaptation techniques to improve the climate resilience of the road infrastructure are not carried out. This is despite the fact the climate change has significant effect, predominantly on the low volume sealed roads serving rural populations. Comparatively to the trunk roads, the low volume sealed roads are made to lower standards using locally available materials and labour techniques, and are therefore more vulnerable to climate damage.

The low capacity of the regional bodies to control axle loading of the completed roads is a major hindrance to the completed roads meeting the designed life. Most of the roads completed by the program are important links to sources of raw construction materials, and access to agricultural areas and therefore end up carrying loading in excess of the expected loading.

1.3 Research Questions

This study seeks to answer the following:

a) Are the roads constructed under the Roads 2000 programme in Kiambu and Murang'a regions exhibiting good serviceability?

b) Is the priority for maintenance by the road authorities covering the completed roads under phase two in Kiambu and Murang'a regions objective?

c) Does the traffic loading exceed the limit for low volume roads, and are there axle loading mechanisms on the completed roads under phase two in Kiambu and Murang'a regions?

d) Are there suitable adaptation techniques in place to improve the climate resilience of the completed under phase two in Kiambu and Murang'a regions?

1.4 Objectives of the study

1.4.1. Overall Objective of the Study

The overall objective of the study was to investigate the performance of low volume sealed road pavements: a case study of Roads 2000 Strategy in Central Kenya

1.4.2. Specific Objectives of the Study

This study is aimed:

a) To establish the present serviceability of road pavements constructed under the Roads 2000 program in central Kenya.

b) To identify the factors that affect the priority for maintenance by the road authorities and county governments covering the completed roads under phase two in Kiambu and Murang'a regions.

c) To assess the axle loading and the extent of axle load control on the completed roads under phase two in Kiambu and Murang'a regions.

d) To evaluate the climate resilience of the completed low volume roads, in line with the adaptive measures for climate change in place.

1.5 Research Hypothesis

Road maintenance in Kenya is not given the priority needed to ensure roads meet their design life. In that scenario, many roads constructed under the Roads 2000 program exhibit low serviceability. The investment on the maintenance regimes, as supported by fuel levy, is controlled by other factors such as opening other roads in the network that get the first priority, at the expense of maintaining the already completed roads already in fair condition. In addition, axle loading control is an issue to the regional authorities receiving the roads upon construction completion, and this is due to low capacity, both in resources and manpower.

The design and construction of roads should be done while integrating the important aspects of climate adaptation where practical, notwithstanding the fact that it may not be achievable at all instances, and it is equally expensive. For completed roads, it is imperative to find out those that are not resilient to climate change, and prioritise them for implementation of adaptation measures. The precedence would be guided by: road classification, road purpose, number of affected people, and the existence of substitute routes. In order to put in place the necessary adaptation measures towards improvement of climate resilience and assist with the prioritisation, it is essential to conduct visual assessments, as an addition to the normal routine assessments for pavement and structures, of existing roads with specific attention being given to those issues explicitly associated with climatic effects.

This research was aimed at investigating the low volume roads in relation to the performance of the pavements, the maintenance priority, the traffic loading and level of axle loading in place, and to evaluate the climate resilience of the completed low volume roads, in line with the adaptive measures for climate change in place. Data that was collected included surface condition survey, roughness and rutting measurements, and rating of the present serviceably index, in addition to the visual assessment of the adaptive measures towards climate resilience. The analysed data informed on the conclusions and drawing of the recommendations.

1.6 Scope of the study

This research was limited to the roads undertaken within Kiambu and Murang'a regions of Kenya under the phase two of the Roads 2000 program. Data collected was limited to that in line with pavement performance and measurements aligned to deterioration, axle loading, maintenance prioritisation and testing of climate adaptation measures in place. The findings of the study were drawn solely from the field assessments and measurements, out of which the conclusions and recommendations were arrived at.

1.7 Justification of the Study

Successful pavement management practices require pavement condition data. A lack of maintenance accounts is a major challenge that face the pavement management process for local transportation agencies. Information related to climate resilience assessments and the implementation of appropriate adaptation techniques to improve the climate resilience of the infrastructure are normally not collected nor analysed. Review of performance of low volume roads in other regions showed that whereas the improved roads were having great impact on the recipient populace, the lack of adequate maintenance was in most cases leading to early failure of the completed roads, and inadequate drainage was a leading factor in the uncontrolled deterioration of these roads. The findings of this study will change the approach to maintenance, and the factors that affect prioritisation for maintenance. The general approach in data collection will be guided by this study, with a keen focus on the climate resilience of infrastructure.

1.8 Significance of the Study

This study will provide a guideline to policy makers and those in road authorities mandated with road maintenance in regards to fund allocation and prioritisation for maintenance. Data collected by the road authorities, guided by this research, will be objective and will ensure that the scarce resources are well utilisation to deter uncontrolled deterioration f completed roads. Further, the data collected will see to it that the road infrastructure has adaptive measures towards climate change.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The chapter presents information on the Roads 2000 Strategy, its evolution and implementation in Kenya, pavement design for low volume roads, including the use of theoretical models for determination of stresses and strains within individual pavement layers, research on performance of roads done using this method of construction both in Kenya and other locations. A conclusion of the review of recent and relevant publications is given at the end of the chapter.

2.2 Road Sector in Kenya

The road sector in Kenya is an important component of the country's economy. The sector is managed by the Ministry of Transport, Infrastructure, Housing, Urban Development and Public Works (MoTIHUD) who play the overall task of funding, coordination and regulation of the sector (KeRRA, 2015).

The definite administration of the road network is mandated to authorities under MoTIHUD:

(i) Kenya National Highways Authority (KeNHA) for the administration of the Class A, B and C major roads.

(ii) Kenya Urban Roads Authority (KURA) for the administration of all urban roads excluding Class A, B, C roads.

(iii) Kenya Rural Roads Authority (KeRRA) for the administration of all rural roads excluding Class A, B, C roads.

(iv) Kenya Roads Board (KRB) for the administration of maintenance funds for all public roads.

The Kenya Wildlife Services (KWS) is also a recognised road agency under the KRB act, in control of the administration of roads within the National Parks and Reserves. Subsequent to the promulgation of the new constitution in 2010, the County Governments were mandated to manage all County roads.

2.3 The Kenyan Roads 2000 (R2000) Strategy

Kenya has nearly 170,000 kms of road network in the country. Insufficient fiscal funds, administrative and operational systems with inadequate investment in maintenance has prompted the devaluation of the network, as well as increasing the vehicle operating costs that negatively impacts on the economy (KeRRA, 2015).

The inadequate condition of these road assets led the Government of Kenya to shift its emphasis from the construction of new roads to the maintenance and restoration of the existing road network using the maintenance strategy known as the Roads 2000 Strategy. R2000 concept as a technique of road construction and management warrants the optimal usage of locally available resources where technically and economically viable and in an environmentally receptive way (KeRRA, 2015).

The R2000 is a major initiative in this regard since it aims to improve the maintenance of road assets by presenting suitable technology on a road network basis for the careful rehabilitation, spot improvement and maintenance of prioritised links. KeRRA, in 2015, observed that the approach to Roads 2000 was characterised by:

(i) **The provision of rural road infrastructure through a prioritized approach,** which concentrates resources on areas which can deliver the greatest impact: This means that for low volume roads, the focus is on maintaining accessibility (ability of travellers and transporters to reach their destination throughout the year) and trafficability (ability of motorized vehicles to use a road throughout the year) rather than ride quality. Where there is more traffic, the focus shifts to providing levels of service that are appropriate for the particular traffic mix – such as Low Volume Seal roads. The approach requires detailed planning and agreement of priorities at local level, so consultation with road users and stakeholders is important. These priorities are then reconciled with the network as a whole, so that road links within the region and beyond are considered and any improvements extend the accessibility/trafficability of the network as a whole.

(ii) **Preference for labour-based road works:** Kenya has a long experience with labour-based road works, and this has demonstrated that earth and gravel roads can be rehabilitated and maintained to a comparable standard and quality as equipment-based technologies. Moreover, the employment generating effects of labour-based works has the potential to help address localized poverty and under employment as well as provide an opportunity for increasing the capacity of the local contracting industry.

(iii) **Stakeholder involvement in road selection and prioritization:** The involvement of local stakeholders in the selection process for rural roads is regarded as essential for the sustainability of the interventions and strengthening civil societies' involvement in road improvement decisions and the governance of maintenance resources.

(iv) **Research and Development into Sustainable Rural Roads:** The traditional approach of either providing gravel roads that require continuous re-gravelling or very expensive highway upgrading projects are not sustainable in the long run. An alternative approach of providing Low Volume Sealed Roads has therefore been researched and tried.

The strategic goal of the R2000 program is to bring the rural road network of Class D, E and Special Purpose roads including parts of the unclassified network to a maintainable standard and ensure that Kenya Roads Board (KRB) Road Maintenance Levy Fund (RMLF) resources are used to maintain the maintainable and recently improved road network. The R2000 strategy also envisages rehabilitation as a means of providing access as well as creating effective maintenance capacity at Regional/County level (KeRRA, 2015).

2.4 Roads 2000 Programme in the National Plan and Vision 2030

Kenya, in its vision 2030, purposes to transmute the country into a developing "middle-income country providing a high-quality life to all its citizens by the year 2030". Infrastructure is a key basis expected "to provide cost effective world-class infrastructure facilities and services in support of vision 2030" (MRPW, 2013).

In addition to roads being recognised as a requirement in improving the quality of life of both farmers and pastoralists, it advances security, and significantly contributes to decrease in cost of undertaking business. The development plan has identified the following infrastructure goals to be attained by 2030 (MRPW, 2013):

(i) Fast-tracking the development of quality and functional infrastructure;
(ii) Construction of infrastructural projects that have social equity and economic contribution;
(iii) Increasing infrastructure efficiency and effectiveness at planning, contracting and construction levels.

The R2000 programme was acknowledged in the first medium term plan (2008 – 2012) as a leading project during the time plan, with the aim of generating immediate labour-intensive hiring of people. The plans that were pursued included (MRPW, 2013):

(i) Consolidating the existing frameworks and fast-tracking their speed of execution. This consisted of increasing effectiveness and value.
(ii) Increasing homegrown content of recognised projects.
(iii) Modelling the infrastructure amenities with worldwide recognised standards.

(iv) Directing plans in then abandoned regions to upsurge connectivity and induce economic activities.

(v) Increasing the private sector involvement in delivery of infrastructure amenities and facilities purposefully complimented by public sector participation.

The R2000 programme is consequently pertinent in the Kenya's national plan and is vital towards the realisation of Vision 2030 (MRPW, 2013).

2.5 Roads 2000 Projects

2.5.1 The AfD/GoK Phase 1 Project

The AfD/GoK Phase 1 project was implemented in Nyandarua and Murang'a regions from 2007 to 2011 with an overall budget of 22 million Euro (Kshs 3.1 billion). The project met most of its objectives including training of contractors and supervisors, rehabilitation of 1,000 km of gravel roads and construction of a 6.7 Km low volume seal demonstration road (KeRRA, 2018).

2.5.2 The AfD/GoK Phase Two Project

In 2010 the Board of AfD approved a loan of €40 million to assist the Government of Kenya in developing its rural road network, to increase employment opportunities and wealth creation, and help reduce poverty in the central area of the country through the Roads 2000 Central phase two project covering Kiambu, Murang'a, Kirinyaga, Nyeri, Nyandarua and Laikipia regions. The Road Sector Investment Programme (RSIP), provided the sector framework within which this assistance was delivered. The Government of Kenya and AfD subsequently signed a financing agreement in which GoK provided four million Euro as development counterpart funding for road works, 11.4 million Euro for Maintenance and seven million Euro for taxes (KeRRA, 2018).

The phase two project was modelled on the Phase 1 project but with a wider coverage and a larger budget. The phase two project also put more emphasis on Quality Control and Maintenance. The main outputs of the phase two project as formulated were;

(i) Training of Routine Maintenance, Gravelling and Low Volume Seal (LVS) contractors.
(ii) Training of Public and Private Sector Contract Managers and Supervisors.
(iii) Capacity building of KeRRA at Regional and National level.
(iv) Rehabilitation of 1,100 km of Gravel roads.
(v) Construction of 165 km of Low Volume Sealed roads.

(vi) Maintenance of all Phase one and phase two improved roads.

(vii) Maintenance of 6,000 km of roads within the 6 regions

The road works under Phase two consisted of improvement works to gravel and low volume seal standard which were implemented by trained Labour Based Contractors in three batches of contracts. KeRRA, the implementing agency of the projects, procured two Design and Supervision Consultants (DSC) to support their Regional Managers (RMs). The two DSCs covered the projects of (i) Kiambu, Murang'a and Kirinyaga (Area 1) and (ii) Nyeri, Nyandarua and Laikipia (Area 2) (KeRRA, 2018).

The roadworks covered under phase two, which included batch one, two and three, both gravel and low volume sealed roads are as shown in Appendix A. A location map for the roads is shown in Appendix B.

2.6 Design of Low Volume Roads

These roads are taken as roads that have a design equivalent standard axle loading of maximum one million. Pavement design for such roads is carried out according to requirements of Pavement Design Guideline for Low Volume Sealed Roads manual (MoTIHUD, 2017).

2.6.1 Pavement Terminology

The pavement terminology as applied in low volume sealed roads is shown in Figure 2.1. The capping, also known as the improved subgrade, has a function of improving the insitu subgrade to the selected design foundation class (MoTIHUD, 2017).

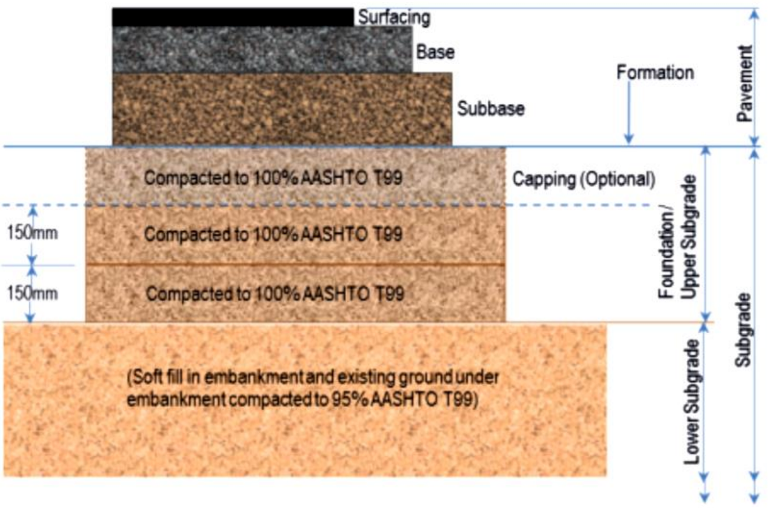


Figure 2.1: Pavement Terminology used in low volume sealed roads (MoTIHUD, 2017).
(MoTIHUD, 2017).

2.6.2 Design Traffic, Subgrade and Foundation Classes

For low volume roads, the design traffic loading classes are as given in Table 2.1. The traffic loading class T5-4 is normally for road pavements intended to have a gravel surfacing. However, the roads could be sealed when considered to be cost-effective. Some sections, for instance the steep gradients greater than 6%, may be sealed selectively. The subgrade and foundation classes used for these roads are given in Table 2.2 and Table 2.3, respectively (MoTIHUD, 2017).

Table 2.1: Design Traffic Classes (MoTIHUD, 2017)

Traffic Loading Class	Cumulative Equivalent Standard Axles
T5-4	< 25,000
T5-3	25,000 – 100,000
T5-2	100,000 – 250,000
T5-1	250,000 – 500,000
T5-0	500,000 – 1,000,000

Table 2.2: Subgrade Classes (MoTIHUD, 2017)

Subgrade Class	CBR Range (%)	Median
S1	2 – 5	3.5
S2	4 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	> 30	

Table 2.3: Pavement Foundation Classes and Stiffness Modulus (MoTIHUD, 2017)

Foundation Class	Surface Stiffness Modulus (MPa)	Minimum CBR (%)	Equivalent Subgrade Class
F1	65	10	S3
F2	90	14	S4
F3	125	23	S5
F4	250	30	S6
F5	400	80	

2.6.3 Typical Pavement Structures for Low Volume Sealed Roads

Typical pavements for low volume sealed roads are as given in Table 2.4 and options for surfacing are as given in Table 2.5 (MoTIHUD, 2017).

Table 2.4: Typical pavement structures: Low Volume Sealed Roads (MoTIHUD, 2017)

Catalogue No.	Material for Road Base	Material for Subbase	Applicable Traffic
LV1	G30 Material	Not Required	T5-3, T5-4
LV2	G50 Material	G25 Granular Material	T5-1, T5-2
LV3	G80 Material	G30 Granular Material	T5-0
LV4	HIG60 Material	Not Required	T5-3, T5-4
LV5	HIG100 Material	G25 Material	T5-1, T5-2
LV6	HIG100 Material	HIG50 Material	T5-1, T5-2
LV7	HIG160 Material	G30 Material	T5-0
LV8	HIG160 Material	HIG60 Material	T5-0
LV9	BESM 3 Material	G25 Material	T5-0, T5-1, T5-2
LV10	BESM 3 Material	G30 Material	T5-0
LV11	Hand Packed Stone	G30 Material	T5-0
LV12	Interlocking Cobblestone Pavement	G30 Material	T5-0, T5-1, T5-2
LV13	Interlocking Cobblestone Pavement	G30 Material	T5-0, T5-1, T5-2
LV14	Cement Concrete Pavement	G30 Material	T5-0, T5-1, T5-2

**LV1 – LV14 – indicates the 14No. pavement types provided by the Low Volume Design Manual*

**G 'X' – indicates gravel material of minimum CBR 'X'%*

**HIG 'X' – indicates hydraulically improved gravel material of minimum CBR 'X'%*

** BESM 3 Material – indicates bitumen stabilised material*

Table 2.5: Surfacing Options for Low Volume Sealed Roads (MoTIHUD, 2017)

Road base Material	Recommended Surface Treatment/ Prime	Recommended Surfacing Type
G30 Material	MC30	Cold Asphalt Concrete, Otta seal or Double Surface Dressing
G50 Material	MC30	Cold Asphalt Concrete, double Otta seal, Double Surface Dressing or Cape Seal
G80 Material	MC30 or MC70	Cold Asphalt Concrete, double Otta seal, Double Surface Dressing or Cape Seal
HIG60 Material	MC30	Cold Asphalt Concrete, double Otta seal, Double Surface Dressing or Cape Seal
HIG100 Material	MC30	Cold Asphalt Concrete, double Otta seal or Double Surface Dressing, Cape Seal
HIG160 Material	MC30	Cold Asphalt Concrete, double Otta seal, Double Surface Dressing or Cape Seal
BESM 3 Material	MC30	K1-60 tack coat and cold Asphalt Concrete, Single/Double Surface Dressing, or Cape Seal
Hand Packed Stone	MC70	Cold Asphalt Concrete, Asphalt Concrete type II or Bitumen Emulsion Stabilised Materials (BESM) plus Single/Double Surface Dressing
Cobblestone Concrete Paving Block Pavement	MC 30 or MC 70	Not Required

**MC30 – Medium curing cutback bitumen that takes 30 seconds to flow and fill a volume of 60ml on a viscosity test*

**MC70 – Medium curing cutback bitumen that takes 70 seconds to flow and fill a volume of 60ml on a viscosity test*

**K1-60– Tack coat K1-60 cationic bitumen emulsion is an emulsified asphalt containing minimum 57 % bitumen. It is water based, ready to use and conform to the requirements of BS 434: Part 1 and is applied in accordance with BS434: Part 2.*

2.6.4 Cold Mix Asphalt used Low Volume Sealed Roads

The cold mix asphalt for surfacing is a blend of uniformly graded aggregates and bitumen emulsion that is cold mixed and cold laid. For the emulsion, either a slow setting anion A3 or slow acting cationic K3 with minimum 60% residue binder content is used. The quantity of residue bitumen is typically 6.0 to 7.5% (MoTIHUD, 2017).

The mix normally has a void of 3% to 8%. When there are plenty of voids present, due to the mix design, then a mist spray of K1-70 and 0/6 mm aggregates are applied to seal the surface. In labour-based construction, the bitumen emulsion and aggregates are frequently mixed in pans and laid on the road using labour. Then the compaction is done by use of rollers to the point where the surface attains stability (MoTIHUD, 2017).

2.6.5 Theoretical Mechanistic-Empirical Modelling of the Pavements

The important components of the Mechanistic-Empirical Pavement Design Guide (MEPDG) method are (1) a mechanistic model to calculate the critical responses of the system, and (2) empirical performance or damage models that relate the critical responses to the accumulated damage and distress levels (Christopher, 2016).

Major steps of the MEPDG are: (a) selection of pavement structure (layers, type of materials, and thicknesses); (b) characterization of climate, traffic, and materials for the specific project location; (c) analysis of the mechanistic model of the pavement structure; (d) calculation of critical responses (stresses and strains); (e) evaluation of accumulated damage and associated distress with reference to preset criteria. The design may require several iterations considering different pavement structures. Design is completed when for a specific section, the distress levels do not exceed the acceptable levels for the design life of the structure (AASHTO, 2008).

The mechanistic-empirical method (M-E) of design and analysis is primarily based on the mechanics of the individual pavement materials (normally used in different layers) that relates inputs such as tyre load and contact stresses (as well as environmental stresses) to pavement responses such as stresses and strains (Huang, 1993). The schematic diagram of M-E design procedure is as shown in Figure 2.2.

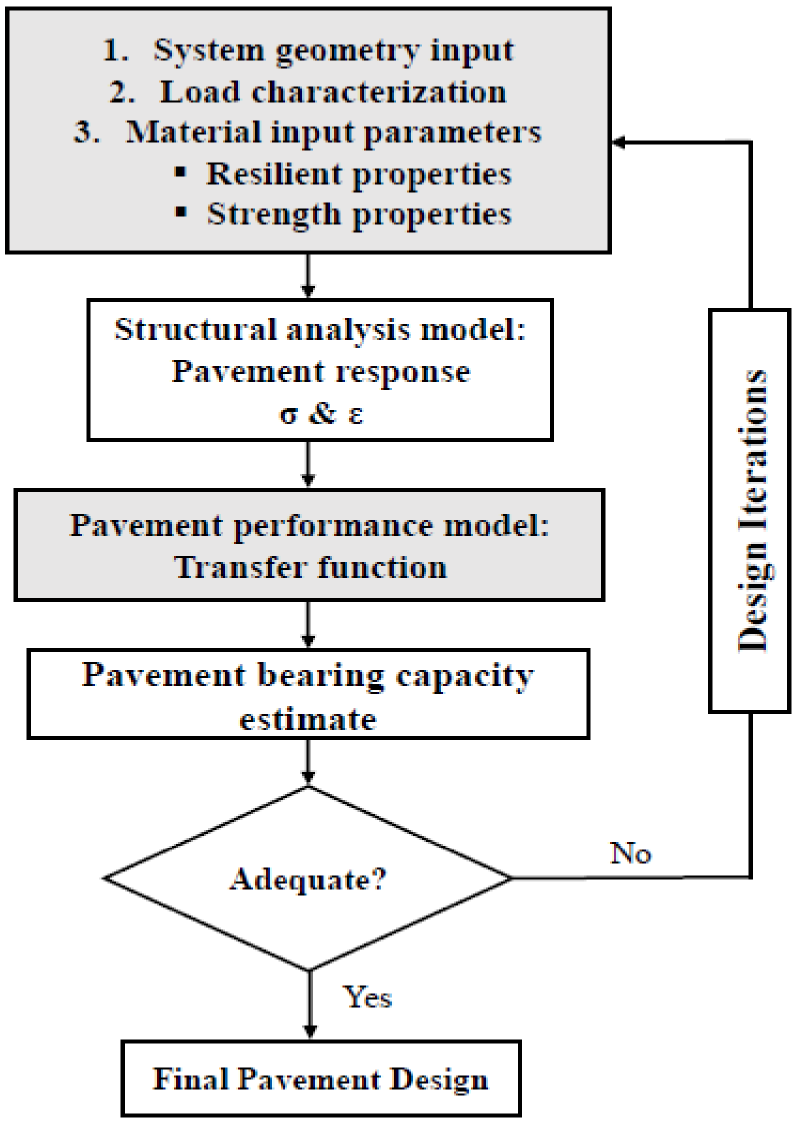


Figure 2.2: Schematic Diagram of a Mechanistic-Empirical design procedure (Theyse H. L. & M. Muthen, 2000)

The Mechanistic Empirical (M-E) design method uses a layered elastic theory model to calculate stresses and strains in the pavement structure, under a predefined standard axle load. The Mechanistic Empirical Pavement Analysis Design Software (mePADS) uses selected failure criteria (transfer functions) to relate the stress/strain condition to the number of pre-defined standard axle loads that can be sustained at that stress/strain level before a certain terminal condition in the pavement is reached. The transfer functions used in the analysis converts stresses and strains to number of axles (Theyse H. L. & M. Muthen, 2000).

The software requires design input such as layer thickness, material properties and layer stiffness (Resilient Modulus). The software (*me*PADS) contains a mechanistic-empirical design method, using layered elastic theory combined with South African transfer functions that is an adaptation of the Mechanistic Empirical Pavement Design Guide (MEPDG) of AASHTO 2002 and 2007 versions (Theyse H. L. & M. Muthen, 2000).

2.6.5.1 Software Input Parameters

Pavement Structure (Theyse H. L. & M. Muthen, 2000).

The Pavement Structure worksheet contains the following input boxes for defining the pavement system:

Number of Layers: defines the unique layers in the pavement structure. A maximum of 5 layers can be defined.

Material: Refers to the type of pavement material, according to the South African Material Classification in TRH4. Select the material type from the drop-down list.

- AC: Continuously Graded Asphalt Surfacing
- AG: Gap Graded Asphalt Surfacing
- C1 – C4: Lightly Cement Treated Materials
- G1 – G6: Granular Materials
- EG4 – EG6: Equivalent Granular Materials
- Soils: In-situ or imported Subgrade material
- BC: Asphalt Bases

Thickness: Layer thickness in mm. A rigid layer will be assumed to exist at the bottom of the last layer, unless a value of zero is specified, in which case the rigid layer will be assumed to exist at 1000 mm below the defined pavement. No provisions have been made for semi-infinite pavements.

E-modulus: The modulus of elasticity of the selected material in MPa. Suggested value will be displayed as default, when the material type is selected.

Number of Phases: defines the number of design phases to be considered in the analysis, as a result of the multi-phase nature of cemented materials. The number of phases in the analysis will be automatically selected depending on the number of cemented layers in the structure. This may be changed if a different number of phases in the analysis are required. Remember to also provide the Material codes, E-moduli and Poisson's ratio for each of the phases.

Climatic Region: Refers to rainfall region.

Road Category: Defines the design reliability:

- A: 95 % reliability
- B: 90 % reliability
- C: 80 % reliability
- D: 50 % reliability

Terminal Rut: Failure rut-depth criteria for Subgrade rutting.

Design Traffic Class (in standard axles)

- ES 0.003: 0 to 3 000
- ES 0.01: 3 000 to 10 000
- ES 0.03: 10 000 to 30 000
- ES 0.1: 30 000 to 100 000
- ES 0.3: 100 000 to 300 000
- ES 1: 300 000 to 1 000 000
- ES 3: 1 000 000 to 3 000 000
- ES 10: 3 000 000 to 10 000 000
- ES 30: 10 000 000 to 30 000 000
- ES 100: 30 000 000 to 100 000 000

Loads and Evaluation Points (Theyse H. L. & M. Muthen, 2000).

Design Location: The point at the pavement surface where the pavement design is to be carried out.

Load definition: The number, magnitude (kN & kPa) and position of wheel loads. At least 1 load must be defined.

Stresses and Strains: The location in the pavement for evaluating stresses and strains. This analysis will be done independently from the bearing capacity analysis and the results are reported on the "Stresses and Strains" worksheet.

Load Position Plot: shows a plan view of the loads defined in the system. Press the Update Plot button to refresh the plotted loads.

Design Parameters (Theyse H. L. & M. Muthen, 2000).

The stress and strain parameters at critical points in the pavement are displayed on this worksheet. These parameters are used in the bearing capacity calculations. The parameters and critical points vary for different material types as follows:

Asphalt Layers: The horizontal tensile strain at the bottom of the layer controls the fatigue life of the layer.

Cemented Layers: The horizontal tensile strain at the bottom of the layer controls the fatigue life of the layer, while the vertical compressive stress at the top of the layer defines the crushing life.

Granular Layers: The principal stresses at the middle of the layer controls the shearing capacity of the layer.

Soil (Subgrade) Layers: The vertical compressive strain at the top of the layer controls the rutting life of the layer.

2.6.5.2 Software Output Parameters (Theyse H. L. & M. Muthen, 2000).

Pavement Life: The worksheet displays the main design outputs of the software. The worksheet will only become visible once a successful design has been completed after the Calculate button has been clicked

Layer Bearing Capacity: The bearing capacity (in terms of the defined load) of the layers at the selected design reliability is shown in the table and the figure. The design traffic class (in terms of Standard Axles) is also shown as lines on the bar chart. The bearing capacity is calculated using transfer functions, specially formulated for the material type. Certain materials, such as asphalt, have various transfer functions depending on the thickness and grading.

Approximate Pavement Life Distribution: The distribution of pavement lives obtained by varying the design reliability input in the transfer functions.

Crushing in cemented layers: The bearing capacity of the cemented layers with respect to failure by crushing.

Cemented Life: The effective duration of the cemented life phase of the cemented layer.

Calculation Table: Provides the transfer function outputs for a selected design reliability. This functionality is provided so that detailed information on the calculation procedure can be viewed. Select the desired reliability level and view the results in the table.

Contour Plot: Provides a contour plot of the selected stress or strain parameter for a region in the pavement, on a vertical or horizontal plane. The desired plot region, plane and parameter can be selected, and clicking on the plot button will generate the plot.

2.6.6 AASHTO Flexible Pavement Structural Design

Empirical equations are used to relate observed or measurable phenomena (pavement characteristics) with outcomes (pavement performance). Equation 2.1, based on the 1993 AASHTO Guide for flexible pavements, is widely used (FDOT, 2024).

$$\log_{10}(W_{18}) = Z_R S_o + 9.36\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.4+\frac{1094}{(SN+1)^{5.19}}} + 2.32\log_{10} M_R - 8.07 \quad \text{……Equation 2.1}$$

Whereby;

W_{18} = traffic loading (ESALs);

Z_R = standard normal deviate;

S_o = standard deviation;

SN = structural number;

ΔPSI = change in present serviceability index; and

M_R = resilient modulus of subgrade in pound per square inch (psi).

The structural number is an abstract number expressing the structural strength of a pavement required for given combinations of soil support (M_R), total traffic expressed in ESALs, terminal serviceability and environment. The structural number is converted to actual layer thicknesses (D) using a layer coefficient (a) that represents the relative strength of the construction materials in that layer. In addition, all the layers below the bituminous surfacing layer are assigned a drainage coefficient (m) that represents the relative loss of strength in a layer due to its drainage characteristics and the total time it is exposed to near-saturation moisture conditions. Equation 2.2 is used to compute the structural number (FDOT, 2024).

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2.2}$$

Where;

SN = Structural Number;

a_i = i[th] layer coefficient;

D_i = i[th] layer thickness (inches), and;

m_i = i[th] layer drainage coefficient.

The 1993 AASHTO Guide equation requires a number of inputs related to loads, pavement structure and subgrade support. These inputs are (AASHTO, 1993):

(a) **The predicted loading.** The predicted loading is simply the predicted number of 80 kN ESALs that the pavement will experience over its design lifetime.

(b) **Reliability.** The reliability of the pavement design-performance process is the probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental conditions for the design period. The Z_R and S_o variables account for reliability.

(c) **Pavement structure.** The pavement structure is characterized by the Structural Number (SN).

(d) **Serviceable life.** The difference in present serviceability index (PSI) between construction and end-of-life is the serviceability life. The equation compares this to default values of 4.2 for the immediately-after-construction value and 1.5 for end-of-life (terminal serviceability).

(e) **Subgrade support.** Subgrade support is characterized by the subgrade's resilient modulus (M_R). Intuitively, the amount of structural support offered by the subgrade should be a large factor in determining the required pavement structure.

The 1993 AASHTO Guide equation can be solved for any one of the variables as long as all the others are supplied. Typically, the output is either total ESALs or the required Structural Number (or the associated pavement layer depths). This solution method is an iterative process that solves for ESALs in both equations by varying the Structural Number (FDOT, 2024).

2.7 Project Management of Roads 2000 Strategy Projects

2.7.1 Improvement Projects

Roads 2000 is the government's routine maintenance approach to the entire classified road network in Kenya. The aim is to carry out most of the activities by use of resources available locally, such as contractors, materials, labour and equipment (Road Department, 2005).

However, most of the unpaved roads have a considerable build-up of maintenance work. In most cases the drainage system is not functioning and the road surface is defective. Routine maintenance operations using labour and/or equipment can only be effectively carried out if these roads are first brought to a maintainable standard. This is achieved through a partial rehabilitation exercise. Spot improvement activities are also required to solve serious problems that often occur on particular trouble spots, like washouts, landslides and flooding (Road Department, 2005).

For carrying out partial rehabilitation works, three principal approaches are possible depending on a number of criteria. The first approach, using labour alone, is suitable for roads harbouring low traffic levels, and where adequate local labour is readily available. The initial labour team establishes the road centre line, sets out the road formation and reserve width, and clears bush and grass from the road reserve. The subsequent labour team excavates the side drains and formation of the road camber. Roller compacter is utilised to achieve the needed compaction effort. The third labour team carries out the opening of mitre drains, cross water drains and construction/replacement of culvert lines (Road Department, 2005).

The second approach, using equipment and labour, is suitable for roads harbouring high traffic levels and where adequate local labour is readily available. The initial labour team establishes the road centre line, sets out the road formation and reserve width, and clears bush and grass from the road reserve. The subsequent team consists of motor graders and forms the road camber. The grader however does not cut the drains. Towed or self-propelled rollers re utilised to achieve the required compaction effort. The third labour team carries out the opening of mitre drains, cross water drains and construction/replacement of culvert lines (Road Department, 2005).

The third approach, which mainly uses equipment, is suitable for roads where adequate local labour availability is a problem. The initial labour team establishes the road centre line, sets out the road formation and reserve width, and clears bush and grass from the road reserve. Majority of the clearance is carried out by equipment, and only minor works are done using labour. The subsequent team consists of motor graders to excavate/clean the side and mitre drains and to form the road camber. The final team, mostly labour, takes care of other drainage works, that includes installation of scour-checks, culverts cleaning, and repair or construction of new culvert lines (Road Department, 2005).

2.7.2 Project Organisation

The phase two projects of the roads 2000 program were managed by two consultants: the Design and Supervision Consultant (DSC) and the Management Support Consultant (MSC). Both consultants work hand in hand with the respective KeRRA regional offices.

a) Design and Supervision Consultant

The role of the design and supervision consultant was to enhance the supervision capacities in the KeRRA project regions. The consultant provided technical support to the regional managers, to certify that the road network is constructed to the required quality. Additionally, the consultant assisted in building the capacity of the regions and impart technology transfer (KeRRA, 2015).

b) Management Support Consultant

The Management Support Consultant (MSC) assisted KeRRA in managing and implementing to completion the Roads 2000 Central Phase 2 project. The activities of the MSC team were directed at building management capacity within the KeRRA regional offices and to a lesser extent to the county government road staff within the project area (KeRRA, 2015).

Capacity building was undertaken within the framework of KeRRA's evolving management strategy, and further developed its regional offices as rural road management agencies for their constituencies. The MSC team assisted and carried out peer review of the design and implementation of management systems, contract preparation and procurement of services and works as well as assisting with training programmes covering the needs of KeRRA regions, its Design and Supervision Consultant (DSC) and Contractors, County Government Road staff and to lesser extent to KeRRA head office (KeRRA, 2015).

The MSC ensured that management skills and supporting technology and systems were transferred and installed and were used to deliver the works component in a timely, cost-effective manner. The MSC team also monitored and evaluated the constructed low volume seal roads and other alternative construction methods and through this exercise improved the regional materials' laboratories and provided input to improved low volume seal design and construction manuals and guidelines (KeRRA, 2015).

2.7.3 Enabling Environment

Roads 2000 implementation also meant a shift from force account (government execution) operations to using the private construction sector for work execution. The government's role was to maintain overall control over public projects and funds and to provide an enabling environment for the private sector to operate effectively and profitably. The private sector's role was to execute efficient and cost-effective quality work for the public (Road Department, 2005).

In Kenya, the private construction sector is well developed for the execution of large-scale projects for the Government. However, locally based emerging and small-scale contractors find it difficult to enter the construction market. Traditionally most government contracts in the road sector are large and demand from contractors the fulfilment of preconditions that small-scale and emerging contractors can never meet, for instance equipment owning, capital holding, insurance bonds and guarantees.

One of the objectives of Roads 2000 was to facilitate the participation of small-scale contractors in road works. Routine maintenance and improvement works are particularly suited to involve locally based contractors. Relatively little capital was required to enter the market. The Roads 2000 Programme prepared consultants and contractors for their involvement through a dedicated training programme. Through this training, and the work opportunities offered by Roads 2000, small-scale contractors were able to establish a good starting platform for further development and gaining access to other construction market segments (Road Department, 2005).

2.8 Performance Evaluation in Low Volume Sealed Roads

Flexible pavements deterioration is normally brought about by actions of traffic and climate. The deterioration is exhibited by (a) reduction in skidding resistance, as a result of polishing of the surfacing stone; (b) surface texture loss, leading to a reduction of skid resistance; (c) surface deformation as a result of traffic loading; (d) cracking and surface deterioration as a result of binder oxidation; and (e) foundation fatigue strain, that results in structural deterioration (O'Flaherty, 2002).

Performance can be evaluated by collecting data on/and analysing the road condition. Highway condition needs to be monitored effectively and in ways that minimize disruption to the road users. Therefore, condition survey plans should apply quick, first-pass, survey methods to acquire an indication of the condition of the pavement. The regularity of the surveys is informed prior information regarding the pavement's condition and age. The rapid survey outcome determines the essence for, and frequency of, detailed surveys to establish if and what type of maintenance treatment is needed. Additional investigations may comprise of material analysis to precisely establish the exact treatment (O'Flaherty, 2002).

For low volume sealed roads, three methods are normally used to carry out condition survey: (i) Average Speed (ii) Road Inventory and Condition Survey (RICS), and the (iii) Present Serviceability Rating (PSR).

2.8.1 Average Speed Method

In this method, the average speed from the start to the end of the road is measured and the road condition is reported as three different types as shown in Table 2.6. Prior to the start of the run, a trial is done to calibrate the vehicle and orient the driver on the road conditions, and for awareness of the existing environmental conditions (Mariano et al, 2022).

Table 2.6: Average Speed Method (Mariano et al, 2022)

Average Speed	Road Condition
< 30 kms/hr	Poor
30-45 kms/hr	Fair
>45 kms/hr	Good

The survey is undertaken on each road twice a year (during the dry and wet season) and the average figure reported as the road condition for the year.

The average speed method enables the survey to be done quickly (estimated 100-150 kms/day depending on the location and state of the roads). The method is cheap due to speed of data collection and simplicity as only one vehicle is required to undertake the survey. The method is particularly focused on the needs of the road user who is mainly interested in the time taken to travel along the road (and not the various maintenance defects) (Mariano et al, 2022).

The method is also considered a fairly accurate assessment of the state of all elements of the road including the side drainage. It is based on objective data, that is the time taken to travel the length of the road and therefore minimises personal opinions as to the road condition (Mariano et al, 2022).

However, the method does not measure any major defects along the roads (other than what can be deduced by the average speed), although as the trend towards performance-based contracts is increased major defects in the drainage system and road pavement should be minimised so as to make average speed more accurate as an indicator of road condition (Mariano et al, 2022).

2.8.2 Road Inventory and Condition Survey (RICS)

This method has a number of forms to be filled so as to give enough information of the road. The road condition is assessed as well as the need for spot improvements and repair of drainage structures. The road surface condition is assessed at 200m intervals stating the road surface, the drainage structures along the road and the sections requiring spot improvement (KRB, 2009).

Good experience on roadworks is required of the raters. The average rate of deterioration is used to determine the type of road condition as given in Table 2.7 (KRB, 2009).

Table 2.7: Point Scale for Visual Condition Rating (KRB, 2009).

Average Deterioration	1	2	3	4	5
Road Condition	Excellent	Good	Fair	Poor	Very Poor

For a road to receive an Excellent (1) rating, it is new looking, in a good maintenance condition and completely functional. A Good (2) rating specifies that the road is in an almost new condition, and requires only some slight maintenance work. At a Good rating, the road’s serviceability, functionality and capacity is expected to have reduced by a maximum of 10 percent. A Fair (3) rating shows that the road is demonstrating sporadic signs of distress that are instigating a conspicuous reduction in serviceability, functionality and capacity, of between 10 and 25 percent. At a Fair rating, a considerable maintenance or repair effort is needed (KRB, 2009).

A Poor (4) rating shows that the road is displaying recurrent signs of distress, thereby reducing serviceability, functionality and capacity of the road significantly, in the range of 25 to 50 percent. At a Poor rating, significant maintenance or reconstruction is required to restore the road. A Very Poor (5) rating specifies that above half of the road is past the restoration condition by routine maintenance and reconstruction or replacement is essential (KRB, 2009).

2.8.3 Present Serviceability Rating (PSR)

This procedure involves determination of present serviceability rating of a road section based on visual condition survey conducted through walking or windscreen inspection. The trained raters of the road section are required to observe its riding quality and defects and record impressions on a standard form. Rating varies from “0” (Very poor) to “5” (Excellent). The lower ratings give an indication of poor surface conditions and calls for a detailed examination of the pavement. The PSR is employed as an initial step in assessing the pavement adequacy. Each individual rating should be an overall opinion or impression of the pavement’s present serviceability, based upon the past experience and training of the rater (Kenya Road Department, 1988).

The rules and procedure for determining the PSR are:

(i) Only the present condition of the surface should be considered, and therefore a pavement may be rated ‘good’ even though it is highly suspected that it has an imminent possibility of failure;

(ii) The fact that the road pavement is meant to harbour mixed traffic under all types of weather conditions rating should guide the rating;

(iii) The geometric characteristics (alignment, carriageway and shoulders width) of the section of the road being rated should be ignored;

(iv) The rating should be concerned primarily with longitudinal and transverse distortion of the surface, potholes, bumps, cracking and patching;

(v) The rater needs disregard isolated conditions, such as bumps owing to settlement at culverts and bridges, rough railway crossings;

(vi) In rating a series of pavement sections, each section should be rated independently.

Ratings of 0 to 5 are assigned to each criterion with a higher number indicating more satisfactory condition. The rating form and the rating criteria are shown in Appendix C. One such form is required for each rater for each section. Immediately after driving over the section, the rater should note the main factors influencing the rating, without weighing them and assign a rating to the pavement by assigning value to each of the twelve criteria given (Kenya Road Department, 1988).

2.9 Maintenance of the Low Volume Sealed Roads (LVSR)

Maintenance is a key activity for low volume sealed roads, and the type and cost of maintenance is heavily reliant on the decisions made during their planning, design and construction phases. Appropriate maintenance activities have a bearing on the preservation of these roads, in addition to extending their intended service life. Deprived of sufficient maintenance, these roads will rapidly deteriorate, become a danger and costly to the users, and eventually, the negative impacts to the economy are considerable (SADC, 2003).

2.9.1 Deterioration Characteristics

Road deteriorates with time, regardless of the standard of construction. The extent at which they deteriorate varies depending on climate, subgrade and pavement strength, volume of traffic and axle loading. The deterioration of road surface by traffic is heightened by runoff and by changes in temperature. Cracking arises in the bituminous surfacing, and with water ingress, the pavement fails (SADC, 2003).

With time, all roads deteriorate. LVSRs are however more sensitive to the changes in the physical environment and timely and efficient control of their deterioration is very critical. The Figure 2.3 illustrates the relationship between deterioration and time, and the service life of a road can be prolonged through maintenance (SADC, 2003).

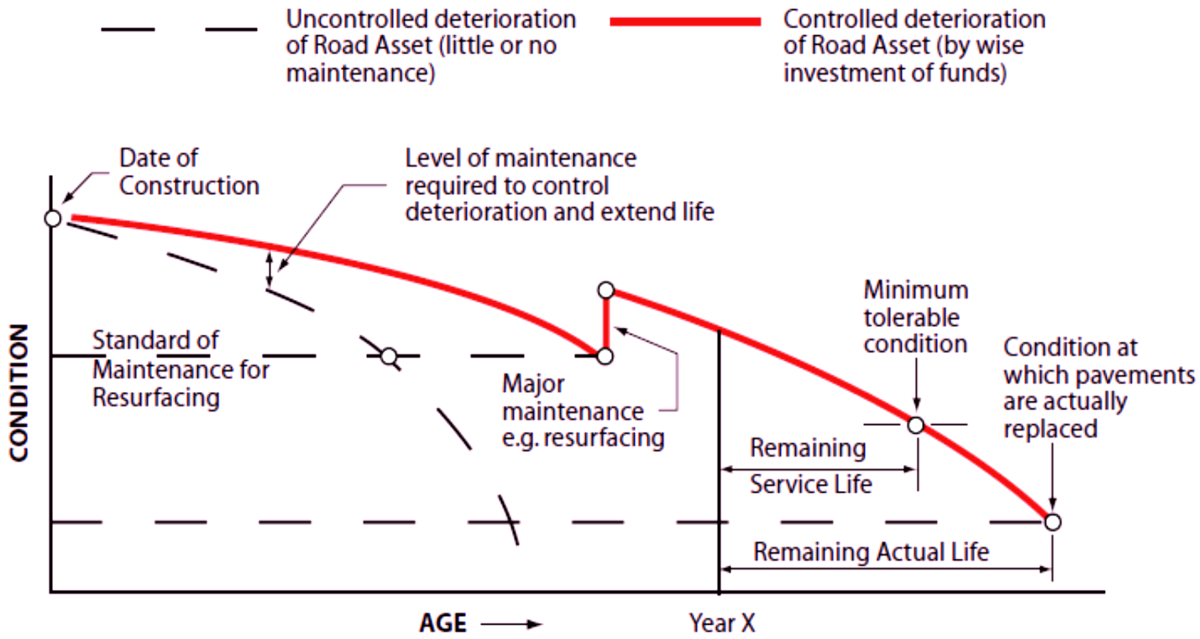


Figure 2.3: Typical Road condition deterioration with time (SADC, 2003).

2.9.2 Traffic Loading and Environmental Factors in Relation to Low Volume Road Deterioration

In 2013, a study conducted by Henning et al in New Zealand to determine the relative damage brought about by the heavy traffic loading alone in comparison to the joint effect of loading and environmental impacts. A cluster analysis was carried out, with the objective of understanding how the low volume pavements had deteriorated under different traffic and environmental conditions.

The research found out that roads rut 0.1 mm/year quicker in wet climates and areas with sensitive in-situ soil conditions. The study noted that presence of drainage in good condition was more significant than just the environmental conditions alone. The gathered data informed that the rutting of LVSRs was 2.5 times high on poor drainage sections in comparison to sections where adequate drainage existed (Henning et al, 2013).

2.9.3 Effect of Traffic and Environmental Factors on Roughness Progression Rate of Sealed Low Volume Arterials

In 2015, Alaswadko et al conducted a study to develop an empirical deterministic roughness prediction model for managing low volume rural roads in Australia. The study approach involved collection of road condition data (roughness), data preparation process and model splitting (model development and model validation). Multiple regression analysis was employed to develop a roughness model for the data, and included three phases: initial, gradual and rapid deterioration. The gradual phase was the only one considered (Alaswadko et al, 2015).

The study concluded that traffic loading and soil reactivity were key forecasters of pavement roughness progression. Road segments with subgrade built on expansive soils were connected with high roughness values and progression rates in comparison with those with soils that were not expansive. Expansive soils are sensitive to moisture fluctuations. Road segments in dry areas display high roughness progression as compared to those in wet areas, notwithstanding the type of subgrade soil reactivity (Alaswadko et al, 2015).

2.10 Road Maintenance Program in Kenya

In Kenya, the Kenya Roads Board (KRB) holds the mandate for funding, oversight and coordination of road maintenance, rehabilitation and development by optimally utilizing resources towards a sustainable road network (KRB, 2018).

KRB was established in 1999 to manage the Road Maintenance Levy Fund (RMLF) and Transit Tolls, a sustainable source of funding for the maintenance of the road network. Each year, KRB funds the maintenance of the road network by using the Kenya Roads Board Fund (KRBF). The monies are disseminated among the road agencies mandated with maintenance. KRB analyses, independently, the Annual Road Works Programmes (ARWPs) submitted by the road agencies and combine these ARWPs into an Annual Public Roads Programme (APRP), that guides the splitting of funds on prioritised works (KRB, 2018).

In addition, the APRP offers a strategy for road maintenance in subsequent years, gives a basis for disbursement of funds and a foundation for monitoring of the utilization of the fund by the agencies. The document is issued annually and is availed to the stakeholders, thereby enhancing transparency and responsibility. The fuel levy is distributed to the road agencies in the basis of the legislated formula of forty percent to KeNHA, twenty two percent to KeRRA, ten percent to KURA, one percent to Kenya Wildlife Services (KWS) and fifteen percent to County Governments (KRB, 2018).

Table 2.8 shows the funds received by KeRRA and County Governments for maintenance over five years from 2018 to 2014. The two agencies cover the areas that the R2000 program had completed projects.

Table 2.8: KRB Funding to KeRRA and County Governments (KRB, 2018).

Road Agency/ Financial year	Approved Amounts in APRP				
	2018/19 (Kshs)	2017/18 (Kshs)	2016/17 (Kshs)	2015/16 (Kshs)	2014/15 (Kshs)
KeRRA	12,427,801,418	11,438,297,872	10,893,617,021	9,188,761,519	3,835,276,968
County Governments	8,269,000,000	7,875,000,000	7,500,000,000	3,3000,000,000	-

2.11 Performance Based Routine Maintenance

Traditional road construction contracts have been in use for many decades despite a significant drawback: they are founded on the quantity of work implemented, which can create the wrong incentive for some contractors to maximize profits by inflating the volume of work. Additionally, construction contracts don’t take long-term maintenance into account, which can result in substandard road conditions and a lack of accountability. This approach can lead to inefficiencies, higher costs, and a misalignment of incentives between governments and contractors. The end result is that the road users will end up with high operating costs (The World Bank, 2022).

The development of Performance Based Contracts (PBCs) started some ten years before the tun of the 21st century. This type of contracting was introduced in North America, and used to contract out maintenance of roads to the private sector by setting some performance levels to be attained in the course of routine maintenance. Consequently, some countries in South America began to contract out most of their trunk roads by use of performance levels for maintenance works, with a consequence charge for not meeting the set times for remedying road failures. Over the years thereafter, PBCs have been adopted worldwide, as they were found to deliver better value for money than traditional contracts, as well as ensuring better road conditions (ADB, 2018).

In their study, Prasad et al studied the use of PBCs for maintenance. PBCs were compared to conventional contract types, and the study also evaluated their effect on cost savings, benefits on users, quality of maintenance achieved, covering Zambia, Brazil, Argentina, Sri Lanka, and Indonesia. The study observed that PBCs achieved scored in the improvement of road quality and increased the occurrence of maintenance operations. PBCs also led to lower costs when compared with conventional contracts (Prasad et al, 2022)

At procurement of PBCs, the service providers compete amongst one another, by offering fixed costs per unit length per month for rehabilitating the road to the needed service levels, and then sustaining them for a stated timeline. During implementation, the contractor's payments are based on measured productivities commensurate to the stated target conditions of the contracted. In addition, a monthly lumpsum payment is made to the contractor to cater for all physical and non-physical maintenance activities undertaken, save for unanticipated emergency works. The client is additionally able to add to the scope of the contractor essential rehabilitation activities to bring the road up to the pre-stated condition, and for such works, the contractor is compensated at unit charges using standard bills of quantities (JICA, 2016).

Service levels go together with response times and the allowable tolerance. Service levels are set appropriately by consideration of road function, capacity of the contractor, volume of traffic, climate and type of road surface. The service levels should neither be set too low nor too high. The purpose of level setting is: (i) to provide a typical method of setting the scope, response times and acceptable tolerances of the service level, and (ii) to settle on different sets of service levels dependent on the road type and the volume of traffic on the road (JICA, 2016).

PBCs provide better ride quality to the road users in comparison with the conventional contracts. The contracts hold a likely economic advantage owing to reduced maintenance cost in the long run. Moreover, in consideration of the social and economic losses due to ill maintained roads, PBC offer substantial benefits. In addition, PBCs permit the service providers to exploit innovation since the concept shifts the procedure and regularity of maintenance activities from the project owner to the contractor (JICA, 2016).

Zietlow (2017) highlighted the learnt lessons in the execution of the PBCs in several jurisdictions and observed that by shifting from conservative maintenance contracts, based on similar levels of service, between 20% and 30% savings had been attained. The study also noted that better competition among competent and innovative contractors, long-term contracts, and harmonising of risks between the project owner and contractor were the leading factors for cost savings (Zietlow, 2017).

Gelderman et al (2019) investigated PBCs in Netherlands, finding issues that lead to poor contractor performance. The study observed that contracting out road maintenance created many challenges and multiple risks induced by PBCs. It was suggested that a good awareness of the diverse risks would improve the ability to successfully manage maintenance PBCs. Specifications related to the road are normally not well expounded into technical provisions by the contractor, in line with the intent of the project owner. The efficiency of the incentive compensation method is another serious subject in using PBCs (Gelderman et al, 2019). During the formulation of incentive plans, the project owners need to put into consideration inadvertent effects as well as desired performance (McDonald et al, 2009).

Mostafa, in 2018, investigated the road maintenance in Africa, its tactics and outlooks. The study observed that the road maintenance's effort in most African countries was significant, but these efforts were meagre in comparison to those of other developing nations in the world. The study recommended integration of maintenance into infrastructure and sector policies, consideration of establishing of road fund concept, incorporation of PBCs for maintenance works, and participation of public-private partnership business concept (Mostafa, 2018).

Mulmi, in 2016, undertook an assessment of performance-based road maintenance practices in Nepal. The study observed that most of the maintenance work was founded on the conservative quantity and unit price based short term maintenance contracts, where maintenance of physical works was outsourced. Here, the project owner prescribed to the contractor which activities were to be carried out, the timeline and the scope of the work. The study reported that a trial had been undertaken, based on PBCs, in 2003. Comparison of the maintenance cost based on the conventional practice and PBCs was carried out, and the cost comparison showed that PBCs led to more cost savings (Mulmi, 2016).

2.12 Axle Load Monitoring

The low volume sealed roads experience deterioration typically by rutting, owing to their structural layers being granular in nature. With time, their pavements completely fail, and become impassable, as a result of excessive rutting, and this requires costly reconstruction. In principle, the most proximal cause of rutting in pavements is overloading (Dawson et al, 2008).

All roads are designed to bear certain traffic loading over their design lives, and therefore, the applied axle loads have a huge bearing on the damaging effect to pavements. In order to protect the roads from premature failure as a result of excessive loading, Axle Load Controls (ALC) in Kenya have been in operation from the 1970s. ALC is carried out by KeNHA at the nine static weighbridge sites (Juja, Webuye, Rongo, Busia, Isinya, Mtwapa, Mariakani, Athi River and Gilgil) on the Mombasa-Nairobi-Malaba Road, Kisumu-Busia Road and on other International and National trunk roads. There are five weighbridge clusters, namely Mariakani/Mtwapa, Athi River/ Isinya/Juja, Gilgil, Webuye and Busia/Rongo. On each cluster the adjacent road network is managed through a mobile weigh scale (KRB, 2019).

In addition, KeNHA were establishing virtual weighbridge stations at selected points including Ahero and Maai Mahiu. In April 2018, a special police unit was formed to assist KeNHA in Road Asset Protection and Axle Load Enforcement. KURA and KeRRA also carry out random axle load monitoring on their network by use of the mobile weighbridges (KRB, 2019).

In December 2014, KRB concluded a two-year ALC monitoring study. From the study, several positive improvements in ALC were noted; reduction of overloading to less than 20%, enhanced efficiency of KeNHA weighbridge operations through outsourcing, reduced congestion and queuing times at the weighbridge stations with the utilisation of the High-Speed Weigh-in-Motion. In addition, the passing of the East African Community Vehicle Load Control Act 2013 (EAC VLC) was expected to improve trade facilitation in the East Africa region (KRB, 2019).

Kenya Roads Board carried out in-house periodic studies between 2015 and 2018 to independently monitor the effectiveness and compliance levels of axle load control procedures. Several critical weaknesses were noted: low compliance on individual axles (less than 50%), most of the overloaded trucks carry containerized cargo and sand trucks, overloading was more prevalent on links which are currently not being regularly monitored on the paved rural and urban networks and recommendations to decriminalize ALC under EAC VLC has not been implemented. Notable discrepancies were also noted in ALC statistics between KRB/ KeNHA which could have arisen from high percentage of un-diverted heavy goods vehicles as not all are diverted by police for weighing at the weighbridge stations (KRB, 2019).

Another emerging issue which impacts on ALC is devolution. In 2010, Kenya implemented a devolved system of government which introduced two levels of government; National Government and County Government (47 No.). Under the Constitution, the management of county roads was transferred to the county governments. In February 2016, a gazette notice was released that gave rise to Kenya Roads Register, categorizing National Roads and County Roads. Most of the manufacturing and agricultural production centres are located along county roads and hence there is need to support county governments to manage ALC (KRB, 2019).

2.13 Condition of Completed Projects in Kenya

2.13.1 Socio-Economic Baseline Study, 2018

Kenya Rural Roads Authority (KeRRA) (2018) conducted a Socio-Economic Baseline Study on selected sections of roads completed under Batch 3 Phase 2 program. The main objective of the study was to provide information base against which to monitor and assess the current transport and socio-economic situation in the study area (KeRRA, 2018).

On the gains of the program, the study noted that accessibility was enhanced in project locations as roads became passable all over the year. That meant larger goods and passenger transport, where significant decrease time of travel was noted. The volume of traffic was noted to grow by up to 30%, including a threefold increase in volume of motor cycles. In addition, farm gate prices of cash crops increased while extraneous travel reduced. School enrolment and attendance to the health centres also increased (KeRRA, 2018).

However, on the serviceability of the roads, out of the 28 sections sampled, 16 were found to be due for improvement. It was noted that the great majority of the roads at 79% are either poor or bad. In Kiambu Region, 5 of the roads at 73% were either poor or bad. For Nyeri 50% and

75% Kirinyaga of the roads were either bad or poor. Quite significantly, all 4 (100%) roads in Laikipia were either poor or bad. The conclusion was that all the roads required urgent intervention (KeRRA, 2018).

2.13.2 Baseline Survey for 11 Low Volume Sealed Roads, 2017

Kenya Materials Testing and Research Division (MTRD) (2017) investigated eleven trial road sections to evaluate the performance of the non-standard pavement construction materials used on those trial roads. The studied roads were located in Nyandarua, Murang'a, Kiambu and Nyeri counties of central Kenya. The roads were constructed and completed by the year 2014, to low volume standards, and were in service of rural populations, majorly the small-scale farmers (MTRD, 2017).

Tests and studies undertaken included axle load surveys, deflection tests, visual condition surveys, roughness measurements, rutting measurements, dynamic cone penetration tests, relative moisture content determination, rainfall recording, and trial pitting and sampling for testing, using methods based on British Standards and AASHTO standards (MTRD, 2017).

Observed deteriorations on each of the roads were scrutinized closely to determine their extent. The defects included potholes, delamination of pavement layers, longitudinal, transverse and crocodile cracking, and overgrown of vegetation onto the carriageway. Each of the eleven roads had specific widespread defects, attributed to factors such as the construction materials used, the prevailing weather conditions and the usage of the roads (MTRD, 2017).

Poor carriageway drainage was identified as a cross-cutting problem on all roads, and was attributed to extensive rutting. Notwithstanding the fact that the roads had been constructed with suitable side drains, the usage of the roads by heavily loaded vehicles had led in both the outer and inner wheel paths, which lead to water accumulation on the pavement. This water ingresses into the base material, undermining it, leading to failure when subjected to pressure by the wheels of the vehicles. These weaknesses had manifested themselves in the form of potholes on some of the road sections (MTRD, 2017).

Edge subsidence was a cross-cutting problem for all the roads owing to the failure to seal the access roads. At the points where the earth access roads joining the sealed roads, edge breaks were most pronounced, and were expected to get worse unless remedies were done (MTRD, 2017).

2.14 Performance of Low Volume Sealed Roads in Southern Africa

Gourley et al (1999) investigated the usage of natural gravel for road base and recommended inventive methods for its use, in an economical and environmentally subtle way. Road segments were chosen on road networks in Botswana, Malawi and Zimbabwe, where they were tested and observed to assist in evaluation of designs. The research concentrated on assessing the performance of flexible pavements with respect to time traffic and climate (Gourley et al, 1999).

The study concluded that traffic loading of between 300,000 and 500,000 design equivalent standard axles had no significant contribution to pavement deterioration. The research observed that many road segments, for instance on the trunk road network, had been exposed to excessive overloading but the level of deterioration was inconsequential even on road bases with plasticity index of eighteen (Gourley et al, 1999).

It was established that drainage was an important element on performance of flexible pavements. A structural and maintenance benefit is derived if the shoulders are paved, and was recommended for low volume sealed roads (Gourley et al, 1999).

2.15 Performance of Low Volume Unsealed Rural Roads in Vietnam

Cook et al (2005) investigated the performance of low volume unsealed rural roads providing basic access for communities in forty provinces in Vietnam. The roads were done to gravel surfacing. The research comprised data collection on key aspects including: general road environment, road link condition, detailed condition of selected profiles within each link and in-situ and laboratory test results (Cook et al, 2005).

The study found that it was necessary to improve the evaluation of the appropriate usage of local natural gravel materials in rural road programmes in Vietnam. It was documented that an important objective in sustainable road construction was to properly match the available material to its road task and local environment. Local non-standard materials needed to be adopted within the design, as many designs in use did incorporate this. The wide-ranging options for dealing with this situation were recommended as: (i) modifying the material to suit the designs, (ii) modifying the design options to suit the materials available, and (iii) defining areas where the existing unsealed options are suitable (Cook et al, 2005).

The study also found out that suitable maintenance was not being achieved on the roads. Gravel roads experiencing upwards of 20mm/year of gravel loss without adequate maintenance normally diminish sustainability after 4-5 years. Construction of gravel roads should also allow for maintenance to be carried out cost-effectively (Cook et al, 2005).

2.16 Performance Review of Design Standards and Technical Specifications for Low Volume Sealed Rural Roads in Malawi

Pinard (2011) undertook an analysis of performance of constructed low volume sealed roads, and the design standards and specifications in use in Malawi. The study sought to establish an appropriate design methodology for low volume sealed roads, and give suggestions towards the development of appropriate guidelines on low volume road standards by the road sector. The study included initial activities like stakeholder awareness campaigns, desk study, site reconnaissance, development of programme on field investigations and laboratory testing, and traffic loadings determination. Field investigations included visual condition surveys, drainage analysis, rutting measurements, dynamic cone penetrometer measurements, and bulk sampling for lab testing (which included classification tests, compaction and strength tests) (Pinard, 2011).

The study found out that all the low volume sealed roads investigated had performed tremendously well under the prevailing environments. Those roads harbouring light traffic, of less than a quarter million equivalent standard axles from the base year, remained structurally intact with a controlled deterioration. Based on conservative pavement design standards, the roads in question would have since failed. This was interpreted as an indication that conventional design standards and specifications were unsuitable for use with low volume sealed roads (Pinard, 2011).

The study also found out that despite the good performance of the examined low volume sealed roads, the drain conditions were rated to be mostly poor to very poor in terms of the Drainage Factor (DF). Adherence to a minimum DF > 7.5 would significantly improve the performance and life of low volume sealed roads (Pinard, 2011).

2.17 The Impact of Drainage on the Performance of Low Volume Sealed Roads

Otto et al (2020) investigated the influence of drainage features including provision of sealed shoulders and adequate camber and crown height, on the performance of low volume sealed roads. The road features were evaluated individually, by employing three levels performance matrix for each factor (Otto et al, 2020).

The study found out that the incorporation of a sealed shoulder meaningfully improved the road performance. Where the shoulder is sealed, high plasticity materials (PI ≤ 16 and PM ≤ 560) can be used in the base layer and good performance can still be achieved. However, to achieve a better performance when having unsealed shoulders, strict limits need to be executed on the plasticity of the base layer (PI ≤ 10 and PM ≤ 240) in a bid to guarantee a good performance. It was reported that there was no major difference in the minimum permissible strength of the base layer for roads with sealed or unsealed shoulders to ensure good performance (CBR 40–46%). Additionally, it was noted a properly maintained and grassed shoulder could be effective in improving performance of low volume sealed roads (Otto et al, 2020).

Where a high crown height (>0.75 m) is used, high plasticity materials (PI ≤ 10 and PM ≤ 188) could be used in the base layer and good performance could still be achieved. Nevertheless, to attain a good performance when the crown height is less than 0.5 m, stern limits need to be enforced on the plasticity of the base layer (PI ≤ 2 and PM ≤ 79) to guarantee good performance. It was noted that there is no significant difference in the minimum permissible strength (CBR 40–46%) for good performance of the base layer for the low crown height (< 0.5 m) and that for the high crown height (> 0.75 m). If the crown height is at least equal to 0.5 m, then the limits for materials characteristics for shoulder type supersedes those for the crown height. Equally, if the crown height is less than 0.5 m, then the limits for materials characteristics for the crown height prevails those for the shoulder type (Otto et al, 2020).

The study further noted that though good performance could be achieved even with road camber between 1% and 2%, it is safer to provide a minimum camber of 3% if natural gravels are used, particularly in view of potentially extreme events in sub-Saharan Africa, such as the climate changes. Moreover, natural gravels are vulnerable to rutting, which in turn could lead to rainwater ponding and ingress into the road pavement. With a camber that is high (3%), rainwater has a high likelihood of draining off. Sufficiently sized culverts that consider periodic silting capacity would be used at critical points on any low volume road (Otto et al, 2020).

2.18 Field Assessment of Gravel Loss on Unsealed Roads in Australia

Pardeshi et al (2020) studied the loss of gravel on unsealed roads in Australia. Gravel loss monitoring stations were set up to evaluate the losses, and the consequences of using good quality gravel material. The study observed that there was a great possibility of cost savings by reducing gravel loss on roads that are unsealed. Major gravel loss rates ranged between 6 and 10 mm per year (Pardeshi et al, 2020).

The study concluded that gravel loss was a key setback for unsealed roads and it needed major maintenance every year. The recurrent loss of gravel process leads to the unsustainability of these roads. The management of unsealed road faces several problems that include the difficulty to predict behaviour, enormous data collection needs, and a susceptibility in the service and maintenance practices. The quality of gravel material used on a road additionally plays a significant role in the gravel loss process (Pardeshi et al, 2020).

2.19 Climate Adaptation and Resilience

Climate change points to a variation in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change could be owed to natural internal processes or external forces such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use (Head et al, 2019).

Adaptation, in human systems, is the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities (that is, actions that reduce hazard, exposure and vulnerability). In natural systems, it is the process of adjustment to actual climate and its effects. Human intervention may facilitate adjustment to expected climate and its effects (Head et al, 2019).

Resilience is the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation (Head et al, 2019).

The African continent has experienced abrupt changes in climate, which is still instigating extensive damage to road infrastructure. Accessibility in the rural setup is becoming impossible over great periods in a year, thereby affecting both directly and indirectly the livelihoods and associated socio-economic development (Head et al, 2019).

For the low volume sealed road networks, the environment plays a more pronounced role in contributing to deterioration than the traffic does, as shown in Figure 2.4 (Paige-Green et al, 2019).

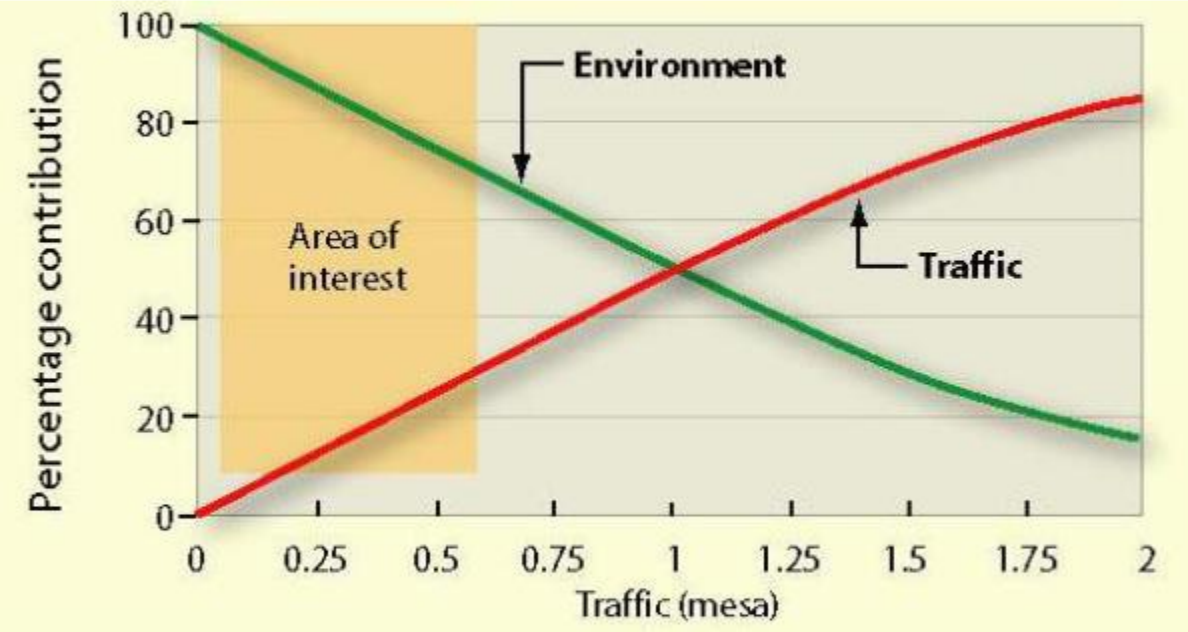


Figure 2.4: Relationship between road deterioration and environment and traffic (Paige-Green et al, 2019).

With the probable changes in climate over most of Africa ensuing from global climate change, the continuing and periodic deterioration of the constructed low volume roads in the rural networks can therefore be expected to progress more frequently and on a growing scale, perhaps higher than for the high traffic roads. Occurrences of impassability while roads and structures are awaiting maintenance could upsurge, and the public and local economies are expected to be unfavourably affected (Paige-Green et al, 2019).

Measures to make rural roads more resilient to extreme weather events and to ensure all-season passability on important road links are therefore promptly needed. It is improbable that all such occurrences can be evaded without substantial cost implications. Nevertheless, new road infrastructure, inclusive of their drainage and bridge structures, in addition to rehabilitation and upgrading projects, should preferably be planned and designed to integrate climate resilience to reduce the potential for road closures and expensive damage rehabilitation (Paige-Green et al, 2019).

2.19.1 Climate Change Effects

The negative impacts of climate change are rendering a major chunk of the world's road network at danger and therefore the need for these impacts to be considered in both present road operation scenarios in addition to decisions on future road infrastructure investments (Verhaeghe et al, 2019).

In Sub-Saharan Africa, the climate changes likely to occur include: (i) temperature increases (average, maximum and number of extremely hot days (> 35°C) per year); (ii) decreased rainfall and longer dry periods; (iii) extreme weather events increase, including violent storms, heavy rain and heat waves; (iv) rising water levels; (v) northbound migration of the tropical cyclone belt, and (vi) Increased wind speeds (Verhaeghe et al, 2019).

These climate changes could be accompanied by associated secondary effects including: (i) longer or shorter crop seasons and probable changes in crop types, possibly impacting on farm-to-market traffic loading conditions; (ii) increase or reduction in overall soil moisture; (iii) greater variations in groundwater levels; (iv) fluctuations in vegetation density, type and rate of growth, impacting on sight distances around road curves and slope stability; (v) Flooding; (vi) changed occurrence of extreme storm flows; (vi) ecological balance changes, and (vi) changes in the optimal construction period (timing and length) and conditions due to rainfall and temperature restrictions, affecting accessibility of resources for road construction and maintenance, while also impacting on the gap of safe working and productivity of outside workers The negative impacts of the climatic changes on road infrastructure are summarised in Appendix D (Paige-Green et al, 2019).

2.19.2 Visual Condition Assessment

Paige-Green et al, in 2019, proposed a method for evaluating the susceptibility of road infrastructure to the effect of climate change. The method described the nature of data to be collected, and the method to be used, as the data is usually not included in routine data collection towards the assets management. The data includes matters such as erosion, problematic soils, drainage both from the road and its near environment, and also from outside the road reserve, embankments and cuttings instability, issues during construction and problems related to maintenance (Paige-Green et al, 2019).

The evaluation for climate resilience is different from that taken for road pavement and road structures, which is used for routine asset management, in the following ways: (i) this is undertaken one time only for each particular road during an assessment sequence. Since climate change is quite a slow process occurring over several years, the assessment cycle upwards of ten years is suggested. However, infrequent limited areas like drainage and slope stability problems need to be observed periodically to guarantee that continuous damage and weakening does not lead to greater unforeseen failures; (ii) it needs meaningfully high comprehensive observations, conducted without haste, different from the routine asset management visual inspections typically undertaken rapidly by use of a vehicle; (iii) the evaluations for asset management is strictly based on field observations during inspection, while for climate resilience, the effects of the likely imminent climatic changes need to be interpreted from the observations made; (iv) these assessments need to be updated occasionally in line with the progress of climate change (Paige-Green et al, 2019).

2.19.2.1 Data Collection

In order to design climate resilient roads, several issues need to be evaluated. The issues comprise: (i) potential for erosion; (ii) problematic subgrade materials; (iii) efficient drainage on the road reserve; (iv) drainage from outside the road reserve; (v) stability of slopes, both in cuttings and embankments; (vi) quality of construction; and (vii) efficiency of maintenance (Paige-Green et al, 2019).

2.19.2.2 Degree of Distress

The degree of a specific distress type refers to the measure of its severity. Considering distress degree varies over the road segment being evaluated, the degree is normally documented in concurrence with the extent of occurrence, as this provides the best mean assessment of the gravity of the distress. The length of a segment is typically 100 m. The overall description of degree of each category of distress is presented in Table 2.9 (Paige-Green et al, 2019).

Table 2.9: General description of degree classification (Paige-Green et al, 2019).

Degree	Severity	Description
0	-	No potential vulnerabilities visible
1	Slight	Only the first signs of distress are visible but these are difficult to discern. No adaptation measures necessary
2	Slight to Warning	Distress obvious but not at degree 3
3	Warning	Start of secondary defects. (Distress notable with respect to possible consequences). Adaptation in the medium term may be necessary. Usually requires repair
4	Warning to Severe	Secondary defects clearly visible but not at degree 5 yet
5	Severe	Secondary defects are well developed (high degree of secondary defects) and/or extreme severity of primary defect. Adaptation measures should be implemented immediately. Usually requires reconstruction

2.19.2.3 Extent of Distress

The extent of a distress refers to the measure of how widespread the distress is over the length of the road segment. This is summarised in Table 2.10 (Paige-Green et al, 2019).

Table 2.10: General description of the extent classification of a distress (Paige-Green et al, 2019).

Extent	Description	Percentage of Length
1	Isolated occurrence	< 5
2	Occurs over parts of the segment length More than isolated	5 - 10
3	Intermittent (scattered) occurrence over most of the segment length (general), or Extensive occurrence over a limited portion of the segment length.	10 - 25
4	More frequent occurrence over a major portion of the segment length	25 - 50
5	Extensive occurrence over the entire segment	> 50

2.19.3 Criteria of Assessment

2.19.3.1 Erodibility

The erodibility of the surface of a road, its embankment slopes and side drains could result in substantial problems, both towards aesthetic and environmental, and also in the road management setting, thereby leading to extreme maintenance requirements, and possibly to total failure of the rad infrastructure. Damage to the road surface instigated by erosion results in water concentrations, excessive material loss as silt, and amplified water flow speeds. Uninhibited erosion of the road support layers can ultimately lead to the collapse of the pavement or structure, in addition to excessive siltation of drainage structures. Changes in the volume or intensity of rainfall will usually multiply any problems observed in the course of the assessment (Verhaeghe et al, 2019).

The descriptions of degrees of the various types of erosion are presented in Table 2.11 to Table 2.14 with degrees 2 and 4 being interpolated between 1 and 3 and 3 and 5 respectively (Verhaeghe et al, 2019).

Table 2.11: Degrees of erosion of the road surround (Verhaeghe et al, 2019).

Degree	Description
1	Evidence of localised and minor material loss due to channelized water flows
3	Obvious surface erosion and channelling of water – regular inspection necessary
5	Severe loss of material and formation of deep erosion gullies – requires urgent adaptation measures

Table 2.12: Degrees of erosion of the road surface (and shoulders of unpaved roads) (Verhaeghe et al, 2019).

Degree	Description
1	Evidence of minor water damage
3	Material loss can be easily seen – speed reduction necessary. Channels > 30 mm deep x 75 mm wide
5	Severe loss of material and road shape – vehicles avoid these areas. Channels > 60 mm deep x 250 mm wide – urgent improvement of drainage and material quality required

Table 2.13: Degrees of erosion of side and mitre drains (Verhaeghe et al, 2019).

Degree	Description
1	Minor evidence of material loss and damage due to water.
3	Erosion of drains requiring periodic maintenance and reshaping to restore flow – still functional.
5	Severe loss of material and deformation of drains – dangerous to traffic and causing severe siltation down-stream – urgent adaptation measures required – impaired drain performance.

Table 2.14: Degrees of erosion of embankments and cut slopes (Verhaeghe et al, 2019).

Degree	Description
1	Minor evidence of water damage
3	Can be easily seen – protection measures should be considered. Channels >75 mm deep x 300 mm wide
5	Severe loss of vegetation and material and deposition in drains. Channels > 200 mm deep x > 300 mm wide – adaptation measures urgently required

2.19.3.2 Subgrade Problems

a) Materials

Long term variations in temperature and rainfall will result in higher moisture fluxes in subgrade materials. Problem soils like dispersive and expansive clays will be affected by both moistening up of subgrades owing to increased precipitation and drying out of the soils instigated by extended dry periods, increased temperatures, winds and drought (Verhaeghe et al, 2019).

Throughout the assessment of climate resilience, precise attention should be given to the presence of problematic soils. Awareness should be made of the areas where the pavement structure is failing owing to subgrade conditions, mostly due to poor materials. This is typically related to localised drainage issues and the distress would generally be recorded during the routine visual assessment for asset maintenance. The assessor should look at the exposed soil next to the road and on the side drains for evidence of problematic materials. Table 2.15 shows the degrees of problematic soils – expansive soils (Verhaeghe et al, 2019).

Table 2.15: Degrees of problematic soils – expansive soils (Verhaeghe et al, 2019).

Degree	Description
1	Minor evidence of cracks
3	Moderately expansive clays – cracks 5 – 10 mm wide
5	Highly expansive clays – cracks > 10 mm wide

b) Moisture

Additional probable subgrade problem is the occurrence of excessive moisture in the subgrade. This could be as a result of localised natural water sources as opposed to drainage issues that could be corrected by adequate control of periodic water. Where there is excessive moisture present owing to presence of swampy areas, high water tables or springs, this should be recorded, in addition to the cause of the moisture if determined. If the assessment is conducted in the dry season, pointers such as dry marshy areas and indication of aquatic animals next to the road show potential water problems. Table 2.16 shows the degrees of moisture effects on the road (Verhaeghe et al, 2019).

Table 2.16: Degrees of moisture effects on the road (Verhaeghe et al, 2019).

Degree	Description
1	Minor evidence of localised, but controllable water problem or seepage
3	Standing water adjacent to road surface or evidence of prolonged perennial water accumulation or standing water
5	Marshy areas or areas with permanent high-water tables

2.19.3.3 Drainage (in road reserve)

The aim of this rating is to find out if water is being effectively removed away from the road surface and sides so that the pavement structure is not affected. Numerous issues need to be evaluated including: (i) shape of the road; (ii) shoulders; (iii) side slopes; (iv) side drains; and (v) mitre drains (Paige-Green et al, 2019).

It is critical that water is removed from the road surface and its adjacent areas, and into suitable side drains, and eventually removed from the road reserve by mitre drains and culverts, and this should occur as fast and as efficiently as possible. The assessment should estimate this efficiency with regard to whether runoff remains on the road for long so as to necessitate structural damage to the road. This problem is generally a case of poor road profile displayed by potholes, depressions and rutting on paved roads and lack of road camber, every so often instigated by poor maintenance (Paige-Green et al, 2019).

The water stagnation adjacent to the road, on unpaved or paved roads, can lead to localised pavement failures and such areas should be noted. Likewise, shoulders that are higher than the edge of paved road surfaces will result in water being retained on the road surface, possibly leading to saturation of the susceptible outer wheel track areas. Shoulders need to be properly compacted and graded to remove water into the side drains. Depressions on the shoulders and next to the surfacing on paved roads need to be recorded (Paige-Green et al, 2019).

The occurrence of accumulations of soil materials and trash in side drains is suggestive of poor maintenance or design of the drain. This is normally the case on low areas where water is not removed from the side drains by suitable culverts. In practise, the side drains need to be 3m from the road, and 250mm (dry areas) and 350mm (wet areas) below the top of the formation and 650 – 750 mm below the crown of the road. They need to be shaped to necessitate free flow towards nearby mitre drains and culverts. Vegetation growth should impede flow of water causing ponding, which is an indication of inadequate maintenance (Paige-Green et al, 2019).

Mitre drains need to remove the water collected in the side drains to a satisfactory distance from the road to discourage ponding that could affect the road. The mitre drains should be open and leading into watercourses or open fields where the runoff can drain away. Through the assessment, the lack of adequate mitre drains needs to be noted as a problem, since there is a possibility of water build up, with increased velocities and greater potential for erosion (Paige-Green et al, 2019).

a) Road shape

The shape of the road will determine if water is removed quickly from the road surface. For paved roads, potholes and rutting may bring about water ponding on the surface. But as long as the bituminous surfacing remains undamaged and the depressions aren't too deep (< 25 mm), water will not be retained for long so as to cause any excessive distress. Table 2.17 shows the rating for road shape (Verhaeghe et al, 2019).

Table 2.17: Road shape (unpaved and paved roads) (Verhaeghe et al, 2019).

Degree	Description
1	Good shape and cross-fall - minor susceptibility to retaining shallow water on the surface.
3	Uneven road with poor camber leading to ponding of water on road surface.
5	Road is below surrounding ground level and water will not be removed before distress is caused.

b) Shoulders

The evaluation of shoulders should indicate if they are well shaped so as to remove water from the road surface and into the side slopes and side drains. A particular attention should be drawn to the presence of unpaved areas between the sealed road pavement and the lined side drains, which is considered undesirable as they allow water ingress into the pavement layers. Table 2.18 shows the rating for shoulder condition (Verhaeghe et al, 2019).

Table 2.18: Shoulder condition (Verhaeghe et al, 2019).

Degree	Description
1	Shoulders allow flow of most water with minor ponding.
3	Significant ponding of water occurs on shoulders – could lead to structural failure of pavement.
5	Water retained on shoulders for extended periods allowing weakening of carriage-way materials.

c) Side slopes

The side-slopes are the normal formation (up to 750 mm high) and embankments (> 750 mm) constructed to raise the road and provide for culverts. Poorly shaped side slopes will generally give rise to erosion and undercutting of the shoulders and even the road structure if they are not repaired properly. Side slopes that allow accumulation of water need to be observed and recorded. Table 2.19 shows the rating for drainage effectiveness of side slopes (Verhaeghe et al, 2019).

Table 2.19: Drainage effectiveness of side slopes (Verhaeghe et al, 2019).

Degree	Description
1	Slopes remove water with minimal ponding or erosion damage
3	Poor removal of water from road and shoulders into side drains – may be erosion that could block drains
5	Uneven slopes with severe loss of shape and development of deep channels (> 400 mm deep x 400 mm wide)

d) Side drains

The effectiveness of side drains to remove water quickly and with effectiveness from the road side is evaluated and is basically related to their shape and grade. Table 2.20 shows the rating for effectiveness of side drains (Verhaeghe et al, 2019).

Table 2.20: Effectiveness of side drains (Verhaeghe et al, 2019).

Degree	Description
1	Most water is effectively removed but localised ponding of short duration may occur
3	Drains are incorrectly graded or have uneven surfaces, that retain water for prolonged periods
5	No effective drains or else water is not removed from road side

e) Mitre drains

Adequate mitre drains need to be constructed to remove water from the side drains in order to discourage accumulation of water and avoid the accrual of extreme water velocities that necessitate the erosion of the side drains. The mitre drains need to be long so as to remove water far enough from the road not to affect the road structure. It is critical that maintenance grading doesn't retain windrows blocking access into the mitre drains. Table 2.21 shows the rating for effectiveness of mitre drains (Verhaeghe et al, 2019).

Table 2.21: Effectiveness of mitre drains (Verhaeghe et al, 2019).

Degree	Description
1	Mitre drains mostly effective but localised ponding
3	Mitre drains poorly graded or too short
5	Insufficient mitre drains or totally ineffective

2.19.3.4 Drainage from outside the road reserve (streams)

Normally, water collects outside the road reserve in bigger catchment areas, and needs to cross the road via structures such as bridges and culverts. Proper observation of structures needs to be carried out to establish high water levels, if any damage has been done to the structures by previous water flows, the existence of any damage to wing-walls, erosion protection measures, erosion of the river bank near the structure or the presence of rubble reducing capacity of the structures. On dry season, the foundations of the abutments and piers are normally observable and can be inspected for scouring and damage. Structure elements like drainage pipes, bearings and expansion joint seals need to be inspected for wear or damage. Approach embankments and fills around the abutments need to be inspected for settlement, undermining, erosion or probable saturation (Paige-Green et al, 2019).

a) Structures

During the vulnerability assessment inspections, the evaluation will focus on if the structure could perform sufficiently under changing rainfall, temperature or wind conditions, not expected at the time of design of existing structures. Table 2.22 shows the rating for damage to large drainage structures (Paige-Green et al, 2019).

Table 2.22: Damage to large drainage structures (Paige-Green et al, 2019).

Degree	Description
1	Minor evidence of localised damage
3	Obvious damage to the bridge or culvert structure, but which can be repaired
5	Severe damage to the structure that requires reconstruction of the bridge

b) Approach fills and embankments

The approach fills and embankments related to structures need to be evaluated for any damage instigated by runoff or waters flowing away from or around the structures. Table 2.23 shows the rating for damage to approach fills and embankments (Paige-Green et al, 2019).

Table 2.23: Damage to approach fills and embankments (Paige-Green et al, 2019).

Degree	Description
1	Minor evidence of water damage
3	Localised loss of material from embankment. Can be repaired
5	Severe loss of fill material - closure of road – needs reconstruction

c) Erosion of river banks

Erosion of the river banks in the area around the structure indicating potential for imminent damage to the structure or embankments under high water levels and strong flows need to be evaluated. Table 2.24 shows the rating for erosion of stream banks (Paige-Green et al, 2019).

Table 2.24: Erosion of river banks (Paige-Green et al, 2019).

Degree	Description
1	Minor evidence of stream erosion
3	Loss of material from river banks. Signs of erodibility
5	Severe erosion and loss of material from river/stream banks near structure

d) Protection works

The impairment to protection works such as stone pitching and gabions related with drainage structures brought about by high water levels is bound to increase under extreme events and these works need to be evaluated in terms of their capacity to resist future damage. Table 2.25 shows the rating for damage to protection works (Paige-Green et al, 2019).

Table 2.25: Damage to protection works (Paige-Green et al, 2019).

Degree	Description
1	Minor evidence of water damage
3	Damage to protection works requiring significant repairs
5	Damage to protection works requiring reconstruction and/or replacement

2.19.3.5 Slope Stability

Slope failures have the ability to cause loss of life. Cuts and embankments need to be adequately stable to resist changes in precipitation. A thorough inspection for signs of instability needs to be undertaken. Cut slopes need to be inspected for movement signs behind the slope (tension cracks) or at the slope toe (bulging or deformation of side-drains). Signs such as movement of trees, fences, minor cracking and seepage of water from out of the slope are all suggestive of possible instability. Indications of instability in embankments are typically seen as the presence of arced cracks on the shoulders or the road surface, uncommon settlement of parts of the fill, bulging at the base of the fill and periodic seepage of water from underneath of the fill. Majority of properly designed and constructed fills experience failure through a lack of shear resistance in the subgrade materials, mostly when they are in a saturated condition (Verhaeghe et al, 2019).

a) Cut slopes

The cut slope issues that affect low volume roads normally only affect the shallow soil mantle except if the cuts comprise of deep excavations, wherein the hill slope above the cut would become unstable as the toe is removed. In the course of evaluation, it is essential to examine the overall stability of the vicinity of the cut slopes, in addition to any evidence of instability directly affecting the distinct slopes. Table 2.26 shows the rating for cut slope stability (Verhaeghe et al, 2019).

Table 2.26: Cut slope stability (Verhaeghe et al, 2019).

Degree	Description
1	Minor evidence of surface instability – major failures unlikely – shallow cuttings below small slopes
3	Evidence of slump or localised movement of material on slope – failure likely to cause short disruptions to traffic flow
5	Major slope failure likely – long-term closure of roads caused by slope failure and expensive rehabilitation

b) Embankments

There is need to assess the stability of embankments. Disparate from cuts, there is typically indication of arched cracking on the surface of the embankment before failure and signs of such cracking need to be assessed. Table 2.27 shows the rating for stability of embankment slopes (Verhaeghe et al, 2019).

Table 2.27: Embankment slopes stability (Verhaeghe et al, 2019).

Degree	Description
1	Minor evidence of surface instability – localised arcuate cracking of road surface
3	Evidence of widespread or large arcuate cracks with minimal vertical displacement – failure unlikely (restricted to one lane) or will only cause short-term disruptions to traffic flow
5	Evidence of or potential for large failure causing closure of road for extended period

2.19.3.6 Construction

The major construction issue that affects the resilience of road infrastructure to extreme climatic conditions is inadequate compaction. This is normally displayed as ruts, undulations and undue vertical deformation in the areas affected. During assessment, these failures should be established, since these areas allow higher permeability of the materials as compared with properly compacted materials, and the probability of early failure owed to water ingress is bigger (Verhaeghe et al, 2019).

The overall finish of a road is a good sign of the quality of construction, and is used to make a decision if the quality of construction could possibly lead to problems. Characteristics of poor overall finish includes oversized material lying around, deviations that are not well rehabilitated, rough shoulders and poor finishing of the road reserve. Furthermore, erosion protection measures need to be continuous and undamaged, and be able to perform as effectively (Verhaeghe et al, 2019).

2.19.3.7 Maintenance

Maintenance is an integral activity towards preserving road infrastructures, and must be carried out in timely manner. As climate changes, the necessity for further and good quality maintenance increases. In the course of evaluation, matters including preservation of the shape of shoulders, vegetation control, shaping and cleaning of side and mitre drains and ensuring that culverts and drains are free flowing need to be observed and recorded (Paige-Green et al, 2019).

It is also important that potholes are regularly repaired with properly compacted asphalt concrete and all cracks in the road surface are frequently sealed, to deter the water ingress into the pavement structure. While evaluating the quality of maintenance, the evenness and the shape of the road surface needs to be assessed. Depressions bring about ponding of water, and if there is occurrence of unsealed cracks, it will lead to ingress into the pavement, thereby weakening the materials. Uncontrolled vegetation on the shoulders and side drains inhibits water flow and should be discouraged. Efficient maintenance of the drains is important and the quality and effectiveness of this needs to be assessed (Paige-Green et al, 2019).

2.20 Roads 2000 in Western Kenya

The Roads 2000 programme in Western Kenya, titled "The Improvement of Marketing Infrastructure and Agricultural Roads in Western Kenya", started with a needs assessment and programme concept study in May/June 2007 (Grontmij et al, 2019).

The main goal of the programme was the alleviation of rural poverty through increased agricultural production and marketing. The latter were considered achievable if rural transport and marketing activities were improved, since this would result in higher prices for agricultural produce, an increase in productivity, reduce the amount of harvest rotting in the farms, reduce spoilage at the markets and both reduce poverty and give incentives for increased future production or a shift to high value crops.

To conduct the needs assessment, information and data was collected on rural poverty, agricultural production and potential, the road network and condition and any needs for capacity building. The consensus was that there was high potential for increased agricultural production but that the state of the roads was a major constraint resulting in (i) higher transport costs and lower farm gate prices, (ii) transport of produce by more expensive non-motorable means at times when the roads are impassable, and (iii) a high percentage of produce rotting in the farms due to missing transport. It was estimated that if roads were in a good condition, the transport costs could be reduced by 30-50%, with significant increases in farm produce and farm incomes (Grontmij et al, 2019).

To implement the infrastructure improvement, a consultant was sought, to support the District Roads Engineers (DREs) in implementation of the road works (rehabilitation and maintenance), training of DRE staff and contractors and assisting Ministry of Agriculture (MoA) in managing the implementation of market improvements (Grontmij et al, 2019).

The consultant conducted stakeholder workshops in each district to select roads and markets. The R2000 criteria was applied in rehabilitation of unmaintainable roads and using the labour-based approach. The allocation of funds for each district was based on factors including population, road length and agricultural production. Small and medium contractors were used to implement the works (Grontmij et al, 2019).

Once the roads were completed, the Kenya Roads Board were encouraged to explore innovative approaches for roads maintenance, including performance-based maintenance contracts. Regular maintenance of all improved roads was required starting just after the end of the works (final acceptance). Annual work programs were to be established, and maintenance to be done by small contractors (Grontmij et al, 2019).

The program realised the improvement of the roads, in batches, but it was realised that there were roads improved under batch one that had deteriorated to a level requiring new rehabilitation after only four years. Although this may have been due to lack of adequate maintenance, there were cases of increased diverted and local traffic and heavy rainfall that affected road condition and led to rapid deterioration (Grontmij et al, 2019).

It was learnt that due to environmental issues and depletion of gravel materials in many areas, adopting low volume sealing, including use of Otta seals could be considered. The use of labour-based methods was highly encouraged and more training of small-scale labour-intensive contractors should be considered. Many people expressed their happiness of the technology due to cash earned to help in economic activities (Grontmij et al, 2019).

2.21 Roads 2000 Nyanza Programme in Kenya

Ahmed et al, in 2010, conducted a socio-economic monitoring study on the Roads 2000 Programme in the Nyanza region in Kenya. The programme, implemented by the Kenya Rural Roads Authority (KeRRA), was financed by Swedish International Development Cooperation Agency (SIDA). One component of the programme dealt with the improvement and maintenance of roads. The objective of the program was to place seventy five percent of the road network under routine maintenance upon improvement (Ahmed et al, 2010).

The study observed that the road improvement had given rise to a large increase in the volume of motorised traffic. Nevertheless, there was no noteworthy change in the volume of travel on the non-motorized traffic, including pedestrians. In addition, minimal change was noted on the seasonal flow of traffic after the development of the roads. Further, both passenger and cargo volumes increased, with motorised traffic substantially increasing their share of passengers carried (Ahmed et al, 2010).

It was determined that the road development triggered a modal shift from non-motorised to motorised mode. Travel for work purpose and socio-economic needs remained the main travel purpose after the road improvement. The poorer sections of the local population had increased their share of such trips at the expense of other trip types such as travel for health, education, social and recreational purposes. This potentially reflected the increased economic opportunities then available. Road development had encouraged more households to own a transport vehicle and there had been a significant increase in the average number of motorised vehicles owned by households living along the improved roads (Ahmed et al, 2010).

2.22 Literature Review Summary and Research Gap

In Kenya, the vast majority of the road network is comprised of low volume roads that are extensively distributed in rural communities and low-population areas. These roads are under the jurisdiction of local road authorities such as KeRRA and County Governments, who have funding constraints, and therefore optimal serviceability on the roads is not well maintained. The low volume sealed roads are guided by a newly developed pavement design manual for low-volume paved roads. The manual deals very effectively with different input variables required for the pavement design process. Traffic data and soil strength of the subgrade are the most common inputs when designing these roads. Maintenance regimes for low volume sealed roads are funded by Kenya Road Board, through the Road Maintenance Levy Fund (RMLF) charged on fuel. The roads are prioritised and incorporated in the annual road works program, which forms the basis of the fund allocation, determined by the current condition of the road. It is determined that the priority for maintenance of completed low volume roads is usually affected by the surrounding poor network, and therefore, maintenance is not routine.

In the context of axle loading control on the low volume sealed roads, the completed roads, upon completion, are handed over to the regional road authorities. Some fall under the jurisdiction of County Governments. The capacity in these government entities is low and axle loading control is not efficient. Also, the completed roads border the sources of construction materials and agricultural farms where heavy farm equipment are used. Control of loading in such circumstances call for organised coordination and resources, which are limited in the regional authorities.

Review of the similar projects following the low volume roads construction concept both in western and eastern parts of Kenya showed that the projects had been heading to their conclusion, and were reported as successful. However, on both cases, the concept of maintenance of completed roads had not been factored at planning stage, and responsibility was being left to the road authorities in those regions. Review of performance of low volume roads in other regions showed that whereas the improved roads were having great impact on the recipient populace, the lack of adequate maintenance was in most cases leading to early failure of the completed roads, and inadequate drainage was a leading factor in the uncontrolled deterioration of these roads.

The normal practice, for road management and maintenance and rehabilitation planning purposes, visual condition assessments of the road network are usually routinely carried out at specified frequencies. These normally look at the road condition, classifying problems such as cracking, deformation, rutting and potholing, by degree and extent to prioritise and budget for follow-up management operations. Generally, only the road carriageway area is assessed. Similar assessments for bridge management systems are also carried out, and these are mostly related to the planning and management of maintenance and repairs of road structures. Information related to climate resilience assessments and the implementation of appropriate adaptation techniques to improve the climate resilience of the infrastructure are normally not collected nor analysed. There exists no clear guidance in Kenyan manuals and guidelines on the methods for conditional survey that incorporates climate resilience measures.

2.23 Conceptual Framework

The overall objective of the study was to investigate the performance of low volume sealed road pavements: a case study of Roads 2000 Strategy in Central Kenya. Data collected related to pavement performance included the maintenance priority, the traffic loading and level of axle loading in place, and climate resilience of the completed low volume roads, in line with the adaptive measures for climate change in place. Surface condition survey, roughness and rutting measurements, and rating of the present serviceably index, in addition to the visual assessment of the adaptive measures towards climate resilience assessments were done. It was the analysis of the independent variables (rutting, roughness, traffic loading, visual condition survey and serviceability rating, climate adaptability measure) that informed the output variables (pavement performance, climate resilience, maintenance). Figure 2.5 presents the conceptual framework diagram, informed through review of relevant literature.

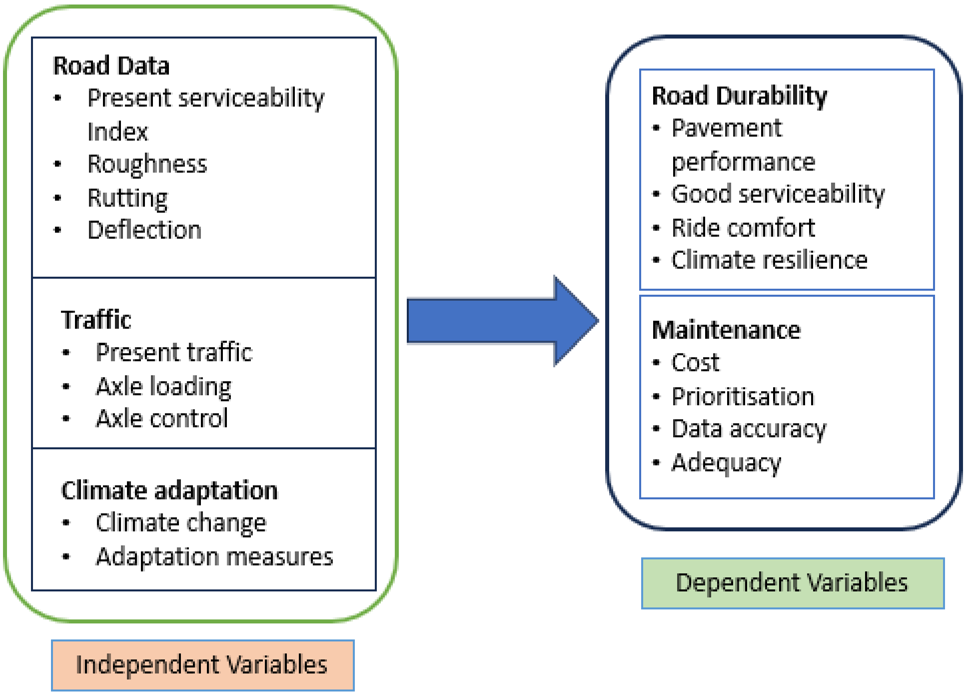


Figure 2.5: Conceptual framework for the study.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter details the scope of data collection, the sample, and methodology adopted for data analysis, including the use of theoretical models for determination of stresses and strains within individual pavement layers on completed roads. It is to be noted that the works were carried out in Kenya between the years 2011 and 2019, and the project costs were reported in Kenya Shillings, and the exchange rate over the period averaged ninety Kenya shillings to one US dollar.

3.2 Research Design

This research aimed at evaluating the Roads 2000 Strategy in the central Kenya, and particularly in Kiambu and Murang'a regions. The recorded objectives of the Roads 2000 program were:

(i). Training of routine maintenance, gravelling and low volume seal (LVS) contractors;
(ii). Training of public and private sector contract managers and supervisors;
(iii). Capacity building of KeRRA at Regional and National level;
(iv). Rehabilitation of 1,100 km of gravel roads;
(v). Construction of 165 km of low volume sealed roads;
(vi). Maintenance of all phase one and phase two improved roads; and,
(vii). Maintenance of 6,000 km of roads within Kiambu, Murang'a, Kirinyaga, Nyeri, Laikipia and Nyandarua regions.

To achieve the overall objective of the study, which was to investigate the performance of low volume sealed road pavements: a case study of Roads 2000 Strategy in Central Kenya, the following aspects of the program were assessed:

(i). A condition survey of the completed roads under the Roads 2000 program and those handed over for maintenance was conducted.
(ii). The factors that affect the priority for maintenance by the road authorities and county governments covering the completed roads under phase two in Kiambu and Murang'a regions.
(iii). The traffic axle loading and the extent of axle load control on the completed roads under phase two in Kiambu and Murang'a regions.

(iv). The climate resilience of the completed roads was assessed to evaluate whether adaptive measures for climate change were in place.

3.2.1 Road Surface Condition Survey

A representative sample, based on the monetary unit sampling method (Christensen et al, 2015) was taken, using the accepted contract project costs as basis for sampling. Of the total cost of the batch under consideration, the sampled roads had a cumulative project cost of at least forty percent of the total cost of implementation of the roads under that batch.

3.2.1.1 Visual Condition Survey of Pavement and Drainage

In order to identify signs of distress and pavement defects that could affect the roads' performance, a visual assessment of the sampled roads was conducted. The assessment included the describing and checking on (i) type of surface; (ii) extent of pothole formation; (iii) degree of pavement edge breaks; (iv) presence of surface cracking, extent and type; and (vi) drainage condition of the pavement.

3.2.1.2 Pavement Condition

The road surface condition (nature and extent of defects) was assessed and the cause of any defects established. The defect identified included cracks, potholes, edge breaks, pumping, shoving, depressions and ruts.

Based on the visual assessment, a Present Serviceability Rating (PSR) was calculated with the intention of categorising the pavement condition. A PSR value of 2.0, which is considered as the terminal value for low volume roads, was used as the minimum criteria.

3.2.1.3 Roughness Measurements

The road pavement roughness is taken as a measure of its functional condition. High levels of roughness contribute to the increase in road user costs. Pavement deterioration leads to an increase in the roughness of the road pavement, either directly from a distorted surface or indirectly because of repair work of cracking and potholes. Changes in the roughness value over time is an indication of occurrence of pavement distress.

The road roughness for all roads was measured using the Rough-o-meter and Road-Lab equipment. The Merlin Apparatus was used on two roads as a calibration for the two methods.

The roughness values were expressed in terms of the International Roughness Index (IRI) value in m/Km for each road surveyed and the condition rated according to Table 3.1.

Table 3.1: Roughness Measurements (KRB, 2009)

Parameters	**Condition Rating (Sound, Warning, Severe) Threshold values (IRI value m/km)**		
	All Traffic Classes		
	Sound	**Warning**	**Severe**
Roughness	< 3	3 - 6	> 6

3.2.1.4 Rut Depth Measurements

The rut depth measurement was carried out using a three-metre-long straight edge and a wedge. The straight edge was positioned on one side of the road, then transferred to the other side, in one continuous transverse profile. The rut depths were determined in both outer and inner wheel paths. Additional measurements were taken at spots with visible rut development and the exact location and extent of the problematic section recorded.

The rut depth rating was based on the following scale (Kenya Road Department, 1988):

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

3.2.1.5 Road Condition Rating

The overall pavement condition based on the visual assessment was carried out and described based on Table 3.2.

Table 3.2: Description of overall pavement condition ratings (KRB, 2009)

Degree	Description
Very Good	Very few or no defects. Degree of defects < 3 (less than warning).
Moderate	Few defects. Degree of structural defects mostly less than warning.
Poor	A few defects with degree of defects seldom severe. Extent is only local if degree is severe (excluding surfacing defects).
Very Poor	General occurrence of particular structural defects with degrees warning to severe.

3.2.1.6 Present Serviceability Rating

The Present Serviceability Rating (PSR) was used to provide a quantitative evaluation of the overall condition of the pavement. The PSR for each pavement section rated was taken as the mean of the individual rating values assigned to each rating criterion. The criteria considered the following twelve defects, while Table 3.3 shows the rating used to evaluate the performance of the road sections.

(i) Crazing (Block and Alligator cracking)
(ii) Longitudinal cracking
(iii) Transverse cracking
(iv) Edge spalling
(v) Rutting
(vi) Corrugation/Waves
(vii) Depression/Longitudinal irregularity
(viii) Shoving/Heaving/Upheaval
(ix) Bleeding/Glazing
(x) Stripping/Raveling
(xi) Patched areas
(xii) Pothole/Disruption

Table 3.3: Present Serviceability Rating Scale (Kenya Road Department, 1988)

Average Points	4.5 – 5.0	4.0 – 4.5	3.0 – 4.0	2.0 – 3.0	1.0 – 2.0	0.5 – 1.0	0 – 0.5
Rating	Excellent	Very Good	Good	Fair	Poor	Very Poor	Failed

3.2.2 Maintenance Prioritisation of the Completed Roads

The sampled completed roads, based on the monetary unit sampling method (Christensen et al, 2015), and already handed over to the authorities comprising of KeRRA and County Governments, were assessed, with a keen emphasis on the budgetary allocation for maintenance by the authorities.

The authorities receive road maintenance levy fund from the Kenya Roads Board (KRB). KRB disburses maintenance funds informed by the priority work plans by the authorities, consolidated on the Annual Public Roads Programme (APRP).

The APRPs for seven years, financial years of 2011/2012 to 2017/2018, were analysed to see the level of investment put in place on the sampled roads for the maintenance regimes. Comparisons were drawn on the level of maintenance priority and the present condition of the roads.

3.2.3 Traffic Loading and Axle Loading Control of the Completed Roads

The low volume sealed roads are meant for axle loading of below one million standard axles. If axle loading is not monitored, the completed roads cannot meet the expected design life. Axle load surveys were conducted at selected census points that ensured minimal disruption to traffic, and portable calibrated weigh pads were used to weigh the vehicles. The task included working out of the vehicle equivalence factors for commercial vehicle classes as per the recommended standards, and estimating the traffic loading based on realistic assumptions of traffic growth rates for each vehicle class.

The determination of annual traffic growth rates was based on traffic census carried out on the region within which the road is located. Where such information was not available, national development survey information was used. The choice of the appropriate growth rates used in traffic projection and pavement design loading was based on the national socio-economic profiles and trends in national and regional development.

This survey was done in accordance with the recommendations of Overseas Road Note 40 (ORN 40). The survey involved recording vehicle origin and destination, axle weights, wheel configuration and cargo or service description. The objective of carrying out the axle load survey was to determine the vehicle equivalence axle load factor for each vehicle and vehicle class. The factors for each axle load in kilogram was calculated using the Liddle's formula presented by Equation 3.1 (MoTIHUD, 2017).

$$EF = \left(\frac{P}{8160}\right)^{n} \text{ .... Equation 3.1}$$

Where: *P* = axle load (in kg); and *n* = power exponent (n = 4.5 was adopted)

The vehicle equivalence axle load factor for each vehicle weighed during the survey was calculated by summing up the factors for all axles. The average factor was then determined for each vehicle class.

The Daily Equivalence Standard Axles (DESA) was computed by totalling up the product of vehicle equivalence axle load factor and the total average daily traffic for both directions for each vehicle type, as presented by Equation 3.2 (MoTIHUD, 2017).

$$DESA = \sum(AADT \times VEF) \text{ .... Equation 3.2}$$

The design daily equivalent standard axles were converted to cumulative equivalent standard axles, as presented by Equation 3.3 (MoTIHUD, 2017).

$$CESA = 365\ x\ DESA\ x\ [(1+r)^{N} - 1]/r \text{ .... Equation 3.3}$$

Where: *CESA* = cumulative equivalent standard axles

DESA = average DESAs for each vehicle class in the first design year

r = assumed annual growth rate expressed as a decimal fraction

N = design period in years

A sensitivity analysis was done so as to assess traffic variation at various growth rates with the DESA of the road sections. The cumulative equivalent standard axles from the analysis included for all the roads.

A theoretical model was adopted to simulate the stresses and strains resulting from within the individual pavement layers at the computed traffic loading, using mechanistic-empirical design modelling, with the South African mePADS software. The various pavement response parameters within the pavement layers (or components) as a result of the applied tyre loading and contact stresses adopted are as illustrated in Figure 3.1.

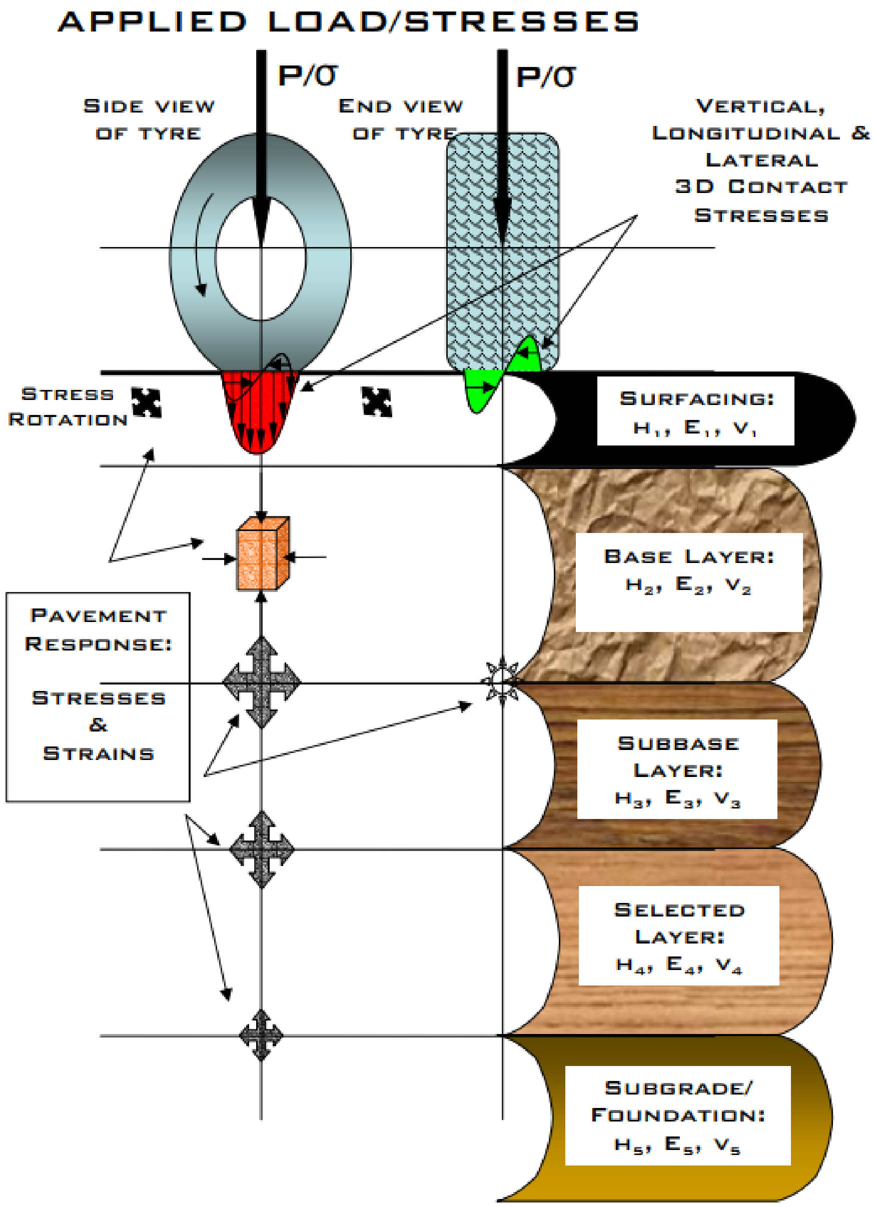


Figure 3.1 Basic layout of a multi-layered pavement system with applied tyre load and 3D contact stresses as inputs (Theyse H. L. & M. Muthen, 2000)

In addition, the pavement adequacy was checked using the empirical equation 3.4, based on the 1993 AASHTO Guide for flexible pavements (AASHTO, 1993).

$$\log_{10}(W_{18}) = Z_R S_o + 9.36\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.4+\frac{1094}{(SN+1)^{5.19}}} + 2.32\log_{10} M_R - 8.07 \quad \text{......Equation 3.4}$$

Whereby;

W_{18} = traffic loading (ESALs);
Z_R = standard normal deviate;
S_o = standard deviation;
SN = structural number;
ΔPSI = change in present serviceability index; and
M_R = resilient modulus of subgrade in pound per square inch (psi).

The required and designed structural numbers were calculated iteratively using Equation 3.5 (AASHTO, 1993). The two structural numbers were compared for pavement adequacy.

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 \quad \text{……………………………… Equation 3.5}$$

Where;
SN = Structural Number;
a_i = i^{th} layer coefficient;
D_i = i^{th} layer thickness (inches), and;
m_i = i^{th} layer drainage coefficient.

Further to this, the capacity of the local authorities that receive the completed roads for control of axle loading was assessed, in relationship to the personnel and equipment resources available for real-time axle data monitoring on the sampled roads. The information was obtained by orally interviewing the officers in charge on the local authorities.

3.2.4 Climate Resilience Assessments

Roads constructed to Low volume standards are normally constructed to lower standards by incorporating local materials into the pavement, and by utilising labour methods of construction. Thereby, these roads are more vulnerable to climate variability damage than those roads of higher order harbouring higher traffic volumes and constructed using higher standards.

The application of appropriate measures for adaptation, to improve the climate resilience of the roads, was assessed, and data obtained included issues to do with erosion, problem soils, road and surrounding areas' drainage, road reserve and outer drainage, embankments and cuttings instability, issues during construction and maintenance. Other indications of possible problems observed included the build-up of sand and debris, by actions of wind and flooding, uncontrolled vegetation resulting in sight distance problems.

A standard form for recording the data was used, as shown in Appendix E. The cells in the assessment form were completed for degree and extent of the issue being assessed, and the entries on the form included:

i) Road name;
ii) Road length;
iii) Date of assessment;
iv) Assessor's name;
v) Prevailing weather;
vi) Topography of the road location;
vii) Project location land cover and land use;
viii) Chainage along the road that was assessed;
ix) Road grade of slope;
x) Common vehicle types, indicating the dominant traffic types using the road.

3.3 Research Sample

The study focussed on the Phase 2 of the R2000 program in Kiambu and Murang'a regions. The Phase 2 had been implemented in three batches, with the level of investment as detailed in Table 3.4.

Table 3.4: Phase 2 Project Investment in Kiambu and Murang'a

Batch No.	Gravel Roads Amount (Kshs)	Low Volume Sealed Roads Amount (Kshs)	TOTAL (Kshs)
Batch 1	258,591,783.60	186,064,818.84	444,656,602.44
Batch 2	812,522,729.26	487,171,684.74	**1,299,694,414.00**
Batch 3	-	1,126,152,837.67	**1,126,152,837.67**
TOTAL (Kshs)	**1,071,114,512.86**	**1,799,389,341.25**	**2,870,503,854.11**

In order to obtain a representative sample of the investment for investigation, a monetary unit sampling method (Christensen et al, 2015) was used, with the total value of the roads sampled being minimum forty percent of the total investment. Appendix F shows the sampled roads investigated in the three batches of phase two projects. Table 3.5 gives the cost summary of the sampled roads.

Table 3.5: Summary of sample investigated

Batch No.	Total Investment Amount (Kshs)	Sample Value Amount (Kshs)	Sample Percentage
Batch 1	444,656,602.44	337,542,432.49	75.91%
Batch 2	1,299,694,414.00	892,775,079.84	68.69%
Batch 3	1,126,152,837.67	1,126,152,837.67	100%
TOTAL (Kshs)	**2,870,503,854**	**2,356,470,350**	**82.09%**

CHAPTER FOUR: RESULTS, ANALYSIS AND DISCUSSION

4.1 Introduction

The collected data was analysed and then deductions were made in response to the research objectives. This chapter presents the analysis of condition survey findings, maintenance priority and investment, axle loading and monitoring, including the use of theoretical models for determination of stresses and strains within individual pavement layers on completed roads, and the appropriate adaptation measures in place towards climate change resilience.

4.2 Pavement Performance and Climate Resilience of Roads in Murang'a Region, LVS Batch One Roads

The sample roads were assessed in a bid to take account of their existing condition. In addition, the factual data in regarding to the last intervention made were recorded.

4.2.1 Maragwa Town – Gakoigo Junction road - D419 (I)

4.2.1.1 Data Sheet

Table 4.1 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch one, in Murang'a region. Plate 4.1 shows the status of the Maragwa Town – Gakoigo Junction road - D419(I) during the study.

Table 4.1: Maragwa Town – Gakoigo Junction road - D419 (I)

Road: Maragwa Town – Gakoigo Junction road - D419(I)	**Length (Km):** 2.52	**Location:** Maragwa Constituency in Murang'a KeRRA Region **Phase:** 2 **Batch:** 1	**Commencement:** 30th May, 2013. **Date of Final Completion:** 19th February, 2016
Roadworks undertaken during initial construction: (i). Setting out (survey works) (ii). Site clearance: stripping and grubbing by labour; (iii). Earthworks – Benching to widen the carriageway from the existing width of 4m to 5.5m – 6.5m; use material from side drain excavation/approved imported material to fill and compact the benches in layers of 150mm to 100% Modified AASTHO T99; (iv). Drainage works and concrete works which included a 4x2m twin box culvert; (v). Grading and gravelling; (vi). Natural material Base - Mix, place and compact 100mm Composite Emulsion Treatment Base (ETB) for carriageway, shoulders and junctions, with 67mm cement stabilized gravel – bottom layer and 33mm Emulsion Treated Base (ETB) – upper layer over the entire carriageway and shoulders;			

(vii). Bituminous surface treatment: Provision of a prime coat over the ETB layer (1:6 diluted A4 Anionic Emulsion, sprayed at a rate of 0.8 l/m^2);
(viii). Bituminous Mixes: provision of 20mm of Cold Asphalt Concrete wearing course;
(ix). Road furniture

Expenditure:
Original Contract Sum: Kshs. 43,141,835.00
Revised Contract Sum: Kshs. 53,618,230.00


(a) Road start at Maragwa town. Asphalt surface intact, but poor drainage system noted (Author, 2023).


(b) Twin-box culvert in good operating condition, but water pooling was noted at the exit side of the structure. Poor routine maintenance noted. (Author, 2023).


(c) Road transcends an urban setup, still in good serviceability, but in poor maintenance condition (Author, 2023).


(d) Towards the end stretch of the road, a good ride quality was experienced, and the road was in good service. Poor drainage and lack of timely routine maintenance was noted (Author, 2023).

Plate 4.1: Status of the Maragwa Town – Gakoigo Junction road - D419(I) during the study

4.2.1.2 Deflection Measurements

The deflection measurements are as shown in Appendix G. Tests were done on the four segments of the wheel path. Figures 4.1 to 4.3 show graphical representation of the pavement strengths.

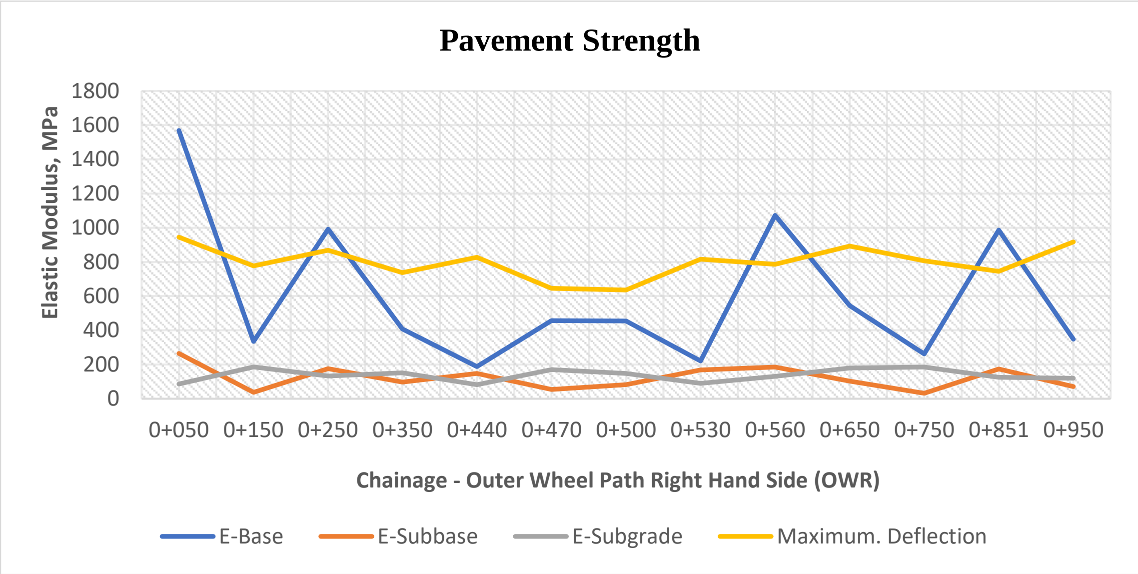


Figure 4.1: Representation of deflection test on Outer Wheel Path Right Hand Side (OWR)

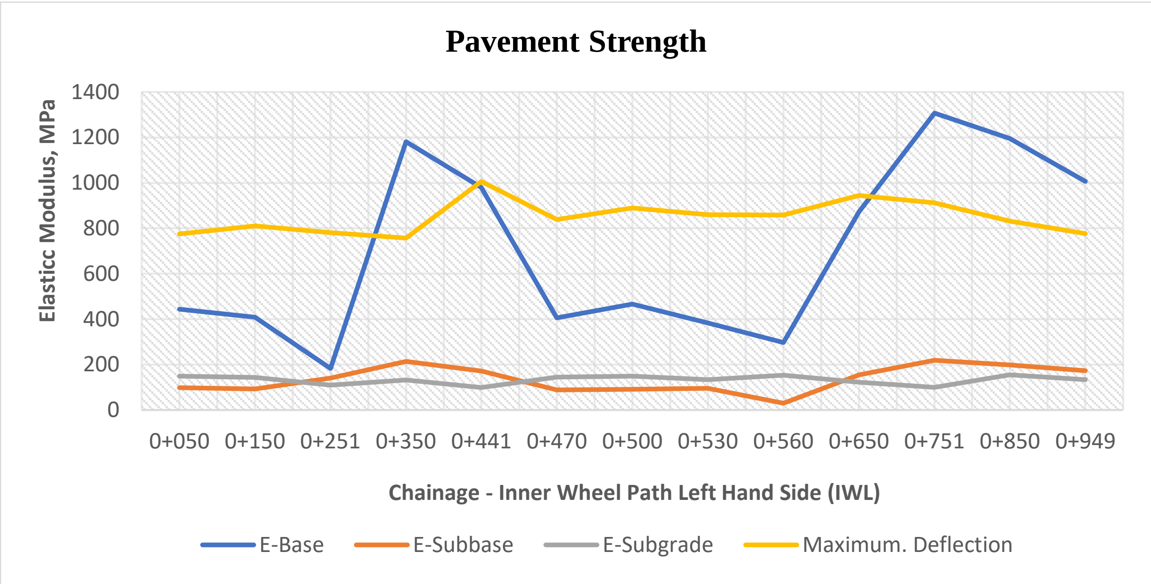


Figure 4.2: Representation of deflection test on Inner Wheel Path Left Hand Side (IWL)

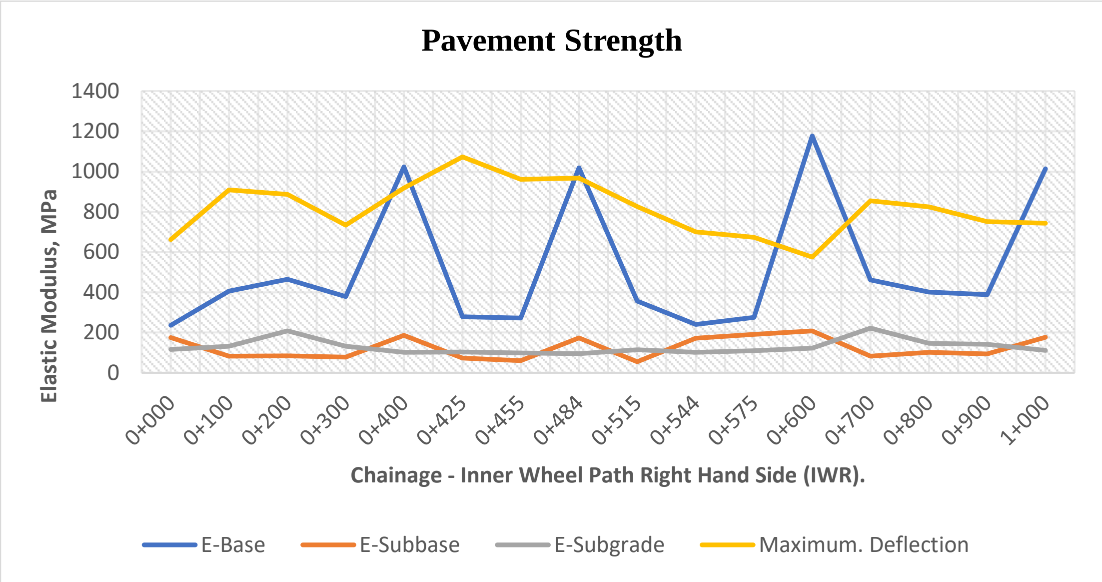


Figure 4.3: Representation of deflection test on Inner Wheel Path Right Hand Side (IWR)

4.2.1.3 Drainage Assessment

The average depth of the side drainage of the road is less than the required 0.4m depth below the formation level, while the description of the drain is as shown in Table 4.2.

Table 4.2: Description of Degree of side drain

Chainage	**Left Hand Side**				**Left Hand Side**			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.35	0.40	-0.05	Inadequate	0.32	0.40	-0.08	Inadequate
Average	**0.35**	**0.40**	**-0.05**	**Inadequate**	**0.32**	**0.40**	**-0.08**	**Inadequate**

4.2.1.4 Rut Depth Measurement

Table 4.3 shows the average rut depths for both road sides measured on the road. The average rut depths for the left-hand side and right-hand side were rated at Very Good. Figure 4.4 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.3: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	To	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0+000	0+500	4.5	6.3	1.5	-2.5
0+500	1+000	5.4	3.5	3	-0.5
1+000	1+500	5.8	4.8	0	-4.4
1+500	2+000	4.6	4.5	3.1	1.1
2+000	2+100	4.2	5.1	4.7	3.24
Average		**4.9**	**4.8**	**2.4**	**0.7**
Rut depth rating		**Very Good**	**Very Good**	**Very Good**	**Very Good**

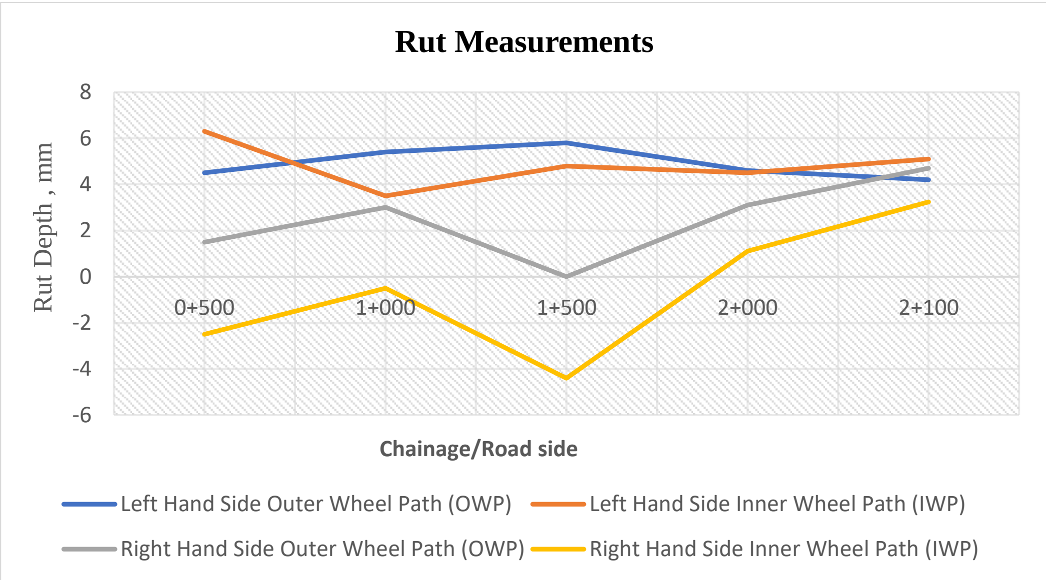


Figure 4.4: Representation of rut measurements along the road

4.2.1.5 Roughness Measurement

Table 4.4 shows the International Roughness Indices (IRI) values in m/km for each direction using different methods. The average roughness was categorised as Warning based on measurement using Rough-o-meter and also Warning based on measurements using Road-Lab Pro.

Table 4.4: Roughness Measurements

Road Side	IRI (m/km)	IRI (m/km)
	Rough-o-meter	Road-Lab Pro
Left Hand Side	5.1	3.08
Right Hand Side	4.6	2.89

4.2.1.6 Present Serviceability Rating (PSR)

The road had an overall PSR value of 2.8 which is rated as Fair. The PSI value exceeds 2.0 which is the terminal value for low volume roads. The road therefore meets the PSI criteria. However, urgent interventions on sections with crazing, rutting, stripping/ravelling, parching and potholes are highly recommended, as shown in Table 4.5.

Table 4.5: Present Serviceability Rating

Date of Survey	28th January, 2023	
Road Name	Maragwa Town – Gakoigo Junction road - D419 (I)	
Section	5.8km	
Rater	PGM	
Pavement Structure	Surfacing	20mm cold mix
	Base	100mm composite emulsion treated base
	Sub-base	-
	Improved subgrade/capping	150mm neat gravel
	Subgrade class	S3
Summary		
Defect	**Points**	
1. Crazing (Block and alligator cracks)	2	
2. Longitudinal cracking	3	
3. Transverse cracking	4	
4. Edge spalling	3	
5. Rutting	2	
6. Corrugation/waves	4	
7. Depression/Longitudinal irregularity	3	
8. Shoving/Heaving/Upheaval	4	
9. Bleeding/Glazing	3	
10. Stripping/Raveling	2	
11. Patch	2	

12. Pothole/Disruption	2	
Total	**34**	
Points	**34/12**	**Rating: 2.8**

4.2.1.7 Climate Resilience Assessment

Table 4.6 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.6: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	2/2	Slight to warning/more than isolated
		Embankment slopes	2/2	Slight to warning/more than isolated
		Cut slopes	1/2	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/2	Warning/more than isolated
		Mitre drains	5/2	Severe/more than isolated
4	Drainage (Streams)	*Structure*	1/5	Slight/Isolated Occurrence
		Embankments	2/1	Slight to warning/ Isolated Occurrence
		Erosion	1/1	Slight/Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence

Sn	Description		Rating	Degree/Extent
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	1/1	Slight/Isolated Occurrence
		Erosion protection works	1/1	Slight/Isolated Occurrence
7	Maintenance	*Quantity*	4/5	Warning to severe/Extensive occurrence over the entire segment
		Quality	4/5	Warning to severe/Extensive occurrence over the entire segment

4.2.2 Gakoigo Junction – Nginda Sec. School - D419 (II)

Table 4.7 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch one, in Murang'a region. Plate 4.2 shows the status of the Gakoigo Junction – Nginda Sec. School - D419 (II) during the study.

Table 4.7: Gakoigo Junction – Nginda Sec. School - D419 (II)

Road: Gakoigo Junction – Nginda Sec. School - D419(II)	**Length (Km):** 3.34	**Location:** Maragwa Constituency in Murang'a KeRRA Region **Phase:** 2 **Batch:** 1	**Commencement:** 30th May, 2013. **Completion/ Handover Date:** 8th October, 2016

Roadworks undertaken during initial construction:

(i). Setting out (survey works)
(ii). Site clearance: stripping and grubbing by labour;
(iii). Earthworks – Benching to widen the carriageway from the existing width of 4m to 5.5m – 6.5m; use material from side drain excavation/approved imported material to fill and compact the benches in layers of 150mm to 100% Modified AASTHO T99.
(iv). Drainage works and Concrete works;
(v). Grading and gravelling;
(vi). Natural material Base - Mix, place and compact 100mm Composite Emulsion Treatment Base (ETB) for carriageway, shoulders and junctions; with 67mm cement stabilized gravel – bottom layer and 33mm Emulsion Treated Base – upper layer over the entire carriageway and shoulders;
(vii). Bituminous surface treatment: Provision of a prime coat over the ETB layer (1:6 diluted A4 Anionic Emulsion, sprayed at a rate of 0.8 l/m^2);
(viii). Bituminous Mixes: Provision of 20mm of Cold Asphalt Concrete wearing course;
(ix). Road furniture

Expenditure:
Original Contract Sum: Kshs. 43,141,835.00
Revised Contract Sum: Kshs. 53,618,230.00


(a) Road start at Gakoigo junction. Asphalt surface intact, but poor drainage system noted (Author, 2023).


(b) Section showing pothole patching maintenance works in progress. The ride quality was rough on most sections (Author, 2023).


(c) Section showing the road geometry, drainage and surfacing. Asphalt surface intact on most sections, but poor drainage system noted even after routine maintenance. (Author, 2023).


(d) Section showing unprotected slopes prone to erosion, leading to siltation of the drains and culverts (Author, 2023).

Plate 4.2: Status of the Gakoigo Junction – Nginda Sec. School - D419 (II) during the study

4.2.2.1 Drainage Assessment

The average depth of the side drainage of the road is less than the required 0.4m depth below the formation level, while the description of the drain is as shown in Table 4.8.

Table 4.8: Description of Degree of side drain

Chainage	**Left Hand Side**				**Left Hand Side**			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.34	0.4	-0.06	Inadequate	0.29	0.4	-0.11	Inadequate
2+500 – 3+300	0.31	0.4	-0.09	Inadequate	0.3	0.4	-0.1	Inadequate

Chainage	Left Hand Side				Left Hand Side			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
Average	**0.33**	**0.4**	**-0.08**	**Inadequate**	**0.3**	**0.4**	**-0.11**	**Inadequate**

4.2.2.2 Rut Depth Measurement

Table 4.9 shows the average rut depths for both road sides measured on the road. The average rutting depth for the left-hand side and the right-hand side are generally rated at Very Good. Figure 4.5 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.9: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	To	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0+000	0+500	4.2	6.3	1.5	-2.5
0+500	1+000	4.8	3.5	3	-0.5
1+000	1+500	5.3	4.8	0	-4.4
1+500	2+000	4.4	4.5	3.1	1.1
2+000	2+500	4.1	5.1	4.7	3.24
2+500	3+000	4.9	7.5	3.5	5.2
3+000	3+300	5.8	3.5	4.8	3.0
Average		**4.8**	**4.8**	**2.8**	**0.9**
Rut depth rating		**Very Good**	**Very Good**	**Very Good**	**Very Good**

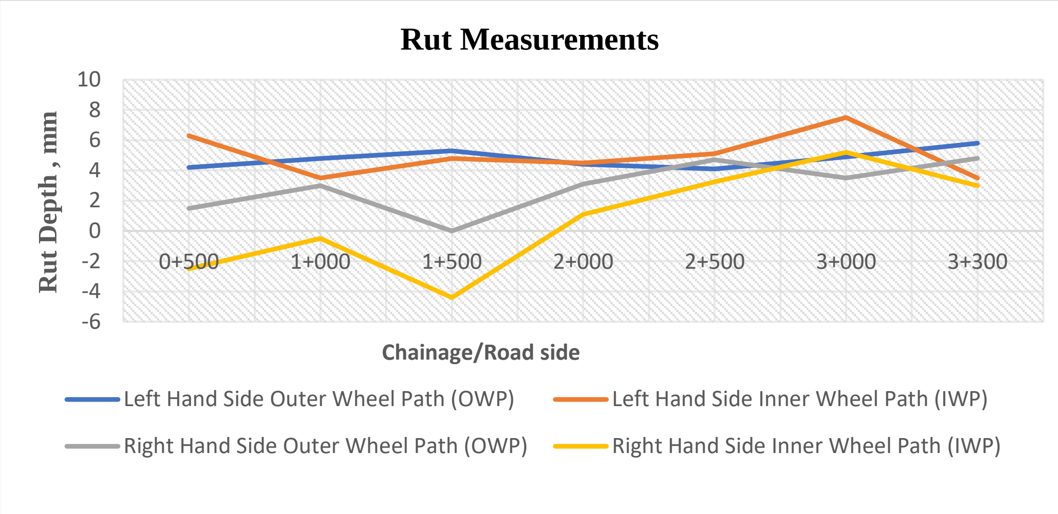


Figure 4.5: Representation of rut measurements along the road

4.2.2.3 Climate Resilience Assessment

Table 4.10 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.10: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	2/2	Slight to warning/more than isolated
		Embankment slopes	1/2	Slight/more than isolated
		Cut slopes	1/1	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/2	Warning/more than isolated

Sn	Description		Rating	Degree/Extent
		Mitre drains	5/2	Severe/more than isolated
4	Drainage (Streams)	*Structure*	-	-
		Embankments	2/1	Slight to warning/ Isolated Occurrence
		Erosion	2/1	Slight to warning/ Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	3/5	Warning/ Extensive occurrence over the entire segment
		Erosion protection works	2/1	Slight to warning/ Isolated Occurrence
7	Maintenance	*Quantity*	4/5	Warning to severe/Extensive occurrence over the entire segment
		Quality	4/5	Warning to severe/Extensive occurrence over the entire segment

4.2.3 Gakoigo Junction – Maragwa River Road - D421

4.2.3.1 Data Sheet

Table 4.11 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch one, in Murang'a region. Plate 4.3 shows the status of the Gakoigo Junction – Maragwa River road - D421 during the study.

Table 4.11: Gakoigo Junction – Maragwa River road - D421

Road: Gakoigo Junction – Maragwa River road - D421	**Length (Km):** 3.3	**Location:** Maragwa Constituency in Murang'a KeRRA Region **Phase:** 2 **Batch:** 1	**Commencement:** 30^{th} May, 2013. **Date of Final Completion:** 8^{th} November, 2015

Roadworks undertaken during initial construction:

(i). Setting out (survey works);
(ii). Site clearance: stripping and grubbing by labour;
(iii). Earthworks – Benching to widen the carriageway from the existing width of 4m to 5.5m – 6.5m; use material from side drain excavation/approved imported material to fill and compact the benches in layers of 150mm to 100% Modified AASTHO T99;
(iv). Drainage works and Concrete works;
(v). Grading and gravelling;
(vi). Natural material Base - Mix, place and compact 100mm Composite Emulsion Treatment Base (ETB) for carriageway, shoulders and junctions; with 67mm cement stabilized gravel – bottom layer and 33mm Emulsion Treated Base – upper layer over the entire carriageway and shoulders;
(vii). Bituminous surface treatment: Provision of a prime coat over the ETB layer (1:6 diluted A4 Anionic Emulsion, sprayed at a rate of 0.8 l/m^2);
(viii). Bituminous Mixes: Provision of 20mm of Cold Asphalt Concrete wearing course;
(ix). Road furniture

Expenditure:
Original Contract Sum: Kshs. 56,919,115.00
Revised Contract Sum: Kshs. 70,267,509.64

(a) Section showing the finished smooth surface. The drainage system was however not well defined (Author, 2023).

(b) Section showing the road geometry on a curve with poor visibility. Case of inadequate routine maintenance (Author, 2023).

(c) Section showing a section still in good serviceability (Author, 2023).

(d) Section showing unprotected slopes prone to erosion, leading to siltation of the drains and culverts (Author, 2023).

Plate 4.3: Status of the Gakoigo Junction – Maragwa River road - D421 during the study

4.2.3.2 Deflection Measurements

The deflection measurements are as shown in Appendix G. Tests were done on the four segments of the wheel path. Figures 4.6 to 4.9 show graphical representation of the pavement strengths.

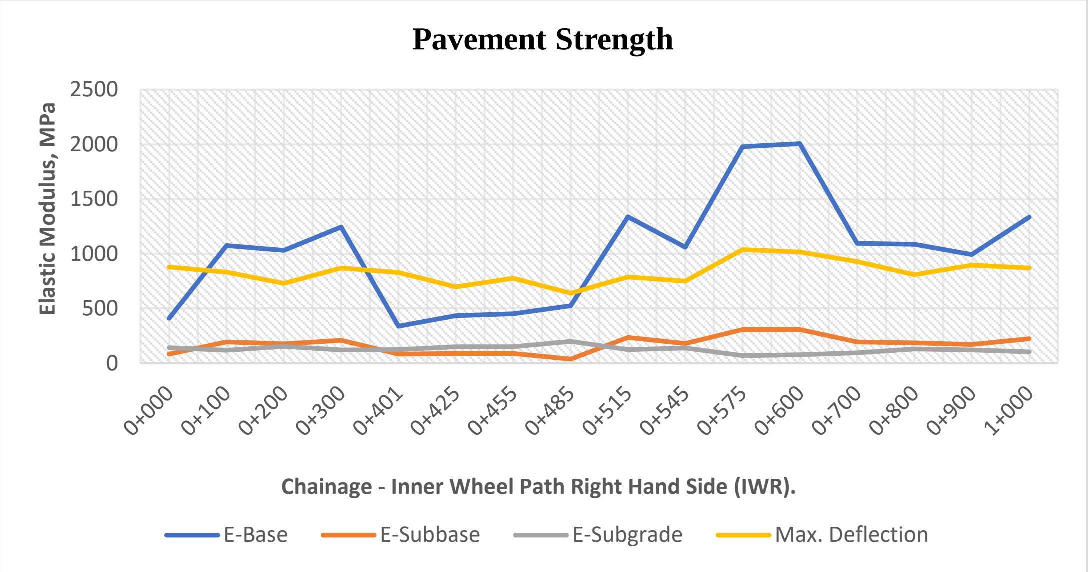


Figure 4.6: Representation of deflection test on Outer Wheel Path Left Hand Side (OWL)

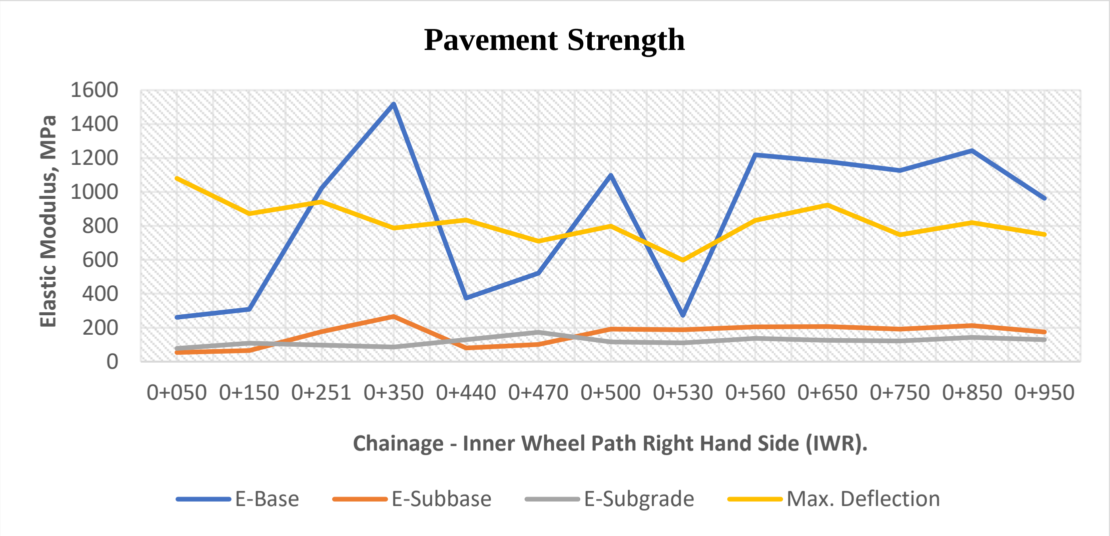


Figure 4.7: Representation of deflection test on Outer Wheel Path Right Hand Side (OWR)

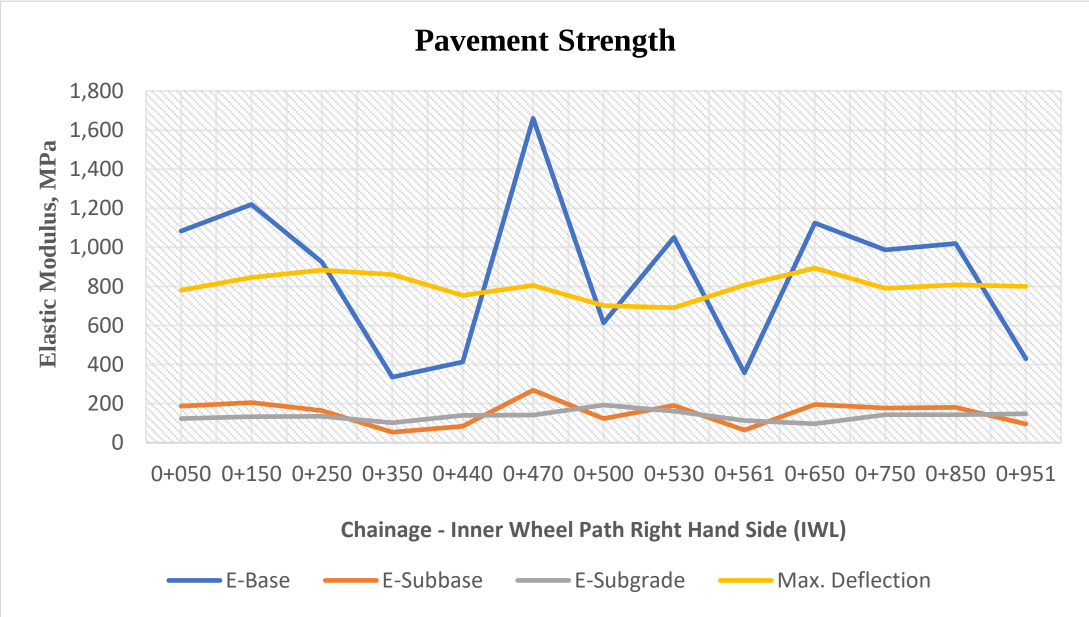


Figure 4.8: Representation of deflection test on Inner Wheel Path Left Hand Side (IWL)

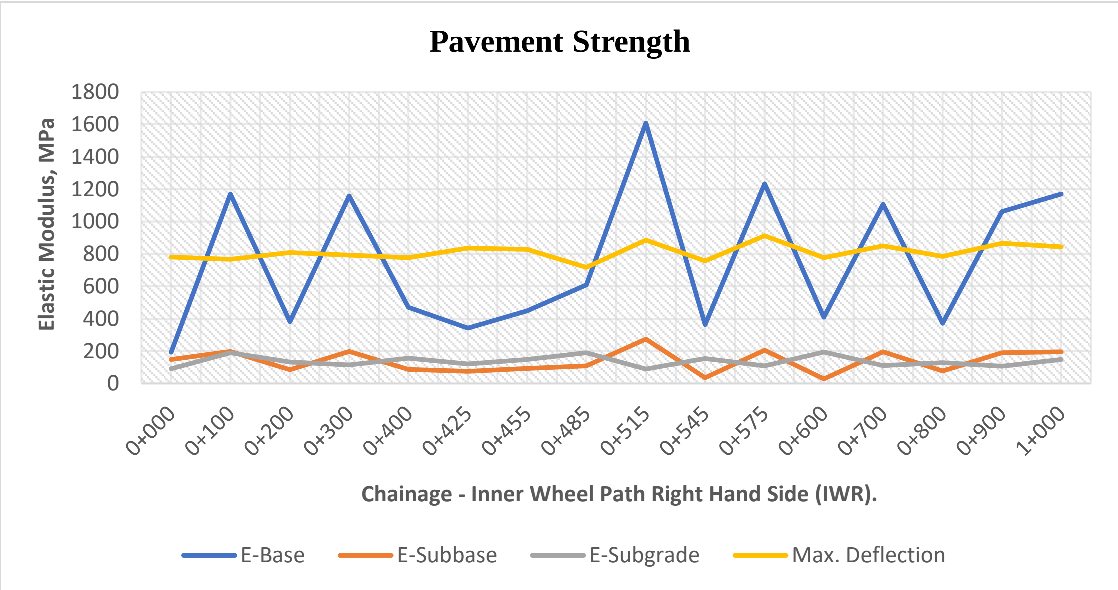


Figure 4.9: Representation of deflection test on Inner Wheel Path Right Hand Side (IWR)

4.2.3.3 Drainage Assessment

The average depth of the side drainage of the road is less than the required 0.4m depth below the formation level, while the description of the drain is as shown in Table 4.12.

Table 4.12: Description of Degree of side drain

Chainage	Left Hand Side				Left Hand Side			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.38	0.40	-0.02	Inadequate	0.39	0.4	-0.01	Inadequate
2+500 – 3+300	0.41	0.40	0.01	Inadequate	0.37	0.4	-0.03	Inadequate
Average	**0.40**	**0.40**	**-0.01**	**Inadequate**	**0.38**	**0.4**	**-0.02**	**Inadequate**

4.2.3.4 Rut Depth Measurement

Table 4.13 shows the average rut depths for both road sides measured on the road. The average rut depths for the left-hand side and right-hand side are generally rated at Good and Very Good respectively. Figure 4.10 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.13: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	**To**	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	4.5	6.3	1.5	-2.5
0 + 500	1 + 000	5.4	3.5	3	-0.5
1 + 000	1 + 500	5.8	4.8	0	-4.4
1 + 500	2 + 000	4.6	4.5	3.1	1.1
2 + 000	2 + 500	4.2	5.1	4.7	3.24
2 + 500	3 + 000	5.2	7.5	3.5	5.2
3 + 000	3 + 300	5.8	3.5	4.8	3.0
Average		**5.1**	**5.0**	**2.9**	**0.7**
Rut depth rating		**Good**	**Good**	**Very Good**	**Very Good**

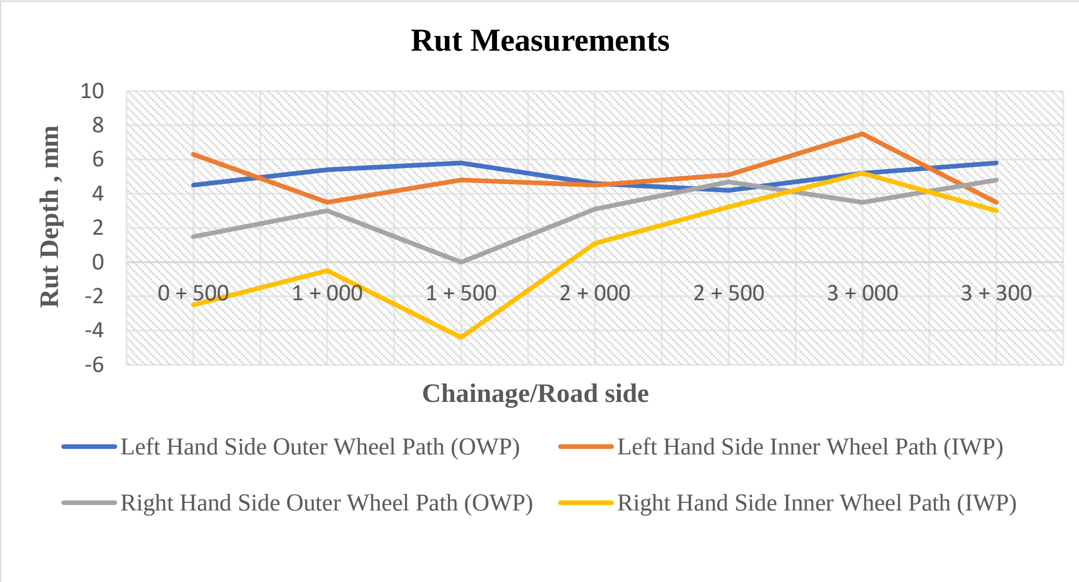


Figure 4.10: Representation of rut measurements along the road

4.2.3.5 Roughness Measurement

Table 4.14 shows the International Roughness Indices (IRI) values in m/km for each direction using different methods. The average roughness was categorised as Warning based on measurement using Rough-o-meter and Sound based on measurements using Road-Lab Pro.

Table 4.14: Roughness Measurements

Road Side	IRI (m/km)	IRI (m/km)
	Rough-o-meter	Road-Lab Pro
Left Hand Side	4.0	2.35
Right Hand Side	4.1	2.54

4.2.3.6 Present Serviceability Rating

The road has an overall PSR value of 4.0 which is rated as Good. The PSI value exceeds 2.0 which is the terminal value for low volume roads. The road does not require any urgent intervention therefore meets the PSI criteria. Table 4.15 shows the filled form for the road.

Table 4.15: Present Serviceability Rating

Date of Survey	28th January, 2023	
Road Name	D421 - Gakoigo – Maragwa river	
Section	3.2km	
Rater	PGM	
Pavement Structure	Surfacing	20mm cold mix

	Base	100mm composite emulsion treated base
	Sub-base	-
	Improved subgrade/capping	150mm neat gravel
	Subgrade class	S3

Summary		
Defect	**Points**	
1. Crazing (Block and alligator cracks)	4	
2. Longitudinal cracking	4	
3. Transverse cracking	4	
4. Edge spalling	4	
5. Rutting	4	
6. Corrugation/waves	4	
7. Depression/Longitudinal irregularity	4	
8. Shoving/Heaving/Upheaval	4	
9. Bleeding/Glazing	4	
10. Stripping/Raveling	4	
11. Patch	4	
12. Pothole/Disruption	4	
Total	**48**	
Points	**48/12**	**Rating: 4.0**

4.2.3.7 Climate Resilience Assessment

Table 4.16 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.16: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	2/3	Slight to warning/Extensive occurrence
		Embankment slopes	1/2	Slight/more than isolated

Sn	Description		Rating	Degree/Extent
		Cut slopes	1/1	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in road reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/2	Warning/more than isolated
		Mitre drains	5/2	Severe/more than isolated
4	Drainage (Streams)	*Structure*	-	-
		Embankments	2/1	Slight to warning/ Isolated Occurrence
		Erosion	2/1	Slight to warning/ Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	3/5	Warning/ Extensive occurrence over the entire segment
		Erosion protection works	2/1	Slight to warning/ Isolated Occurrence
7	Maintenance	*Quantity*	4/5	Warning to severe/Extensive occurrence over the entire segment
		Quality	4/5	Warning to severe/Extensive occurrence over the entire segment

4.3 Pavement Performance and Climate Resilience of Roads in Murang'a Region, LVS Batch Two Roads

4.3.1 Muruka - Kandara Town - D415 (I)

4.3.1.1 Data Sheet

Table 4.17 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch two, in Murang'a region. Plate 4.4 shows the status of the Muruka - Kandara Town - D415 (I) during the study.

Table 4.17: Muruka - Kandara Town - D415 (I)

Road: Muruka - Kandara Town - D415 (I)	**Length (Km):** 3.75	**Location:** Kandara Constituency in Murang'a KeRRA Region **Phase:** 2 **Batch:** 2	**Commencement:** 1st April, 2015. **Final Completion Date:** 31st March, 2017

Roadworks undertaken during initial construction:

(i). Setting out (survey works);
(ii). Site clearance - Light bush clearing; Heavy bush clearing; Pruning tree branches; Tree stumps removal; Stumps removal (500 – 1500mm girth); Stump removal (>1500mm girth); Rock / boulder removal; Stripping and grubbing;
(iii). Earthworks – Benching to widen the carriageway from the existing width of 4m to 5.5m – 6.5m; use material from side drain excavation/approved imported material to fill and compact the benches in layers of 150mm to 100% Modified AASTHO T99;
(iv). Drainage works and Concrete works;
(v). Grading and gravelling;
(vi). Natural material for Sub-base/ Base – Provide, lay, water, mix, spread and compact to 95% MDD (AASTHO T180) gravel for sub-base, base;
(vii). Treated Sub-base/ Base - Provide, Mix, place and compact 100mm Composite Emulsion Treatment Base (ETB) at mix ratio 2% cement stabilized gravel for lower layer and 2% cement, 1.5% Emulsion and 1% lime in the ETB layer (top layer);
(viii). Bituminous surface treatment: Prepare surface for Carriageway, Shoulders, Busbays, Accesses and Junctions; Provide and spray MC 30 cutback bitumen as Prime Coat at a spray rate of 1.0 - 1.2 l/m^2;
(ix). Bituminous surface treatment: Prepare surface, provide and spray Anionic Emulsion, A4-60 with 1:6 dilution at the rate of $0.8l/m^2$ as prime coat;
(x). Bituminous Mixes: Provide, mix, place and compact 20mm Cold Mix Asphalt - Prepare primed surface of carriageways, shoulders, busbays and junctions; provide and spray Anionic Emulsion bitumen A4-60% tack coat with 1:6 dilution at the at a spray rate of 1.0-1.2 l/m^2.
(xi). Road furniture

Expenditure:
Original Contract Sum: Kshs. 80,473,261.05

Performance based Maintenance Cost – Instructed works amounting to Kshs. 812,150.00
Performance based Maintenance Cost – Performance Based maintenance works - Kshs. 688,500

 (a) Section showing the geometry at road start, and the bituminous wearing course in good condition (Author, 2023).	 (b) Section shows siltation of the shoulder and part of carriageway due to inadequate drainage system (Author, 2020)
 (c) Long stretch of the road still on good serviceability, but poor drainage system noted (Author, 2023).	 (d) Section showing edge subsidence on some section owing to erosion from the roadside (Author, 2023).

Plate 4.4: Status of the Muruka - Kandara Town - D415 (I) during the study

4.3.1.2 Deflection Measurements

The deflection measurements are as shown in Appendix G. Tests were done on the four segments of the wheel path. Figures 4.11 to 4.13 show graphical representation of the pavement strengths.

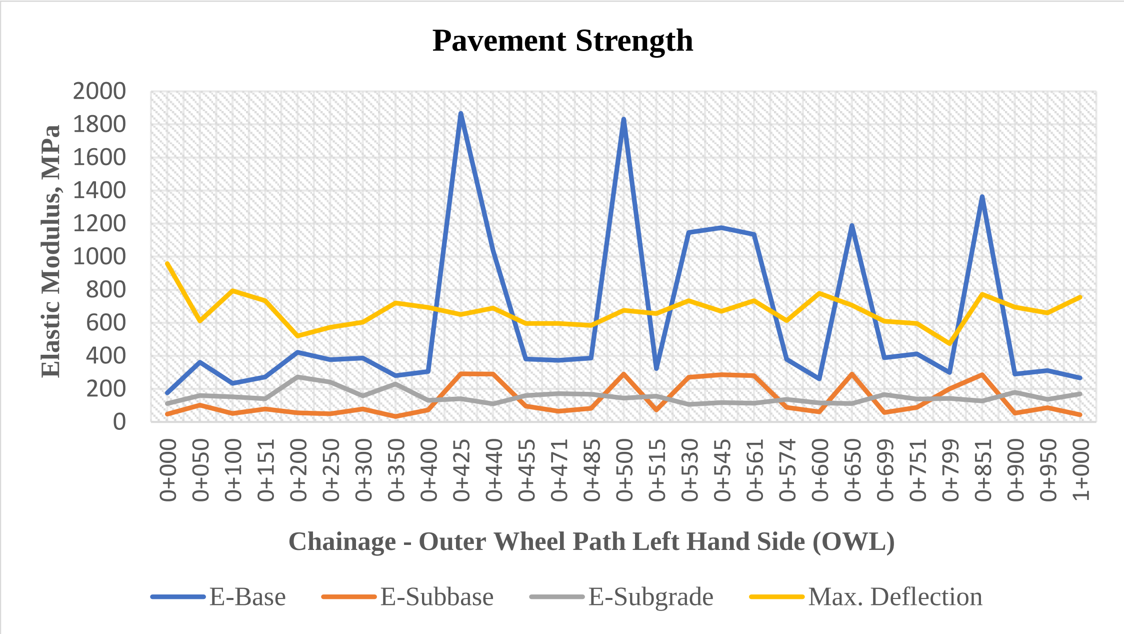


Figure 4.11: Representation of deflection test on Outer Wheel Path Left Hand Side (OWL)

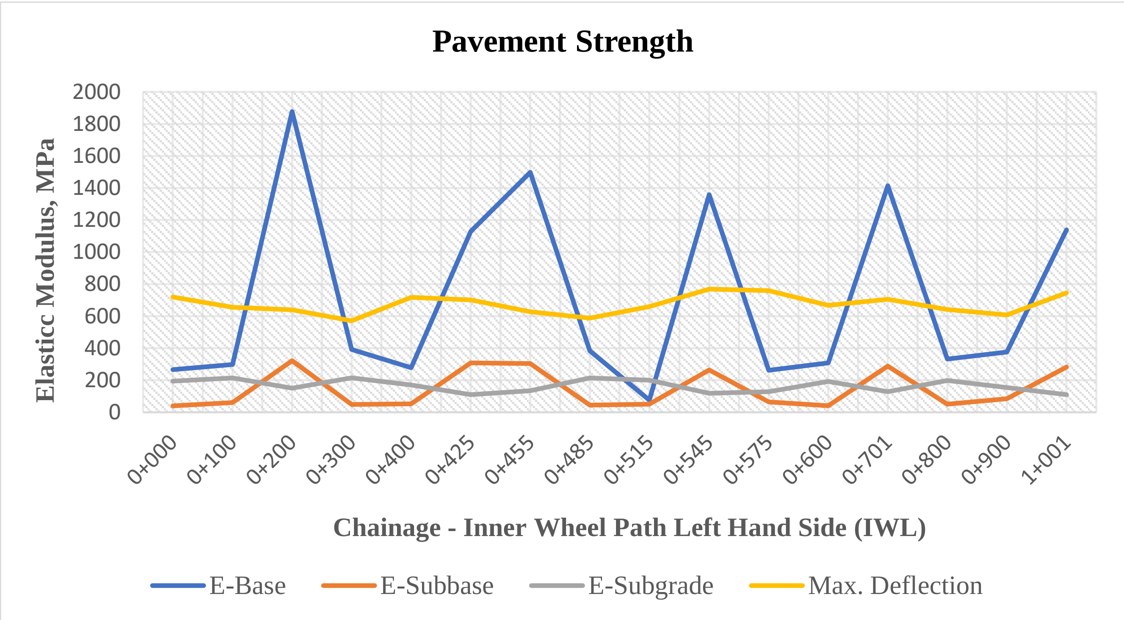


Figure 4.12: Representation of deflection test on Inner Wheel Path Left Hand Side (IWL)

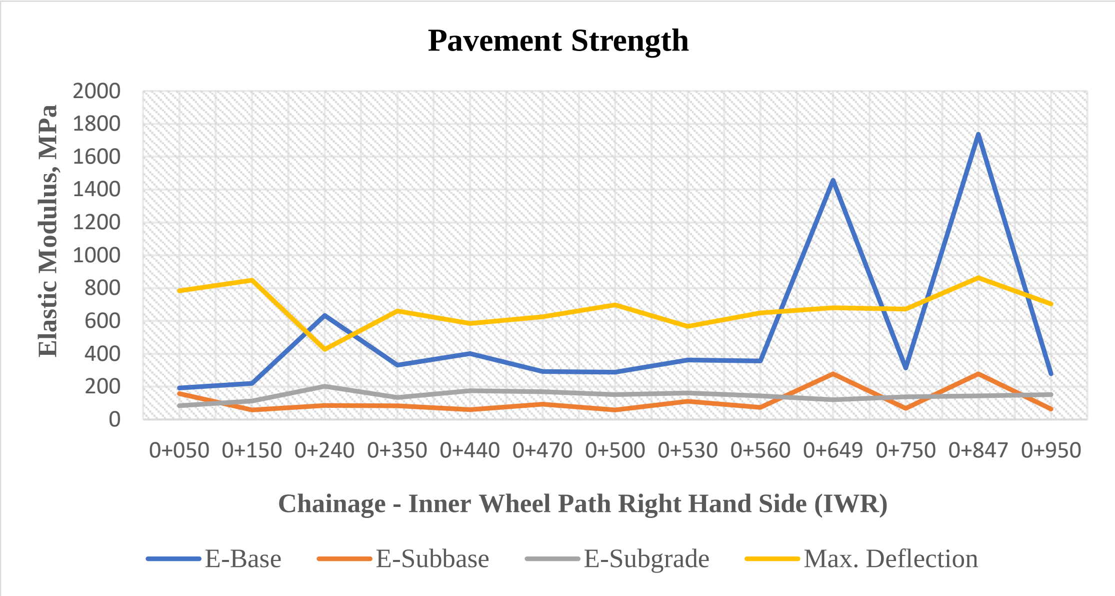


Figure 4.13: Representation of deflection test on Inner Wheel Path Right Hand Side (IWR)

4.3.1.3 Drainage Assessment

The average depth of the side drainage of the road is less than the required 0.4m depth below the formation level, while the description of the drain is as shown in Table 4.18.

Table 4.18: Description of Degree of side drain

Chainage	**Left Hand Side**				**Left Hand Side**			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.41	0.4	0.01	Adequate	0.39	0.4	-0.01	Inadequate
2+500 – 3+750	0.38	0.4	-0.02	Adequate	0.38	0.4	-0.02	Inadequate
Average	**0.39**	**0.4**	**-0.01**	Adequate	**0.39**	**0.4**	**-0.02**	**Inadequate**

4.3.1.4 Rut Depth Measurement

Table 4.19 shows the average rut depths for both road sides measured on the road. The mean rutting depths for the left-hand side and the right-hand side are generally rated at Good to Very Good. Figure 4.14 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.19: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	To	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	5.7	3.7	4.2	5.8
0 + 500	1 + 000	2.5	7.8	9.0	9.0
1 + 000	1 + 500	4.9	8.4	3.0	6.6
1 + 500	2 + 000	1.0	6.0	4.7	4.7
2 + 000	2 + 500	-2.0	2.9	0.9	4.4
2 + 500	3 + 000	1.5	4.4	0.3	5.9
3 + 000	3 + 500	2.2	3.3	2.1	7.5
3 + 500	3 + 750	0.0	3.5	1.3	-0.3
Average		**2.0**	**5.0**	**3.2**	**5.5**
Rut depth rating		**Very Good**	**Good**	**Very Good**	**Good**

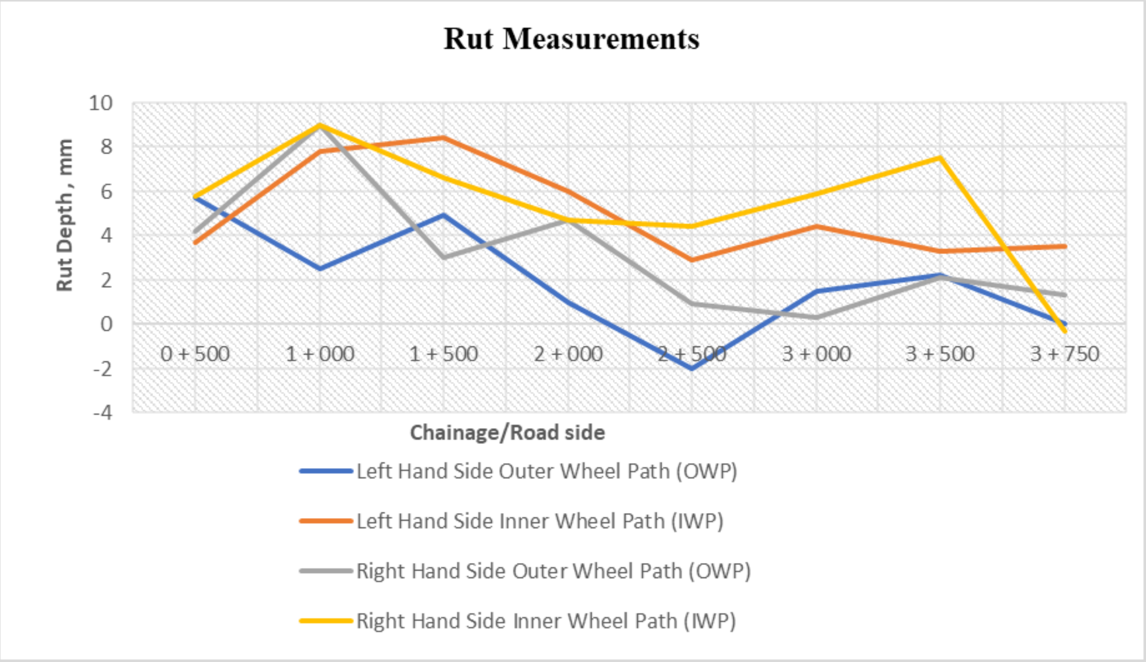


Figure 4.14: Representation of rut measurements along the road

4.3.1.5 Roughness Measurement

Table 4.20 shows the International Roughness Indices (IRI) values in m/km for each direction using different methods. The average roughness was categorised as Severe based on measurement using Rough-o-meter and Warning based on measurements using Road-Lab Pro.

Table 4.20: Roughness Measurements

Road Side	IRI (m/km)	IRI (m/km)
	Rough-o-meter	Road-Lab Pro
Left Hand Side	6.3	3.79
Right Hand Side	6.4	3.81

4.3.1.6 Present Serviceability Rating (PSR)

The road has an overall PSR value of 2.2 which is rated as Fair. The PSI value exceeds 2.0 which is the terminal value for low volume roads. The road therefore meets the PSI criteria. However, the road requires urgent intervention on sections with crazing, longitudinal cracking, transverse cracking, edge spalling, stripping, patch and potholes, as shown in Table 4.21.

Table 4.21: Present Serviceability Rating

Date of Survey	28th January, 2023	
Road Name	D415 - Muruka -Kandara	
Section	6.7km	
Rater	PGM	
Pavement Structure	Surfacing	20mm cold mix
	Base	100mm composite emulsion treated base
	Sub-base	-
	Improved subgrade/capping	150mm neat gravel
	Subgrade class	S3
Summary		
Defect	**Points**	
1. Crazing (Block and alligator cracks)	1	
2. Longitudinal cracking	2	
3. Transverse cracking	2	
4. Edge spalling	2	
5. Rutting	3	
6. Corrugation/waves	3	

7. Depression/Longitudinal irregularity	3	
8. Shoving/Heaving/Upheaval	3	
9. Bleeding/Glazing	3	
10. Stripping/Raveling	1	
11. Patch	2	
12. Pothole/Disruption	1	
Total	**26**	
Points	**26/12**	**Rating: 2.2**

4.3.1.7 Climate Resilience Assessment

Table 4.22 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.22: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	2/3	Slight to warning/Extensive occurrence
		Embankment slopes	1/2	Slight/more than isolated
		Cut slopes	1/1	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in road reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/2	Warning/more than isolated
		Mitre drains	5/2	Severe/more than isolated
4	Drainage (Streams)	*Structure*	-	-
		Embankments	2/1	Slight to warning/ Isolated Occurrence

Sn	Description		Rating	Degree/Extent
		Erosion	2/1	Slight to warning/ Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	3/5	Warning/ Extensive occurrence over the entire segment
		Erosion protection works	2/1	Slight to warning/ Isolated Occurrence
7	Maintenance	*Quantity*	4/5	Warning to severe/Extensive occurrence over the entire segment
		Quality	4/5	Warning to severe/Extensive occurrence over the entire segment

4.3.2 Muruka - Kandara Town - D415 (II)

4.3.2.1 Data Sheet

Table 4.23 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch two, in Murang'a region. Plate 4.5 shows the status of the Muruka - Kandara Town - D415 (II) during the study.

Table 4.23: Muruka - Kandara Town - D415 (II)

Road: Muruka - Kandara Town - D415 (II)	**Length (Km):** 3.75	**Location:** Kandara Constituency in Murang'a KeRRA Region **Phase:** 2 **Batch:** 2	**Commencement:** 1st April, 2015. **Final Completion Date:** 31st December, 2015

(i). Site clearance: stripping and grubbing;
(ii). Benching to widen the carriageway to achieve 8.0m wide Formation; use materials from side drain excavation to fill and compact the benches in layers of 150mm to 100% Modified AASTHO T99;
(iii). Top sub grade preparation – scarify the existing ground to a depth of 150mm below the ground level, spread, add lateritic gravel to improve the sub-grade water and compact to 100% MDD AASHTO T99;
(iv). Provision of 100mm gravel sub-base for carriageway, shoulders and junctions compacted to 95% MDD AASHTO T180;
(v). Provision of 100mm gravel base for carriageway, shoulders and junctions compacted to 95% MDD AASHTO T180;
(vi). Provision of 100mm composite base for carriageway, shoulders and in potholes (of the surface dressed section) and selected sections, with 67mm cement stabilized gravel – bottom layer and 33mm Emulsion Treated Base (ETB) – upper layer over the entire carriageway and shoulders;
(vii). Provision of a prime coat over the gravel layer (MC 30 cutback bitumen, sprayed at 1.0 - 1.2 l/m^2);
(viii). Provision of a prime coat over the ETB layer (1:6 diluted A4-60 Anionic Emulsion, sprayed at a rate of 0.8 l/m^2);
(ix). Provision of 20mm of Cold Asphalt Concrete wearing course;
(x). Installation and Cleaning of culverts and other drainage works such as mitre drains, catch waters drains;
(xi). Provision of road furniture, road marking;
(xii). Defects notification period of 12 Months.

Expenditure:
Original Contract Sum: Kshs. 77,193,603.45


(a) Road start showing signs of edge subsidence, but the surfacing still intact (Author, 2023).


(b) Section showing the erodibility potential of the embankment slopes (Author, 2023)

 (c) Section showing the inadequate and unmarked drainage system, leaving the pavement exposed (Author, 2023)	 (d) Long stretch section showing the road geometry and the road still on good serviceability (Author, 2023)

Plate 4.5: Status of the Muruka - Kandara Town - D415 (II) during the study

4.3.2.2 Drainage Assessment

The average depth of the side drainage of the road is less than the required 0.4m depth below the formation level, while the description of the drain is as shown in Table 4.24.

Table 4.24: Description of Degree of side drain

Chainage	**Left Hand Side**				**Left Hand Side**			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.42	0.40	0.02	Adequate	0.38	0.4	-0.02	Inadequate
2+500 – 3+750	0.40	0.40	0.00	Adequate	0.35	0.4	-0.05	Inadequate
Average	**0.41**	**0.40**	**0.01**	**Adequate**	**0.37**	**0.4**	**-0.03**	**Inadequate**

4.3.2.3 Rut Depth Measurement

Table 4.25 shows the average rut depths for both road sides measured on the road. The average rut depths for the left-hand side and right-hand side are generally rated at Very Good to Good. Figure 4.15 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.25: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	To	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	5.5	3.6	4	5.7
0 + 500	1 + 000	2.3	7.7	8.8	8.9
1 + 000	1 + 500	4.7	8.3	2.8	6.5
1 + 500	2 + 000	0.8	5.9	4.5	4.6
2 + 000	2 + 500	-2.2	2.8	0.7	4.3
2 + 500	3 + 000	1.3	4.3	0.1	5.8
3 + 000	3 + 500	2	3.2	1.9	7.4
3 + 750	3 + 750	-0.2	3.4	1.1	-0.5
Average		**1.8**	**4.9**	**3.0**	**5.3**
Rut depth rating		**Very Good**	**Very Good**	**Very Good**	**Good**

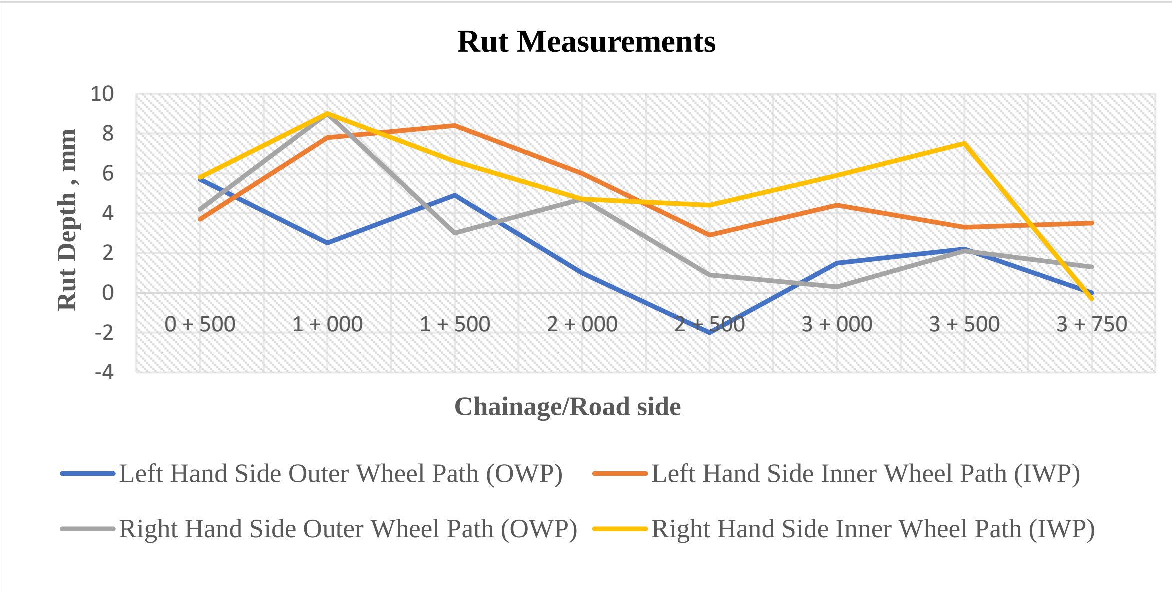


Figure 4.15: Representation of rut measurements along the road

4.3.2.4 Climate Resilience Assessment

Table 4.26 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.26: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	2/3	Slight to warning/Extensive occurrence
		Embankment slopes	1/2	Slight/more than isolated
		Cut slopes	1/1	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/2	Warning/more than isolated
		Mitre drains	5/2	Severe/more than isolated
4	Drainage (Streams)	*Structure*	-	-
		Embankments	2/1	Slight to warning/ Isolated Occurrence
		Erosion	2/1	Slight to warning/ Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	3/5	Warning/ Extensive occurrence over the entire segment
		Erosion protection works	2/1	Slight to warning/ Isolated Occurrence
7	Maintenance	*Quantity*	4/5	Warning to severe/Extensive occurrence over the entire segment
		Quality	4/5	Warning to severe/Extensive occurrence over the entire segment

4.4 Pavement Performance and Climate Resilience of Roads in Kiambu Region, LVS Batch Two Roads

4.4.1 Gichiengo – Kijabe Hospital Road – E443/1

Road E443 is located in Kiambu County. The road commences at Gichiengo town centre, along Road A104 Nairobi – Nakuru road and ends at Kijabe Hospital. The constructed section is 6.5 km.

4.4.1.1 Data Sheet

Table 4.27 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch two, in Kiambu region. Plate 4.6 shows the status of the Gichiengo – Kijabe Hospital Road – E443/1 during the study.

Table 4.27: Gichiengo – Kijabe Hospital Road – E443/1

Road: Gichiengo – Kijabe Hospital Road – E443/1	**Length (Km):** 3.25	**Location:** Kiambu **Phase:** 2 **Batch:** 2	**Commencement:** 23rd March, 2015. **Completion Date:** 31st December, 2019.
Roadworks undertaken during initial construction: (i). Site clearance; stripping and grubbing by labour; (ii). Benching to widen the carriageway from the existing width of 4m to 5.5m – 6.5m; use material from side drain excavation/approved imported material to fill and compact the benches in layers of 150mm to 100% Modified AASTHO T99; (iii). Subbase preparation – scarify the existing pavement to a depth of 150mm below the ground level, spread, add gravel to improve the subbase, water and compact to 100% MDD AASHTO T99; (iv). Provision of a prime coat over the Subbase (MC-30 at a spray rate of 1 litre/m^2); (v). Provision of 75mm Emulsion Stabilised Materials (ESM) Base over the entire carriageway, shoulders and junctions; (vi). Provision of a tack coat over the ESM Base (A4-60 at a spray rate of 0.8L/ m^2); (vii). Provision of 20mm of Cold Asphalt Concrete wearing course; (viii). Installation and Cleaning of culverts and other drainage works such as mitre drains, catch waters drains; (ix). Widening of the river crossing at chainage 2+000; (x). Provision of safety and speed calming measures such road furniture, road signs, road marking rumble strips and speed bumps. (xi). Defects notification period of 12 months. (xii). Performance Based Maintenance over a period of 36 Months.			
Expenditure: **Contract Sum: Kshs.** 78,416,287.00 ▪ Improvement Works and Defects Liability Period of 12 months = Kshs. 76,951,787.00 ▪ 36 months of Performance Based Routine Maintenance (PBRM) = Kshs. 1,464,500.00 **Revised Contract Sum: Kshs.** 89,027,846.53			

(a) Road start showing a failed section due to edge subsidence at a junction. Drainage system non-existent (Author, 2023).

(b) Section showing rough wearing course, that does not offer a smooth ride. Drainage system noted to be inadequate (Author, 2023).

(c) Section showing geometry and the embankment slopes with potential for collapse (Author, 2023)

(d) Long stretch section showing the road geometry and the road still on good serviceability (Author, 2023)

Plate 4.6: Status of the Gichiengo – Kijabe Hospital Road – E443/1 during the study

4.4.1.2 Classified Traffic Counts

The Annual Average Daily Traffic (AADT) for the road is as shown in Table 4.28. Figure 4.16 shows a pie chart representation of traffic composition.

Table 4.28: Annual Average Daily Traffic (AADT)

Vehicle Type	AADT
Motor Bikes	694
Cars	985
Minibus	300
Bus	0

Vehicle Type	AADT
Omnibus	0
LGV	73
MGV	47
HGV	4
TOTAL	**2,108**

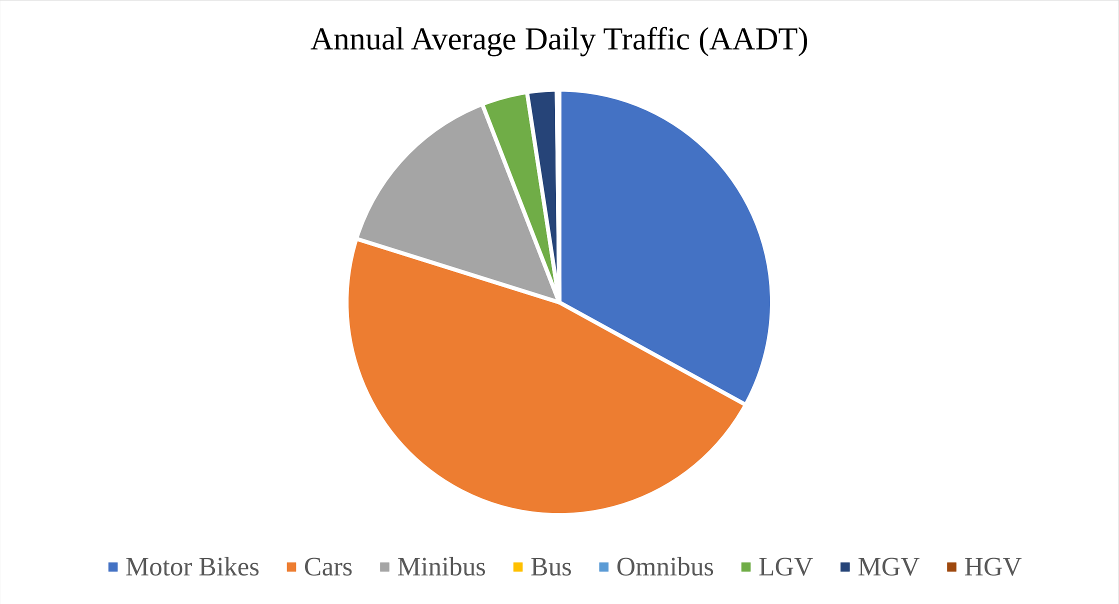


Figure 4.16: Pie Chart of traffic composition

4.4.1.3 Axle Load Survey

The axle load survey was carried out with the objective of determining the Vehicle Equivalence Factor (VEF) for each vehicle and vehicle class. The VEF values obtained for the road are summarised in Table 4.29.

Table 4.29: Average Vehicle Equivalence Factor (VEF)

Vehicle Type	Average VEF
Bus	0.007
Minibus	0.002
Medium Goods Vehicles	0.282
Heavy Goods Vehicles	0.003
Articulated Heavy Goods Vehicles	0.000

The Daily Equivalent Standard Axles (DESA) was then obtained by totalling up the product of vehicle VEF and the total average Annual Average Daily Traffic (AADT) for both directions for each vehicle type. Table 4.30 shows a summary of DESA by vehicle type and the total ESA/ day for the road.

Table 4.30: Daily ESA on road based on Average Vehicle Equivalence Factor (VEF)

Vehicle Type	Daily ESA
Bus	0.003
Minibus	0.044
Medium Goods Vehicles	13.298
Heavy Goods Vehicles	0.010
Articulated Heavy Goods Vehicles	0.000
Total	**13.355**

Based on the adopted annual growth rate of traffic of 5.0%, the cumulative equivalent standard axles were obtained and the corresponding design traffic class determined for 10-year and 15-year design periods as summarized in Table 4.31.

Table 4.31: Design Traffic Classes

Design Period	Cumulative Equivalent Standard Axles (CESA)	Design Traffic Class
10-Year	61,313.92	T5-3
15-Year	105,189.82	T5-2

A mechanistic-empirical modelling of the pavement, as shown in Appendix H and summarised in Figures 4.17 and 4.18, showed that the layer bearing capacity distributions were within the capacities required for low volume roads, that is one million standard equivalent axles, based on the estimated traffic for the 15-year period, and that the pavement was able to support the existing traffic adequately. The estimated layer bearing capacities were also found to be adequate to support the current loading.

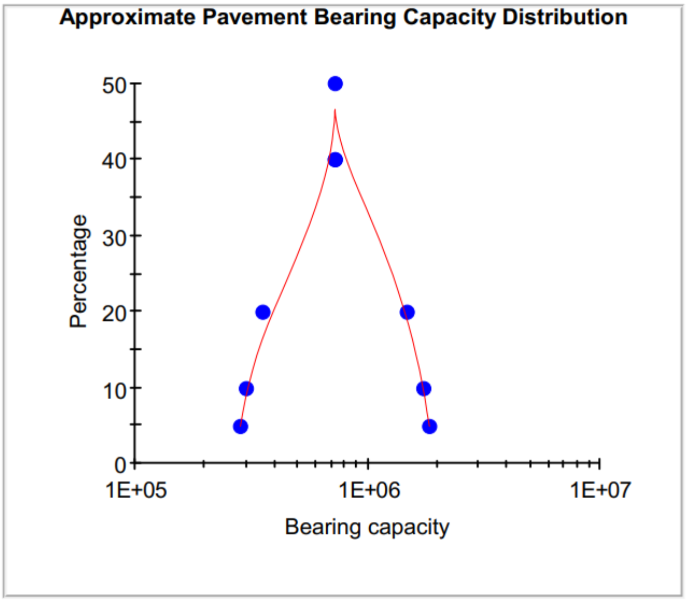


Figure 4.17: Approximate Pavement Bearing Capacity Distribution

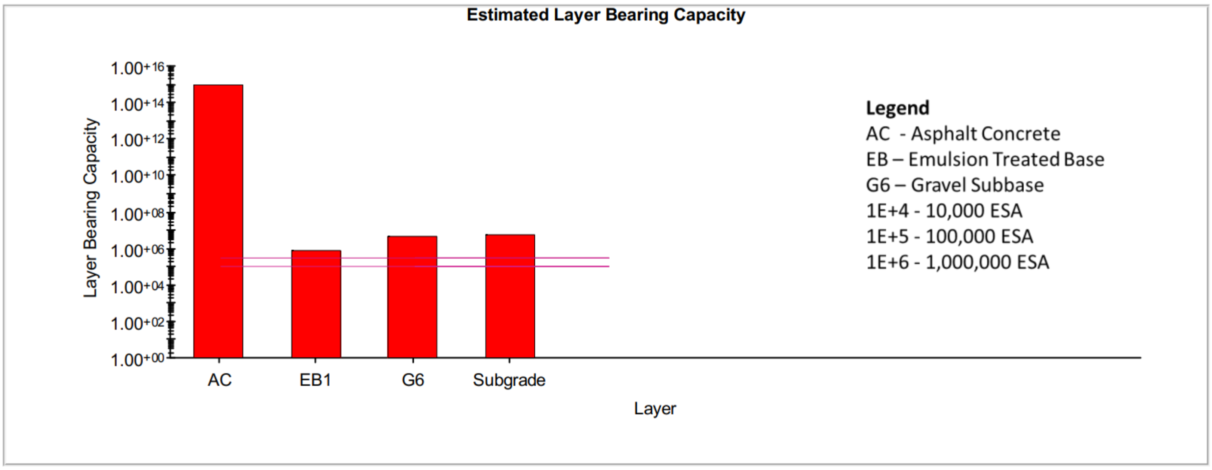


Figure 4.18: Estimated Layer Bearing Capacity

Using the structural number approach to check the adequacy of the pavement, Table 4.32 shows the input data for the road into the empirical Equation 3.4 and 3.5.

Table 4.32: Pavement Design Inputs (AASHTO, 1993)

Item Description	Value
CNSA during the design period (W_{18})	105,189.82
Reliability (R in %)	95
Standard Deviation (ZR)	-1.645
Combined Standard Error (S_o)	0.49
Initial Serviceability Index (P_o flexible pavement)	4.2
Terminal Serviceability Index (P_t)	2.5

Item Description	Value
Subgrade CBR	16
Subgrade Resilient Modulus (M_R) as above	24,000 psi

Layer coefficients were assigned to each layer material in the pavement structure in order to convert actual layer thickness, D_i into a structural number, SN. This layer coefficient expressed the empirical relationship between SN and the layer thickness and is a measure of the relative ability of the material to function as a structural component of the pavement. The layer coefficients and thickness of pavement layers are presented in the Table 4.33. The required and provided structural computations are summarised in Table 4.34.

Table 4.33: Layer Coefficients for Pavement Materials

Layer Type		Layer Coefficients a_1, a_2, a_3	Layer Thickness
a_1	Cold Asphalt Concrete	0.45	20mm
a_2	Emulsion Stabilised Materials (ESM) Base	0.23	75mm
a_3	Subbase (Granular natural or crushed soaked CBR >30%)	0.11	150mm
Drainage Coefficient, m_1 and m_2 = 1.2			

Table 4.34: Pavement Structure Adequacy

Item Description	Value
$Log_{10}(W_{18})$	5.021973
$Z_R \times S_0 + 9.36 \times Log_{10}(SN+1) - 0.20 + Log_{10}((Po-Pt) / (4.2-1.5)) / (0.40+1094/(SN+1)^{5.19}) + 2.32 \times Log_{10}(M_R) - 8.07$	5.021940
Required SN	1.6511
Provided SN	1.9205
Pavement Structure Adequacy	Pavement Adequate

4.4.1.4 Drainage Assessment

The average depth of the side drainage of the road is less than the required minimum of 0.4m depth below the formation level, while the description of the drain is as shown in Table 4.35.

Table 4.35: Description of Degree of side drain

Chainage	Left Hand Side				Left Hand Side			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.3	0.4	-0.1	Inadequate	0.38	0.4	-0.02	Inadequate
2+500 – 3+250	0.35	0.4	-0.05	Inadequate	0.34	0.4	-0.06	Inadequate
Average	**0.33**	**0.4**	**-0.07**	**Inadequate**	**0.36**	**0.4**	**-0.04**	**Inadequate**

4.4.1.5 Rut Depth Measurement

Table 4.36 shows the average rut depths for both road sides measured on the road. The average rut depth for both directions is rated very good for both wheel paths in both directions. Figure 4.19 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.36: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	**To**	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	-4.2	-5.2	-5.3	-3.3
0 + 500	1 + 000	-6.8	-6.9	8.0	-7.5
1 + 000	1 + 500	-1.8	-0.5	-1.6	-5.6
1 + 500	2 + 000	-3.1	-3.3	-1.8	-3.6
2 + 000	2 + 500	-2.8	-2.9	-5.4	-4.0
2 + 500	3 + 000	3.2	0.6	-2.8	-4.3
3 + 000	3 + 500	-5.8	3.3	0.6	-1.5
3 + 250	4 + 000	0.0	0.0	10.0	11.0
Average		**-1.9**	**-1.4**	**1.0**	**-2.2**
Rut depth rating		**Very Good**	**Very Good**	**Very Good**	**Very Good**

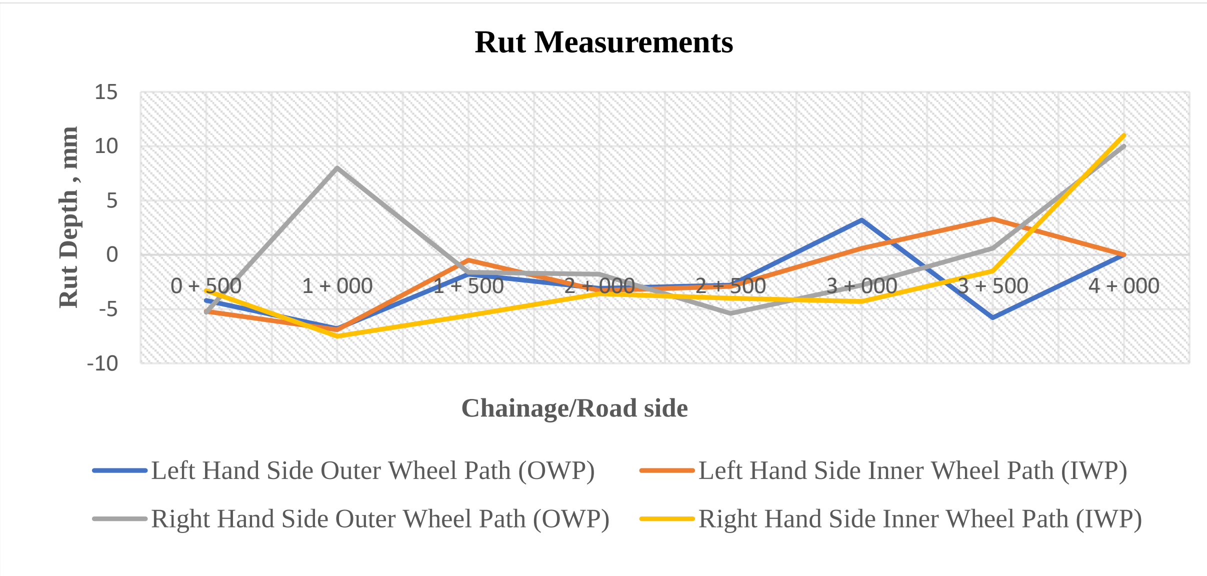


Figure 4.19: Representation of rut measurements along the road

4.4.1.6 Roughness Measurement

Table 4.37 shows the International Roughness Indices (IRI) values in m/km for each direction using different methods. The average roughness was categorised as Severe based on measurement using Rough-o-meter and Warning based on measurements using Road-Lab Pro.

Table 4.37: Roughness Measurements

Road Side	IRI (m/km)	IRI (m/km)
	Rough-o-meter	Road-Lab Pro
Left Hand Side	7.3	4.18
Right Hand Side	7.0	4.29

4.4.1.7 Present Serviceability Rating (PSR)

The road has an overall PSR value of 2.75 which is rated as Fair. The PSI value exceeds 2.0 which is the terminal value for low volume roads. The road therefore meets the PSI criteria. However, urgent interventions on sections with transverse cracking, edge spalling, shoving, and potholes are highly recommended, as shown in Table 4.38.

Table 4.38: Present Serviceability Rating

Date of Survey	4th February, 2023	
Road Name	Gichiengo – Kijabe Hospital Road – E443/1	
Section	3.25km	
Rater	PGM	
Pavement Structure	Surfacing	20mm cold mix
	Base	75mm Emulsion Stabilised Materials (ESM) Base
	Sub-base	150mm scarified existing pavement
	Improved subgrade/capping	-
	Subgrade class	S3
Summary		
Defect	**Points**	
1. Crazing (Block and alligator cracks)	4	
2. Longitudinal cracking	3	
3. Transverse cracking	2	
4. Edge spalling	1	
5. Rutting	3	
6. Corrugation/waves	4	
7. Depression/Longitudinal irregularity	3	
8. Shoving/Heaving/Upheaval	2	
9. Bleeding/Glazing	4	
10. Stripping/Raveling	3	
11. Patch	3	

12. Pothole/Disruption	1	
Total	**33**	
Points	**33/12**	**Rating: 2.75**

4.4.1.8 Climate Resilience Assessment

Table 4.39 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.39: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	2/3	Slight to warning/Extensive occurrence
		Embankment slopes	2/2	Slight to warning/more than isolated
		Cut slopes	1/1	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/2	Warning/more than isolated
		Mitre drains	5/2	Severe/more than isolated
4	Drainage (Streams)	*Structure*	-	-
		Embankments	2/2	Slight to warning/more than isolated
		Erosion	2/1	Slight to warning/ Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence

Sn	Description		Rating	Degree/Extent
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	3/5	Warning/ Extensive occurrence over the entire segment
		Erosion protection works	2/1	Slight to warning/ Isolated Occurrence
7	Maintenance	*Quantity*	4/5	Warning to severe/Extensive occurrence over the entire segment
		Quality	4/5	Warning to severe/Extensive occurrence over the entire segment

4.4.2 Gichiengo – Kijabe Hospital Road – E443/2

4.4.2.1 Data Sheet

Table 4.40 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch two, in Kiambu region. Plate 4.7 shows the status of the Gichiengo – Kijabe Hospital Road – E443/2 during the study.

Table 4.40: Gichiengo – Kijabe Hospital Road – E443/2

<table>
<tr><td>Road: Gichiengo – Kijabe Hospital Road – E443/2</td><td>Length (Km): 3.25</td><td>Location: Lari Constituency in Kiambu KeRRA Region.
Phase: 2
Batch: 2</td><td>Commencement: 23rd March, 2015.

Completion Date: 17th October, 2018</td></tr>
<tr><td colspan="4">Roadworks undertaken during initial construction:
(i). Site clearance- stripping and grubbing by labour;
(ii). Benching to widen the carriageway from the existing width of 4-5m to 6 m; use material from side drain excavation/approved imported material to fill and compact the benches in layers of 150mm to 100% Modified AASTHO T99;
(iii). Subbase preparation – scarify the existing pavement to a depth of 150mm below the ground level, spread, add gravel to improve the subbase, water and compact to 100% MDD AASHTO T99;
(iv). Provision of a prime coat over the Subbase (MC-30 at a spray rate of 1 Litre/m^2);
(v). Provision of 75mm Emulsion Stabilised Materials (ESM) Base over the entire carriageway, shoulders and junctions;
(vi). Provision of a tack coat over the ESM Base (A4-60 at a spray rate of 0.8L/ m^2);
(vii). Provision of 20mm of Cold Asphalt Concrete wearing course;
(viii). Installation and Cleaning of culverts and other drainage works such as mitre drains, catch waters drains;
(ix). Slope Protection Works using Gabions at Chainage KM 3+640;
(x). Provision of safety and speed calming measures such road furniture, road signs, road marking rumble strips and speed bumps;</td></tr>
</table>

(xi). Defects notification period of 12 months;
(xii). Performance Based Maintenance over a period of 36 Months.

Expenditure:
Contract Sum: Kshs. 87,163,498.24

- Improvement Works and Defects Liability Period of 12 months = Kshs. 85,615,702.92
- 36 months of Performance Based Routine Maintenance (PBRM) = Kshs. 1,547,796.00

(a) Section showing road geometry on a curve offering inadequate sight distance due to overgrown vegetation (Author, 2023).

(b) A railway intersection with the road, with the underpass only offering one way movement (Author, 2023).

(c) Section showing deterioration of the edges and no clear drainage system (Author, 2023).

(d) Section exhibiting good serviceability but poor routine maintenance noted (Author, 2023).

Plate 4.7: Status of the Gichiengo – Kijabe Hospital Road – E443/2 during the study

4.4.2.2 Drainage Assessment

The average depth of the side drainage on the road was less than the required minimum of 0.4m depth below the formation level, while the description of the drain is as shown in Table 4.41.

Table 4.41: Description of Degree of side drain

Chainage	Left Hand Side				Left Hand Side			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.28	0.4	-0.12	Inadequate	0.33	0.4	-0.07	Inadequate
2+500 – 3+250	0.31	0.4	-0.09	Inadequate	0.29	0.4	-0.11	Inadequate
Average	**0.29**	**0.4**	**-0.11**	**Inadequate**	**0.31**	**0.4**	**-0.09**	**Inadequate**

4.4.2.3 Rut Depth Measurement

Table 4.42 shows the average rut depths for both road sides measured on the road. The average rut depth for both directions is rated very good for both wheel paths in both directions. Figure 4.20 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.42: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	**To**	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	-0.4	0.5	4.5	5.0
0 + 500	1 + 000	5.8	7.8	4.2	1.5
1 + 000	1 + 500	5.3	8.0	2.8	-6.2
1 + 500	2 + 000	0.5	4.5	2.8	-6.2
2 + 000	2 + 500	-2.8	-2.9	-5.4	-4.0
2 + 500	3 + 000	3.2	0.6	-2.8	-4.3
3 + 000	3 + 250	-5.8	3.3	0.6	-1.5
Average		**0.8**	**3.1**	**0.9**	**-3.5**
Rut depth rating		**Very Good**	**Very Good**	**Very Good**	**Very Good**

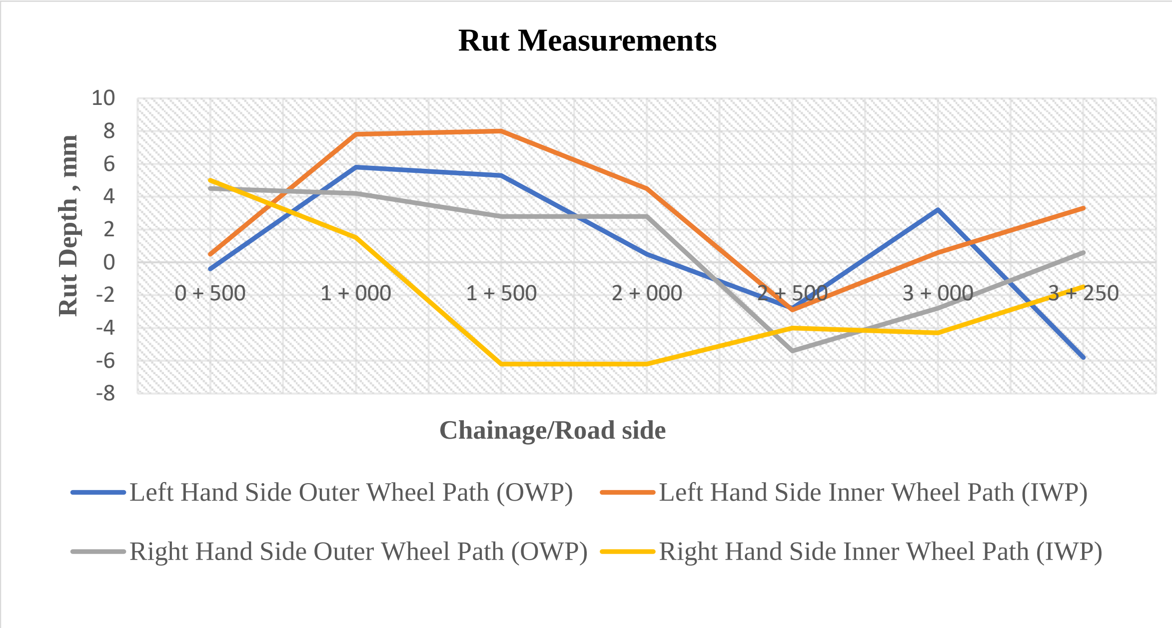


Figure 4.20: Representation of rut measurements along the road

4.4.2.4 Roughness Measurement

Table 4.43 shows the International Roughness Indices (IRI) values in m/km for each direction using different methods. The average roughness was categorised as Severe based on measurement using Rough-o-meter and Warning based on measurements using Road-Lab Pro (Norken et al, 2021).

Table 4.43: Roughness Measurements

Road Side	IRI (m/km) Rough-o-meter	IRI (m/km) Road-Lab Pro
Left Hand Side	7.4	4.23
Right Hand Side	7.2	4.18

4.4.2.5 Present Serviceability Rating (PSR)

The road has an overall PSR value of 2.75 which is rated as Fair. The PSI value exceeds 2.0 which is the terminal value for low volume roads. The road therefore meets the PSI criteria. However, urgent interventions on sections with transverse cracking, edge spalling, shoving, and potholes are highly recommended, as shown in Table 4.44.

Table 4.44: Present Serviceability Rating

Date of Survey	4th February, 2023	
Road Name	Gichiengo – Kijabe Hospital Road – E443/2	
Section	3.25km	
Rater	PGM	
Pavement Structure	Surfacing	20mm cold mix
	Base	75mm Emulsion Stabilised Materials (ESM) Base
	Sub-base	150mm scarified existing pavement
	Improved subgrade/capping	-
	Subgrade class	S3
Summary		
Defect	**Points**	
1. Crazing (Block and alligator cracks)	3	
2. Longitudinal cracking	2	
3. Transverse cracking	2	
4. Edge spalling	1	
5. Rutting	2	
6. Corrugation/waves	3	
7. Depression/Longitudinal irregularity	2	
8. Shoving/Heaving/Upheaval	2	
9. Bleeding/Glazing	3	
10. Stripping/Raveling	2	
11. Patch	2	
12. Pothole/Disruption	1	
Total	**25**	
Points	**25/12**	**Rating: 2.08**

4.4.2.6 Climate Resilience Assessment

Table 4.45 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.45: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	2/3	Slight to warning/Extensive occurrence
		Embankment slopes	2/2	Slight to warning/more than isolated
		Cut slopes	1/1	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in road reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Road shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/2	Warning/more than isolated
		Mitre drains	5/2	Severe/more than isolated
4	Drainage (Streams)	*Structure*	-	-
		Embankments	2/2	Slight to warning/more than isolated
		Erosion	2/1	Slight to warning/ Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	3/5	Warning/ Extensive occurrence over the entire segment
		Erosion protection works	2/1	Slight to warning/ Isolated Occurrence
7	Maintenance	*Quantity*	4/5	Warning to severe/Extensive occurrence over the entire segment
		Quality	4/5	Warning to severe/Extensive occurrence over the entire segment

4.4.3 Kang'oo - Kamwangi Road - E1531

Road E1531 is located in Kiambu County, Gatundu North Constituency. It starts at Kang'oo town to Kamwangi town. The sealed section is 5.6 km long.

4.4.3.1 Data Sheet

Table 4.46 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch two, in Kiambu region. Plate 4.8 shows the status of the Kang'oo - Kamwangi Road - E1531 during the study.

Table 4.46: Kang'oo - Kamwangi Road - E1531

Road: Kang'oo - Kamwangi Road - E1531	**Length (Km):** 5.6	**Location:** Gatundu North Constituency in Kiambu KeRRA Region. **Phase:** 2 **Batch:** 2	**Commencement:** 23rd March, 2015. **Final Completion Date:** 17th October, 2018
Roadworks undertaken during initial construction: (i). Site clearance-stripping and grubbing by labour; (ii). Benching to widen the carriageway from the existing width of 4-5m to 7 m; use material from side drain excavation/approved imported material to fill and compact the benches in layers of 150mm to 100% Modified AASTHO T99; (iii). Improved Sub-base preparation–scarify the existing pavement to a depth of 150mm below the ground level, spread, add gravel to improve the sub base, water and compact to 95% MDD AASHTO T99; (iv). Provision of a prime coat over the Subbase (MC-30 at a spray rate of 1 Litre/m^2); (v). Provision of 75mm Emulsion Stabilised Materials (ESM) Base over the entire carriageway, shoulders and junctions; (vi). Provision of a tack coat over the ESM Base (A4-60 at a spray rate of 0.8L/ m^2); (vii). Provision of 20mm of Cold Asphalt Concrete wearing course; (viii). Installation and cleaning of culverts and other drainage works such as mitre drains, catch waters drains; (ix). Provision of safety and speed calming measures such road furniture, road signs, road marking rumble strips and speed bumps; (x). Defects notification period of 12 months; (xi). Performance Based Maintenance over a period of 36 Months.			
Expenditure: **Contract Sum: Kshs.** 163,925,034.50 ▪ Improvement Works and Defects Liability Period of 12 months = Kshs. 160,915,298.50 ▪ 36 months of Performance Based Routine Maintenance (PBRM) = Kshs. 3,009,936.00			

(a) Road section exhibiting good serviceability, but poor maintenance noted (Author, 2023).

(b) Road end showing the road geometry, with vegetation impeding the sight distance (Author, 2023).

(c) Section showing road section in good condition on the surfacing, but poor drainage system and no road marking (Author, 2023).

(d) Road end showing some failure at a junction (Author, 2023).

Plate 4.8: Status of the Kang'oo - Kamwangi Road - E1531 during the study

4.4.3.2 Classified Traffic Counts

Traffic studies along this road were carried out from 31st July 2021 to 6th August 2021 at Mukuyuini centre. The mean daily traffic based on the vehicle volumes was summarised in terms of Annual Average Daily Traffic (AADT) as shown in Table 4.47. It was observed that the road exhibits high percentage of motor bikes (52.9%) and cars/taxis (31.1%). There is a significant percentage of light goods vehicles (9.7%) as a result of agricultural activities in the region. Bicycles, minibuses, buses and heavy goods vehicles contribute the minimum percentage of traffic on the road. Figure 4.21 shows a pie chart representation of traffic composition.

Table 4.47: Annual Average Daily Traffic (AADT)

Vehicle Type	AADT
Motor Bikes	975
Cars	573
Minibus	50
Bus	2
Omnibus	0
LGV	178
MGV	37
HGV	5
TOTAL	**1,842**

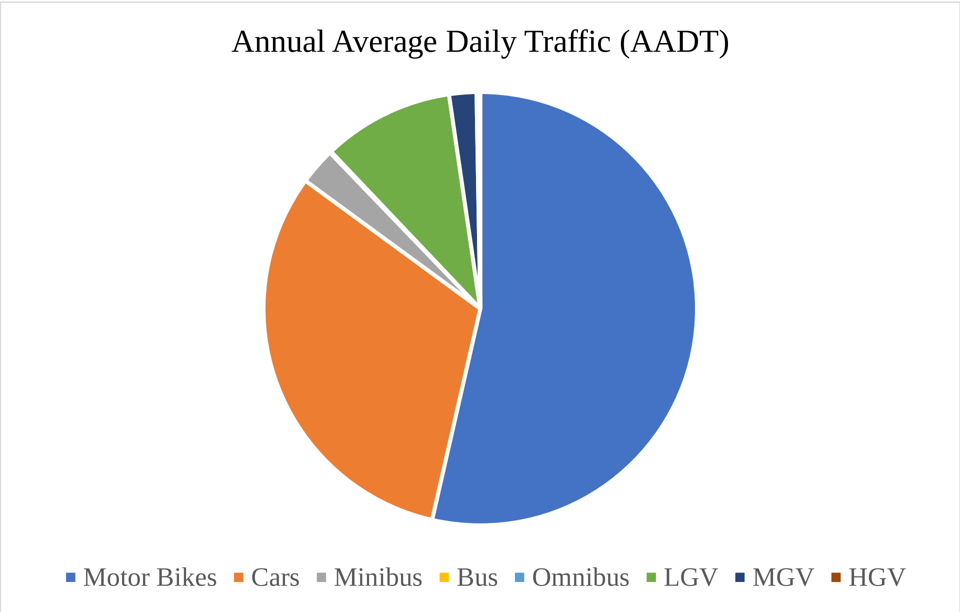


Figure 4.21: Pie Chart of traffic composition

4.4.3.3 Axle Load Survey

The axle load survey was carried out with the objective of determining the Vehicle Equivalence Factor (VEF) for each vehicle and vehicle class. The VEF values obtained for the road are summarised in Table 4.48.

Table 4.48: Average Vehicle Equivalence Factor (VEF)

Vehicle Type	Average VEF
Bus	0.003
Minibus	0.002
Medium Goods Vehicles	0.417
Heavy Goods Vehicles	0.265
Articulated Heavy Goods Vehicles	0.095

The Daily Equivalent Standard Axles (DESA) was then obtained by totalling up the product of vehicle VEF and the total average Annual Average Daily Traffic (AADT) for both directions for each vehicle type. Table 4.49 shows a summary of DESA by vehicle type and the total ESA/ day for the road.

Table 4.49: Daily ESA on road based on Average Vehicle Equivalence Factor (VEF)

Vehicle Type	Daily ESA
Bus	0.007
Minibus	0.006
Medium Goods Vehicles	15.338
Heavy Goods Vehicles	0.652
Articulated Heavy Goods Vehicles	0.245
Total	**16.249**

Based on the adopted annual growth rate of traffic of 5.0%, the cumulative equivalent standard axles were obtained and the corresponding design traffic class determined for 10-year and 15-year design periods as summarized in Table 4.50.

Table 4.50: Design Traffic Classes

Design Period	Cumulative Equivalent Standard Axles (CESA)	Design Traffic Class
10-Year	74,596.92	T5-3
15-Year	127,977.84	T5-2

A mechanistic-empirical modelling of the pavement, as shown in Appendix H and summarised in Figures 4.22 and 4.23, showed that the layer bearing capacity distributions were within the capacities required for low volume roads, that is one million standard equivalent axles, based on the estimated traffic for the 15-year period, and that the pavement was able to support the existing traffic adequately. The estimated layer bearing capacities were also found to be adequate to support the current loading.

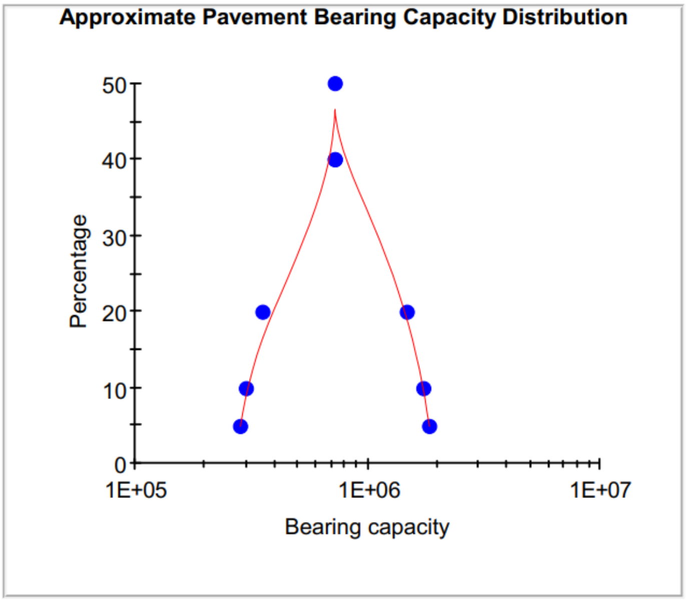


Figure 4.22: Approximate Pavement Bearing Capacity Distribution

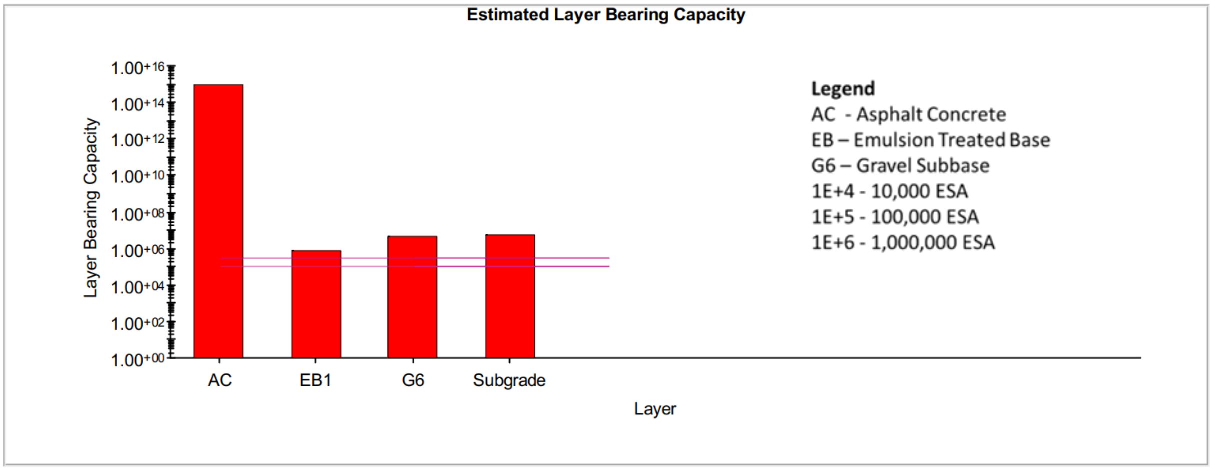


Figure 4.23: Estimated Layer Bearing Capacity

Using the structural number approach to check the adequacy of the pavement, Table 4.51 shows the input data for the road into the empirical Equation 3.4 and 3.5.

Table 4.51: Pavement Design Inputs (AASHTO, 1993)

Item Description	Value
CNSA during the design period (W_{18})	127,977.84
Reliability (R in %)	95
Standard Deviation (ZR)	-1.645
Combined Standard Error (S_o)	0.49
Initial Serviceability Index (P_o flexible pavement)	4.2
Terminal Serviceability Index (P_t)	2.5
Subgrade CBR	16
Subgrade Resilient Modulus (M_R) as above	24,000 psi

Layer coefficients were assigned to each layer material in the pavement structure in order to convert actual layer thickness, D_i into a structural number, SN. This layer coefficient expressed the empirical relationship between SN and the layer thickness and is a measure of the relative ability of the material to function as a structural component of the pavement. The layer coefficients and thickness of pavement layers are presented in the Table 4.52. The required and provided structural number computations are summarised in Table 4.53.

Table 4.52: Layer Coefficients for Pavement Materials

Layer Type		Layer Coefficients a_1, a_2, a_3	Layer Thickness
a_1	Cold Asphalt Concrete	0.45	20mm
a_2	Emulsion Stabilised Materials (ESM) Base	0.23	75mm
a_3	Subbase (Granular natural or crushed soaked CBR >30%)	0.11	150mm
Drainage Coefficient, m_1 and m_2 = 1.2			

Table 4.53: Pavement Structure Adequacy

Item Description	Value
$Log_{10} (W_{18})$	5.107134
$Z_R \times S_0 + 9.36 \times Log_{10} (SN+1) - 0.20 + Log_{10}((Po-Pt) / (4.2-1.5)) / (0.40+1094/(SN+1)^{5.19}) + 2.32 \times Log_{10}(M_R) - 8.07$	5.107118

Item Description	Value
Required SN	1.9205
Provided SN	1.7093
Pavement Structure Adequacy	Pavement Adequate

4.4.3.4 Drainage Assessment

The average depth of the road side drain was less than the required 0.40m depth below the formation level, and was found to be inadequate. Table 4.54 gives the description of the road drainage.

Table 4.54: Description of Degree of side drain

Chainage	Left Hand Side				Left Hand Side			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.36	0.4	-0.04	Inadequate	0.34	0.4	-0.06	Inadequate
2+500 – 5+000	0.30	0.4	-0.1	Inadequate	0.31	0.4	-0.09	Inadequate
5+000 – 5+500	0.33	0.4	-0.07	Inadequate	0.33	0.4	-0.07	Inadequate
Average	**0.33**	**0.40**	**-0.07**	**Inadequate**	**0.33**	**0.40**	**-0.22**	**Inadequate**

4.4.3.5 Rut Depth Measurement

Table 4.55 shows the average rut depths for both road sides measured on the road. The average rut depth for both directions is rated as very good. Figure 4.24 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.55: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	**To**	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	8.3	4.7	3.3	2.5
0 + 500	1 + 000	6.1	3.8	2.5	4.5
1 + 000	1 + 500	6.3	7.3	2.3	3.2
1 + 500	2 + 000	-1.4	4.1	1.4	4.2
2 + 000	2 + 500	6.1	5.3	4.2	6.5
2 + 500	3 + 000	1.3	3.3	0.0	6.9
3 + 000	3 + 500	3.1	4.3	4.4	6.9
3 + 500	4 + 000	2.4	2.1	0.0	5.1
4 + 000	4 + 500	1.3	2.4	1.0	3.5
4 + 500	5 + 000	5.3	7.8	1.7	3.8
5 + 000	5 + 500	0.9	3.0	2.3	2.5
Average		**3.6**	**4.4**	**2.1**	**4.5**
Rut depth rating		**Very Good**	**Very Good**	**Very Good**	**Very Good**

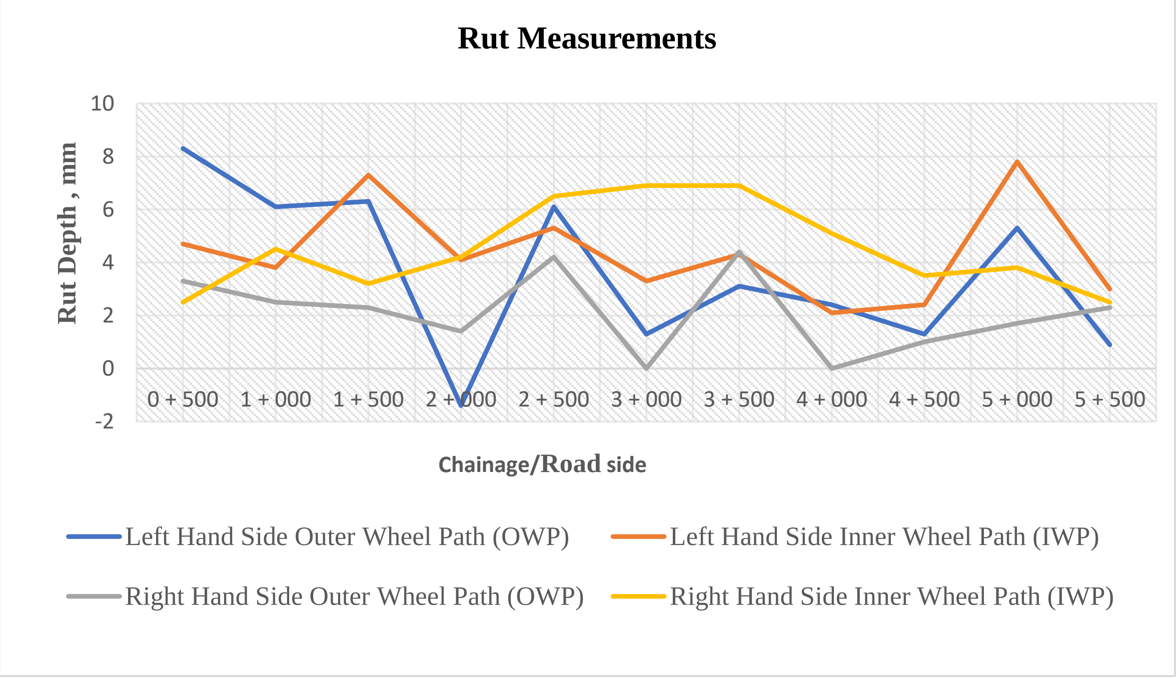


Figure 4.24: Representation of rut measurements along the road

4.4.3.6 Roughness Measurement

Table 4.56 shows the International Roughness Indices (IRI) values in m/km for each direction using different methods. The average roughness was categorised as Warning based on measurement using Rough-o-meter and also Warning based on measurements using Road-Lab Pro.

Table 4.56: Roughness Measurements

Road Side	**IRI (m/km)**	**IRI (m/km)**
	Rough-o-meter	Road-Lab Pro
Left Hand Side	5.9	5.04
Right Hand Side	5.9	5.07

4.4.3.7 Present Serviceability Rating (PSR)

The road has an overall PSR value of 3.3 which is rated as Good. The PSI value exceeds 2.0 which is the terminal value for low volume roads. The road therefore meets the PSI criteria. However, urgent interventions on sections with edge spalling and potholes are highly recommended, as shown in Table 4.57.

Table 4.57: Present Serviceability Rating

Date of Survey	4th February, 2023	
Road Name	E1531 - Kangoo - Kamwangi	
Section	5.6km	
Rater	PGM	
Pavement Structure	Surfacing	20mm cold mix
	Base	75mm Emulsion Stabilised Materials (ESM)
	Sub-base	150mm scarified existing pavement
	Improved subgrade/capping	-
	Subgrade class	S3
Summary		
Defect	**Points**	
1. Crazing (Block and alligator cracks)	4	
2. Longitudinal cracking	4	
3. Transverse cracking	3	
4. Edge spalling	2	
5. Rutting	3	

6. Corrugation/waves	4	
7. Depression/Longitudinal irregularity	4	
8. Shoving/Heaving/Upheaval	4	
9. Bleeding/Glazing	4	
10. Stripping/Raveling	3	
11. Patch	3	
12. Pothole/Disruption	2	
Total	**40**	
Points	**40/12**	**Rating: 3.3**

4.4.3.8 Climate Resilience Assessment

Table 4.58 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.58: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	2/3	Slight to warning/Extensive occurrence
		Embankment slopes	1/2	Slight/more than isolated
		Cut slopes	1/1	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/2	Warning/more than isolated
		Mitre drains	5/2	Severe/more than isolated
4		*Structure*	-	-

Sn	Description		Rating	Degree/Extent
	Drainage (Streams)	*Embankments*	2/1	Slight to warning/ Isolated Occurrence
		Erosion	2/1	Slight to warning/ Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	3/5	Warning/ Extensive occurrence over the entire segment
		Erosion protection works	2/1	Slight to warning/ Isolated Occurrence
7	Maintenance	*Quantity*	4/5	Warning to severe/Extensive occurrence over the entire segment
		Quality	4/5	Warning to severe/Extensive occurrence over the entire segment

4.5 Pavement Performance and Climate Resilience of Roads in Kiambu Region, LVS Batch Three Roads

4.5.1 Wangige - Nyathuna - D378-1

Road D378-1 is located in Kiambu County. It starts at Wangige and ends at Nyathuna. The road is 3.40 km long and was completed in the year 2020 under Batch 3 programme.

4.5.1.1 Data Sheet

Table 4.59 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch three, in Kiambu region. Plate 4.9 shows the status of the Wangige- Nyathuna - D378-1 during the study.

Table 4.59: Wangige- Nyathuna - D378-1

Road: Wangige- Nyathuna - D378	**Length (Km):** 6.4	**Location:** Kabete Constituency in Kiambu KeRRA Region. **Phase:** 2 **Batch:** 3	**Commencement:** 18th October, 2018. **Completion Date:** 15th July, 2020.
Roadworks undertaken during initial construction: (i). Site clearance-stripping and grubbing by labour; (ii). Setting out (survey works); (iii). Site clearance;			

(iv). Earthworks; (v). Improvement to drainage and installation of culverts (vi). Construction of erosion protection works; (vii). Maintenance of passage of traffic through works; (viii). Relocation and reinstatement of services; (ix). Benching to widen the carriageway using material of characteristics similar to the existing pavement; (x). Provision of 200mm improved subgrade layer; (xi). Provision of 100mm neat gravel sub-base layer across the carriageway and shoulders; (xii). Provision of 75mm Emulsion Stabilized Material (ESM) base across the carriageway and shoulders; (xiii). Provision of A4-60 bitumen emulsion as prime coat; (xiv). Application of 20mm cold asphalt surfacing layer across the carriageway and shoulders; (xv). Provision of road furniture; (xvi). Defects notification period of 12months; (xvii). Performance based routine maintenance works for a period of 3 years.	
Expenditure: **Contract Sum: Kshs.** 167,748,041.50 ▪ Improvement Works and Defects Liability Period of 12 months = Kshs. 161,957,785.50 ▪ 36 months of Performance Based Routine Maintenance (PBRM) = Kshs. 5,790,256.00	
 (a) Section of the road exhibiting failure by edge subsidence and potholing (Author, 2023).	 (b) Road section still in good condition and offering a smooth rideability (Author, 2023).
 (c) Section showing embankment slopes with a potential for erosion, and drainage system inadequate (Author, 2023).	 (d) Section offering good serviceability but poor maintenance showing on silted drains and culverts (Author, 2023).
Plate 4.9: Status of the Wangige- Nyathuna - D378-1 during the study	

4.5.1.2 Drainage Assessment

The depth of the side drain is less than the required depth of 0.75m below the formation level. Table 4.60 gives the description of the road drainage.

Table 4.60: Description of Degree of side drain

Chainage	Left Hand Side				Right Hand Side			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.37	0.4	-0.03	Inadequate	0.36	0.4	-0.04	Inadequate
2+500 – 5+000	0.44	0.4	0.04	Inadequate	0.39	0.4	-0.01	Inadequate
5+000 – 6+400	0.3	0.4	-0.1	Inadequate	0.39	0.4	-0.01	Inadequate
Average	**0.37**	**0.4**	**-0.03**	**Inadequate**	**0.38**	**0.4**	**-0.02**	**Inadequate**

4.5.1.3 Rut Depth Measurement

Table 4.61 shows the average rut depths for both road sides measured on the road. The average rut depth for both directions is rated as very good. Figure 4.25 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.61: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	To	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	2.5	4.8	0.5	0.1
0 + 500	1 + 000	2.7	2.7	-2.6	2.5
1 + 000	1 + 500	3.1	3.4	4.4	1.2
1 + 500	2 + 000	4.1	4.4	2.8	1.5
2 + 000	2 + 500	5.2	6.1	2.5	6.5
2 + 500	3 + 000	4.6	9.0	2.6	0.5
3 + 000	3 + 400	3.2	6.5	3.2	4.2
Average		**3.6**	**5.3**	**1.9**	**2.4**
Rut depth rating		**Very Good**	**Very Good**	**Very Good**	**Very Good**

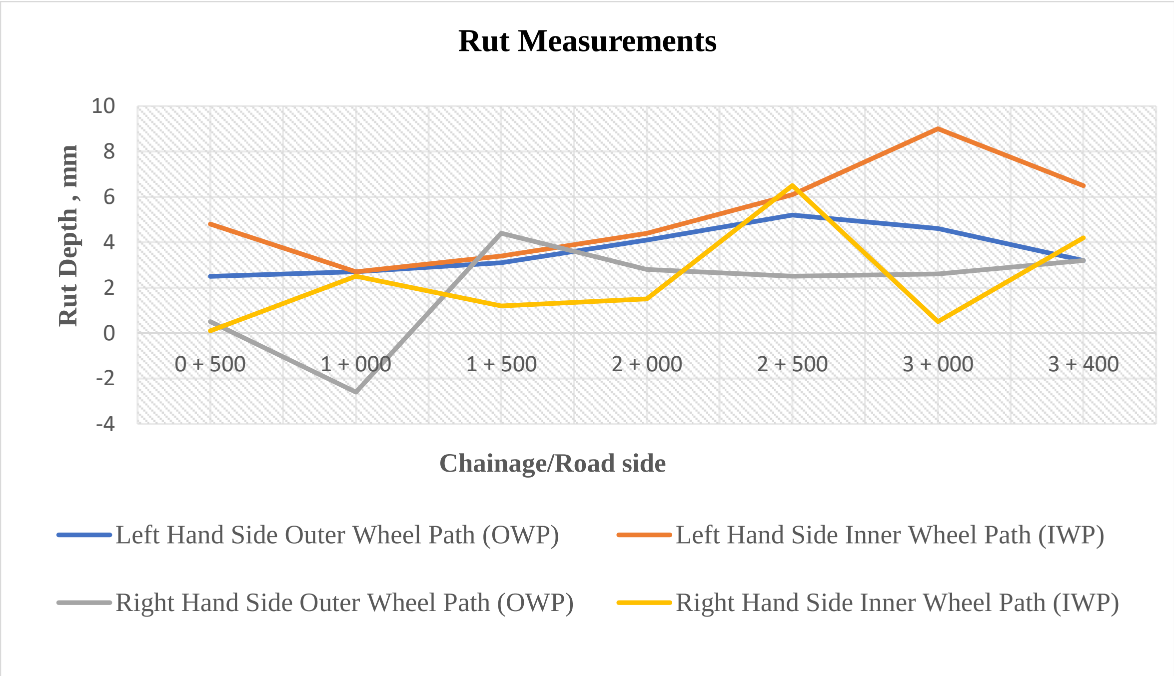


Figure 4.25: Representation of rut measurements along the road

4.5.1.4 Present Serviceability Rating (PSR)

The road has an overall PSR value of 3.8 which is rated as Good. The PSI value exceeds 2.0 which is the terminal value for low volume roads. The road therefore meets the PSI criteria, as shown in Table 4.62.

Table 4.62: Present Serviceability Rating

Date of Survey	28th January, 2023		
Road Name	D378-1 Wangige - Nyathuna		
Section	6.2km		
Rater	PGM		
Pavement Structure	Surfacing		20mm cold mix
	Base		75mm Emulsion Stabilized Material
	Sub-base		100mm neat gravel sub-base
	Improved subgrade/capping		200mm improved subgrade
	Subgrade class		S3
Summary			
Defect		**Points**	
1. Crazing (Block and alligator cracks)		3	
2. Longitudinal cracking		3	
3. Transverse cracking		5	
4. Edge spalling		3	
5. Rutting		5	
6. Corrugation/waves		5	
7. Depression/Longitudinal irregularity		5	
8. Shoving/Heaving/Upheaval		3	
9. Bleeding/Glazing		5	
10. Stripping/Raveling		3	
11. Patch		3	
12. Pothole/Disruption		3	
Total		**45**	
Points		**45/12**	**Rating: 3.8**

4.5.1.5 Climate Resilience Assessment

Table 4.63 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.63: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	2/3	Slight to warning/Extensive occurrence
		Embankment slopes	1/2	Slight/more than isolated
		Cut slopes	1/1	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/2	Warning/more than isolated
		Mitre drains	5/2	Severe/more than isolated
4	Drainage (Streams)	*Structure*	-	-
		Embankments	2/1	Slight to warning/ Isolated Occurrence
		Erosion	2/1	Slight to warning/ Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	2/3	Warning/ Extensive occurrence over the entire segment
		Erosion protection works	2/1	Slight to warning/ Isolated Occurrence
7	Maintenance	*Quantity*	4/4	Warning to severe/Extensive occurrence over the entire segment
		Quality	4/4	Warning to severe/Extensive occurrence over the entire segment

4.5.2 Nyathuna - Ngecha – Rironi - D378-2

Road C562 is located in Kiambu County. It starts at Nyathuna and ends at Rironi. The road is 5.40 km long and was completed in the year 2020 under Batch 3 programme.

4.5.2.1 Data Sheet

Table 4.64 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch three, in Kiambu region. Plate 4.10 shows the status of the Nyathuna - Ngecha – Rironi - D378-2 during the study.

Table 4.64: Nyathuna - Ngecha – Rironi - D378-2

Road: Nyathuna - Ngecha – Rironi - D378-2	**Length (Km):** 5.4	**Location:** Kabete Constituency in Kiambu KeRRA Region. **Phase:** 2 **Batch:** 3	**Commencement:** 4th October, 2018. **Substantial Completion Date:** 15th July, 2020.
Roadworks undertaken during initial construction: (i). Setting out (survey works); (ii). Site clearance; (iii). Earthworks; (iv). Improvement to drainage and installation of culverts (v). Construction of erosion protection works; (vi). Maintenance of passage of traffic; (vii). Relocation and reinstatement of services; (viii). Benching to widen the carriageway using material of characteristics similar to the existing pavement; (ix). Provision of 200mm improved sub-grade layer; (x). Provision of 100mm neat gravel sub-base layer across the carriageway and shoulders; (xi). Provision of 75mm Emulsion Stabilized Material (ESM) base across the carriageway and shoulders; (xii). Provision of A4-60 bitumen emulsion as prime coat; (xiii). Application of 20mm cold asphalt surfacing layer across the carriageway and shoulders; (xiv). Provision of road furniture; (xv). Defects notification period of 12months; (xvi). Performance based routine maintenance works for a period of 3 years.			
Expenditure: **Contract Sum: Kshs.** 140,524,254.00 ▪ Improvement Works and Defects Liability Period of 12 months = Kshs. 135,792,846.00 ▪ 36 months of Performance Based Routine Maintenance (PBRM) = Kshs. 4,731,408.00			

(a) Road start showing the geometry, and section in good condition (Author, 2023).

(b) Section showing high embankments on the left side, with high erodibility potential, and silted drainage system (Author, 2023).

(c) Section exhibiting failure by pothole development (Author, 2023).

(d) Long section of the road still in good serviceability (Author, 2023).

Plate 4.10: Status of the Nyathuna - Ngecha – Rironi - D378-2 during the study

4.5.2.2 Drainage Assessment

The depth of the side drain is less than the required depth of 0.40m below the formation level. Table 4.65 gives the description of the road drainage.

Table 4.65: Description of Degree of side drain

Chainage	Left Hand Side				Right Hand Side			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.34	0.4	-0.06	Inadequate	0.38	0.4	-0.02	Inadequate
2+500 – 5+000	0.34	0.4	-0.06	Inadequate	0.40	0.4	0.00	Inadequate
5+000 – 5+400	0.36	0.4	-0.04	Inadequate	0.40	0.4	0.00	Inadequate
Average	**0.35**	**0.4**	**-0.05**	**Inadequate**	**0.39**	**0.4**	**-0.01**	**Inadequate**

4.5.2.3 Rut Depth Measurement

Table 4.66 shows the average rut depths for both road sides measured on the road. The average rut depth for both directions is rated as very good. Figure 4.26 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.66: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	**To**	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	4.5	2.4	0.9	9.9
0 + 500	1 + 000	5.3	4.5	4.5	8.8
1 + 000	1 + 500	5.5	4.2	5.3	9.2
1 + 500	2 + 000	6.0	6.4	1.3	2.7
2 + 000	2 + 500	0.3	5.6	1.8	0.6
2 + 500	3 + 000	-1.8	4.6	-2.3	0.7
3 + 000	3 + 500	1.8	5.8	-5.5	1.7
3 + 500	4 + 000	2.8	2.8	-3.4	2.5
4 + 000	4 + 500	4.2	5.6	-0.3	0.6
4 + 500	5 + 000	5.5	7.3	1.3	6.2
5 + 000	5 + 400	-1.5	2.0	2.7	5.8
Average		**3.0**	**4.7**	**0.6**	**4.4**
Rut depth rating		**Very Good**	**Very Good**	**Very Good**	**Very Good**

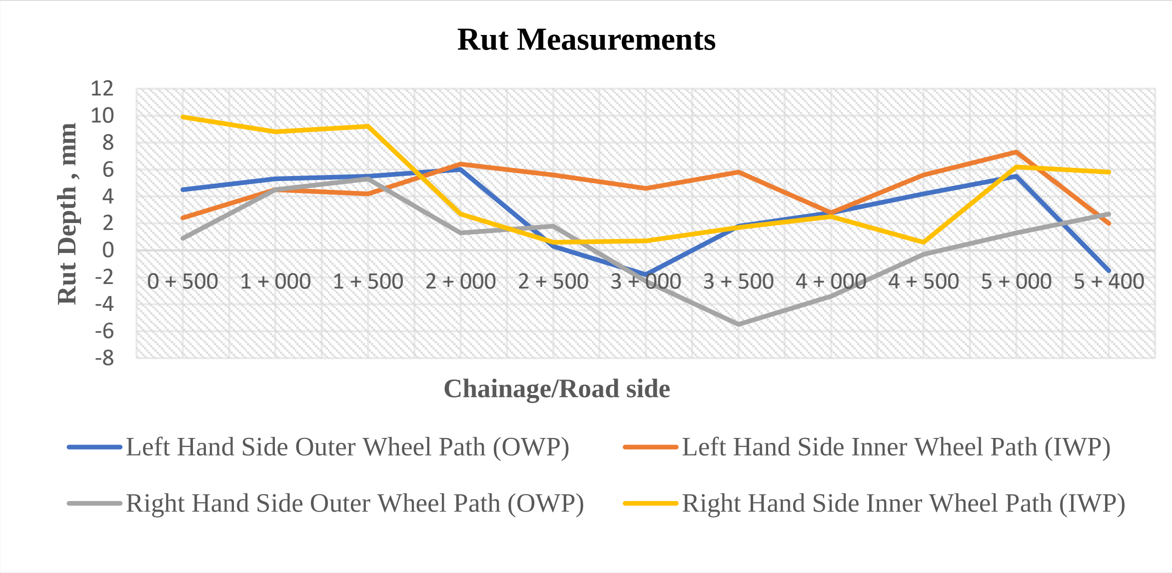


Figure 4.26: Representation of rut measurements along the road

4.5.2.4 Present Serviceability Rating (PSR)

The road has an overall PSR value of 3.2 which is rated as Good. The PSI value exceeds 2.0 which is the terminal value for low volume roads. The road therefore meets the PSI criteria. However, urgent interventions on sections with transverse cracking are highly recommended, as shown in Table 4.67.

Table 4.67: Present Serviceability Rating

Date of Survey	4th February, 2023	
Road Name	D378-2 - Nyathuna – Ngecha - Rironi	
Section	4.2km	
Rater	PGM	
Pavement Structure	Surfacing	20mm cold mix
	Base	75mm Emulsion stabilized material
	Sub-base	100mm improved sub-grade layer
	Improved subgrade/capping	200mm improved subgrade
	Subgrade class	S3
Summary		
Defect	**Points**	
1. Crazing (Block and alligator cracks)	5	
2. Longitudinal cracking	3	
3. Transverse cracking	2	
4. Edge spalling	3	
5. Rutting	3	
6. Corrugation/waves	3	

7. Depression/Longitudinal irregularity	3	
8. Shoving/Heaving/Upheaval	3	
9. Bleeding/Glazing	5	
10. Stripping/Raveling	3	
11. Patch	3	
12. Pothole/Disruption	3	
Total	**38**	
Points	**38/12**	**Rating: 3.2**

4.5.2.5 Climate Resilience Assessment

Table 4.68 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.68: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	2/3	Slight to warning/Extensive occurrence
		Embankment slopes	1/2	Slight/more than isolated
		Cut slopes	1/1	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/2	Warning/more than isolated
		Mitre drains	5/2	Severe/more than isolated
4	Drainage (Streams)	*Structure*	-	-
		Embankments	2/1	Slight to warning/ Isolated Occurrence

Sn	Description		Rating	Degree/Extent
		Erosion	2/1	Slight to warning/ Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	2/3	Warning/ Extensive occurrence over the entire segment
		Erosion protection works	2/1	Slight to warning/ Isolated Occurrence
7	Maintenance	*Quantity*	4/4	Warning to severe/Extensive occurrence over the entire segment
		Quality	4/4	Warning to severe/Extensive occurrence over the entire segment

4.5.3 Kimende - Kagwe - Ruiru River - D402-1

Road D402 is located in Kiambu County. It starts at Kimende through Kagwe, Ruiru river and ends at Githunguri.

4.5.3.1 Data Sheet

Table 4.69 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch three, in Kiambu region. Plate 4.11 shows the status of the Kimende - Kagwe Ruiru River - D402-1 during the study.

Table 4.69: Kimende - Kagwe Ruiru River - D402-1

Road: Kimende - Kagwe Ruiru River - D402-1	**Length (Km):** 6.0	**Location:** Githunguri Constituency in Kiambu KeRRA Region. **Phase:** 2 **Batch:** 3	**Commencement:** 18th October, 2018. **Completion Date:** 30th June, 2020.

Roadworks undertaken during initial construction:

(i). Setting out (survey works);
(ii). Site clearance;
(iii). Earthworks;
(iv). Improvement to drainage and installation of culverts
(v). Construction of erosion protection works;
(vi). Maintenance of passage of traffic;
(vii). Relocation and reinstatement of services;
(viii). Benching to widen the carriageway using material of characteristics similar to the existing pavement;
(ix). Provision of 200mm improved sub-grade layer;
(x). Provision of 200mm neat gravel sub-base layer across the carriageway and shoulders;
(xi). Provision of 100mm Emulsion stabilized material (ESM) base across the carriageway and shoulders;
(xii). Provision of A4-60 bitumen emulsion as prime coat;
(xiii). Application of 20mm cold asphalt surfacing layer across the carriageway and shoulders;
(xiv). Provision of road furniture;
(xv). Defects notification period of 12months;
(xvi). Performance based routine maintenance works for a period of 3 years.

Expenditure:

Contract Sum: Kshs. 147,155,598.00

- Improvement Works and Defects Liability Period of 12 months = Kshs. 141,393,588,00
- 36 months of Performance Based Routine Maintenance (PBRM) = Kshs. 5,762,010.00

(a) Road start that was quite rough showing the continuing deterioration of the surfacing on that section (Author, 2023).

(b) Section showing continuous failure of the pavement by potholing. Inadequate drainage system noted (Author, 2023).

	
(c) Advanced deterioration noted on this section of the road, and embankment slopes showing high erodibility potential. No clear drainage system in place (Author, 2023).	(d) Long section of the road still in good serviceability. Inadequate routine maintenance noted (Author, 2023).

Plate 4.11: Status of the Kimende - Kagwe Ruiru River - D402-1 during the study

4.5.3.2 Drainage Assessment

The depth of the side drain is less than the required depth of 0.40m below the formation level. The side drainage depth is therefore considered inadequate. Table 4.70 gives the description of the road drainage.

Table 4.70: Description of Degree of Side Drain

Chainage	Left Hand Side				Right Hand Side			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.41	0.4	0.01	Inadequate	0.39	0.4	-0.01	Adequate
2+500 – 5+000	0.38	0.4	-0.02	Inadequate	0.41	0.4	0.01	Inadequate
5+000 – 6+000	0.38	0.4	-0.02	Inadequate	0.38	0.4	-0.02	Inadequate
Average	**0.39**	**0.4**	**-0.01**	**Inadequate**	**0.39**	**0.4**	**-0.01**	**Inadequate**

4.5.3.3 Rut Depth Measurement

Table 4.71 shows the average rut depths for both road sides measured on the road. The average rut depth for both directions is rated as very good. Figure 4.27 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.71: Rut Depths

Chainage		**Left Hand Side**		**Right Hand Side**	
From	**To**	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	3.8	3.9	2.9	4.2
0 + 500	1 + 000	6.5	3.4	4.5	5.5
1 + 000	1 + 500	3.7	1.8	4.6	3.1
1 + 500	2 + 000	5.0	3.1	2.4	3.2
2 + 000	2 + 500	-1.6	3.0	3.2	3.5
2 + 500	3 + 000	1.6	4.2	3.4	2.9
3 + 000	3 + 500	3.9	4.0	2.0	3.6
3 + 500	4 + 000	3.7	2.8	5.1	3.7
4 + 000	4 + 500	1.9	1.6	2.7	2.8
4 + 500	5 + 000	-0.1	-0.4	2.8	2.3
5 + 000	5 + 500	5.4	4.5	5.1	3.5
5 + 500	6 + 000	4.4	2.1	-1.4	3.5
6 + 000	6 + 500	5.0	3.25	3.7	3.3
Average		**3.3**	**2.9**	**3.2**	**3.5**
Rut depth rating		**Very Good**	**Very Good**	**Very Good**	**Very Good**

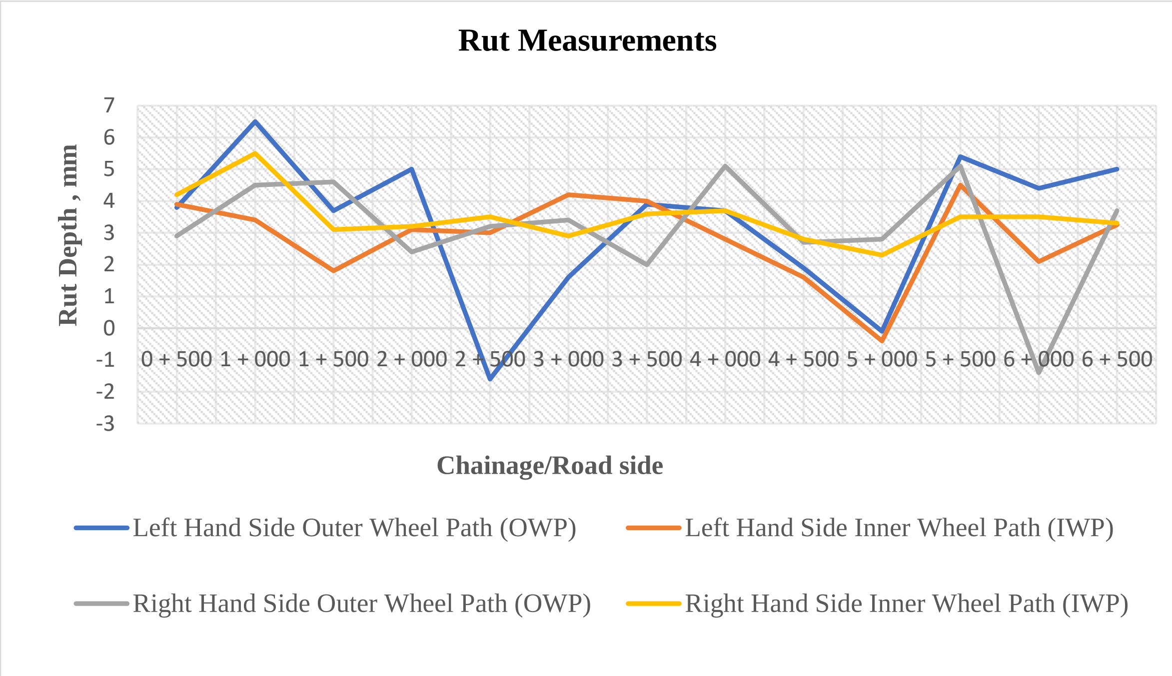


Figure 4.27: Representation of rut measurements along the road

4.5.3.4 Present Serviceability Rating (PSR)

The road has an overall PSR value of 2.3 which is rated as Fair. The PSI value exceeds 2.0 which is the terminal value for low volume roads. However, urgent interventions on sections with potholes, edge subsidence, longitudinal cracking, transverse cracking and stripping/ravelling are highly recommended, as shown in Table 4.72.

Table 4.72: Present Serviceability Rating

Date of Survey	4th February, 2023	
Road Name	Kimende - Kagwe Ruiru River - D402-1	
Section	6.0km	
Rater	PGM	
Pavement Structure	Surfacing	20mm cold mix
	Base	100mm Emulsion stabilized material (ESM) base
	Sub-base	200mm neat gravel sub-base
	Improved subgrade/capping	200mm improved subgrade
	Subgrade class	S3
Summary		
Defect	**Points**	
1. Crazing (Block and alligator cracks)	4	
2. Longitudinal cracking	2	
3. Transverse cracking	1	

4. Edge spalling	2	
5. Rutting	2	
6. Corrugation/waves	3	
7. Depression/Longitudinal irregularity	4	
8. Shoving/Heaving/Upheaval	2	
9. Bleeding/Glazing	4	
10. Stripping/Raveling	1	
11. Patch	1	
12. Pothole/Disruption	1	
Total	**28**	
Points	**28/12**	**Rating: 2.3**

4.5.3.5 Climate Resilience Assessment

Table 4.73 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.73: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	3/2	Warning/more than isolated
		Embankment slopes	3/2	Warning/more than isolated
		Cut slopes	1/2	Slight/ more than isolated
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/4	Warning/More frequent
		Mitre drains	5/4	Severe/ More frequent
4		*Structure*	-	-

Sn	Description		Rating	Degree/Extent
	Drainage (Streams)	*Embankments*	2/1	Slight to warning/ Isolated Occurrence
		Erosion	1/1	Slight / Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	3/4	Warning/More frequent
		Erosion protection works	2/4	Slight to warning/ More frequent
7	Maintenance	*Quantity*	5/5	Severe/Extensive occurrence over the entire segment
		Quality	5/5	Severe/Extensive occurrence over the entire segment

4.5.4 Kimende- Kagwe -Ruiru River - D402-2

4.5.4.1 Data Sheet

Table 4.74 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch three, in Kiambu region. Plate 4.12 shows the status of the Kimende- Kagwe -Ruiru River - D402-2 during the study.

Table 4.74: Kimende- Kagwe -Ruiru River - D402-2

Road: Kimende- Kagwe -Ruiru River - D402-2	**Length (Km):** 6.6	**Location:** Githunguri Constituency in Kiambu KeRRA Region. **Phase:** 2 **Batch:** 3	**Commencement:** 18th October, 2018. **Completion Date:** 30th Sept, 2020.

Roadworks undertaken during initial construction:

(i). Setting out (survey works);
(ii). Site clearance;
(iii). Earthworks;
(iv). Improvement to drainage and installation of culverts
(v). Construction of erosion protection works;
(vi). Maintenance of passage of traffic;
(vii). Relocation and reinstatement of services;
(viii). Benching to widen the carriageway using material of characteristics similar to the existing pavement;
(ix). Provision of 200mm improved sub-grade layer;
(x). Provision of 200mm neat gravel sub-base layer across the carriageway and shoulders;
(xi). Provision of 100mm Emulsion stabilized material (ESM) base across the carriageway and shoulders;
(xii). Provision of A4-60 bitumen emulsion as prime coat;
(xiii). Application of 20mm cold asphalt surfacing layer across the carriageway and shoulders;
(xiv). Provision of road furniture;
(xv). Defects notification period of 12months;
(xvi). Performance based routine maintenance works for a period of 3 years.

Expenditure:

Contract Sum: Kshs. 148,978,397.80

- Improvement Works and Defects Liability Period of 12 months = Kshs. 144,012,451.80
- 36 months of Performance Based Routine Maintenance (PBRM) = Kshs. 4,965,946.00

(a) Road start showing road in a good condition (Author, 2023).

(b) Section showing the embankment slopes on the left with high erosion potential and already silted drainage system (Author, 2023).

(c) Section showing vegetation overgrown up to the carriageway due to inadequate routine maintenance (Author, 2023).

(d) Long section still offering good serviceability, albeit the poor drainage system (Author, 2023).

(e) Failed section by potholing, attributed to base failure (Author, 2023).

(f) Observation of locals sealing the potholes, a case of poor maintenance by the authorities (Author, 2023).

Plate 4.12: Status of the Kimende- Kagwe -Ruiru River - D402-2 during the study

4.5.4.2 Drainage Assessment

The depth of the side drain is less than the required depth of 0.40m below the formation level. The side drainage depth is therefore considered inadequate. Table 4. gives the description of the road drainage.

Table 4.75: Description of Degree of Side Drain

Chainage	**Left Hand Side**				**Right Hand Side**			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.39	0.4	-0.01	Inadequate	0.33	0.4	-0.07	Inadequate
2+500 – 5+000	0.34	0.4	-0.06	Inadequate	0.35	0.4	-0.05	Inadequate

Chainage	Left Hand Side				Right Hand Side			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
5+000 – 6+600	0.31	0.4	-0.09	Inadequate	0.32	0.4	-0.08	Inadequate
Average	**0.35**	**0.4**	**-0.05**	**Inadequate**	**0.33**	**0.4**	**-0.07**	**Inadequate**

4.5.4.3 Rut Depth Measurement

Table 4.76 shows the average rut depths for both road sides measured on the road. The average rut depth for both directions is rated as very good. Figure 4.28 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.76: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	To	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	3.6	3.8	3.0	4.0
0 + 500	1 + 000	6.3	3.3	4.6	5.3
1 + 000	1 + 500	3.5	1.7	4.7	2.9
1 + 500	2 + 000	4.8	3.0	2.5	3.0
2 + 000	2 + 500	-1.8	2.9	3.3	3.3
2 + 500	3 + 000	1.4	4.1	3.5	2.7
3 + 000	3 + 500	3.7	3.9	2.1	3.4
3 + 500	4 + 000	3.5	2.7	5.2	3.5
4 + 000	4 + 500	1.7	1.5	2.8	2.6
4 + 500	5 + 000	-0.3	-0.5	2.9	2.1
5 + 000	5 + 500	5.2	4.4	5.2	3.3
5 + 500	6 + 000	4.2	2.0	-1.3	3.3
6 + 000	6 + 500	4.8	3.2	3.8	3.1
6 + 600	7 + 000	3.3	6.4	4.0	5.0
Average		**3.5**	**3.3**	**3.3**	**3.5**
Rut depth rating		**Very Good**	**Very Good**	**Very Good**	**Very Good**

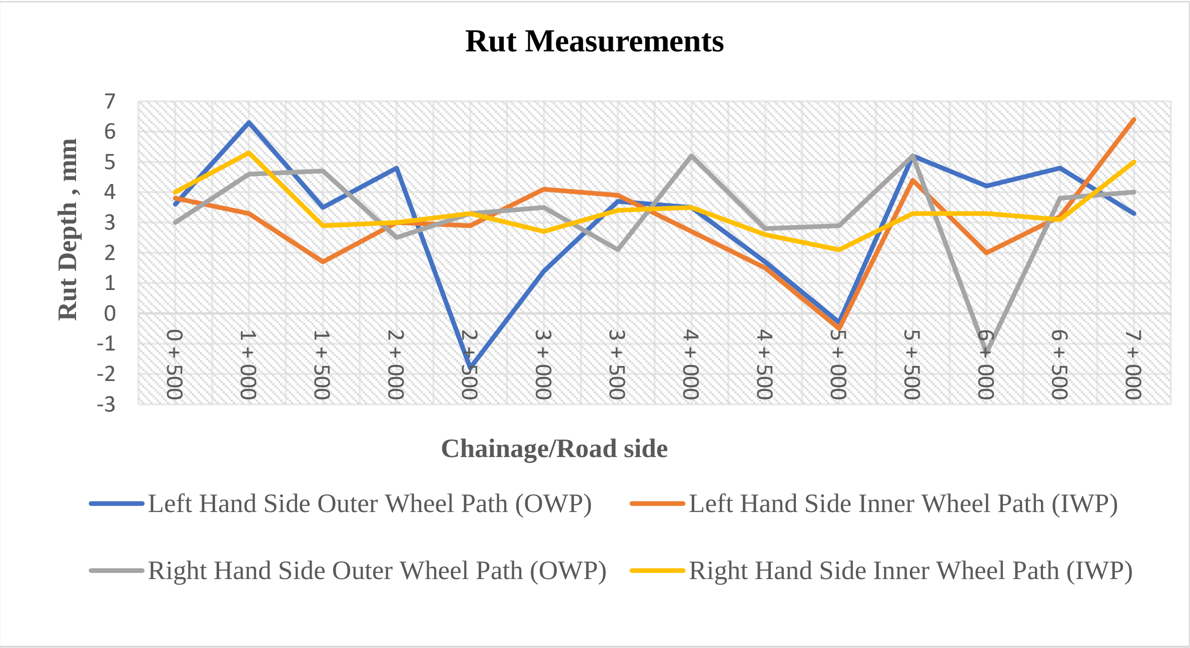


Figure 4.28: Representation of rut measurements along the road

4.5.4.4 Present Serviceability Rating (PSR)

The road has an overall PSR value of 3.4 which is rated as Good. The PSI value exceeds 2.0 which is the terminal value for low volume roads. However, urgent interventions on sections with potholes, edge subsidence, longitudinal cracking, transverse cracking and stripping/ravelling are highly recommended, as shown in Table 4.77.

Table 4.77: Present Serviceability Rating

Date of Survey	4th February, 2023		
Road Name	D402-2 - Kimende- Kagwe -Ruiru River		
Section	6.6km		
Rater	PGM		
Pavement Structure	Surfacing		20mm cold mix
	Base		100mm Emulsion stabilized material
	Sub-base		200mm gravel subbase
	Improved subgrade/capping		200mm subgrade
	Subgrade class		S3
Summary			
Defect		**Points**	
1. Crazing (Block and alligator cracks)		4	
2. Longitudinal cracking		3	
3. Transverse cracking		2	
4. Edge spalling		4	
5. Rutting		3	
6. Corrugation/waves		5	
7. Depression/Longitudinal irregularity		4	
8. Shoving/Heaving/Upheaval		4	
9. Bleeding/Glazing		5	
10. Stripping/Raveling		3	
11. Patch		2	
12. Pothole/Disruption		2	
Total		**41**	
Points		**41/12**	**Rating: 3.4**
RATING SCALE			

4.5.4.5 Climate Resilience Assessment

Table 4.78 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.78: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Side drains	3/2	Warning/more than isolated
		Embankment slopes	3/2	Warning/more than isolated
		Cut slopes	1/2	Slight/ more than isolated
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/4	Warning/More frequent
		Mitre drains	5/4	Severe/ More frequent
4	Drainage (Streams)	*Structure*	-	-
		Embankments	2/1	Slight to warning/ Isolated Occurrence
		Erosion	1/1	Slight / Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	3/4	Warning/More frequent
		Erosion protection works	2/4	Slight to warning/ More frequent
7	Maintenance	*Quantity*	5/5	Severe/Extensive occurrence over the entire segment
		Quality	5/5	Severe/Extensive occurrence over the entire segment

4.5.5 Kimende- Kagwe -Ruiru River - D402-3

Table 4.79 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch three, in Kiambu region. Plate 4.13 shows the status of the Kimende- Kagwe -Ruiru River - D402-3 during the study.

Table 4.79: Kimende- Kagwe -Ruiru River - D402-3

<table>
<tr><td>Road: Kimende- Kagwe -Ruiru River - D402-3</td><td>Length (Km): 2.4</td><td>Location: Githunguri Constituency in Kiambu KeRRA Region.
Phase: 2
Batch: 3</td><td>Commencement: 18th October, 2018.

Completion Date: 21st Sept, 2020.</td></tr>
<tr><td colspan="4">Roadworks undertaken during initial construction:
(i). Setting out (survey works);
(ii). Site clearance;
(iii). Earthworks;
(iv). Improvement to drainage and installation of culverts
(v). Construction of erosion protection works;
(vi). Maintenance of passage of traffic;
(vii). Relocation and reinstatement of services;
(viii). Benching to widen the carriageway using material of characteristics similar to the existing pavement;
(ix). Provision of 200mm improved sub-grade layer;
(x). Provision of 200mm neat gravel sub-base layer across the carriageway and shoulders;
(xi). Provision of 100mm Emulsion stabilized material (ESM) base across the carriageway and shoulders;
(xii). Provision of A4-60 bitumen emulsion as prime coat;
(xiii). Application of 20mm cold asphalt surfacing layer across the carriageway and shoulders;
(xiv). Provision of road furniture;
(xv). Defects notification period of 12months;
(xvi). Performance based routine maintenance works for a period of 3 years.</td></tr>
<tr><td colspan="4">Expenditure:
Contract Sum: Kshs. 68,483,444.30
▪ Improvement Works and Defects Liability Period of 12 months = Kshs. 64,918,381.50
▪ 36 months of Performance Based Routine Maintenance (PBRM) = Kshs. 3,565,062.80</td></tr>
<tr><td colspan="4">Current Status of the road:
Upon completion of the road in 2020, the road stayed in service for 2-years, and thereafter, was taken up by the Mau Mau Roads Project, Lot 1A, a central government of Kenya project to improve the road from the low volume to a high-capacity major link.
As of February 2023, the road improvement was in progress.</td></tr>
</table>

 (a) Old pavement, at Km 0+010 where damaged surfacing had been repaired (Author, 2021)	 (b) Km 0+010 where asphalt layer has been damaged (Author, 2020).
 (c) Road start where upgrading works were on-going (Author, 2023)	 (d) Ongoing box culvert works at the road upgrading project (Author, 2023)
 (e) Completed asphalt surfacing where upgrading works were on-going (Author, 2023)	 (f) Completed section of the upgrade showing erodible and unprotected embankment slopes (Author, 2023)

Plate 4.13: Status of the Kimende- Kagwe -Ruiru River - D402-3 during the study

4.5.6 Kanunga - Banana - E1520

4.5.6.1 Data Sheet

Table 4.80 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch three, in Kiambu region. Plate 4.14 shows the status of the Kanunga - Banana - E1520 during the study.

Table 4.80: Kanunga - Banana - E1520

Road: Kanunga - Banana - E1520	**Length (Km):** 3.0	**Location:** Kiambaa Constituency in Kiambu KeRRA Region. **Phase:** 2 **Batch:** 3	**Commencement:** 18th October, 2018. **Completion Date:** 21st Sept, 2021.
Roadworks undertaken during initial construction: (i). Setting out (survey works); (ii). Site clearance; (iii). Earthworks; (iv). Improvement to drainage and installation of culverts (v). Construction of erosion protection works; (vi). Maintenance of passage of traffic; (vii). Relocation and reinstatement of services; (viii). Benching to widen the carriageway using material of characteristics similar to the existing pavement; (ix). Provision of 200mm improved sub-grade layer; (x). Provision of 200mm neat gravel sub-base layer across the carriageway and shoulders; (xi). Provision of 100mm Emulsion stabilized material (ESM) base across the carriageway and shoulders; (xii). Provision of A4-60 bitumen emulsion as prime coat; (xiii). Application of 20mm cold asphalt surfacing layer across the carriageway and shoulders; (xiv). Provision of road furniture; (xv). Defects notification period of 12months; (xvi). Performance based routine maintenance works for a period of 3 years.			
Expenditure: **Contract Sum: Kshs.** 78,254,673.50 ▪ Improvement Works and Defects Liability Period of 12 months = Kshs. 73,876,771.50 ▪ 36 months of Performance Based Routine Maintenance (PBRM) = Kshs. 4,377,902.00			

(a) Road start with smooth surface offering good rideability (Author, 2023).

(b) Long section showing a well-defined drainage system (Author, 2023).

(c) Section showing signs of pavement failure by edge subsidence. Overgrow vegetation noted (Author, 2023).

(d) Section showing clogged drainage system, and embankment slopes not well protected (Author, 2023).

Plate 4.14: Status of the Kanunga - Banana - E1520 during the study

4.5.6.2 Drainage Assessment

The average depth of the side drainage of the road is less than the required 0.40m depth below the formation level, while the description of the drain is as shown in Table 4.81.

Table 4.81: Description of Degree of side drain

Chainage	**Left Hand Side**				**Left Hand Side**			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.44	0.4	0.04	Adequate	0.46	0.4	0.06	Adequate
2+500 – 3+750	0.41	0.4	0.01	Adequate	0.38	0.4	-0.02	Adequate
Average	**0.43**	**0.4**	**0.03**	**Adequate**	**0.42**	**0.4**	**0.02**	**Adequate**

4.5.6.3 Rut Depth Measurement

Table 4.82 shows the average rut depths for both road sides measured on the road. The mean rutting depths for the left-hand side and the right-hand side are generally rated at Good to Very Good. Figure 4.29 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.82: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	**To**	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	5.6	3.5	4.0	5.5
0 + 500	1 + 000	2.4	7.6	8.8	8.7
1 + 000	1 + 500	4.8	8.2	2.8	6.3
1 + 500	2 + 000	0.9	5.8	4.5	4.4
2 + 000	2 + 500	-2.1	2.7	0.7	4.1
2 + 500	3 + 000	1.4	4.2	0.1	5.6
Average		**2.2**	**5.3**	**3.4**	**5.7**
Rut depth rating		**Very Good**	**Good**	**Very Good**	**Good**

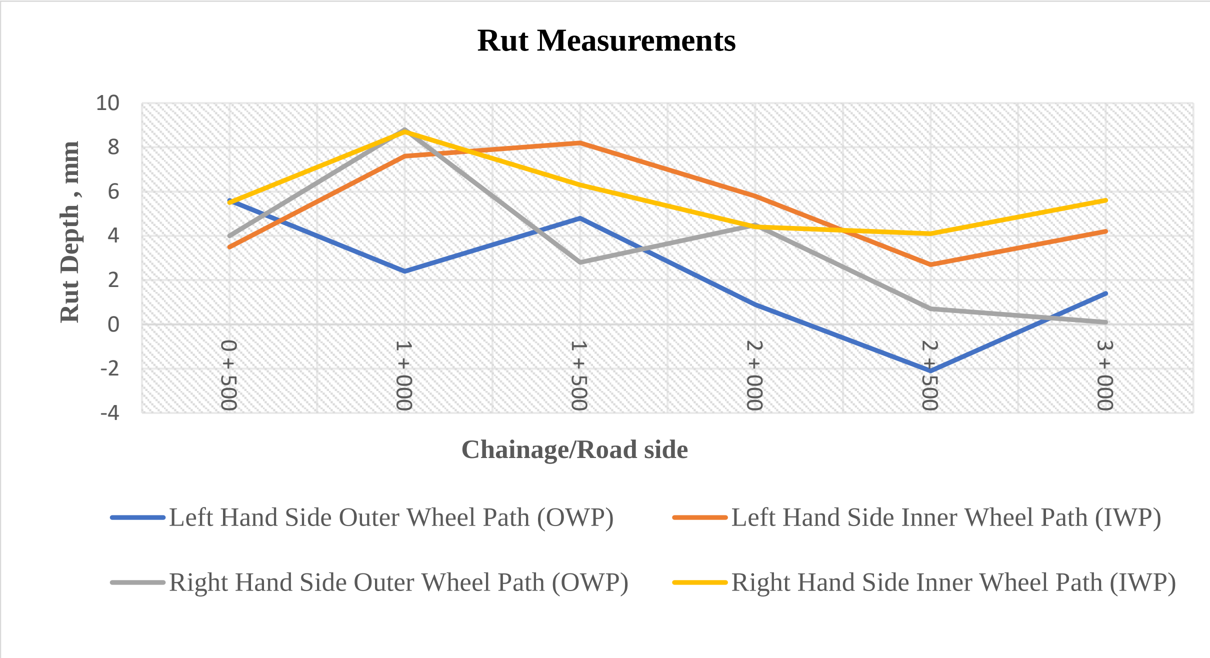


Figure 4.29: Representation of rut measurements along the road

4.5.6.4 Roughness Measurement

Table 4.83 shows the International Roughness Indices (IRI) values in m/km for each direction using different methods. The average roughness was categorised as Warning based on measurement using both the Rough-o-meter and using Road-Lab Pro.

Table 4.83: Roughness Measurements

Road Side	**IRI (m/km)**	**IRI (m/km)**
	Rough-o-meter	Road-Lab Pro
Left Hand Side	4.2	3.21
Right Hand Side	4.1	3.18

4.5.6.5 Present Serviceability Rating (PSR)

The road has an overall PSR value of 3.0 which is rated as Good. The PSI value exceeds 2.0 which is the terminal value for low volume roads. The road therefore meets the PSI criteria. However, the road requires urgent intervention on sections with crazing, longitudinal cracking, transverse cracking, edge spalling, stripping, patch and potholes, as shown in Table 4.84.

Table 4.84: Present Serviceability Rating

Date of Survey	4^{th} February, 2023	
Road Name	E1520 - Kanunga - Banana	
Section	3.0km	
Rater	PGM	
Pavement Structure	Surfacing	20mm cold mix
	Base	100mm Emulsion Stabilized Material (ESM)
	Sub-base	200mm neat gravel
	Improved subgrade/capping	200mm subgrade
	Subgrade class	S3
Summary		
Defect	**Points**	
1. Crazing (Block and alligator cracks)	1	
2. Longitudinal cracking	2	
3. Transverse cracking	2	
4. Edge spalling	2	
5. Rutting	3	
6. Corrugation/waves	3	
7. Depression/Longitudinal irregularity	3	
8. Shoving/Heaving/Upheaval	3	
9. Bleeding/Glazing	3	
10. Stripping/Raveling	1	
11. Patch	2	
12. Pothole/Disruption	1	
Total	**36**	
Points	**36/12**	**Rating: 3.0**

4.5.6.6 Climate Resilience Assessment

Table 4.85 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.85: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Side drains	2/3	Slight to warning/Extensive occurrence
		Embankment slopes	1/2	Slight/more than isolated
		Cut slopes	1/1	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/2	Warning/more than isolated
		Mitre drains	5/2	Severe/more than isolated
4	Drainage (Streams)	*Structure*	-	-
		Embankments	2/1	Slight to warning/ Isolated Occurrence
		Erosion	2/1	Slight to warning/ Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	3/5	Warning/ Extensive occurrence over the entire segment
		Erosion protection works	2/1	Slight to warning/ Isolated Occurrence
7	Maintenance	*Quantity*	4/5	Warning to severe/Extensive occurrence over the entire segment
		Quality	4/5	Warning to severe/Extensive occurrence over the entire segment

4.5.7 Kirangari - Gikuni - Nyathuna Hosp - Junction - E1520

Road E1520 is located in Kiambu County. It starts at Kirangari and ends at Nyathuna. The road is 6.0 km long and was completed in the year 2020 under Batch 3 programme

4.5.7.1 Data Sheet

Table 4.86 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch three, in Kiambu region. Plate 4.15 shows the status of the Kirangari - Gikuni - Nyathuna Hosp – Junction - E1520 during the study.

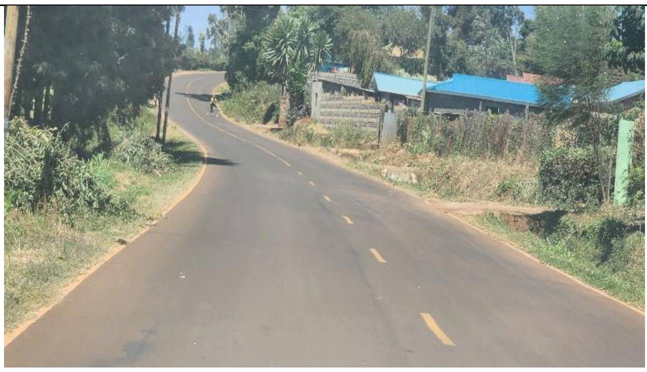
Table 4.86: Kirangari - Gikuni - Nyathuna Hosp – Junction - E1520

Road: Kirangari - Gikuni - Nyathuna Hosp - Junction - E1520	**Length (Km):** 6.0	**Location:** Kabete Constituency in Kiambu KeRRA Region. **Phase:** 2 **Batch:** 3	**Commencement:** 18th October, 2018. **Substantial Completion Date:** 17th December, 2020
Roadworks undertaken during initial construction: (i). Setting out (survey works); (ii). Site clearance; (iii). Earthworks; (iv). Improvement to drainage and installation of culverts; (v). Construction of erosion protection works; (vi). Maintenance of passage of traffic; (vii). Relocation and reinstatement of services; (viii). Benching to widen the carriageway using material of characteristics similar to the existing pavement. (ix). Provision of 200mm improved sub-grade layer; (x). Provision of 175mm neat gravel sub-base layer across the carriageway and shoulders using labour; (xi). Provision of 100mm Emulsion Stabilised Materials (ESM) base across the carriageway and shoulders; (xii). Provision of A4-60 bitumen emulsion as prime coat; (xiii). Provision of A4-60 bitumen emulsion as tack coat and application of 20mm cold asphalt surfacing layer across the carriageway and shoulders; (xiv). Provision of road furniture; (xv). Defects notification period of 12months; (xvi). Performance based routine maintenance works for a period of 3 years.			
Expenditure: **Contract Sum: Kshs.** 141,607,486.00 ▪ Improvement Works and Defects Liability Period of 12 months = Kshs. 136,537,590.00 ▪ 36 months of Performance Based Routine Maintenance (PBRM) = Kshs. 5,069,896.00			

(a) Road start section still in good condition (Author, 2023).

(b) Section showing overgrown vegetation blocking the drainage system (Author, 2023).

(c) Road start showing well defined drainage system in good condition (Author, 2023).



(d) Long section showing the road geometry and the surfacing still offering good rideability (Author, 2023).

Plate 4.15: Status of the Kirangari - Gikuni - Nyathuna Hosp – Junction - E1520 during the study

4.5.7.2 Drainage Assessment

The depth of the side drain is less than the required depth of 0.75m below the formation level. The side drainage depth is therefore considered inadequate. Table 4.87 gives the description of the road drainage.

Table 4.87: Description of Degree of Side Drain

Chainage	Left Hand Side				Right Hand Side			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.43	0.4	0.03	Adequate	0.38	0.4	-0.02	Inadequate
2+500 – 5+000	0.34	0.4	-0.06	Inadequate	0.3	0.4	-0.1	Inadequate
5+000 – 5+800	0.36	0.4	-0.04	Inadequate	0.3	0.4	-0.1	Inadequate
Average	**0.38**	**0.4**	**-0.02**	**Inadequate**	**0.33**	**0.4**	**-0.07**	**Inadequate**

4.5.7.3 Rut Depth Measurement

Table 4.88 shows the average rut depths for both road sides measured on the road. The average rut depth for both directions is rated as very good. Figure 4.30 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.88: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	**To**	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	10.0	9.5	0.0	0.0
0 + 500	1 + 000	5.2	5.0	3.0	6.3
1 + 000	1 + 500	5.3	8.0	-15.5	5.5
1 + 500	2 + 000	5.0	5.5	-1.8	-3.5
2 + 000	2 + 500	-0.8	5.3	2.8	4.5
2 + 500	3 + 000	2.8	6.8	4.0	4.9
3 + 000	3 + 500	1.5	4.4	4.5	4.9
3 + 500	4 + 000	3.1	4.6	0.0	0.0
4 + 000	4 + 500	5.9	5.8	10.0	7.5
4 + 500	5 + 000	4.0	8.6	0.3	4.6
5 + 000	5 + 500	4.0	5.9	5.2	5.8
5 + 500	6 + 000	4.8	9.3	4.8	3.8
Average		**4.2**	**6.6**	**1.4**	**3.7**
Rut depth rating		**Very Good**	**Very Good**	**Very Good**	**Very Good**

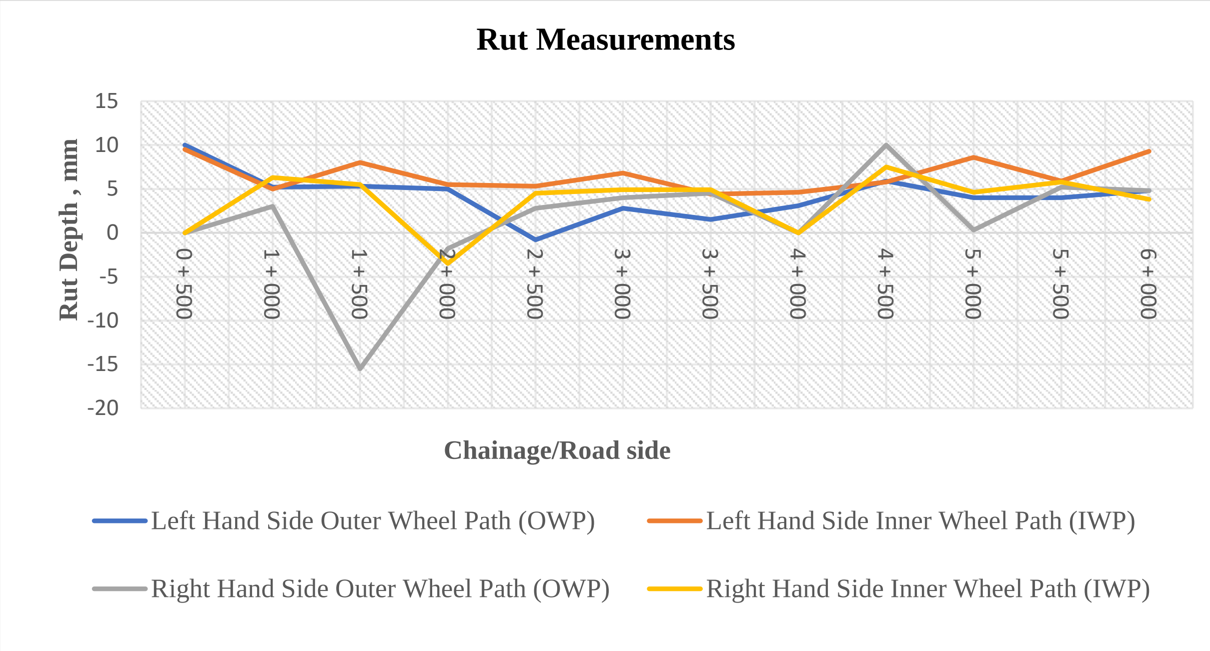


Figure 4.30: Representation of rut measurements along the road

4.5.7.4 Present Serviceability Rating (PSR)

The road has an overall PSR value of 3.7 which is rated as Good. The PSI value exceeds 2.0 which is the terminal value for low volume roads. The road therefore meets the PSI criteria. However, urgent interventions on sections with overgrown vegetation, longitudinal cracking, transverse cracking and stripping/ravelling are highly recommended, as shown in Table 4.89.

Table 4.89: Present Serviceability Rating

Date of Survey	4th February, 2023	
Road Name	E1520 - Kirangari - Gikuni - Nyathuna Hosp. Junction	
Section	6.0km	
Rater	PGM	
Pavement Structure	Surfacing	20mm cold mix
	Base	100mm Emulsion stabilized material
	Sub-base	175mm gravel sub-base
	Improved subgrade/capping	200mm subgrade
	Subgrade class	S3
Summary		
Defect	**Points**	
1. Crazing (Block and alligator cracks)	5	
2. Longitudinal cracking	2	
3. Transverse cracking	2	
4. Edge spalling	3	

5. Rutting	5	
6. Corrugation/waves	5	
7. Depression/Longitudinal irregularity	5	
8. Shoving/Heaving/Upheaval	3	
9. Bleeding/Glazing	5	
10. Stripping/Raveling	2	
11. Patch	3	
12. Pothole/Disruption	3	
Total	**43**	
Points	**43/12**	**Rating: 3.7**

4.5.7.5 Climate Resilience Assessment

Table 4.90 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.90: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	2/2	Slight to warning /more than isolated
		Embankment slopes	2/2	Slight to warning /more than isolated
		Cut slopes	1/1	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/4	Warning/More frequent
		Mitre drains	5/2	Severe/ more than isolated

Sn	Description		Rating	Degree/Extent
4	Drainage (Streams)	*Structure*	-	-
4	Drainage (Streams)	*Embankments*	2/2	Slight to warning/ more than isolated
4	Drainage (Streams)	*Erosion*	2/1	Slight / Isolated Occurrence
4	Drainage (Streams)	*Protection works*	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
5	Slope stability	*Fill stability*	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	2/3	Slight to warning /Extensive Occurrence
6	Construction	*Erosion protection works*	2/1	Slight to warning/ Isolated Occurrence
7	Maintenance	*Quantity*	3/4	Warning/More frequent
7	Maintenance	*Quality*	3/4	Warning/More frequent

4.5.8 Wamwangi - Ruburi - D379

4.5.8.1 Data Sheet

Table 4.91 gives the project datasheet of this Low Volume Sealed (LVS) road, done under phase two, batch three, in Kiambu region. Plate 4.16 shows the status of the Wamwangi - Ruburi - D379 during the study.

Table 4.91: Wamwangi - Ruburi - D379

Road: Wamwangi - Ruburi - D379	**Length (Km):** 7.1	**Location:** Gatundu South Constituency in Kiambu KeRRA Region. **Phase:** 2 **Batch:** 3	**Commencement:** 18th October, 2018. **Substantial Completion Date:** 14th January, 2020

Roadworks undertaken during initial construction:

(i). Setting out (survey works);
(ii). Site clearance;
(iii). Earthworks;
(iv). Improvement to drainage and installation of culverts;
(v). Construction of erosion protection works;
(vi). Maintenance of passage of traffic;
(vii). Relocation and reinstatement of services;
(viii). Benching to widen the carriageway using material of characteristics similar to the existing pavement;
(ix). Provision of 200mm improved sub-grade layer;
(x). Provision of 200mm neat gravel sub-base layer across the carriageway and shoulders in two layers 100mm;
(xi). Provision of MC30 cut-back bitumen as prime coat;
(xii). Application of 20mm cold asphalt surfacing layer across the carriageway and shoulders;
(xiii). Provision of road furniture;
(xiv). Defects notification period of 12months;
(xv). Performance based routine maintenance works for a period of 3 years.

Expenditure:

Contract Sum: Kshs. 233,400,942.56

- Improvement Works and Defects Liability Period of 12 months = Kshs. 227,626,056.57
- 36 months of Performance Based Routine Maintenance (PBRM) = Kshs. 5,774,885.99

(a) Road start showing signs of failure by potholing. Overgrown vegetation also noted obstructing flow of water on the drainage system (Author, 2023).

(b) Unlined drains with embankment slopes exhibiting high erodibility potential (Author, 2023).

 (c) Extended section of the road showing the road geometry and the section intact with a good ride quality (Author, 2023).	 (d) Road section showing repairs of the potholes maintenance already done on the several road stretches (Author, 2023).

Plate 4.16: Status of the Wamwangi - Ruburi - D379 during the study

4.5.8.2 Drainage Assessment

The depth of the side drain is less than the required depth of 0.75m below the formation level. The side drainage depth is therefore considered inadequate. Table 4.92 gives the description of the road drainage.

Table 4.92: Description of Degree of Side Drain

Chainage	**Left Hand Side**				**Right Hand Side**			
	H_{act}	H_{req}	H_{diff}	Description	H_{act}	H_{req}	H_{diff}	Description
0+000 – 2+500	0.39	0.4	-0.01	Inadequate	0.32	0.4	-0.08	Inadequate
2+500 – 5+000	0.31	0.4	-0.09	Inadequate	0.39	0.4	-0.01	Inadequate
5+000 – 6+000	0.39	0.4	-0.01	Inadequate	0.39	0.4	-0.01	Inadequate
6+000 – 7+100	0.36	0.4	-0.04	Inadequate	0.38	0.4	-0.02	Inadequate
Average	**0.36**	**0.4**	**-0.04**	**Inadequate**	**0.37**	**0.4**	**-0.03**	**Inadequate**

4.5.8.3 Rut Depth Measurement

Table 4.93 shows the average rut depths for both road sides measured on the road. The mean rutting depth for both directions is rated as very good. Figure 4.31 gives a graphical representation of the rut measurements.

The rut depth rating was based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

Table 4.93: Rut Depths

Chainage		Left Hand Side		Right Hand Side	
From	**To**	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)	Outer Wheel Path (OWP)	Inner Wheel Path (IWP)
0 + 000	0 + 500	9.0	6.5	1.6	2.6
0 + 500	1 + 000	4.2	2.0	2.6	5.9
1 + 000	1 + 500	4.3	5.0	3.6	5.1
1 + 500	2 + 000	4.0	2.5	-2.2	-4.0
2 + 000	2 + 500	-1.8	2.3	2.4	4.1
2 + 500	3 + 000	1.8	3.8	3.6	4.5
3 + 000	3 + 500	0.5	1.4	4.1	4.5
3 + 500	4 + 000	2.1	1.6	-0.4	-0.5
4 + 000	4 + 500	4.9	2.8	9.6	7.1
4 + 500	5 + 000	3.0	5.6	-0.1	4.2
5 + 000	5 + 500	3.0	2.9	4.8	5.4
5 + 500	6 + 000	3.8	6.3	4.4	3.4
6 + 000	7 + 100	3.8	6.3	4.4	3.4
Average		**4.2**	**3.3**	**3.7**	**3.0**
Rut depth rating		**Very Good**	**Very Good**	**Very Good**	**Very Good**

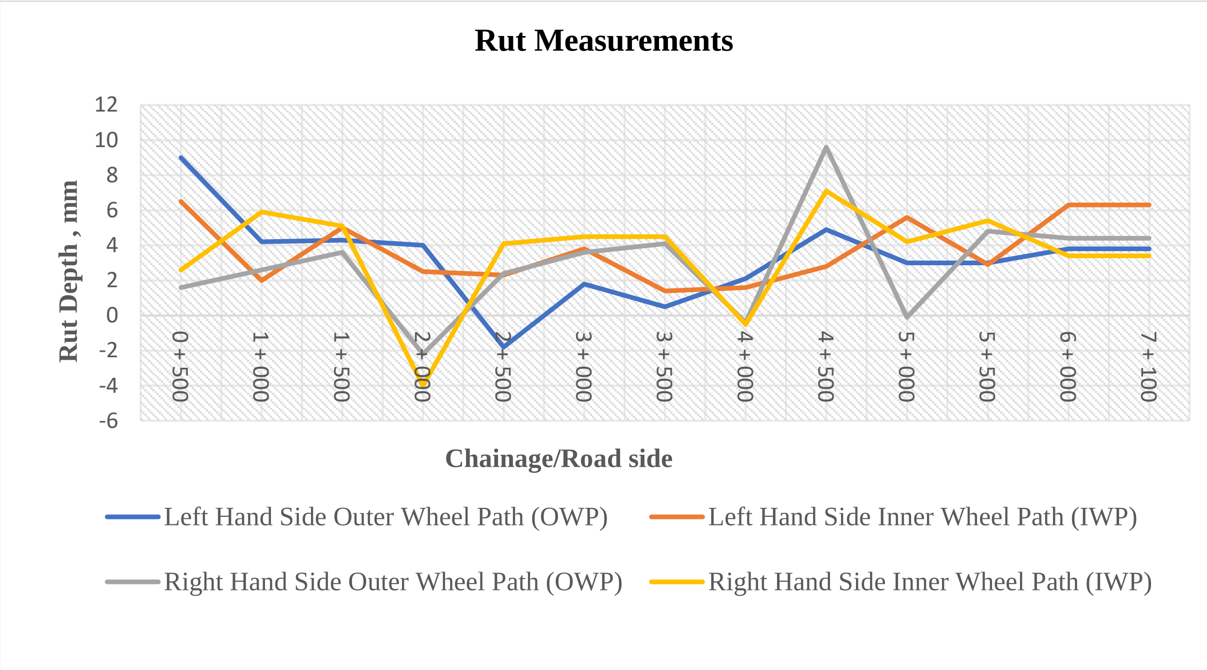


Figure 4.31: Representation of rut measurements along the road

4.5.8.4 Present Serviceability Rating (PSR)

The road has an overall PSR value of 3.2 which is rated as Good. The PSI value exceeds 2.0 which is the terminal value for low volume roads. The road therefore meets the PSI criteria. However, urgent interventions on sections with overgrown vegetation, potholes, ruts, longitudinal cracking, transverse cracking and stripping/ravelling are highly recommended, as shown in Table 4.94.

Table 4.94: Present Serviceability Rating

Date of Survey	4th February, 2023	
Road Name	D379 - Wamwangi - Ruburi	
Section	7.1km	
Rater	PGM	
Pavement Structure	Surfacing	20mm cold mix
	Base	100mm Emulsion stabilized material
	Sub-base	175mm gravel sub-base
	Improved subgrade/capping	200mm subgrade
	Subgrade class	S3
Summary		
Defect	**Points**	
1. Crazing (Block and alligator cracks)	3	
2. Longitudinal cracking	2	
3. Transverse cracking	2	

4. Edge spalling	4	
5. Rutting	4	
6. Corrugation/waves	4	
7. Depression/Longitudinal irregularity	4	
8. Shoving/Heaving/Upheaval	3	
9. Bleeding/Glazing	5	
10. Stripping/Raveling	3	
11. Patch	2	
12. Pothole/Disruption	2	
Total	**38**	
Points	**38/12**	**Rating: 3.2**

4.5.8.5 Climate Resilience Assessment

Table 4.95 shows the general assessment for climate resilience on the road, for the degree and extent of the adaptability measures in place. The degree of a certain distress type was considered as the amount of its severity, while the extent as a measure of how widespread the distress was over the length of the road segment. The first digit recorded represented the degree of occurrence while the second digit represented the extent, as determined on a five-point scale where the vulnerability exists.

Table 4.95: Climate Resilience Assessment

Sn	Description		Rating	Degree/Extent
1	Erodibility	*Subgrade*	1/1	Slight/Isolated Occurrence
		Road surface - unpaved	-	-
		Side drains	2/2	Slight to warning /more than isolated
		Embankment slopes	2/2	Slight to warning /more than isolated
		Cut slopes	1/1	Slight/Isolated Occurrence
2	Subgrade Problems	*Material type*	0/1	No potential vulnerabilities visible/Isolated occurrence
		Moisture	1/1	Slight/Isolated Occurrence
3	Drainage (in reserve)	*Road shape*	1/1	Slight/Isolated Occurrence
		Shoulders	2/1	Slight to warning/ Isolated Occurrence
		Side slopes	3/2	Warning/more than isolated
		Side drains	3/4	Warning/More frequent

Sn	Description		Rating	Degree/Extent
		Mitre drains	5/2	Severe/ more than isolated
4	Drainage (Streams)	*Structure*	-	-
		Embankments	2/2	Slight to warning/ more than isolated
		Erosion	2/1	Slight / Isolated Occurrence
		Protection works	2/1	Slight to warning/ Isolated Occurrence
5	Slope stability	*Cut stability*	1/1	Slight/Isolated Occurrence
		Fill stability	1/1	Slight/Isolated Occurrence
6	Construction	*Overall finish*	2/3	Slight to warning /Extensive Occurrence
		Erosion protection works	2/1	Slight to warning/ Isolated Occurrence
7	Maintenance	*Quantity*	3/4	Warning/More frequent
		Quality	3/4	Warning/More frequent

4.6 Maintenance Prioritisation and Investment

The program defined the targets for routine maintenance of the KeRRA's network in the six regions of central Kenya as shown in Table 4.96.

Table 4.96: Routine Maintenance Network Targets

Project Year/ Financial Year	Project targets (Km)	
	Maintainable roads (Km)	Improved by Project (Km)
Year 1 - 2011/12	**5,057**	**-**
Year 2 - 2012/13	**5,057**	**100**
Year 3 - 2013/14	**5,157**	**100**
Year 4 - 2014/15	**5,257**	**330**
Year 5 - 2015/16	**5,587**	**95**
Year 6 - 2016/17	**5,682**	**240**
Year 7 - 2017/18	**5,922**	**-**
TOTAL	**37,719**	**865**

It was observed that the planned and actual lengths maintained had reduced from FY 2011/12 to FY 2017/18, as also shown in Table 4.97 and Figure 4.32. It was to be noted that shortage of funds and utilisation of the available funds to undertake spot improvement works and/or open new roads were among the reasons for the decrease in road lengths maintained annually.

Table 4.97: Summary of Total Utilised Government of Kenya (GOK) Funds Financial Years (FY) 2011-12 to 2017-18 in the Central Kenya Project Region

Financial Year	Subtotal RMLF Disbursed (Kshs)	GOK/Special Allocation (Kshs)	Coffee Cess (Kshs)	Total Budget (Kshs)	Road Length Planned (Km)	Road Length Done (Km) / Percentage	
Year 1 FY 11/12	860,630,757	188,754,651	96,793,954	**1,146,179,362**	6,022	5,044	**84%**
Year 2 FY 12/13	753,306,259	259,340,089	99,124,595	**1,111,770,942**	5,263	4,802	**91%**
Year 3 FY 13/14	751,870,085	74,969,683	82,420,611	**909,260,379**	4,829	4,472	**93%**
Year 4 FY 14/15	613,797,807	197,256,332	79,024,169	**890,078,307**	4,026	3,848	**96%**
Year 5 FY 15/16	641,521,012	127,706,712	21,174,384	**790,402,108**	4,330	3,580	**83%**
Year 6 FY 16/17	858,724,175	158,437,706	-	**1,017,161,881**	3,219	2,523	**83%**
Year 7 FY 17/18	618,905,561	133,653,239	-	**752,558,801**	2,740	2,269	**81%**
Total/Average	**5,098,755,656**	**1,140,118,412**	**378,537,712**	**6,617,411,781**	**4,347**	**3,791**	**87%**

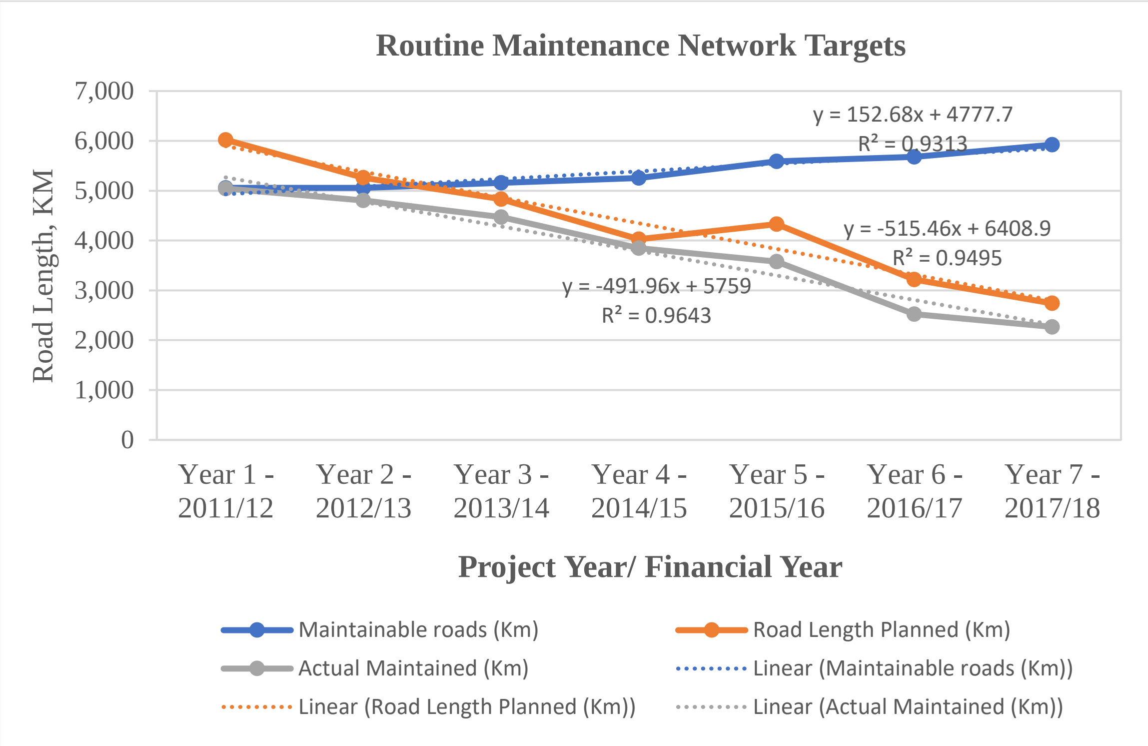


Figure 4.32: Comparison Between Project Maintainable Roads Target Versus Actual Maintained

Further site visual observations of evidence of routine maintenance of the roads showed that there were, on over ninety percent of the roads, overgrown vegetation, and drainage systems were not free flowing owing to siltation and impedance by vegetation. Tables 4.98 and 4.99 shows the observations on maintenance as found out through field visual surveys.

Table 4.98: Maintenance Priority and Fund Allocation – Murang'a

Region	Road No.	Section Name	Length	Level of maintenance following visual observations
Murang'a	**Batch 1**			
	D419 (I)	Maragwa Town – Gakoigo Junction Road	2.1	Poor maintenance observed
	D419 (II)	Gakoigo Junction – Nginda Sec. School	3.6	Poor maintenance observed
	D421	Gakoigo Junction – Maragwa River Road	3.3	Poor maintenance observed
	Batch 2			
	D415(I)	Muruka - Kandara Town	3.75	Poor maintenance observed

Region	Road No.	Section Name	Length	Level of maintenance following visual observations
	D415(II)	Muruka - Kandara Town	3.75	Poor maintenance observed

Table 4.99: Maintenance Priority and Fund Allocation – Kiambu

Region	Road No.	Section Name	Length	Level of maintenance following visual observations
Kiambu	**Batch 2**			
	E443/1	Gichiengo – Kijabe Hospital Road	3.25	Poor maintenance observed
	E443/2	Gichiengo – Kijabe Hospital Road	3.25	Poor maintenance observed
	E1531	Kang'oo - Kamwangi Road	5.6	Poor maintenance observed
	Batch 3			
	D378	Wangige- Nyathuna	6.4	Fair maintenance observed
	D378	Nyathuna - Ngecha - Rironi	5.4	Fair maintenance observed
	D402	Kimende- Kagwe Ruiru River/1	6.0	Fair maintenance observed
	D402	Kimende- Kagwe- Ruiru-Githunguri/2	6.6	Poor maintenance observed
	D402	Kimende- Kagwe- Ruiru-Githunguri/3	2.4	Poor maintenance observed
	E1520	Kanunga - Banana	3.0	Fair maintenance observed
	D378	Kirangari - Gikuni - Nyathuna Hosp - Jnct	6.0	Fair maintenance observed
	D379	Wamwangi- Ruburi	7.1	Fair maintenance observed

4.7 Axle Load Control

Data pertaining axle load control on the completed low volume sealed roads was sought from the regional authorities to whom the roads were handed over to. It was established that the capacity to control axle loading by the said bodies was very minimal and there was no active department dedicated to this activity.

Kenya Roads Board dedicated resources every year towards axle load activities. For instance, in the FY 2021/2022, twenty-three virtual weighbridges and eleven static weigh ridge stations were in operation, and well facilitated. However, these efforts were directed to the Kenya National Highways Authority (KeNHA), whose are responsible for roads in Classes S, A and B.

Such resources had not been made available to Kenya Rural Roads Authority (KeRRA), the authority that is responsible for the management, development and maintenance of National Trunk Roads in Class C. Similarly, no resources were allocated to the forty-seven County Governments who are responsible for the management, development and maintenance of County Roads (Classes D and below).

The constructed and completed low volume sealed roads fall under the classes C, D and E, under the jurisdiction KeRRA and the respective County Governments.

However, traffic data collected from sampled completed roads show that the traffic plying the completed roads are still below the one million equivalent standard axles that can well be accommodated by the roads.

4.8 Summary of Findings

4.8.1 Classified Traffic Count

The findings of the classified traffic counts have been summarised in Table 4.100.

Table 4.100: Summary of Classified Traffic counts

Batch	Road No.	Road Name	Annual Average Daily Traffic (AADT)	
			Design	2021
2	E443	Gichiengo - Kijabe Hospital	1,016	2,108
2	E1531	Kangoo - Kamwangi	890	1,842

Table 4.100 shows that the AADT for the roads surveyed have exceeded the design AADT. This may be attributed to both generated and attracted traffic after paving of the roads to better standards.

4.8.2 Axle Load Survey

The findings of the axle load survey have been summarised in Table 4.101.

Table 4.101: Summary of Daily Equivalent Standard Axles (DESA)

Batch	Road No.	Road Name	Daily ESA					
			Bus	Mini Bus	MGV	MGV-R	MGV-A	DESA
2	E443	Gichiengo - Kijabe Hospital	0.003	0.044	13.298	0.010	0.000	13.355
2	E1531	Kangoo - Kamwangi	0.007	0.006	15.338	0.652	0.245	16.249

On average, it can be deduced that for the roads surveyed, Medium Goods Vehicles are the highest contributor to the calculated daily equivalence standard axles (DESA). This is attributed to the farming economic activities in the area, and the access to construction materials within the road network.

A mechanistic-empirical modelling of the pavement, as shown in Appendix H, showed that the layer bearing capacity distributions were within the capacities required for low volume roads, based on the estimated traffic for the 15-year period.

4.8.3 Design Traffic Class

The traffic design classes for the low volume sealed roads surveyed assuming a 10-year and a 15-year design period are summarised in Table 4.102.

Table 4.102: Design Traffic Classes for 10 and 15-year design periods

Batch	Road No.	Road Name	10-years design period		15-years design period	
			CESA	Design Traffic Class	CESA	Design Traffic Class
2	E443	Gichiengo - Kijabe Hospital	61,314	T5-3	105,190	T5-2
2	E1531	Kangoo - Kamwangi	74,597	T5-3	127,978	T5-2

Table 4.102 shows that whereas the traffic loading had pushed the traffic class from T5-3 (that is Cumulative Equivalent Standard Axles (CESA) 25,000 to 100,000) to T5-2 (that is CESA 100,000 to 250,000) for the assessed roads, the loading was still within the limit for the low volume sealed roads, that is cumulative equivalent standard axles less than one million.

A mechanistic-empirical modelling of the pavements, as shown in Appendix H, showed that the layer bearing capacity distributions were within the capacities required for low volume roads, that is one million standard equivalent axles, based on the estimated traffic for the 15-year period, and that the pavement was able to support the existing traffic adequately. The estimated layer bearing capacities were also found to be adequate to support the current loading.

Analysis using the structural number approach to check the adequacy of the pavement showed that the constructed pavements were still adequate to carry the increased traffic levels and that the pavement reliability was expected to be sustained.

Occasional passage of overloaded trucks was however observed on the roads assessed owing to the importance of the road links to sources of raw road construction materials and there was need to limit and enforce the axle loading on the completed roads.

4.8.4 Drainage Performance

The required minimum depth of side drains below formation in both cuts and low fills need to be 0.4m (MoTIHUD, 2017). The roads with depth exceeding 0.4m below the formation and those with depths less than the required have been summarised in Table 4.103. It was observed that out of the fifteen roads surveyed, only one road had its depth of side drain meeting the requirement. Shallow side drainage is not desirable as it allows water to ingress into the pavement through the edge of the pavement layers, thereby undermining the underlying layers and eventually leading to early deterioration.

Table 4.103: Summary of Drainage Performance Findings

Batch	Road No.	Road Name	Depth Below Formation (m)		Comments
			LHS	RHS	
KIAMBU REGION					
2	E443/1	Gichiengo - Kijabe Hospital	-0.46	-0.42	Inadequate

Batch	Road No.	Road Name	Depth Below Formation (m)		Comments
			LHS	RHS	
2	E443/2	Gichiengo - Kijabe Hospital	-0.11	-0.09	Inadequate
2	E1531	Kangoo - Kamwangi	-0.07	-0.22	Inadequate
3	D378-1	Wangige - Nyathuna	-0.03	-0.02	Inadequate
3	D378-2	Nyathuna - Ngecha – Rironi	-0.05	-0.01	Inadequate
3	D402-1	Kimende - Kagwe - Ruiru River	-0.01	-0.01	Inadequate
3	D402-2	Kimende - Kagwe - Ruiru River	-0.05	-0.07	Inadequate
3	E1520	Kanunga - Banana	0.03	0.02	Adequate
3	E1520	Kirangari - Gikuni - Nyathuna Hosp - Junction	-0.02	-0.07	Inadequate
3	D379	Wamwangi - Ruburi	-0.04	-0.03	Inadequate
MURANG'A REGION					
1	D419 - I	Maragwa Town - Gakoigo Junction	-0.07	-0.04	Inadequate
1	D419 - II	Gakoigo Junction – Nginda Sec. School	-0.08	-0.11	Inadequate
1	D421	Gakoigo - Maragwa River	-0.01	-0.02	Inadequate
2	D415-I	Muruka - Kandara	-0.01	-0.02	Inadequate
2	D415-II	Muruka - Kandara	0.01	-0.03	Inadequate

4.8.5 Roughness Measurement

The findings of the roughness measurement survey have been summarised in Table 4.104.

Table 4.104: Summary of Roughness Measurements

Batch	Road No.	Road Name	Average IRI (m/km)		Condition Rating	
			Rough-o-meter	Road-Lab Pro	Rough-o-meter	Road-Lab Pro
KIAMBU REGION						
2	E443/1	Gichiengo - Kijabe Hospital	7.2	4.2	Severe	Warning
2	E443/2	Gichiengo - Kijabe Hospital	7.3	4.2	Severe	Warning
2	E1531	Kangoo - Kamwangi	5.9	5.1	Warning	Warning
3	E1520	Kanunga - Banana	4.2	3.2	Warning	Warning
MURANG'A REGION						
1	D419 - I	Maragwa Town - Gakoigo Junction	4.9	3.0	Warning	Warning
1	D421	Gakoigo Junction - Maragwa River	4.1	2.5	Warning	Sound
2	D415-I	Muruka - Kandara	6.4	3.8	Severe	Warning

Based on the roughness values measured using rough-o-meter, 43% of the roads surveyed were found to be in Severe condition while the other 57% were in Warning. On the other hand, measurements by the road lab pro show that 86% of the roads are at Warning rating, while 14% are rated as Sound. The two methods indicate high values of roughness and irregularities on the surface of the pavement, that unfavourably affect the ride quality of the motorists. The high roughness values obtained result from ruts, pot holes among other surface defects, and are attributed to inadequate timely maintenance of the roads surface.

4.8.6 Rut Depth Measurement

Ruts were considered as the longitudinal deformation on the wheel paths. The findings of rut depth measurements have been summarised in Table 4.105.

Table 4.105: Summary of Rut Depth Measurements

Batch	Road No.	Road Name	Rut Depth, mm		Rut Depth Rating
			LHS	RHS	
KIAMBU REGION					
2	E443/1	Gichiengo - Kijabe Hospital	-1.7	-0.6	Very Good
2	E443/2	Gichiengo - Kijabe Hospital	2.0	-1.3	Very Good
2	E1531	Kangoo - Kamwangi	4.0	3.3	Very Good
3	D378-1	Wangige - Nyathuna	4.5	2.2	Very Good
3	D378-2	Nyathuna - Ngecha – Rironi	3.9	2.5	Very Good
3	D402-1	Kimende - Kagwe - Ruiru River	3.1	3.4	Very Good
3	D402-2	Kimende - Kagwe - Ruiru River	3.4	3.4	Very Good
3	E1520	Kanunga - Banana	3.8	4.6	Very Good
3	E1520	Kirangari - Gikuni - Nyathuna Hosp - Junction	5.4	2.6	Good
3	D379	Wamwangi - Ruburi	3.8	3.4	Very Good
		Average	**3.20**	**2.40**	
MURANG'A REGION					
1	D419 - I	Maragwa Town - Gakoigo Junction	4.9	1.6	Very Good
1	D419 - II	Gakoigo Junction – Nginda Sec. School	4.8	1.9	Very Good
1	D421	Gakoigo - Maragwa River	5.1	1.8	Very Good
2	D415-I	Muruka - Kandara	3.5	4.4	Very Good
2	D415-II	Muruka - Kandara	3.4	4.2	Very Good
		Average	**4.3**	**2.8**	

The rut depth rating has been based on the following scale:

(i) Very good : < 5mm (difficult to discern unaided)
(ii) Good : 5 – 10 mm
(iii) Fair : 10 – 15 mm (just discernible by eye)
(iv) Poor : 15 – 30 mm
(v) Very Poor : > 30 mm

The results of the rut depth measurements, as summarized in Table 4.105, show that the rut depth values obtained were generally considered good to very good. This indicates that there was minimal structural failure of the road base, sub-base or the subgrade. Low rut depths were likely to originate from the surfacing. It was also deduced that rutting varies with direction of traffic in all the roads surveyed. In the region generally, all the roads fall within agricultural regions where agricultural produce are expected to be transported to various markets.

4.8.7 Present Serviceability Rating

The present serviceability is the ability of a particular road segment to offer a smooth, safe and comfortable ride at that specific time. The existing serviceability value was obtained by subjectively rating the pavement by visual observations. The findings have been summarised in Table 4.106.

It was deduced that all the surveyed roads have a PSR value above 2.0, which is the terminal value for low volume sealed roads. Low ratings specify poor surface condition, and point to the need of a detailed investigation of the pavement being required. Therefore, to allow for timely rehabilitation, the corrective works should be considered and arranged when the present serviceability values reach about 2.5.

Table 4.106: Summary of Present Serviceability Rating (PSR) Values

Batch	Road No.	Road Name	PSR Rating	Rating
KIAMBU REGION				
2	E443/1	Gichiengo - Kijabe Hospital	2.8	Fair
2	E443/2	Gichiengo - Kijabe Hospital	2.1	Fair
2	E1531	Kangoo - Kamwangi	3.3	Good
3	D378-1	Wangige - Nyathuna	3.8	Good
3	D378-2	Nyathuna - Ngecha – Rironi	3.2	Good

Batch	Road No.	Road Name	PSR Rating	Rating
3	D402-1	Kimende - Kagwe - Ruiru River	2.3	Fair
3	D402-2	Kimende - Kagwe - Ruiru River	3.4	Good
3	E1520	Kanunga - Banana	3.0	Fair
3	E1520	Kirangari - Gikuni - Nyathuna Hosp - Junction	3.7	Good
3	D379	Wamwangi - Ruburi	3.2	Good
MURANG'A REGION				
1	D419 - I	Maragwa Town - Gakoigo Junction	2.8	Fair
1	D421	Gakoigo - Maragwa River	4.0	Good
2	D415-I	Muruka - Kandara	2.2	Fair

4.8.8 Climate Resilience Assessment

The degree of a certain distress type is taken as a measure of its severity. Considering that the degree of a distress varies over the segment being assessed, it was recorded in concurrence with the extent of its manifestation for all distresses in consideration. The extent of any distress is a measure of how widespread the distress is over the length of the road segment in consideration. This provided the best average assessment of the seriousness of a particular type of distress.

The findings of the climate resilience assessment have been summarised in Tables 4.107 and 4.108.

Table 4.107: Visual Assessment of Climate Resilience

Road No.	Gichiengo – Kijabe Hospital Road (E443/1)	Gichiengo – Kijabe Hospital Road (E443/2)	Kang'oo - Kamwangi Road (E1531)	Wangige-Nyathuna (D378)	Nyathuna - Ngecha - Rironi (D378)	Kimende-Kagwe Ruiru River/1 (D402)	Kimende-Kagwe- Ruiru-Githunguri/2 (D402)	Kanunga - Banana - E1520	Kirangari - Gikuni - Nyathuna Hosp - Jnctn (D378)	Wamwangi-Ruburi (D379)	Maragwa Town – Gakoigo Junction road (D419-1)	Gakoigo Junction – Nginda Sec. School (D419-2)	Gakoigo Junction – Maragwa River Road (D421)	Muruka - Kandara Town (D415-1)	Muruka - Kandara Town (D415-2)
Erodibility															
Subgrade	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
Road Surface - Unpaved	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Side drains - Unlined	2/3	2/3	2/3	2/3	2/3	3/2	3/2	2/3	2/2	2/2	2/2	2/2	2/3	2/3	2/3
Embankment Slopes	2/2	2/2	1/2	1/2	1/2	3/2	3/2	1/2	2/2	2/2	2/2	1/2	1/2	1/2	1/2
Cut Slopes	1/1	1/1	1/1	1/1	1/1	1/2	1/2	1/1	1/1	1/1	1/2	1/1	1/1	1/1	1/1
Subgrade Problems															
Material Type	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
Moisture	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
Drainage (in reserve)															
Road shape	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
Shoulders	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1
Side slopes	3/2	3/2	3/2	3/2	3/2	3/2	3/2	3/2	3/2	3/2	3/2	3/2	3/2	3/2	3/2
Side drains	3/2	3/2	3/2	3/2	3/2	3/4	3/4	3/2	3/4	3/4	3/2	3/2	3/2	3/2	3/2
Mitre drains	5/2	5/2	5/2	5/2	5/2	5/4	5/4	5/2	5/2	5/2	5/2	5/2	5/2	5/2	5/2
Drainage from outside the road reserve (Streams)															
Structure	-	-	-	-	-	-	-	-	-	-	1/5	-	-	-	-
Embankments	2/2	2/2	2/1	2/1	2/1	2/1	2/1	2/1	2/2	2/2	2/1	2/1	2/1	2/1	2/1
Erosion	2/1	2/1	2/1	2/1	2/1	1/1	1/1	2/1	2/1	2/1	1/1	2/1	2/1	2/1	2/1
Protection Works	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1
Slope Stability															
Cut stability	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
Fill stability	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
Construction															
Overall finish	3/5	3/5	3/5	2/3	2/3	3/4	3/4	3/5	2/3	2/3	1/1	3/5	3/5	3/5	3/5
Erosion Protection works	2/1	2/1	2/1	2/1	2/1	2/4	2/4	2/1	2/1	2/1	1/1	2/1	2/1	2/1	2/1
Maintenance															
Quantity	4/5	4/5	4/5	4/4	4/4	5/5	5/5	4/5	3/4	3/4	4/5	4/5	4/5	4/5	4/5
Quality	4/5	4/5	4/5	4/4	4/4	5/5	5/5	4/5	3/4	3/4	4/5	4/5	4/5	4/5	4/5

Table 4.108: Summary of Climate Resilience Assessment

Sn	Description		Condition Summary
1	Erodibility	*Subgrade*	100% of the roads surveyed showed evidence of localised materials loss due to channelised water flows
		Road surface - unpaved	All roads surveyed were paved.
		Side drains	27% showed slight occurrence of erosion of drains.
			60% showed extensive occurrence of erosion of drains requiring periodic maintenance and reshaping to reinstate flow.
			13% showed warning levels of erosion of drains.
		Embankment slopes	53% showed minor evidence of water damage
			33% had discernible channels on the embankment slopes
			13% showed warning signs of channels on slopes and notable loss of slope material. Channels greater than 75mm deep and 300mm wide.
		Cut slopes	80% had minor evidence of water damage on isolated occurrences.
			20% had minor evidence of water damage over parts of the segment length, more than isolated.
2	Subgrade Problems	*Material type*	100% of the roads surveyed showed no evidence of problematic soils adjacent to the road
		Moisture	100% of the roads surveyed showed minor evidence of localised, but controllable water problem or seepage.
3	Drainage (in reserve)	*Road shape*	100% of the roads surveyed had good shape and crossfall, and showed minor susceptibility to retaining shallow water on the surface.
		Shoulders	100% of the roads surveyed showed slight to warning and more than isolated case of vulnerability to ponding of water on the shoulders.
		Side slopes	100% of the roads surveyed showed evidence of poor removal of water from road and shoulders into side drains, and maybe erosion that could block the drains, on more than isolated occurrences.
		Side drains	73% of the roads surveyed showed evidence of drains being incorrectly graded or having uneven surfaces that had potential to retain water for prolonged periods. Cases more than isolated.

Sn	Description		Condition Summary
			27% of the roads surveyed showed evidence drains being incorrectly graded or having uneven surfaces that had potential to retain water for prolonged periods. Distress more frequent in occurrence over a major portion of the segment length.
		Mitre drains	87% of the roads surveyed had insufficient mitre drains or totally ineffective, on more than isolated occurrences.
			13% of the roads surveyed had insufficient mitre drains or totally ineffective, and more frequent in occurrence over a major portion of the segment length.
4	Drainage (Streams)	*Structure*	One road with new box culvert showed minor evidence of localised damage.
		Embankments	73% of the roads surveyed with existing structures had minor evidence of water damage to approach fills and embankment to the structures
			27% of the roads surveyed with existing structures had slight to warning loss of material from embankment, and could be repaired.
		Erosion	80% of the roads surveyed with existing structures had minor evidence of stream erosion
			20% of the roads surveyed with existing structures had slight loss of material from river bank, and signs of erodibility.
		Protection works	100% of the roads surveyed showed slight evidence of damage to protection works requiring significant repairs, on isolated occurrences.
5	Slope stability	*Cut stability*	100% of the roads surveyed showed minor evidence of surface instability, with major failures unlikely.
		Fill stability	100% of the roads surveyed showed minor evidence of surface instability.
6	Construction	*Overall finish*	7% of the roads surveyed showed minor evidence of failure.
			27% of the roads surveyed showed slight to warning signs of failure, with intermittent occurrence of failure, like potholes and edge subsidence.
			13% of the roads surveyed showed warning signs of failure, with more frequent occurrence of failure, like potholes and edge subsidence, over a major portion of segment lengths.

Sn	Description		Condition Summary
			53% of the roads surveyed showed warning signs of failure, with more extensive occurrence of failure, like potholes and edge subsidence, over entire segments.
		Erosion protection works	7% of the roads surveyed showed minor evidence of distress in erosion protection measures.
			80% of the roads surveyed showed slight to warning evidence of distress in erosion protection measures, on isolated cases.
			13% of the roads surveyed showed slight to warning evidence of distress in erosion protection measures, on more frequent occurrence over a major portion of the segment lengths.
7	Maintenance	*Quality*	13% of the roads surveyed showed warning evidence of poor-quality maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses more frequent.
			13% of the roads surveyed showed warning to severe evidence of poor-quality maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses more frequent.
			60% of the roads surveyed showed warning to severe evidence of poor-quality maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses extensive over entire road segments.
			13% of the roads surveyed showed severe evidence of poor-quality maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses extensive over entire road segments.
		Quantity	13% of the roads surveyed showed warning evidence of inadequate level of maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses more frequent.
			13% of the roads surveyed showed warning to severe evidence of inadequate level of maintenance on vegetation control, cleaning of drains, gravel

Sn	Description		Condition Summary
			shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses more frequent.
			60% of the roads surveyed showed warning to severe evidence of inadequate level of maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses extensive over entire road segments.
			13% of the roads surveyed showed severe evidence of inadequate level of maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses extensive over entire road segments.

From the findings in Tables 4.107 and 4.108, it was deduced that:

a) That there were signs of erosion surface of the road, embankment slopes and side drains of the sampled assessed roads, that can result in significant problems, not only aesthetic and environmental, but more importantly in the road management context, leading to excessive maintenance requirements (both road surface and drains) and potentially to complete failure of the infrastructure facility. Surface damage caused by erosion leads to concentrations of water, excessive loss of material as silt and increased water flow velocities. Uncontrolled erosion of the road support layers can ultimately lead to collapse of the pavement or structure as well as excessive siltation of drainage structures.

b) That there was no visible evidence of problematic soils on the sampled and assessed roads. Changes in rainfall and temperature patterns over time results in high moisture fluctuations in subgrade materials. Most problematic soils such as expansive clays, dispersive clays and collapsible sands will be affected by both wetting up of subgrades due to increased precipitation or more extreme events and drying out of the soils caused by longer dry periods, increased temperatures and windiness and drought conditions.

c) That there were areas where the side drains and metre drains were not adequate and effective. It is critical that water is removed from the road surface and surrounding areas into suitable drainage systems as fast and efficiently as possible.

d) That there were minimal evidences of localized damage to new and existing structures. It was deduced that the existing structures would perform adequately under changing precipitation, temperature or wind conditions. The was minimal damage to protection works (gabions, stone pitching and rip-rap) associated with the drainage structures caused by high water levels.

e) That there was no major evidence of slope instability and failures. It was observed that cuts and embankments are stable enough to resist changes in precipitation. The cut slopes showed no signs of movement behind the slope (tension cracks or subsidence) or at the toe of the slope (bulging or deformation of side-drains). Also, embankments showed no signs of arcuate cracks in the shoulders or the road surface, unusual settlement of parts of the fill, bulging at the base of the fill nor periodic seepage of water from beneath the fill.

f) That there were signs of poor construction overall finish and erosion protection measures. Failures were evident, demonstrated by the various mechanisms of deterioration such as potholes, ruts and edge subsidence. There were signs of failure of erosion protective measures, as some were not intact and allowed water to enter behind them.

g) Maintenance is critical in preserving low volume sealed roads, and should be done in a timely manner. As climatic conditions change, the need for adequate and efficient become more paramount. On the sampled roads, there was huge evidence established of a lack of quantity and quality maintenance on the completed roads. Issues such as poor shape of shoulders, inadequate vegetation control, insufficient cleaning and shaping of side-and mitre drains and lack of free flow in culverts and drains. Quality and quantity maintenance should be availed in regards to vegetation control, cleaning of drains, shaping of gravel shoulders, repair of potholes and cracks in paved roads.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The overall objective of the study was to investigate the. Based on the findings, conclusions were made as discussed in the following sections, in reference to the research specific objectives.

5.1.1 Performance of Implemented Low Volume Sealed Road Pavements Under the Roads 2000 Program in Central Kenya.

5.1.1.1 Present Serviceability

The present serviceability is the ability of a particular road segment to offer a smooth, safe and comfortable ride at that specific time. The existing serviceability value was obtained by subjectively rating the pavement by visual observations.

It was established that of the thirteen assessed roads, 54% had a good serviceability rating, while 46% had a fair rating. Practice recommends that present serviceability values of 2.0 for low volume sealed roads need to be considered as the minimum that indicates when rehabilitation is required. Consequently, to allow for timely corrective works, pavement rehabilitation need to be considered and programmed once the present serviceability values reach about 2.5.

It was concluded that three roads, that is Gichiengo – Kijabe Hospital (E443/1), Kimende – Kagwe – Ruiru River (D402/1) and Muruka – Kandara (D415/1) had their present serviceability values below 2.5 and a more detailed investigation of their pavements was required to determine the appropriate rehabilitation method necessary to improve the structural capacity.

5.1.1.2 Drainage Assessment

It is crucial that runoff is efficiently drained from the road surface and surrounding areas into suitable side drains, and then further away from the road reserve via culverts and mitre drains. Where runoff is allowed to stagnate on the road for long, it has the likely effect of causing structural damage to the road pavement.

The assessment carried out on the side drainage performance showed that 93% of the assessed roads had the drain depths inadequate to allow free flow of water. The presence of siltation and clogged trash on the drains was an indication of inadequate maintenance. Shallow side drainage is not desirable as it allows water to ingress into the pavement via the pavement edge.

5.1.1.3 Roughness Measurement

The roughness of a road section is a good measure of its relative pavement condition, but it does not identify the nature of the failures or their causes. The high roughness values obtained from the field investigations of the roads were deduced to be as a result of ruts, potholes, among other surface defects. This was concluded as an indication of inadequate timely maintenance of the road's surfaces. Properly planned routine maintenance is key in ensuring low roughness values and thus low road user costs.

It was observed that despite the improvement contracts having an inbuilt three years' performance based routine maintenance component, which was being funded by the road maintenance levy fund, and which was administered by local road authorities and County Governments, maintenance was still a challenge as the bodies prioritised opening of new roads and other roads instead of the newly improved roads.

5.1.1.4 Rut Depth Measurement

Deterioration by rutting is normally as a result of (i) ingress of water via the pavement surfacing or road edges in base, sub-base and subgrade; (ii) structural overloading of the pavement and/or insufficient pavement thickness; (iii) unsatisfactory quality of pavement materials; (iv) poor control of construction quality, mainly compaction and drainage; and (v) pavement at terminal condition.

The rut depth values obtained were generally considered to be in good to very good condition. Such low rut depth values indicated that there was minimal structural failure of the base, sub-base or the subgrade. Low rut depths are likely to originate from the surfacing.

It was determined that rutting varied with direction of traffic in all the roads surveyed. The surveyed roads traversed agricultural regions where farm produce is transported to the various markets. Thereby, medium goods vehicles were found to be the main contributor of traffic loading on the assessed roads.

5.1.1.5 Overall performance

The research established that the completed low volume sealed road pavements in Kiambu and Murang'a regions under phase two of the R2000 Strategy were in good condition, offering a fair to good ride quality and the deterioration stages as showcased by rut and pothole distresses which were not at terminal levels.

With proper and all-round conditional assessments, followed by timely, adequate and efficient maintenance regimes, the roads were expected to meet their design lives and continue serving the population in these regions, composed of agricultural and peri-urban communities.

5.1.2 Maintenance of the Implemented Low Volume Roads

The design criteria for low volume sealed roads are normally grounded on the anticipation that essential maintenance shall be undertaken routinely and periodically, to cater for the expected deterioration brought about by actions of traffic, climate and other harmful influences.

In Kenya, road construction and their maintenance are capital intensive. There has been a need to embed the road asset management in the country's development plan. This requires reliable and accurate data, and this data, gathered in the form of Road Inventory and Condition Survey (RICS), is eventually used as a basis for prioritisation for maintenance. Road agencies annually conduct condition surveys to inform their maintenance priorities.

It was observed that consistent collection of the road condition data by the road agencies and county governments vested with maintaining the completed low volume sealed roads still remained a challenge. In a bid to make informed investment decisions on maintenance, given the inadequate funding in place for the same, there was need for acquisition of up to date and reliable road network data. It was also observed that data on non-motorized transport facilities was not normally captured on the condition survey data, despite this transport mode being very significant on the Kenyan road network.

Further, the research established that the essential data covering road climate resilience towards execution of appropriate adaptation measures was never captured as part of the required data during road condition surveys by the road agencies. This data, that covers matters to do with erosion, problem soils, road and surrounding areas' drainage, road reserve and outer drainage, embankments and cuttings instability, issues during construction and maintenance.

5.1.3 Traffic Loading and Axle Control of the Implemented Low Volume Roads

5.1.4.1 Classified Traffic Counts

The main purpose of carrying out traffic surveys and studies is to ensure that sufficient and appropriate data is available to carry out necessary planning, design, implementation and management of the road infrastructure, which is aimed at meeting the prevailing traffic flow, future traffic growth and loading without considerable deterioration in the level of service.

Based on the analysis of the classified volume counts data, that was conducted on sampled roads, the following conclusions were made;

a) The roads harbour large trips made using motorbikes, as opposed to matatus and personal cars. The motorcycles operate in the informal private sector and their impulsive spread has had little regulatory control. The motorcycles can travel on tracks and footpaths, and effectively reach villages and are easy to request rides. Where no other alternative means of transport exist, the motorcycles easily bridge the gap. Motorcycles offer employment and they are profitable, thereby allowing private financing. However, motorbikes, cars and taxis do not have any damaging effect on the pavement, but consideration of their volumes is crucial during geometric sizing of the roads in these regions. Safety issues such as accidents related to motorbikes need to be considered and incorporated in the designs that allows non-motorised traffic.
b) In all the roads surveyed, buses, omnibuses, and heavy goods vehicles contributed the minimal percentage of design traffic.
c) From the traffic data analysis, the annual average daily traffic had exceeded the design traffic prior to construction. This may be attributed to both generated and attracted traffic after improving the roads to better paved standards.

5.1.4.2 Axle Load Survey

Based on the analysis of the axle load data of the surveyed roads, the following conclusions were made:

a) On average, the Medium Goods Vehicles (MGV) were the highest contributor to the calculated Daily Equivalence Standard Axles (DESA). This was attributed to the fact that these roads traverse through agricultural areas. The MGV's are used to transport the farm produce to the market.
b) However, traffic data collected from sampled completed roads show that the traffic plying the completed roads were still below the one million equivalent standard axles that can well be accommodated by the low volume sealed roads.

c) A mechanistic-empirical modelling of the pavement showed that the layer bearing capacity distributions were within the capacities required for low volume roads, that is one million standard equivalent axles, based on the estimated traffic for the 15-year period, and that the pavement was able to support the existing traffic adequately. The estimated layer bearing capacities were also found to be adequate to support the current loading

5.1.4.3 Axle Load Control

It was established that there existed no axle load control mechanism in place to monitor and control the axle loading amongst the traffic causing the completed low volume sealed roads. It was noted that these roads were an important link within the wider network leading to sources of raw materials for construction of roads and other infrastructure. As it is practise, most construction transport vehicles tend to be overloaded.

The lack of control of axle loading poses a great risk to these roads as early failures and uncontrolled deterioration could be experienced in due course. Some pavement distresses, like rutting, though not observed to be terminal ruts, were attributed to occasional passages of overloaded trucks.

The established low capacity to control axle loading by the local road authorities and respective county governments mandated to maintain the completed and handed over roads was concluded to be a high potential risk to the performance of the roads.

5.1.4 Resilience and Climate adaptation of Implemented Low Volume Roads

The effects of climate change on road infrastructure requires that susceptible segments of the are identified and adaptation measures be put in place reduce probable upcoming climate-related damage.

As observed with the Kenyan road agencies, visual condition assessment of the road network is routinely carried out at stated frequencies, towards road management, maintenance and rehabilitation planning purposes. The collected data only assesses the road carriageway for problems such as surfacing cracks, pavement deformation, ruts and potholes, which are rated and inform the prioritisation and funding of the subsequent maintenance.

The research concluded that it was important to incorporate the collection of additional data in the assessment on issues that touch on climate resilience, and the assessment of which should inform the execution of appropriate adaptation measures to improve the climate resilience of the completed low volume sealed roads.

The analysis of the climate resilience assessment of the sampled roads concluded that the climate adaptation measures to improve the resilience of the completed roads had not been put in place, and the potential effects of climate change were a clear possibility.

5.2 Study Recommendations

The study, based on the conclusions, made recommendations as in the following sections.

5.2.1 Recommendations

5.2.1.1 Axle loading Control

Axle loading control on the Kenyan road network has been entirely focussed on the trunk roads in the classes S, A and B. These roads were in the jurisdiction of the Kenya National Highways Authority (KeNHA). Other roads in the network are majorly left unmonitored for overloading.

The constructed low volume sealed roads fall within the network managed by Kenya Rural Roads Authority (KeRRA), and the respective County Governments, who are funded by the Kenya Roads Board through the levy fund towards their management and maintenance. Considering that these roads are designed to cater for traffic loading not exceeding one million standard axles, there is need to control the loading in a bid to ensure the roads meet their design lives.

Therefore, this study recommends that the regional bodies managing the completed roads be resourced, and their capacity to control axle loading be enhanced. This will ensure that the great investment put in place to ensure transportation of goods and services is not interrupted by the uncontrolled deterioration occasioned by overloaded traffic.

5.2.1.2 Maintenance

a) Pavement Surface

Properly planned routine maintenance of all the completed low volume sealed roads is recommended in order to lower the roughness values and subsequently lower the road user costs. The high roughness values obtained, which were deduced to be as result of distresses such as rutting and potholes, were concluded to result from inadequate and untimely maintenance of the roads surface. The recommended maintenance strategy should be such that interventions for the defects such as cracks, potholes, edge breaks among others are carried out as soon as they are identified.

b) Side Drainage

The assessment conducted on the performance of the side drainage showed that majority of the roads had side drainage with inadequate depths. Shallow side drainages are not desirable as they allow water to ingress into the pavement via the edge of the pavement layers.

Routine maintenance of the side drainage is recommended as it is key in ensuring that the water in the side drains do not ingress into the pavement layers. During such maintenance, deepening all the shallow side drains is highly recommended. Other activities such as unblocking of culverts, desilting of side drains, mitre drains and out fall drains should be carried out effectively. Control of vegetation which may grow either on the side drains or at the edges of the pavement should be done judiciously. Such vegetation is usually not good for the pavement as they hold water thus keeping the moisture content of the pavement layers high.

c) Maintenance Prioritisation and Funding Allocation

The projects completed under the phase two of the program had a thirty-six months performance based routine maintenance contracts embedded on their original contracts, and thereafter the roads were to transition to maintenance by Kenya Rural Roads Authority (KeRRA) under the 22% Road Maintenance Levy Fund (RMLF) allocation.

The maintenance funds are administered by KeRRA regional offices and Constituency Road Committees (CRCs). It was established that the committees normally prioritize opening of new roads, as opposed to maintaining the newly improved roads. Given this backdrop, uncontrolled deterioration is occasioned on these roads and most remain unattended.

In addition, where there are attempts to maintain the roads, the scope for implementation is determined by a condition survey, which focusses on collecting data only on the road carriageway for problems such as surfacing cracks, pavement deformation, ruts and potholes, which are rated and inform the prioritisation and funding of subsequent maintenance.

The essential data covering road climate resilience towards execution of appropriate adaptation measures was never captured as part of the required data during road condition surveys by the road agencies. This data, that covers matters to do with erosion, problem soils, road and surrounding areas' drainage, road reserve and outer drainage, embankments and cuttings instability, issues during construction and maintenance.

It is recommended that the Annual Road Inventory and Conditional Survey (ARICS) incorporates collection of additional data in the assessment on issues that touch on climate resilience, and the data collection method proposed herein be put in use, and the assessment of which should inform the execution of appropriate adaptation measures to improve on the climate resilience of the completed low volume sealed roads.

5.2.2 Recommended Areas for further Research

The following areas are recommended for further study:

a) Service level setting for low volume sealed roads

In consideration of the fact that the completed roads under the phase two of the program had a thirty-six months performance based routine maintenance contracts embedded on their original contracts, and that their impact on maintaining good serviceability were not ascertained, further research on the acceptable present serviceability level setting for low volume sealed roads is recommended.

b) Rapid axle weigh-in-motion for low volume sealed roads

Axle loading control is critical for low volume roads, and mechanisms for real-time control of the loading need to be well formulated. The feasibility of adoption of rapid methods including weigh-in-motion (WIM) devices and techniques need to be studied.

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APPENDICES

APPENDIX A: BATCH 1, 2 AND 3 UNDER ROADS 2000 PHASE 2 PROJECT

<u>Batch 1 Roads</u>

Region	Road No.	Section Name	Length
<u>Gravel Roads</u>			
Kiambu	E505/E505B - 1	Gatukuyu - Chania	5.0
	E505/E505B - 2	Gatukuyu - Chania	6.0
	E1529	Ngenia – Mitahato - Miguta	5.9
	E421	Mwimuto - Gikuni	7.8
	E441	Kariaini – Kiirangi – Rukuma	6.7
	RAR 19-1	Gituha - Rwacumari	7.0
	RAR 19-2	Gitutha – Nguirubi	6.0
	URA 7/URP13	Kangoya – Ndumberi / Ndumberi Pri – CPK Hospital	6.1
	URP50, URA 57	Ndumberi – Gichocho – Riabai/ Gatitu - Ndumberi	5.4
	G9	Karuri Centre – DO's Office	1.3
	E496	Juja – Gatundu – Gacharage – Fly Over	4.3
	UNCL	Gatundu – Githaruru – Mararo – Mukinyi	5.0
		Total Kiambu	**66.5**
Murang'a	C66	Thika – C67 Kirwara road	10.0
	E1535	Junction A2 (Juja) – Junction A3 (Munyu) road	10.5
		Total Murang'a	**20.5**
Nyeri	E560	D429 Rutuni	7.8
	E574-C70	Ruringu-E576 (Muthuaini)	6.3
	D450-A2	Kiganjo-D451 Hombe	8.0
	E568-C70	Othaya-D433 Kairuthi	6.5
	E561	Karindundu-Kiambara-E582 Mungetho	7.0
	UNCL	Junction D432 (Kangaita)-Junction E551	5.7
		Total Nyeri	**41.3**
Kirinyaga	E1640/ E1633	D457 Karaini-E614 Mugwandi/ GIDCs office-E614 Kimandi	4.22

Region	Road No.	Section Name	Length
	D455-C73	Kagio-B6 Mutithi	7.0
	E623-D459	Kiamutugu-Forest Edge	6.8
	E1642-E1644	Ndimani-A2 Karima	5.7
		Total Kirinyaga	**23.62**
Laikipia	B5	Nairutia-Karai(E1444)	10.0
	UNCL	Tandare-Maua-Karumaindo (UR) road	10.0
		Total Laikipia	**20.0**
		GRAND TOTAL GRAVEL ROADS	**172.0**
Low Volume Sealed Roads (LVS)			
Murang'a	D419(I)	Maragwa Town – Gakoigo Junction Road	2.1
	D419 (II)	Gakoigo Junction – Nginda Sec. School	3.6
	D421	Gakoigo Junction – Maragwa River Road	3.3
		Total Murang'a	**9.0**
Nyandarua	D381	Ngomongo Bridge-Busara Road	3.1
	D381	Total- Ngomongo	2.3
	D381	Busara Road – Kona mbaya	3.0
		Total Nyandarua	**8.4**
		GRAND TOTAL LVS ROADS	**17.4**

Batch 2 Roads

Region	Road No.	Section Name	Length
Gravel Roads			
Kiambu	E505/E505B	Gatukuyu - Chania	7.5
	D395 -1	Gatukuyu – Mataara	7.0
	D395 - 2	Gatukuyu – Mataara	7.0
	D395 - 3	Gatukuyu – Mataara	6.0
	D395-4	Gatukuyu – Mataara	6.0
	UNCL	Gatundu – Mararo – Wamwangi	4.0
	E1537	Kiamwangi – Muhoho	4.0
	E502/1	Kibichoi – Kigongo –Ndundu	7.0

Region	Road No.	Section Name	Length
	E502/2	Kibichoi – Kigongo – Ndundu	7.0
	E431/E431A – 1	Rioki – Ikinu – Gitiha	7.5
	E431/E431A – 2	Rioki – Ikinu – Gitiha	7.0
	E431/E431A – 2	Rioki – Ikinu – Gitiha	6.0
	D402	Githunguri – Ruiru River	3.4
	E422 – 1	Kabete – Kikuyu	6.8
	E422 – 2	Kabete – Kikuyu	7.0
	E422 – 3	Kabete – Kikuyu	7.0
	E1519	Kaiyaba – Muchatha	4.4
	URP 123	Karura – Gichagi	5.4
	URP 39	Kihingo – Ruthiruini	7.1
	D402 – 1	Ruiru River – Kagwe – Kimende	8.0
	D402 – 2	Ruiru River – Kagwe – Kimende	8.0
	D402 – 3	Ruiru River – Kagwe – Kimende	7.6
	E430/E1451/1	Ngenia – Murengeti – Loromo – Ngeinia	5.0
	E430/E1451/2	Ngenia – Murengeti – Loromo – Ngenia	5.1
	RAR 19	Thigio – Gitutha	9.7
	E1535 (I)	Juja Farm – Junction A3 (Munyu)	6.7
	E1535 (II)	Juja Farm – Junction A3 (Munyu)	7.0
	E1535 (III)	Juja Farm – Junction A3 (Munyu)	7.0
	E1535 (IV)	Juja Farm – Junction A3 (Munyu)	7.1
		Total Kiambu	**188.30**
Murang’a	E1551(I)	C67 Thika – Kigio road	5.0
	E1551(II)	C67 Thika – Kigio road	4.8
	E510(I)	Ndunyu Chege – Thika River	6.4
	E510(II)	Ndunyu Chege – Thika River	5.5
		Total Murang’a	**21.7**
Nyeri	E602	Karatina - Gaikuyu	8.0
	E602	Gaikuyu-Kagochi	7.6
	E582	Gaitiki-Gatina	8.7
	E560	Ngurwe-ini-Rutune	10.0

Region	Road No.	Section Name	Length
	D430	Kanunga-Nyaguathi	8.0
	E1672-D431	Ruring'u Junction - Gatitu	3.8
	D432-D431	Kangaita-Chief Office-Makutano	5.0
	UNCL E1673	Kiawaithanji-Gachima-Kangaita	6.2
	UNCL D432	Gichira-DO Office-Mungaria	4.7
	UNCL D432	Ruruguti-Gitundu-Nyamari	5.0
	D450-D451	Mapema -Karandi	6.0
	D450--D451	Karandi -Hombe	4.7
	B5	Mwiyogo-Uasonyoro	6.0
	D446	Uasonyiro-Endarasha	6.3
		Total Nyeri	**90.0**
Kirinyaga	D456: D454	Njenga Pri. – D456 Ngaru	6.0
	E1633:	GIDCs office-R19 Kiagothe	3.4
	D456	D456 Ngaru – Db Gichugu and D456 – Mukengeria River – D456 Kabare	6.5
	D455	C73 Kagio – B6 Mutithi/ E613 Kangai – D455 Kandongu	8.5
	E613	Junction C73 – Kangai	8.2
	R18	E1639 Kiangombe – D456 Kimunye	6.0
	E616	Kiangwenyi – E616 Kavote	8.0
	E616	Kavote – E623 Kamwana	7.8
	E610	D455 Baricho – E610 Getuya	7.3
	E610	E610 Getuya – Gathambi	7.3
	E610	UR-Karima Town – Ngando/Uncl. Jnct A2 – Thanju	5.0
	E610	Kamathanga – Ngombe Nguu	5.8
		Total Kirinyaga	**79.80**
Laikipia	E1444	Wangata – D558 Karai	8.2
	RAR1	A2 Gatheri-Ka Mwaura	5.0
	RAR1	Ka Mwaura – Akorino D452	4.0
	UR	Maua Junction – Mastoo – Mutuiku	7.6
	E1442	D466 Junction – Thome	5.0
	B5	Nyumba Tatu – Njonjo Girls School	4.4

Region	Road No.	Section Name	Length
		Total Laikipia	**34.20**
		GRAND TOTAL GRAVEL ROADS	**414.0**
Low Volume Sealed Roads (LVS)			
Kiambu	E443/1	Gichiengo – Kijabe Hospital Road	3.25
	E443/2	Gichiengo – Kijabe Hospital Road	3.25
	E1531	Kang'oo - Kamwangi Road	5.6
		Total Kiambu	**12.10**
Murang'a	D415(I)	Muruka - Kandara Town	3.75
	D415(II)	Muruka - Kandara Town	3.75
		Total Murang'a	**7.50**
Nyeri	E561-A2	Karatina-Refuse-Depot	1.1
	E602-E562	E602-E562	4.2
		Total Nyeri	**5.3**
Kirinyaga	R34	Wang'uru - Airstrip Road	2.7
	R34	Airstrip - Miththuni Road.	3.6
	R34	Miththuni - Marurumo road.	3.6
		Total Nyeri	**9.9**
Laikipia	RAR 2	Equator-Mukuru Wa Gathingi	3.3
	RAR 2	Equator-Mukuru Wa Gathingi Sweetwaters	3.2
	RAR 2	Sweet Waters-Mirera	3.2
		Total Laikipia	**9.7**
Nyandarua	D381	Mungetho – Wanganatha Road.	3.0
	D381	Wanganatha-Boiman Road	3.0
		Total Nyandarua	**6.0**
		GRAND TOTAL LVS ROADS	**50.50**
Bridge Works in Laikipia Region			
Laikipia	RAR 1	New box culvert along A2 Gatheri-Akorino road	
	RAR1	Ontilili New Bridge and Foot Path along A2 Gatheri-Akorino Road	
	RAR 2	Barguret Bridge Extension and Footpaths along Nanyuki-Matanya Road	

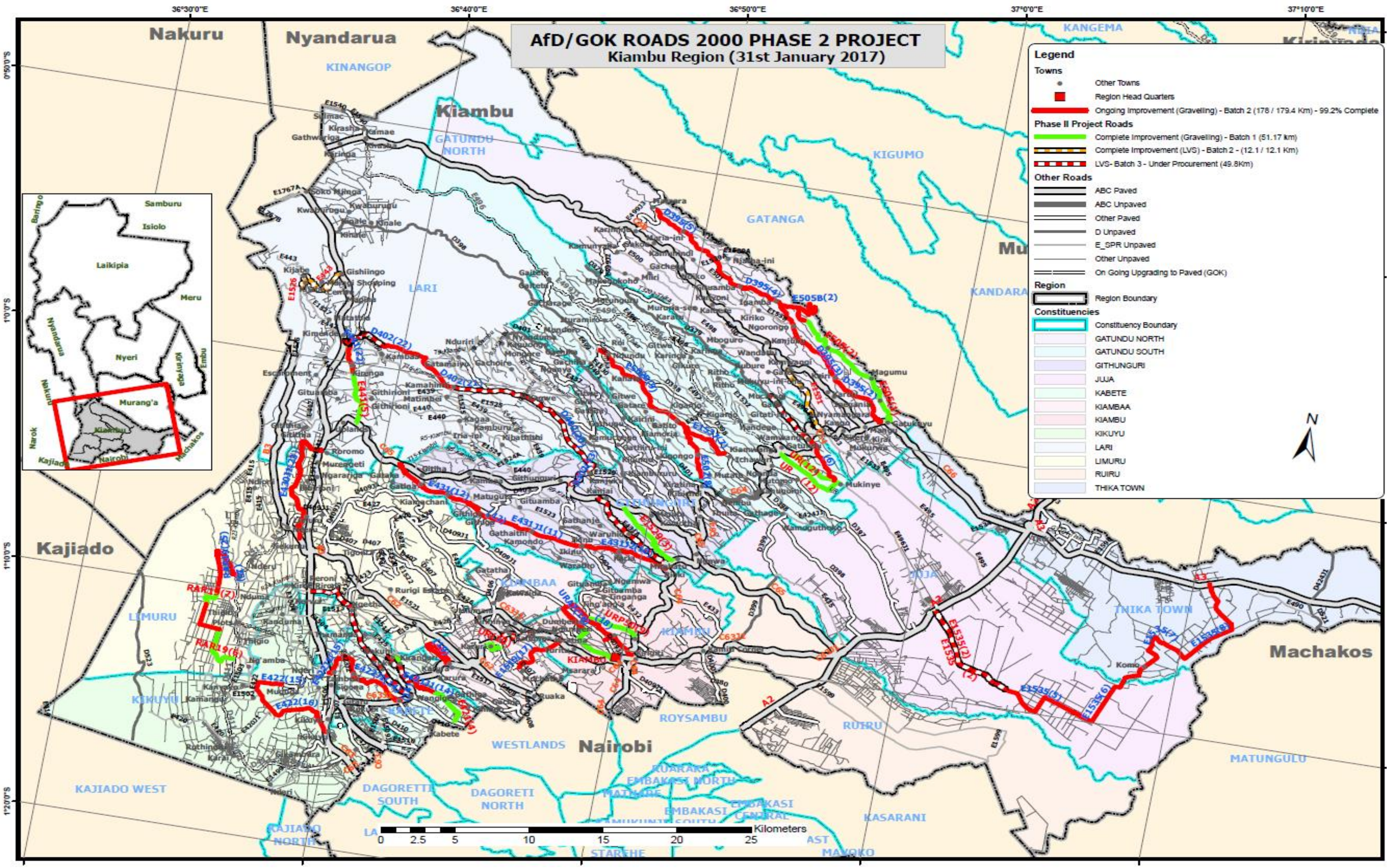
Region	Road No.	Section Name	Length
	RAR 2	Rongai River Box Culvert along Nanyuki-Matanya Road	

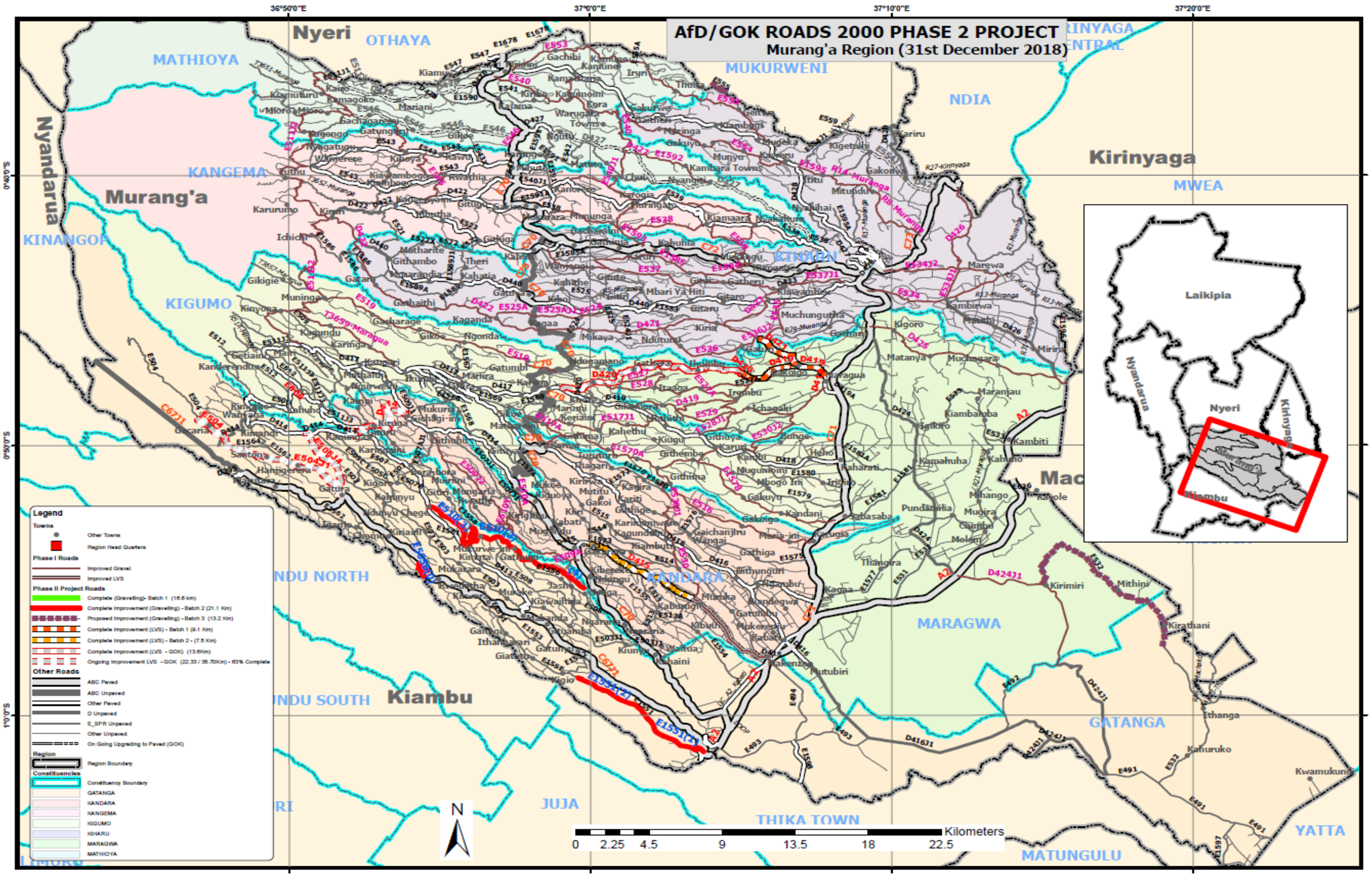
Batch 3 Roads

Region	Class	Section Name	Length
Low Volume Sealed Roads (LVS)			
Kiambu	C562	Wangige – Nyathuna (Ruku)	6.4
	C562	Nyathuna – Rironi (Ngecha)	5.4
	C558	Kimende-Kagwe-Ruiru River/1	6.0
	C558	Kimende-Kagwe-Ruiru R-Githunguri/2	6.6
	C558	Kimende-Kagwe-Ruiru R-Githunguri/3	2.4
	C548	Kanunga-Banana	3.0
	C562	Kirangari-Nyathuna (Kirangari)	6.0
	C556	Wamwangi-Ruburi (Mucharage)	7.1
Kirinyaga	E1641 UP	Kerugoya- Old Kangaita/1	5.0
	E1641 UP	Kerugoya- Old Kangaita/2	4.6
	C396	Kianyaga - Muchagara	5.1
		AREA 1 LVS TOTAL	**57.6**
Nyeri	E560	D429 Rutune-D430 Ichamara	5.2
	D446	B5 Mwiyogo-Endarasha/1	7.0
	D446	B5 Mwiyogo-Endarasha/2	6.6
		AREA 2 LVS TOTAL	**18.8**
		GRAND TOTAL AREA 1 and 2 LVS	**76.4**
Gravel Roads			
Kirinyaga	E620	Muchagara - Kamugunda	4.0
	R28	B6 Mutithi - Kirwara – Makutano/1	5.6
	R28	B6 Mutithi - Kirwara – Makutano/2	5.0
	R28	B6 Mutithi - Kirwara – Makutano/3	5.0
		AREA 1 GRAVEL TOTAL	**19.6**
Laikipia	URA7	Mia Moja-Umande	10.4
	URA9/1	Ngareng'iro - Edana	7.0
	URA9/1	Ngareng'iro - Edana	6.0

Region	Class	Section Name	Length
	URA9/2	Edana-Mutirithia-Naibor	10.0
	UNCL	Losogwa-Kigumu-St Bernard Church	5.3
	URP1	Pesi-Muruku-Salama-Simotwa-C77 Junction	10.0
	URP1	Pesi-Muruku-Salama-Simotwa-C77 Junction	10.0
	URP1	Pesi-Muruku-Salama-Simotwa-C77 Junction	11.4
		Sub-total Laikipia	**70.1**
Nyeri	E582	Gatiki - Gatina (River Sagana)	7.0
	D429	Karundu - Rutune	7.0
	D429	Karundu - Rutune	6.0
		Sub-total Nyeri	**20.0**
		TOTAL AREA 2 Laikipia and Nyeri	**90.1**
		TOTAL AREA 1 and 2 GRAVEL	**109.7**
TOTAL PHASE 2 (BATCH 3) FOR AREA 1 and 2 GRAVEL + LVS			**186.1**

APPENDIX B: LOCATION MAP OF PHASE 2 PROJECTS IN CENTRAL KENYA


AfD/GOK ROADS 2000 PHASE 2 PROJECT
Kiambu Region (31st January 2017)
Legend
Towns
Other Towns
Region Head Quarters
Ongoing Improvement (Gravelling) - Batch 2 (178 / 179.4 Km) - 99.2% Complete
Phase II Project Roads
Complete Improvement (Gravelling) - Batch 1 (51.17 km)
Complete Improvement (LVS) - Batch 2 - (12.1 / 12.1 Km)
LVS- Batch 3 - Under Procurement (49.8Km)
Other Roads
ABC Paved
ABC Unpaved
Other Paved
D Unpaved
E_SPR Unpaved
Other Unpaved
On Going Upgrading to Paved (GOK)
Region
Region Boundary
Constituencies
Constituency Boundary
GATUNDU NORTH
GATUNDU SOUTH
GITHUNGURI
JUJA
KABETE
KIAMBAA
KIAMBU
KIKUYU
LARI
LIMURU
RUIRU
THIKA TOWN
N
Kilometers
0 2.5 5 10 15 20 25
36°30'0"E
36°40'0"E
36°50'0"E
37°0'0"E
37°10'0"E
0°50'0"S
1°0'0"S
1°10'0"S
1°20'0"S
Nakuru
Nyandarua
Kiambu
Kajiado
Nairobi
Machakos
KINANGOP
GATUNDU NORTH
KIGUMO
GATANGA
KANDARA
LARI
LIMURU
KIKUYU
KABETE
KIAMBAA
JUJA
THIKA TOWN
RUIRU
ROYSAMBU
WESTLANDS
KASARANI
MATUNGULU
KAJIADO WEST
DAGORETTI SOUTH
DAGORETI NORTH
KANGEMA
Samburu
Isiolo
Laikipia
Meru
Nyeri
Murang'a
Nairobi
Narok
Kajiado
Machakos
Embu


AfD/GOK ROADS 2000 PHASE 2 PROJECT
Murang'a Region (31st December 2018)
36°50'0"E
37°0'0"E
37°10'0"E
37°20'0"E
0°0'0"S
0°50'0"S
1°0'0"S
Nyeri
Nyandarua
Murang'a
Kirinyaga
Kiambu
OTHAYA
MATHIOYA
MUKURWENI
NDIA
MWEA
KANGEMA
KINANGOP
KIGUMO
KIHARU
KANDARA
MARAGWA
GATANGA
JUJA
THIKA TOWN
MATUNGULU
YATTA
Legend
Towns
Other Towns
Region Head Quarters
Phase I Roads
Improved Gravel
Improved LVS
Phase II Project Roads
Complete (Gravelling)- Batch 1 (16.6 km)
Complete Improvement (Gravelling) - Batch 2 (21.1 Km)
Proposed Improvement (Gravelling) - Batch 3 (13.2 Km)
Complete Improvement (LVS) - Batch 1 (9.1 Km)
Complete Improvement (LVS) - Batch 2 - (7.5 Km)
Complete Improvement (LVS - GOK) (13.6Km)
Ongoing Improvement LVS - GOK (22.33 / 35.70Km) - 63% Complete
Other Roads
ABC Paved
ABC Unpaved
Other Paved
D Unpaved
E_SPR Unpaved
Other Unpaved
On Going Upgrading to Paved (GOK)
Region
Region Boundary
Constituencies
Constituency Boundary
GATANGA
KANDARA
KANGEMA
KIGUMO
KIHARU
MARAGWA
MATHIOYA
N
0 2.25 4.5 9 13.5 18 22.5
Kilometers
Laikipia
Nyeri
Nyandarua
Kirinyaga
Kiambu

APPENDIX C: PRESENT SERVICEABILITY RATING FORM AND RATING FACTORS

PRESENT SERVICEABILITY RATING FORM		
Date of Survey		
Road Name		
Section		
Rater		
Pavement Structure	Surfacing	
	Base	
	Sub-base	
	Improved subgrade/capping	
	Subgrade class	

Summary		
Defect	**Points**	
1. Crazing (Block and alligator cracks)	-	
2. Longitudinal cracking	-	
3. Transverse cracking	-	
4. Edge spalling	-	
5. Rutting	-	
6. Corrugation/waves	-	
7. Depression/Longitudinal irregularity	-	
8. Shoving/Heaving/Upheaval	-	
9. Bleeding/Glazing	-	
10. Stripping/Raveling	-	
11. Patch	-	
12. Pothole/Disruption	-	
Total	**X**	
Points	**X/12**	**Rating:**

RATING SCALE

PSR/PSI			**PCI**	
Average Points	**Rating**		**Percentage (%)**	**Rating**
4.5 – 5.0	Excellent		90 – 100	Excellent
4.0 – 4.5	Very Good		80 – 90	Very Good
3.0 – 4.0	Good		60 – 80	Good
2.0 – 3.0	Fair		40 – 60	Fair
1.0 – 2.0	Poor		20 – 40	Poor
0.5 – 1.0	Very Poor		10 – 20	Very Poor
0 – 0.5	Failed		0 – 10	Failed

	PRESENT SERVICEABILITY RATING (PSR) FOR FLEXIBLE PAVEMENT									
	RATING FACTORS									
	A. Fracture (Cracking or Spalling)									
1. Crazing (Block and Alligator Cracking)			**2. Longitudinal Cracking**			**3. Transverse Cracking**			**4. Edge Spalling**	
Extent	**Points**		**Extent**	**Points**		**Extent**	**Points**		**Extent**	**Points**
None/0-5yrs	5		None/0-5yrs	5		None/0-5yrs	5		None/0-5yrs	5
None/>5yrs	4		None/>5yrs	4		None/>5yrs	4		None/>5yrs	4
1 location	3		1 location	3		1 location	3		1 location	3
2-5 locations	2		2-5 locations	2		2-5 locations	2		2-5 locations	2
6-10 locations	1		6-10 locations	1		6-10 locations	1		6-10 locations	1
>10 locations	0		>10 locations	0		>10 locations	0		>10 locations	0
B. Distortion (Permanent Deformation or Faulting)										
5. Rutting			**6. Corrugation/ Waves**			**7. Depression**			**8. Shoving/Heaving / Upheaval**	
Extent	**Points**		**Extent**	**Points**		**Extent**	**Points**		**Extent**	**Points**
None/0-5yrs	5		None/0-5yrs	5		None/0-5yrs	5		None/0-5yrs	5
None/>5yrs	4		None/>5yrs	4		None/>5yrs	4		None/>5yrs	4
1 location	3		1 location	3		1 location	3		1 location	3
2-5 locations	2		2-5 locations	2		2-5 locations	2		2-5 locations	2
6-10 locations	1		6-10 locations	1		6-10 locations	1		6-10 locations	1
Entire length	0		Entire length	0		Entire length	0		>10 locations	0

	PRESENT SERVICEABILITY RATING (PSR) FOR FLEXIBLE PAVEMENT									
	RATING FACTORS									
C. Disintegration										
9. Bleeding/Gazing			**10. Stripping/ Ravelling**			**11. Patch**			**12. Pothole/ Disruption**	
Extent	**Points**		**Extent**	**Points**		**Extent**	**Points**		**Extent**	**Points**
None/0-5yrs	5		None/0-5yrs	5		None/0-5yrs	5		None/0-5yrs	5
None/>5yrs	4		None/>5yrs	4		None/>5yrs	4		None/>5yrs	4
1 location	3		1 location	3		1 location	3		1 location	3
2-5 locations	2		2-5 locations	2		2-5 locations	2		2-5 locations	2
6-10 locations	1		6-10 locations	1		6-10 locations	1		6-10 locations	1
>10 locations	0		>10 locations	0		>10 locations	0		>10 potholes	0
KEY: yrs. = Years Surfacing										

APPENDIX D: EFFECTS CLIMATIC VARIATIONS ON TRANSPORTATION INFRASTRUCTURE FACILITIES

Table A: Hazards related to increased precipitation

Facility	**Consequence - Possible Problems and Damage**
Unpaved roads	▪ Flooding (excessive surface water) ▪ Softening of surfacing material ▪ More frequent impassability on poor materials ▪ Increased erosion of road surface ▪ Loss of shape of road ▪ Blockage (siltation) of drains
Paved roads	▪ Loss of strength of layer materials, especially in the upper base and subbase layers ▪ Damage to thin surfacing ▪ Damage to pavement edges ▪ Blockage of drains and culverts ▪ Erosion of unpaved shoulders
Earthworks	▪ Increased slope instability ▪ Saturation and weakening of embankment soils ▪ Erosion of soil surfaces and drains ▪ Undercutting of roads by embankment erosion ▪ Excessive (luxuriant) vegetation growth ▪ Siltation and blocking of drains
Subgrade soils	▪ Expansion and cracking of volumetrically unstable materials ▪ Collapse and settlement of collapsible soils ▪ Softening of pavement support materials ▪ More movement and deposition of saline materials ▪ Deformation of rigid structures ▪ Erosion in road reserve
Drainage (water from within road reserve)	▪ Accumulation of water adjacent to road ▪ Erosion of road surface, shoulders and side and mitre drains ▪ Softening of materials beneath road ▪ Weakening of unpaved shoulders ▪ More outer wheel track failures due to increased subgrade moisture contents
Drainage (water from outside road reserve)	▪ Erosion of embankments and abutments of culverts and bridges ▪ Silting/sedimentation of culverts and bridges ▪ Scour of bridge foundations ▪ Overtopping of bridges and damage or destruction ▪ Damage to bridge structures by debris in flood-waters

Facility	Consequence - Possible Problems and Damage
Construction	▪ Excessive moisture in materials – construction delays ▪ Reduced working periods and increased delays ▪ Water damage to partially completed works ▪ Need for more coffer dams or flood-control measures during drainage and bridge construction
Maintenance	▪ Additional maintenance costs incurred ▪ More frequent bush clearing ▪ Additional repairs required to drains ▪ Need to retain good shape of unpaved road surfaces – more frequent maintenance ▪ Increased and improved unpaved shoulder maintenance ▪ Increased pothole patching and crack sealing of paved roads

Table B: Hazards related to decreased precipitation (but more extreme events)

Facility	Consequence - Possible Problems and Damage
Unpaved roads	▪ Increased wear and loss of gravel from drier surface ▪ Increased dust emissions over longer periods ▪ More rapid generation of loose material and roughness (corrugations) ▪ Increased re-gravelling frequency due to deterioration of gravel quality caused by loss of cohesive fines
Paved roads	▪ Damage to thin surfacing and asphalt (binder ageing) ▪ More rapid binder deterioration (binder ageing) ▪ Reduced equilibrium moisture contents – stronger pavements
Earthworks	▪ Increased drying out and cracking of soils ▪ Rapid ingress of moisture into tension cracks in slopes (slope failures from shrinkage and tension cracks) ▪ Increased erosion from more intense storms ▪ Damage to vegetation by more wild-fires ▪ More difficult to establish erosion protection through bio- engineering
Subgrade soils	▪ Larger moisture fluctuations in clayey soils ▪ Increased drying out of materials ▪ Shrinkage and cracking (larger volumetric movements) ▪ More precipitation of salts in saline environments
Drainage (water from within road reserve)	▪ Drying out of drains – more susceptible to erosion when rain does come ▪ Higher risk of burning of roadside vegetation and loss of root stabilization

Facility	Consequence - Possible Problems and Damage
	▪ Less vegetation to bind soil
Drainage (water from outside road reserve)	▪ More erosion ▪ More silting and sedimentation ▪ Overtopping of bridges and more frequent road closures ▪ More severe flooding ▪ Damage to bridges and culverts from debris in flood-waters
Construction	▪ Insufficient and more costly water for construction ▪ Quicker loss of compaction water due to evaporation ▪ Alternative construction methods and equipment required
Maintenance	▪ More unpaved road surface and shoulder maintenance ▪ More maintenance to drain damage ▪ Increased surface erosion repairs ▪ Better vegetation control to minimize wild-fire risks

Table C: Hazards related to increased temperatures

Facility	Consequence - Possible Problems and Damage
Unpaved roads	▪ More rapid drying out of road ▪ Increased cracking of clayey materials ▪ Increased development of roughness (corrugation) ▪ Quicker generation of dust and loose material
Paved roads	▪ More rapid ageing of bituminous binders ▪ Softening of bitumen in asphalt and more rapid deformation when hot ▪ Expansion and buckling of concrete roads
Earthworks	▪ More rapid drying out and cracking ▪ Loss of vegetation (or changes of species) on side slopes due to insufficient water ▪ More wildfires causing loss of root binding ▪ Increased erosion due to loss of vegetation
Subgrade soils	▪ Minimal effects ▪ Some shrinkage of clayey soils ▪ More movement of salts in saline materials caused by increased evaporation
Drainage (water from within road reserve)	▪ More rapid drying out, cracking and erosion ▪ Loss of vegetation (or change of species) on side slopes ▪ More wildfires causing loss of root binding
Drainage (water from outside road reserve)	▪ Greater expansion/contraction of bridge elements ▪ Larger temperature gradients in thick concrete members

Facility	Consequence - Possible Problems and Damage
	▪ More erosion and siltation due to drier ground conditions
Construction	▪ Reduced window of safe working and productivity of outdoor workforces ▪ Quicker reactions when cement stabilizing ▪ Quicker drying of concrete ▪ Greater water requirements for curing concrete and stabilized layers
Maintenance	▪ Ensuring vegetation is kept cut to minimize wild-fires ▪ Regular maintenance of bridge movement components (bearings and construction joints)

Table D: Hazards related to decreased temperatures

Facility	Consequence - Possible Problems and Damage
Unpaved roads	▪ No effects except at extreme altitudes – freezing of water in road ▪ surface leading to loss of strength (expansion and during thaw)
Paved roads	▪ Reduced windows for construction of bituminous surfacing ▪ Less rapid ageing of bituminous binders ▪ More brittle fracture of bitumen when very cold
Earthworks	▪ Possible freezing of soil surfaces at high altitudes
Subgrade soils	▪ Minimal effect
Drainage (water from within road reserve)	▪ Minimal effect
Drainage (water from outside road reserve)	▪ Minimal effect ▪ Steeper temperature gradients in large concrete members
Construction	▪ Reduced construction windows for certain operations (paving, ▪ stabilization)
Maintenance	▪ Increased maintenance of bituminous surfacing (crack sealing and pothole repair) ▪ Road closures after thawing of frozen materials

Table E: Hazards related to increased wind speeds

Facility	Consequence - Possible Problems and Damage
Unpaved roads	▪ More rapid drying out ▪ Increased deterioration rates due to dust and fines loss ▪ Increased accumulation of sand on roads
Paved roads	▪ Increased accumulation of sand on pavements ▪ Possible damage to bituminous surfacing caused by wild-fires
Earthworks	▪ Loss of vegetation due to burning ▪ Higher erosion rates on side slopes
Subgrade soils	▪ No major effects ▪ Increased erosion due to loss of vegetation after fires
Drainage (water from within road reserve)	▪ Higher risk of drain blockage by windblown material, including trash ▪ Loss of vegetation due to burning ▪ More erosion of drains
Drainage (water from outside road reserve)	▪ Greater wind-loads on bridges ▪ Loss of vegetation due to burning ▪ More erosion of drains ▪ More debris in flood waters due to fire damage ▪ Fire damage to bridges (wooden mainly but also concrete) ▪ More damage to erosion protection (waves)
Construction	▪ More dust ▪ Quicker evaporation of construction water
Maintenance	▪ Increased unpaved road maintenance to minimize corrugations resulting from fines (dust) loss ▪ Regular clearing of river debris and catchment vegetation ▪ More sand removal in arid and coastal areas ▪ Improved control of vegetation to minimize fire risk ▪ Increased maintenance of road furniture and signs, particularly those with wooden supports

Table F: Hazards related to sea-level rise and storm-surges

Facility	Consequence - Possible Problems and Damage
Unpaved roads	▪ Flooding and storm damage ▪ Increased subgrade moisture contents ▪ Increased erosion and siltation ▪ Loss of passability
Paved roads	▪ Damage to road surfacing by salts and water hammering ▪ Deposition of debris ▪ Increased subgrade moisture contents and reduced support

Facility	Consequence - Possible Problems and Damage
	▪ Loss of passability ▪ Increased salinity of soil water
Earthworks	▪ Increased soil moisture contents with sea-level rise ▪ Fluctuating moisture levels with storm surges ▪ Reduced soil strengths
Subgrade soils	▪ Increased moisture contents
Drainage (water from within road reserve)	▪ Accumulation of water adjacent to road ▪ Erosion ▪ Softening of materials ▪ Accumulation of debris in drains
Drainage (water from outside road reserve)	▪ Scour of foundations ▪ Deposition of debris ▪ Increased salt damage to concrete and steel structures
Construction	▪ Wetter conditions – reduced working windows ▪ More saline waters
Maintenance	▪ Increased maintenance in coastal and low-lying areas ▪ Increased repairs of damage caused by high storm events (waves)

Table G: Hazards related to changes in ground-water level

Facility	Consequence - Possible Problems and Damage
Unpaved roads	▪ Wetter or drier subgrades ▪ Changes in the extent and wetness of marshlands
Paved roads	▪ Wetter or drier subgrades ▪ More saline conditions affecting pavement structures
Earthworks	▪ Slope instability (localized)
Subgrade soils	▪ Larger seasonal volumetric movements in soils possible
Drainage (water from within road reserve)	▪ Localized seepage and springs
Drainage (water from outside road reserve)	▪ Changes in run-off coefficients in catchment areas
Construction	▪ Areas with difficult (water-logged) working conditions may ▪ increase
Maintenance	▪ No marked changes ▪ Localized high moisture content areas ▪ More sub-soil drainage structures required

APPENDIX E: CLIMATE RESILIENCE ASSESSMENT FORM

Road Name:																		
Road Length:																		
Date:																		
Assesor's Name:																		
Weather:	Sunny		Partly Cloudy		Cloudy		Raining		Hot									
Topography:	Flat (F)		Rolling (R)		Hilly (H)		Mountainous (M)											
Landcover and use:	Agriculture (A)		Forest (F)		Natural Landscape		Peri-urban or Urban (PU)			Degraded (D)			Other (O)					
Common Vehicle Types:																		
Chainage:																		
Grade:																		
Erodibility																		
Subgrade																		
Road Surface - Unpaved																		
Side drains - Unlined																		
Embankment Slopes																		
Cut Slopes																		
Subgrade Problems																		
Material Type																		
Moisture																		
Drainage (in reserve)																		
Road shape																		
Shoulders																		
Side slopes																		
Side drains																		
Mitre drains																		
Drainage from outside the road reserve (Streams)																		
Structure																		
Embankments																		
Erosion																		
Protection Works																		
Slope Stability																		
Cut stability																		
Fill stability																		
Construction																		
Overall finish																		
Erosion Protection works																		
Maintenance																		
Quantity																		
Quality																		
COMMENTS:																		

APPENDIX F: RESEARCH SAMPLE

Sample Phase 2 Batch 1

Region	Road No.	Section Name	Length	Contract Amount (Kshs)
Gravel Roads				
Kiambu	E505/E505B - 2	Gatukuyu - Chania	6.0	18,043,146.55
	E421	Mwimuto - Gikuni	7.8	28,177,099.50
	RAR 19-1	Gituha - Rwacumari	7.0	23,054,163.00
	URA 7/URP13	Kangoya – Ndumberi / Ndumberi Pri – CPK Hospital	6.1	16,558,476.00
	UNCL	Gatundu – Githaruru – Mararo – Mukinyi	5.0	13,733,830.00
Murang'a	C66	Thika – C67 Kirwara road	8.4	25,044,231.30
	E1535	Junction A2 (Juja) – Junction A3 (Munyu) road	8.2	26,866,667.30
Low Volume Sealed (LVS) Roads				
Murang'a	D419 (I)	Maragwa Town – Gakoigo Junction Road	2.1	53,618,230.00
	D419 (II)	Gakoigo Junction – Nginda Sec. School	3.6	62,179,079.20
	D421	Gakoigo Junction – Maragwa River Road	3.3	70,267,509.64
			Total Value of sampled Roads (Kshs)	**337,542,432.49**
			Batch 1 Value of Investment (Kshs)	**444,656,602.44**
			Sample Percentage	**75.91%**

Sample Phase 2 Batch 2

Region	Road No.	Section Name	Length	Contract Amount (Kshs)
Gravel Roads				
Kiambu	E505/E505 B	Gatukuyu - Chania	7.5	28,132,025.00
	D395 - 2	Gatukuyu – Mataara	7.0	29,195,271.60
	D395-4	Gatukuyu – Mataara	6.0	21,676,180.00
	E431/E431 A – 1	Rioki – Ikinu – Gitiha	7.5	25,074,119.40

Region	Road No.	Section Name	Length	Contract Amount (Kshs)
	E431/E431 A – 2	Rioki – Ikinu – Gitiha	7.0	31,788,598.60
	E431/E431 A – 2	Rioki – Ikinu – Gitiha	6.0	28,222,887.00
	E422 – 1	Kabete – Kikuyu	6.8	28,661,499.90
	E422 – 2	Kabete – Kikuyu	7.0	31,413,302.80
	E422 – 3	Kabete – Kikuyu	7.0	23,497,354.65
	D402 – 1	Ruiru River – Kagwe Kimende	8.0	31,617,905.00
	D402 – 2	Ruiru River – Kagwe – Kimende	8.0	38,609,725.00
	D402 – 3	Ruiru River – Kagwe – Kimende	7.6	34,126,235.00
Murang'a	E510(I)	Ndunyu Chege – Thika River	6.4	26,655,336.15
	E510(II)	Ndunyu Chege – Thika River	5.5	26,932,955.00
Low Volume Sealed (LVS) Roads				
Kiambu	E443/1	Gichiengo – Kijabe Hospital Road	3.25	78,416,287.00
	E443/2	Gichiengo – Kijabe Hospital Road	3.25	87,163,498.24
	E1531	Kang'oo - Kamwangi Road	5.6	163,925,034.50
Murang'a	D415(I)	Muruka - Kandara Town	3.75	80,473,261.55
	D415(II)	Muruka - Kandara Town	3.75	77,193,603.45
			Total Value of sampled Roads (Kshs)	**892,775,079.84**
			Batch 2 Value of Investment (Kshs)	**1,299,694,414.00**
			Sample Percentage	**68.69%**

Sample Phase 2 Batch 3

Region	Road No.	Section Name	Length	Contract Amount (Kshs)
Low Volume Sealed (LVS) Roads				
Kiambu	D378	Wangige- Nyathuna	6.4	167,748,041.50
	D378	Nyathuna - Ngecha - Rironi	5.4	140,524,254.00
	D402	Kimende- Kagwe Ruiru River/1	6.0	147,155,598.00
	D402	Kimende- Kagwe- Ruiru-Githunguri/2	6.6	148,978,397.80

Region	Road No.	Section Name	Length	**Contract Amount** (Kshs)
	D402	Kimende- Kagwe- Ruiru- Githunguri/3	2.4	68,483,444.30
	E1520	Kanunga - Banana	3.0	78,254,673.50
	D378	Kirangari - Gikuni - Nyathuna Hosp - Jnct	6.0	141,607,486.00
	D379	Wamwangi- Ruburi	7.1	233,400,942.57
Total Value of sampled Roads (Kshs)				**1,126,152,837.67**
Batch 3 Value of Investment (Kshs)				**1,126,152,837.67**
Sample Percentage				**100%**

APPENDIX G: DEFLECTION TESTS

A. Deflection tests on Maragwa Town – Gakoigo Junction road - D419 (I) (Norken et al, 2021).

Chainage	Location of Test	E-Base	E-Subbase	E-Subgrade	Maximum. Deflection
		MPa	MPa	MPa	µm
1+000	OWL	1048	181	121	813
0+050	OWR	1569	265	86	945
0+150	OWR	336	37	186	777
0+250	OWR	993	176	132	868
0+350	OWR	409	98	151	738
0+440	OWR	188	147	82	827
0+470	OWR	457	54	170	646
0+500	OWR	454	82	147	636
0+530	OWR	220	169	89	817
0+560	OWR	1073	186	131	786
0+650	OWR	545	103	179	893
0+750	OWR	263	32	185	806
0+851	OWR	987	175	126	745
0+950	OWR	349	71	119	918
0+050	IWL	444	98	149	775
0+150	IWL	409	93	143	810
0+251	IWL	183	141	110	781
0+350	IWL	1181	214	132	757
0+441	IWL	979	171	99	1,006
0+470	IWL	406	89	145	838
0+500	IWL	466	92	149	890
0+530	IWL	383	96	134	860
0+560	IWL	297	30	154	858
0+650	IWL	872	155	123	945
0+751	IWL	1307	219	100	912
0+850	IWL	1195	199	155	832
0+949	IWL	1,007	173	134	777
0+000	IWR	236	175	116	662
0+100	IWR	406	83	132	909

Chainage	Location of Test	E-Base	E-Subbase	E-Subgrade	Maximum. Deflection
		MPa	MPa	MPa	µm
0+200	IWR	464	84	209	887
0+300	IWR	379	78	132	734
0+400	IWR	1,024	186	102	919
0+425	IWR	279	73	104	1,073
0+455	IWR	272	61	99	962
0+484	IWR	1019	174	95	968
0+515	IWR	357	55	114	826
0+544	IWR	241	172	102	700
0+575	IWR	276	191	110	673
0+600	IWR	1,177	208	123	575
0+700	IWR	462	83	222	855
0+800	IWR	401	101	147	824
0+900	IWR	388	94	142	751
1+000	IWR	1014	176	111	744
	Average	**625**	**127**	**133**	**824**

** Outer Wheel Path Left Hand Side (OWL)*
** Wheel Path Right Hand Side (OWR)*
**Inner Wheel Path Left Hand Side (IWL)*
**Inner Wheel Path Right Hand Side (IWR)*

B. Deflection tests on Gakoigo Junction – Maragwa River road - D421 (Norken et al, 2021).

Chainage	Location of Test	E-Base	E-Subbase	E-Subgrade	Max. Deflection
		MPa	MPa	MPa	µm
0+000	OWL	412	84	141	878
0+100	OWL	1,075	195	117	833
0+200	OWL	1,031	177	152	729
0+300	OWL	1,244	208	120	870
0+401	OWL	338	84	125	829
0+425	OWL	435	89	149	697
0+455	OWL	452	90	149	775
0+485	OWL	525	37	199	640
0+515	OWL	1,337	236	124	789
0+545	OWL	1,059	180	140	750

Chainage	Location of Test	E-Base	E-Subbase	E-Subgrade	Max. Deflection
		MPa	MPa	MPa	µm
0+575	OWL	1,978	307	69	1,038
0+600	OWL	2,007	307	76	1,016
0+700	OWL	1,094	194	96	929
0+800	OWL	1,086	186	129	809
0+900	OWL	993	171	121	897
1+000	OWL	1,336	224	105	869
0+050	OWR	261	54	78	1,080
0+150	OWR	309	65	109	871
0+251	OWR	1,023	177	98	941
0+350	OWR	1,518	266	86	788
0+440	OWR	374	81	130	834
0+470	OWR	521	101	173	709
0+500	OWR	1,098	191	116	799
0+530	OWR	273	187	111	598
0+560	OWR	1,218	204	137	832
0+650	OWR	1,179	206	125	922
0+750	OWR	1,127	192	121	747
0+850	OWR	1,243	213	143	819
0+950	OWR	963	175	130	750
0+050	IWL	1,084	187	123	781
0+150	IWL	1,220	205	133	846
0+250	IWL	925	165	135	884
0+350	IWL	336	54	102	860
0+440	IWL	414	84	140	755
0+470	IWL	1,660	269	142	805
0+500	IWL	614	124	193	702
0+530	IWL	1,051	191	161	691
0+561	IWL	358	65	114	806
0+650	IWL	1,124	195	97	894
0+750	IWL	987	178	143	791
0+850	IWL	1,020	181	144	809
0+951	IWL	430	96	148	800

Chainage	Location of Test	E-Base	E-Subbase	E-Subgrade	Max. Deflection
		MPa	MPa	MPa	µm
0+000	IWR	193	148	90	780
0+100	IWR	1,170	198	189	766
0+200	IWR	382	85	132	809
0+300	IWR	1,157	197	115	792
0+400	IWR	471	87	156	776
0+425	IWR	342	74	121	835
0+455	IWR	449	92	148	827
0+485	IWR	608	108	189	717
0+515	IWR	1,608	274	89	885
0+545	IWR	363	36	154	757
0+575	IWR	1,234	206	108	912
0+600	IWR	408	28	194	776
0+700	IWR	1,107	196	111	850
0+800	IWR	371	77	128	784
0+900	IWR	1,062	189	107	865
1+000	IWR	1,169	196	148	843
Average		**876**	**156**	**130**	**818**

***** *Outer Wheel Path Left Hand Side (OWL)*
** Wheel Path Right Hand Side (OWR)*
**Inner Wheel Path Left Hand Side (IWL)*
**Inner Wheel Path Right Hand Side (IWR)*

C. Deflection tests on Muruka - Kandara Town - D415 (I) (Norken et al, 2021).

Chainage	Location of Test	E-Base	E-Subbase	E-Subgrade	Max. Deflection
		MPa	MPa	MPa	µm
0+000	OWL	176	47	111	958
0+050	OWL	362	102	160	611
0+100	OWL	234	51	152	793
0+151	OWL	273	78	141	734
0+200	OWL	422	56	272	521
0+250	OWL	377	50	241	573
0+300	OWL	386	79	157	603
0+350	OWL	279	33	229	720
0+400	OWL	306	73	130	692

Chainage	Location of Test	E-Base	E-Subbase	E-Subgrade	Max. Deflection
		MPa	MPa	MPa	µm
0+425	OWL	1867	291	140	650
0+440	OWL	1035	290	109	688
0+455	OWL	380	96	160	596
0+471	OWL	373	65	171	596
0+485	OWL	386	83	168	585
0+500	OWL	1832	289	145	676
0+515	OWL	323	72	155	655
0+530	OWL	1146	271	106	733
0+545	OWL	1175	285	118	670
0+561	OWL	1134	280	114	734
0+574	OWL	379	88	136	613
0+600	OWL	261	61	115	778
0+650	OWL	1188	289	111	707
0+699	OWL	388	57	165	610
0+751	OWL	412	89	139	596
0+799	OWL	300	200	142	474
0+851	OWL	1364	285	127	772
0+900	OWL	289	54	179	695
0+950	OWL	310	87	137	660
1+000	OWL	267	44	169	754
0+000	IWL	266	40	195	720
0+100	IWL	298	61	214	655
0+200	IWL	1877	322	150	640
0+300	IWL	393	49	215	571
0+400	IWL	279	53	171	717
0+425	IWL	1129	308	110	701
0+455	IWL	1498	304	134	627
0+485	IWL	384	45	214	588
0+515	IWL	76	50	201	660
0+545	IWL	1358	264	118	769
0+575	IWL	263	64	128	759
0+600	IWL	309	41	193	668

Chainage	Location of Test	E-Base	E-Subbase	E-Subgrade	Max. Deflection
		MPa	MPa	MPa	µm
0+701	IWL	1413	288	128	705
0+800	IWL	333	51	198	641
0+900	IWL	377	84	154	607
1+001	IWL	1139	282	110	745
0+050	IWR	192	158	84	784
0+150	IWR	219	58	113	848
0+240	IWR	633	85	202	427
0+350	IWR	331	83	135	660
0+440	IWR	401	60	175	585
0+470	IWR	292	93	170	626
0+500	IWR	289	58	152	698
0+530	IWR	363	111	162	567
0+560	IWR	357	74	143	649
0+649	IWR	1457	278	121	681
0+750	IWR	313	67	138	673
0+847	IWR	1737	278	144	863
0+950	IWR	278	63	151	703
Average		**619**	**131**	**154**	**672**

***** *Outer Wheel Path Left Hand Side (OWL)*
** Wheel Path Right Hand Side (OWR)*
**Inner Wheel Path Left Hand Side (IWL)*
**Inner Wheel Path Right Hand Side (IWR)*

APPENDIX H: PAVEMENT MODELLING REPORTS

A. Gichiengo - Kijabe Hospital Road - E443/1 (Author, 2024)

Pavement Analysis and Design Software (mePADS) Report

Heading: Gichiengo - Kijabe Hospital Road - E443/1
Description: Mechanistic - Empirical Design

Input data

General input
Climatic Region: Moderate
Road Category: D
Terminal Rut: 20 mm
Design Traffic Class: ES0,3

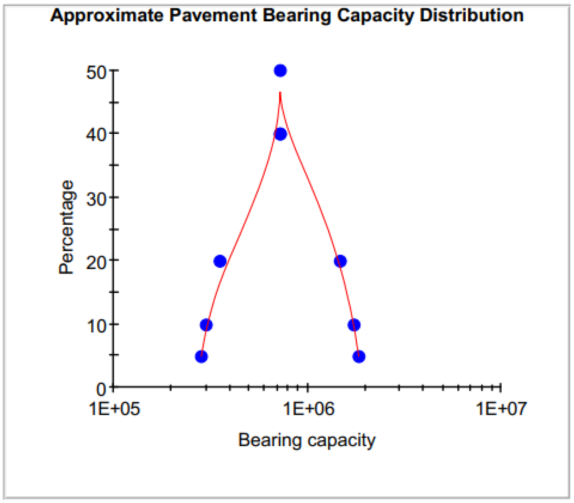
Pavement structure input
Number of Layers: 4
Number of Phases: 2

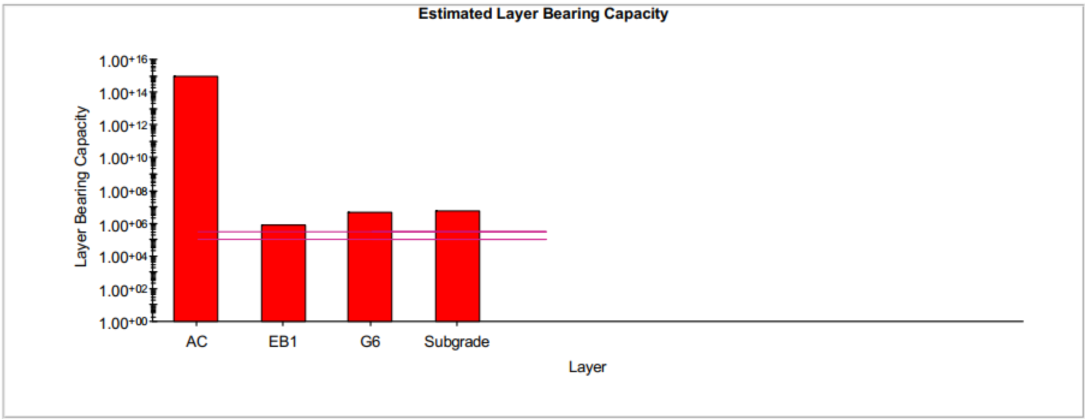
Phase 1				Phase 2			Phase 3		
Material	Thickness	E-Modulus	Poisson's	Material	E-Modulus	Poisson's	Material	E-Modulus	Poisson's
AC	20	3000	0.45	AC	3000	0.45	---	---	---
EB1	75	1000	0.35	EB1	1000	0.35	---	---	---
G6	150	150	0.35	G6	150	0.35	---	---	---
Subgrade	999	90	0.35	Subgrade	90	0.35	---	---	---

Output data

Layer Bearing Capacities

Layer	Bearing Capacity	Cemented Life	Crush Init	Adv. Crushing
AC	1e+015			
EB1	722859			
G6	4.72133e+006			
Subgrade	5.12935e+006			





B. Kang'oo - Kamwangi Road - E1531 (Author, 2024)

Pavement Analysis and Design Software (mePADS) Report

Heading: Kang'oo - Kamwangi Road - E1531
Description: Mechanistic - Empirical Design

Input data

General input
Climatic Region: Moderate
Road Category: D
Terminal Rut: 20 mm
Design Traffic Class: ES0,3

Pavement structure input
Number of Layers: 4
Number of Phases: 2

Phase 1				Phase 2			Phase 3		
Material	Thickness	E-Modulus	Poisson's	Material	E-Modulus	Poisson's	Material	E-Modulus	Poisson's
AC	20	3000	0.45	AC	3000	0.45	---	---	---
EB1	75	1000	0.35	EB1	1000	0.35	---	---	---
G6	150	150	0.35	G6	150	0.35	---	---	---
Subgrade	999	90	0.35	Subgrade	90	0.35	---	---	---

Output data

Layer Bearing Capacities

Layer	Bearing Capacity	Cemented Life	Crush Init	Adv. Crushing
AC	1e+015			
EB1	722859			
G6	4.72133e+006			
Subgrade	5.12935e+006