UNIVERSITY OF NAIROBI

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DEPARTMENT OF CIVIL & CONSTRUCTION ENGINEERING

PAVEMENT EVALUATION OF KAMPI YA MOTO - ELDAMA RAVINE - KAMWOSOR B77 ROAD

MSC THESIS

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BSC CIVIL ENG. (UNIVERSITY OF NAIROBI)

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING (TRANSPORTATION ENGINEERING) OF THE UNIVERSITY OF NAIROBI

NOVEMBER 2023

DECLARATION AND APPROVAL

This research is my original work. To the best of my knowledge, I also affirm that this has not been presented for a degree in any other university.

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DEDICATION

I dedicate this thesis to my Husband, Mr Paul K. Rop, and my children, Daville, Neydine and Jantje, for the tremendous support and prayers they have offered since the beginning of my master's studies.

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ABSTRACT

Assessing the performance of pavements is crucial to determining their serviceability and structural integrity. Pavement failure and deterioration begin shortly after the road is opened to traffic. Various factors, including traffic load, soil, environmental, economic, and stress distribution, contribute to this damage. Consequently, failure and deterioration of flexible pavements can be identified by alligator cracks, potholes, ruts, settlement, and localized depression. Evaluating the pavement's condition helps monitor and plan highway sections' maintenance. Kampi ya Moto-Eldama Ravine-Kamwosor road is a class B road constructed by the Kenya National Highways Authority (KeNHA) in 2008, with a length of approximately 79.5 Km. However, the pavement on this road showed severe distress that developed even before its design life of 15 years was attained. Despite frequent maintenance, the distress continued to reappear. The road had not undergone pavement evaluation since its construction. To minimize maintenance costs within the region, it was necessary to evaluate the road pavement to determine the type and severity level of distress and establish the contributing factors of structural and functional failure, thus allowing for suitable intervention measures. The study found that the main issues affecting the project road were potholes, depression, and edge damage. The severity level of these problems, as rated by the PCI, was fair. The road lacked proper drainage, which was identified as a significant factor contributing to pavement failure. The pavement structural survey revealed varying deflection on the homogeneous section, with higher deflections in some areas. To address these issues, it is recommended to install adequate drainage, repair existing damage as a short-term intervention, and provide a 50mm overlay to address all pavement defects as a long-term intervention.

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ABBREVIATIONS

AC	Asphalt Concrete
DCP	Dynamic Cone Penetrometer test
FWD	Falling Weight Deflectometer
GCS	Graded Crush Stones
GPR	Ground Penetrating Radar
KeNHA	Kenya National Highways Authority
NDT	Non-destructive Testing
PCC	Portland Cement Concrete
PCI	Pavement Condition Index

1 INTRODUCTION

1.1 Background

Kenya is a developing country with more than 10,000 km of paved roads. However, many of these roads suffer from pavement failures and deterioration, which require constant maintenance and rehabilitation. The process of flexible pavement failure and deterioration usually begins soon after the roads are opened to traffic. Initially, pavement failure and deterioration signs may not be noticeable, but they may become more pronounced over time. To prevent early pavement failure and deterioration, it is crucial to develop the best methods for planning, designing, constructing, and maintaining these roads. Also, this can be achieved by regularly inspecting and testing the flexible pavement, whether deteriorated/failed or not.

Pavement deterioration and failure affect the durability of the road. It commonly occurs due to single or joint action of the following-; traffic capacity and axle loads, meteorological conditions/weather changes or drainage systems/channels, and environmental agents. In addition, the presence of potholes, localized depressions, cracks, ruts, and settlements, among others, define flexible pavement failure and deterioration (Tamrakar, 2019). Therefore, pavement evaluation is always performed to determine the functional and structural conditions of the paved road to plan for maintenance works.

When evaluating the condition of a pavement, there are two main aspects to consider: its function and structure. The functional evaluation focuses on the quality of the ride, comfort for road users, and overall safety of the highway or main road section. The structural evaluation measures the pavement volume by assessing deflection, layer thickness, and material properties. Evaluating the existing pavement is essential since it enables an evaluator to determine pavement adequacy and decide on the appropriate maintenance or rehabilitation methods that consistently meet future demands. The processes for pavement evaluation are broadly classified into visual condition surveys and destructive and non-destructive methods. A visual condition survey involves a reconnaissance inspection done by a vehicle moving on the entire surface of the pavement. To ensure accuracy, a more detailed survey is carried out by qualified engineers and technicians who walk over the whole stretch of the road or a selected area. They measure, rate and record all distresses found on the carriageway, shoulders of the paved road, and drainage system/channels.

Destructive tests (DT) involve performing simple tests such as coring (by determining the thicknesses of the pavement layer by measuring core sizes) and performing dynamic modulus testing on recovered asphalt concrete (AC) cores or determining the elastic modulus. In contrast, non-destructive tests involve assessing the pavement strength by conducting deflection tests using (Falling Weight Deflectometer) FWD.

Kampi ya Moto-Eldama Ravine- Kamwasor B77 road falls under the jurisdiction of Kenya National Highways Authority (KeNHA) and was constructed in 2008. The project road is located in the South Rift region of the country Kenya and falls under three counties, namely Nakuru, Baringo, and Elgeyo Marakwet. The road length is approximately 79.5 kilometres. As mentioned above, the road has been under a regular maintenance program for quite some time to address the various distress and failures. Despite frequent maintenance measures, including pothole patching, surface dressing, drainage repairs and cleaning, the problems keep resurfacing. As a result, the road surface remains unsuitable for motorists to use. It was crucial to recommend an adequate method to restore the road to good riding conditions. However, the road's permanent restoration cannot be achieved without pavement evaluation exercises. Therefore, my study focused on evaluating the pavement of Kampi ya Moto – Eldama ravine – Kamwosor road to identify various types of pavement distress and determine their causes. Once the pavement distress types and causes were identified, my research proposed appropriate maintenance and rehabilitation strategies based on the field findings and laboratory testing.

1.2 The Study Area

Figure 1-1 shows the location map of the project area.

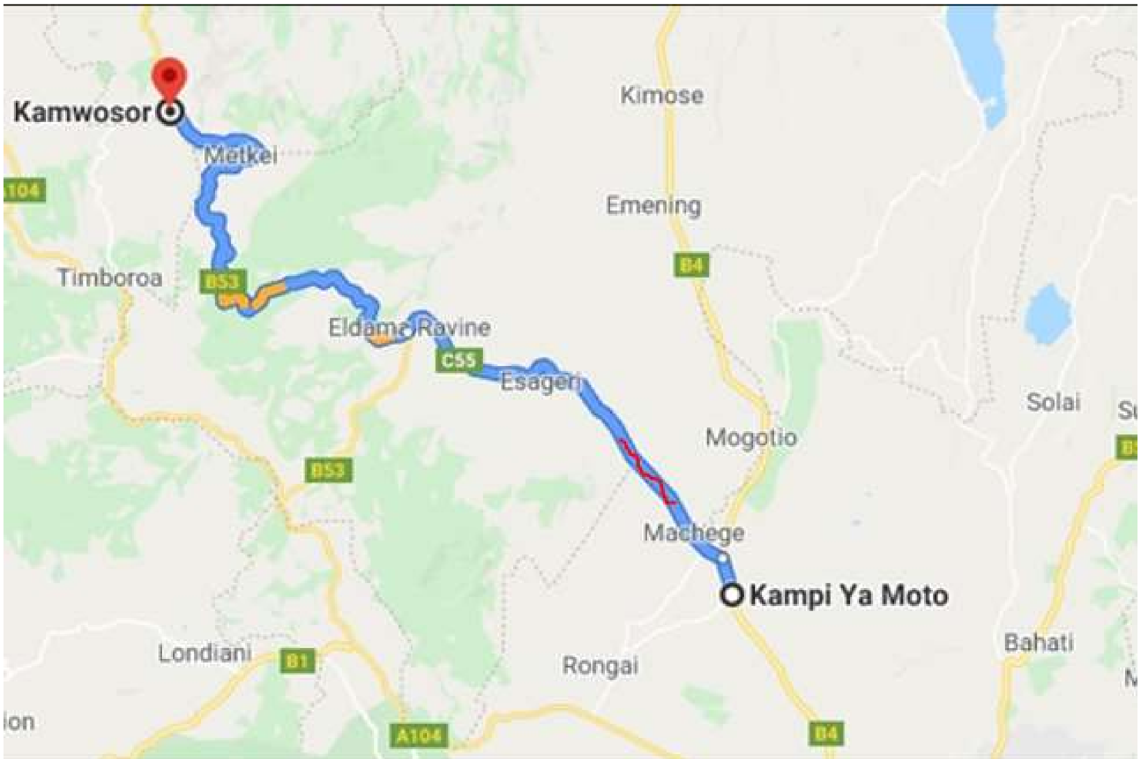

Figure 1-1: Location map of the study area

1.3 Problem Statement

Pavement structure, being complex, is supposed to be protected to serve its design period by providing the needful service to all road users. Flexible pavements deteriorate because of increased traffic loading, poor construction style, low-quality subgrade layers, lack of quality drainage structures, and environmental factors. Pavement evaluation is essential since it is one way of determining a specific road's structural and functional condition before scoping for any intervention measure in case of minor or major failures. Kampi ya Moto- Eldama Ravine-Kamwosor road is one of the roads within the South Rift region which has been in numerous maintenance programs; however, the distresses, such as potholes, depressions and cracks, have been recurring in a very short period even though the process of maintenance has taken place. The project road was built in two different climatic conditions. The first section, from Kampi ya Moto to Eldama Ravine, is dry with minimal rainfall. The second section, Eldama Ravine to Kamwosor, is wet and cold with high rainfall. Several failures have been explicitly observed between Eldama Ravine and Kamwosor, which were thought to be due to the environmental and drainage conditions of that section of the road.

Despite the frequent occurrences of distresses on the Kampi ya Moto - Eldama Ravine - Kamwosor road since 2008, no pavement evaluation has been conducted on this road or any other road in the region to determine the cause of pavement deterioration or failure. It was essential to evaluate this road pavement to identify the contributing factors of structural and functional flexible damage or failure and propose viable maintenance and rehabilitation interventions to address the identified problems.

1.4 Objectives

The general objective of this study was to establish the contributing factors of structural and functional failures on the existing pavement of Kampi ya Moto- Eldama Ravine – Kamwosor B77 Road, a stretch of seventy-nine point-five kilometres. To achieve the general objective, the following specific objectives were considered. They include:

i. To establish the pavement's type and level of severity and how it affects the pavement performance.
ii. To identify the cause of pavement failure.
iii. To establish the scope of maintenance work that will reinstate the road pavement.

1.5 Scope

The scope of the study involved pavement evaluation of Kampi ya Moto –Eldama Ravine – Kamwosor B77 Road, a section of approximately seventy-nine point-five kilometres.

The research identified the pavement's type, severity level, and the cause of these distresses and determined the practical solution and maintenance type.

2 LITERATURE REVIEW

2.1 Introduction

This chapter discusses the literature review of several researchers on pavement performance.

2.2 Theoretical review of pavement performance

(Sharad.S. Adlinge, 2013) stated that the functionality of pavement can be significantly compromised by surface distresses like potholes, cracks, depressions, and ruts. Transportation engineers must identify the root cause of pavement deterioration and failure in a specific area before initiating maintenance and reconstruction activities. Pavement failures and deterioration can be visually identified on the road's surface or associated with underlying pavement layers, requiring field or laboratory tests to be determined. Pavement failure and deterioration can be attributed to a single reason or group of causes. However, in many cases, other pavement distresses are ignored or assumed in maintenance and reconstruction activities, while only a few parameters are considered.

2.3 General review of pavement performance

2.3.1 Sources of pavement deterioration and material properties

(Woods, 2004) cited that pavement failure might be characterized by the following: construction material failure, functional failure, structural condition failure, or unification of the above three factors. He defined structural failure as the absence of the ability of pavement to support or carry loads. This means that the pavement has lost the strength to absorb and transfer the wheel loading throughout the entire structure of the road without causing further pavement damage. Functional failure is a term that may designate the deterioration of the pavement's actual function. These functional failures usually emerge from insufficient skid resistance, inadequate structural capacity, and insufficient serviceability or passenger discomfort. Finally, the pavement material is a crucial element when it comes to pavement stability and durability. Pavement durability cannot be compromised when pavement material properties have been correctly evaluated, and their strength analyzed accordingly. Pavement materials failures occur due to the ruin or loss of material on the road carriageway/pavement surface. Improper grading tests underneath pavement materials and unsuitable surfacing materials also lead to material failures.

(Harishchandra, 2004) investigated and noted that pavement distresses such as cracks (alligators, longitudinal or transverse cracking), depressions, hanging road edges, potholes, ruts, and corrugation are significant for road pavement defects. It also stressed that road traffic loading, age of the pavement, geometry of the road, climate, drainage systems, construction quality, construction materials, and maintenance strategies play a significant role in contributing to the road pavement's deterioration and failure process. This means that if the road is newly constructed or recently maintained, the road will commence with the failure process if the above distresses are not intently considered to be taken care of during the planning of construction and maintenance period.

(Caltrans, 2001) grouped flexible pavement failures and deterioration into two critical types: pavement surface texture failures, and pavement deformation failures. Surface texture failures are those which indicate that the surface of the pavement does not perform its function as designed. However, it may only be noticeable once visually surveyed since the road pavement may still be structurally sound. These failures include Raveling, bleeding, cracking, and stripping, which if dug deeply, are attributed to the pavement materials' properties. He also emphasized that deformation failures may be due to traffic or environmental influences. These failures and their causes include corrugations and shoving- caused due to weak base coarse, ungraded aggregates and extensively soft asphalt; depressions – caused by poor compaction action, settlement of foundation soil, and unevenness of subsequent layers thickness; potholes caused due to pavement fatigue and untreated alligators cracks; and rutting- caused due to improper mixing of material, absence of compaction of pavement layers, moisture infiltration, and inadequate layer thickness. All these types of deformation failures rely on severe underlying structural or material problems.

(T. M. Nyang'au, 2018) noted that the failure of flexible pavement has been widespread in Kenya, a leading worry for road users and the government of Kenya. They categorized bituminous pavement failures and deterioration in Kenya as one of the discomforting conditions for road users. As a result of this road discomfort, road users suffer an increase in vehicles operation costs, an increase in the price of transportation of goods and services, expansion of road safety hazards (an increase in road accidents leading to people losing their lives and properties), delaying of goods delivery to different destinations, delaying journeys to a particular destination as vehicles have to be driven slowly on the failed pavement sections, high maintenance cost for vehicles; increase in budgets and funds spending by government on pavement maintenance and reconstruction.

(Magdi, 2016) stated that traffic loading, unsuitable drainage, heaving subgrade soils, and using poorly graded materials in construction are the leading causes of pavement failures. This means that moderate traffic loading on a given road, provision of best-graded construction materials, and creation/construction of suitable defined drainage within the paved road will eventually minimize early pavement failures and deterioration.

(Abuye, 2019) pointed out that the main pavement failures and deformations that frequently affect paved roads are cracks, such as fatigue cracking and alligator cracking, potholes, depression, corrugations, and ruts, among others. They stressed that these failures and deteriorations affect riding quality and road safety, which sometimes endangers road users, especially when the vehicles pass these defects (potholes) at very high speed.

(Ahmed, 2008) also noted that potholes result from an expansion and break in the road surfacing. Formed due to severe alligator cracking. They are signs of pavement structural surface failure. Immediately rainwater enters pavement layers, the underneath layer (base, sub-base, or subgrade) gets soaked and becomes unstable to provide support to the pavement surfacing layer, and as a result of these layers being ruined, potholes area and depth grow at high speed, thus becoming unsafe to the road users. His elaboration means that the desirable mixed properties of asphalt concrete have lost stability, durability, flexibility, skidding resistance, impermeability and workability as a result, the deterioration hastens, and the pavement condition worsens.

(Sharad.S. Adlinge, 2013) stated that, for flexible pavement structures to be adequate for road users to use, they should be constructed with several layers of naturally graded granular material covered with either one or more well-prepared waterproof bituminous surface material layers. As the name suggests, flexible pavements will tend to change/ deform if a load is applied that defeats their capability for it to be able to support the imposed weight. For example, the heavy load that is felt on the tyre of the vehicle. The main quality objective when designing and constructing flexible pavement is being readily available and friendly to the construction cost. The specific objective is to avoid the excessive bending of any layers, be it on the surface or underneath layers.

The pavement fails when the layers are overstressed. From theories discussed previously, the distribution patterns of loads in flexible pavement layers change from one particular layer to another. This is because pavement layers have different strengths based on the material and the thickness of the layer produced or laid on the road. The pavement layers are arranged in order of flexibility from the least to the most flexible in flexible pavement structures. The topmost layer, the surface or bituminous layer, is the least flexible. On the other hand, the lowest layer underneath, categorized as the weakest material in the flexible pavement structure, is the most flexible. The vehicle is designed in such a manner that the load is experienced on the wheels. When the wheel load is applied to a smaller surface, and the process keeps on recurring, the level of stress experienced is too high compared to the load of the wheel applied to a more extensive area, thus experiencing lower stress levels. For a flexible pavement layer to achieve its aim in a particular area, the level of stress applied should be minimal since the low-strength material laid will automatically withstand the magnitude.

2.3.2 Pavement layers

(Sikdar, 1999) described that potholes occur because of the underlying problems in the pavement layers, which were attributed to inadequate pavement components. As defined by (Caltrans, 2001), Rutting is the permanent sink of the road surface caused by the wheels of a vehicle. These occur due to the deformation of either surfacing materials of the pavement (subbase layer and base layer), the underlying subgrade layer, or a combination of all these layers mentioned. To develop optimal maintenance plans, it is vital to know the original cause of this deformation. For instance, identify which layer of the pavement causes rutting. Once variation in the road surface's transverse profile is recognized, the level of rutting has reached its optimum stage. Due to the above, ruts increase the chance of the occurrence of potholes since there will be an increase in wetting of the upper pavement layers due to stagnant water in the depression. It also decreases road safety and road user comfort.

(Minkwan Kim, 2009) cited that the most used type of pavement for low or medium-volume roads is flexible pavement structures. Flexible pavement structures and rigid pavement structures are both crucial for constructing roads. Rigid pavement structures are often used in areas with heavy traffic flow and large vehicles because they are more durable and sturdier. On the other hand, flexible pavement structures are also essential as they are more suitable for high-volume roads. When heavy loads are applied repeatedly, it becomes crucial to analyze the behavior of the subgrade soil and unbound aggregate layers that comprise the foundation of the flexible pavement structure.

When a wheel load is applied to the pavement's surface, it spreads the stress from one layer to another through a grain-to-grain transfer. This process decreases the stress with depth as the load is distributed over a larger area. Flexible pavements generally have many layers, and their design uses a layered system to take advantage of the stress distribution characteristic. However, this also means flexible pavement structures are susceptible to rutting due to heavy traffic and severe environmental conditions. These structures are characterized by negligible flexural strength and are flexible in structural actions under the loads imposed on them.

(Izabela Skrzypczak, 2018) Stated that the main reasons for the flexible pavement failures are fatigue cracking, rutting, and thermal cracking. She expounded further that flexible pavement structures' fatigue cracking happens due to the horizontal tensile strain at the bottom of the asphaltic concrete (AC). The failure principle narrates the allowable number of load repetitions to tensile strain, and this relation can be determined in a laboratory fatigue test on asphaltic concrete specimens. Rutting occurs only in flexible pavement structures when the rut depth is well-defined, indicating permanent deformation along the wheel load. In the case of the well-constructed flexible pavement structure, the heavily loaded traffic will impose its weight on the structure; thus, the consistent application of wheel load makes rutting one of many major distresses in the flexible pavement.

She also stated that in the case where existing pavement structures experience surface and structural deterioration, it is due to the influence of climatic conditions or traffic load. The type of materials used in the pavement structure construction and the type of pavement will determine the condition of the pavement and, thus, damage. For instance, in the flexible pavement structure, the aforementioned structural damages are usually encountered, especially when deformation occurs in the subgrade of the flexible pavement structure; it tends to transfer the problem to the upper layers. It is said that when the surface layer experiences load, it transfers to the other layer through grain-to-grain contact. Note that the flexible pavement structure always carries low flexural strength. Therefore, flexible pavement has a lower construction cost than rigid pavement structures; the repair cost is also consistently low. Also, the flexible pavement has a shorter life span than the rigid pavement, which is durable with a high maintenance cost. In the design of the flexible pavement, some specifications need to be followed. It is insufficient for the road to be completed with only two subgrade layers and then surfacing. The layers are supposed to be laid according to the specifications provided, and the strength of the layers should be considered.

(Qiao Sun, 2022) cited that the depth of the pavement foundation, the structure of the foundation, the pavement humidity and temperature, the grade of the pavement asphalt, the flow of the traffic and the type of traffic and the depth of the foundation are some of the factors that influence the current condition of the pavement and the pavement performance in terms of its structural and functional performance. The type of loading and the nature of the pavement, in terms of moisture the pavement layers can hold, are primary factors that lead to deformation to a particular magnitude. These damages and deformation lead to pavement roughness; thus, the driver and passengers' comfort are compromised when using the road with such deformation. In order to minimize the situation, it is advised to conduct pavement evaluation/ assessment as often as possible when planning or before the commencement of the rehabilitation/construction or maintenance process.

2.3.3 Advantages of drainage in pavement performance

(Kaare, 2012) stressed that the deterioration and failures of flexible pavements are always achieved with the help of heavy traffic axle loads and climate conditions. In addition, they examined the effect of poor drainage systems on paved roads and noted that the strength of the road pavement decreases with an increase in moisture content.

(Magdi Z. , 2014), wanted to discover why pavement failure sometimes occurs in the first five years of pavement life due to insufficient drainage. It was revealed that there are at least four reasons which link to the premature deterioration and failures of pavements. These four factors include the inadequate design of drainage systems or channels, poor maintenance plans of paved roads, inferior quality materials for construction use, and poor construction methods. Therefore, concentrating on the above reasons and properly providing good intervention will generally minimize flexible pavement deterioration and failures.

(Tiza, 2016) emphasized that drainage is an imperative factor affecting road pavement performance. Premature distress and functional or Structural failures of the pavement can be caused if there is excessive water content in the pavement underneath layers (base, sub-base, and sub-grade soils). This means that pavement structure will only survive the process of early deterioration and failure if drainage systems are sufficiently installed and properly maintained. For instance, in the scenario where the roads are constructed in water-prone regions, it will be significant to introduce adequate drainage structures to avoid water penetrating the pavement structures.

(Zishan, 2016) categories highway drainage systems into surface drainage, sub-surface drainage, cross drainage works and disposal of acceptable quality of water. He defined surface drainage as a type of drainage that removes and diverts the surface water away from the pavement surface structure, pavement shoulder, slope of embankments and cuts, and adjoining section that is road reserve, whereby it is generally collected in existing side drains and then disposed away to the nearest stream, river or watercourse. Sometimes, the water that runs longitudinal, parallel to the road structure, will at some point need cross drainages such as box or pipe culverts (constructed in appropriate size) and stable bridges for the smooth disposal of the surface water from the side drains of the road.

In a scenario where the subgrade layer is soaked and saturated, it will tend to divert and withdraw excessive water from the layer in sub-surface drainage. He noted that the presence of seepage of groundwater fluctuating, rainwater percolating, and capillary water movement and movement of water through water vapour would be taken care of if a sub-drainage structure is introduced. In sub-surface drainage of paved roads, there is an attempt to minimize the variation of moisture in the subgrade soil. (Veeraragavan., 2010) He emphasized that subsurface drainage design is critical in flexible pavement roads, mainly where the road is constructed in areas with a high-water table. An ideal pavement system performance can be accomplished by averting water penetrating by means of producing a well-designed subsurface drainage system.

In low-lying areas, groundwater can be a vast troublesome for pavement. In these particular areas, water may force its way out by seeping upwards from a high ground water table through the existing cracks or flow laterally from the pavement edges, especially where the pavement shoulder has worn out. Therefore, it is appropriate to consider installing sub-surface drainage systems to the pavement structure, especially if constructed in a permanent or seasonal high-water table section, to avoid the early occurrence of pavement deterioration and failure. When the soaked section gets saturated with water, and combined with the likes of traffic loads, very cold temperatures, and the presence of void in the pavement, it can drive a permissive impact in both pavement system performance and material properties. In addition, it was also emphasized that the most significant source of excess water in the pavement structure was literally infiltration through the cracks, surface joints and many other defects that can be seen on the surface, which provide an easy water path. As the pavement road ages, it deteriorates very fast, and in case of cracks, they transform into bigger potholes. Sometimes, when the cracks are near the pavement structure's edge, they change into edge deterioration, thus leaving the pavement structure in a destructive shape. Therefore promoting even more free flow of water into the pavement structure. The indication above shows how the pavement condition can allow more water into the pavement structure, which further promotes rapid development of unwanted moisture that contributes to more damage and failures.

When the main road is constructed, at some point, it will tend to cross a stream or a river; therefore, in such a scenario, a drainage structure must be introduced to ensure the free movement of water and smooth traffic flow. These structures are termed cross drains. Side drains sometimes divert water away from the flexible pavement through cross drains. Usually, cross box/pipe culverts and bridges are generally constructed to take care of the water that tends to cross the paved road. They are generally built to a specific standard according to the magnitude of the flow. Higher discharge is always taken care of by the bridges. Finally, the vast rapid urban developments have led to diverting the course of water that may tend to flow in the particular path to either stagnate or destroy any constructed structure, for instance, pavement, to give its way to the nearest disposal points. Due to that, it was clear that urban stormwater management practices should be employed for the benefit of stormwater control and pollutant removal capabilities. He emphasized that the quality of stormwater should be checked to confirm if it meets its specified standards before it is disposed of. In the case of drainage in the urban area, before water is disposed of, urban stormwater management practice is supposed to be adopted to eliminate all high pollutants, especially litter, that will tend to block the drainage path before exposing them to the nearest disposal area.

The detrimental effects of water in the pavement system:

Water is destructive when it finds its way to the pavement structure. Thus, it will tend to compromise the performance of the pavement structure. When water links itself to the pavement structure, numerous failures and deterioration generally occur, leaving the pavement structures in terrible condition, affecting the road user comfort (both the passengers and the drivers). It also tends to appraise the cost of maintenance and vehicle operations upwards.

Below are some bad results that will likely occur on pavement structures when water is introduced to their layers. They include:

a) Stagnant water on flexible pavement damages it by reducing tensile strength.

b) The base and subbase layers lie beneath the surface of the pavement structure. These layers must be well-laid at varying thicknesses and appropriately compacted to eliminate any chances of voids within them. However, when saturated with water, the maximum moisture content of these layers increases, reducing their stiffness and strength to support the upper layer of the pavement structure. This leads to rapid pavement deterioration.

c) If the base of a pavement structure is treated with cement or lime, the modulus of the pavement may be reduced by up to 30%, depending on the plastic index (PI) percentage. This reduction in modulus could lead to an increase in erosion.

d) Fine-grained soils in saturated roadbeds can experience a reduction modulus of over 50-70 per cent.

2.4 Drainage systems

(Guyer, 2013) state that water in the pavement structure is detrimental to pavement performance. The presence of water causes deterioration of the surface or underlying materials. It also washes away pavement material depending on the water's magnitude. Pavement failure is a common issue in flexible pavements. The primary cause of such failure is the saturation of pavement layers with water, including the base, subbase, or subgrade. This weakens the pavement's performance, making it vulnerable to damage. In the case of rigid pavements, the concrete slab installation can prevent water from seeping through the surface. However, the water may still move due to the pressure caused by loadings. This movement of water may gradually wear away the subsurface material of the rigid pavement structure, leading to openings beneath the concrete surface. Lack of subsurface drainage in the pavement structure also leads to secondary damage, such as the early formation of cracking or swelling of the flexible pavement materials, thus reducing the life span of the pavement structure.

During construction or maintenance, it is essential to take care of two water sources that may lead to an early stage of pavement deterioration. These sources include water that infiltrates the pavement layer and underground water. If left unchecked, these sources can cause significant damage to the pavement. Regarding pavement drainage, infiltration is the leading cause of severe deterioration in most pavement structures. This occurs when water seeps into the pavement structure through cracks, potholes, or edge damage. In the case of underground water, it is crucial to allow underground water in the pavement structure to move freely. Failure to do so, water weakens the pavement layers and reduces their ability to support each other. As a result, the pavement becomes unstable and loses its strength.

Numerous cracks, potholes and shoulders hanging may have resulted from many factors, such as through the cracks or joints of the road carriageway, surface water may have been penetrating the pavement layers in the infiltration process, thus weakening the pavement structures and causing the development of potholes. In addition, the surface water may have also penetrated the pavement layers through the shoulder and adjacent areas, leading to eroding of pieces of layers at the edge of the pavement structure, thus leading to shoulder hanging. Finally, water may also have penetrated the flexible pavement through pores developed or by the movement of water from ditches and other surface channels near the road pavement, causing the development of a single or combination of the above-mentioned destresses.

The leading cause of pavement deterioration is poor drainage. It is essential to have a free-flow path under the pavement surface in areas with high water tables. Sub-surface drainage facilities are crucial in such areas since they help control infiltration by diverting or moving away water that enters the pavement surface through cracks or surface flow, especially during rainy seasons. Additionally, they enable underground water movement by reducing the amount of water that enters the pavement layers, including the base, subbase, top, and bottom subgrades, or by lowering the water table in areas prone to high water levels. It is necessary to perform both sub-surface drainage functions regularly. In some cases, the two may be combined into a single sub-surface drainage system to achieve optimal drainage performance. (Guyer, 2013) state that Darcy's empirical Law expresses water flow through the soil. The Law states that the velocity of the flow of water is directly proportional to the hydraulic gradient, as shown in equation (2.1) below

$v=ki$……………………………………………………………………………(2.1)

Whereby

v- is defined as the velocity flow of water

i- is defined as the hydraulic gradient

k-is defined as the coefficient of proportionality, known as the coefficient of permeability

Equation (2.1) above can be further expanded to accomplish the flow rate through an area of soil.

$Q=kiA_2$……………………………………………………………………………… (2.2)

Whereby

Q -is defined as the flow rate, and A is defined as the flow rate through an area of soil.

The velocity of the flow of water (v) and the degree of discharge through a porous media are directly proportional to the hydraulic gradient (i). The narrative above was stated in Darcy's Law. Therefore, the flow must be either laminar or nonturbulent to make the statement accurate and practical. Moreover, the research indicates that Darcy's law is more operative for various types of soils and hydraulic slopes. However, generous margins have been used to permit turbulent flow in emerging conditions for subsurface drainage. The requirements of these subsurface drainages will depend severely on the permeability of the soils used in the pavement structure. Due to the above, it is accurate to evaluate the result of various factors on the permeability of soils as far as pavement drainage is concerned. This will be highly focused on the materials prone to water saturation on the pavement structure (drainage layers), including the base and subbase material.

2.4.1 Factors influencing permeability

Turbulent flow depends severely on the permeability of the soil. There are quite factors that influence this permeability, and they include

i. Value of Permeability.

The permeability value depends principally on the features of the porous materials in the pavement structure. Nonetheless, the value of the permeability is also considered a role of the properties of the liquid. Therefore, based on the flow through porous media similar to the flow through a bundle of capillary tubes, an equation illustrating the effect of the soil and pore fluid/water properties on permeability was industrialized. This is shown in equation (2.3) below.

$$k = D_s^2 \frac{\gamma}{\mu(1-e)} \frac{e^3}{} C \quad (2.3)$$

ii. Significance of pore fluid and temperature.

Water is considered the primary pore fluid when designing subsurface drainage systems for flexible pavements. Hence, when the permeability is cited in this analysis, the assumption is that pore fluid is water. Equation (iii) above shows the relationship of the permeability effect of the water based on its unit weight viscosity; thus, it is concluded that the permeability is directly proportional to the unit weight of water and the viscosity. (Guyer, 2013). Essentially, the unit weight of water is expected to be constant. Nevertheless, the density of water will always tend to differ with temperature.

iii. Influence of grain size.

The above Equation (iii) recommends that permeability tends to vary with the square of the unit diameter. The statement above is based on the availability of voids on the drainage layers that are associated with the distribution of the grain size of the soil. To avoid the presence of a void in the drainage layers, the grain size of the soil should be significantly less. This will restrict the formation of a waterway, thus lowering the permeability effect. Lack of consistency in layer arrangement contributed to compromising the grain size of the pavement; thus, deterioration occurs.

iv. Impact of void ratio.

Further to grain size and soil structure, the void ratio or porosity of soils, though insignificant, often substantially affects permeability. It is proclaimed that the magnitude of saturation of the soil is a ratio of the volume of water to the volume of the void. This can be elaborated further by stating that the soil's void ratio can successfully dictate the quantity of fluid trapped/stuck inside the soil. It is certain that once the soil has become saturated/ soaked with water, it simply becomes denser; thus, it will not allow more water to penetrate because it has enough water retained there. Furthermore, the rate of permeability at this juncture will automatically be lower. The above shows that the volume of water in the soil highly depends on the void ratio, which is the essential element to consider when selecting a good pavement layer. In the case where water is restored as a tiny film following the soil particles, which are imprisoned by the small water vessel, then water trapped/ stuck in the soil cannot be forcefully eliminated from the soil. Therefore, effective penetrability must be recognized in order to ascertain the quantity of water that can be taken out from the soil. So, effective penetrability can be defined as the ratio of the volume of the voids that can be eliminated forcefully under severe flow to the total volume of soil. However, to avoid soil being saturated with water due to the availability of voids in the drainage layer, it is essential to introduce surface drainage. In pavement roads, a saturation of the pavement soils is not adequate when it comes to performance. Saturated soils are considered to be unfit. Thus, the strength of supporting abutting layers is usually lowered.

v. **Effect of structure and classification of pavement layers**.

Alluvial deposits are usually demonstrated in a manner that horizontal layers formed differ in grain size distribution and penetrability. Usually, these alluvial deposits are considered more permeable in the flat route than in the vertical route. Pavement layers are generally spread and mechanically compressed horizontally, resulting in an entirely different permeability effect in the steep path than in the horizontal route. Naturally, the relatively impermeable layer usually disrupts the vertical water drainage from the pavement. Usually, the base and subbase materials have higher permeability in the pavements than subgrade materials. Therefore, the best flow that can successfully be effective when withdrawing/ removing water from the pavement structure (especially underneath layers) without any interruption is considered to be horizontal flow.

Other factors that contribute to functional and structural pavement failures include

i. **Volume and rate of subsurface flow**

It is crucial to maintain the drainage structures properly. The pavement structure relies primarily on infiltration and groundwater as sources of water. Typically, the flow from infiltration is considered more significant than groundwater, as the latter directs water into the collector drainage systems from the subgrade. The infiltration water flow highly depends on surface conditions, rainfall duration, pavement layer properties, and the drained area. Therefore, it is recommended to pay close attention to these factors
in order to address drainage issues when designing the subsurface drainage system.

ii. Pavement surface condition.

The amount of water penetrating the pavement structure is highly influenced by the nature of the existing pavement surface. It assumed that all rainwater falling on the paved section is a runoff, thus considered in the design of surface drainage facilities. Suppose in the new well-designed and constructed pavements, the designer does not assume 100 per cent runoff. In that case, a bad conservative assumption for the design of surface drainage facilities is probably encountered. When designing subsurface drainage facilities, the designer should focus on the infiltration rate as it is attributed to the deterioration of the flexible pavement. Research has revealed that well over 50 per cent of the rainfall can flow through the pavement surface for badly deteriorated pavements.

iii. Effects of rainfall on the pavement.

The amount of water entering the flexible pavement will be directly proportional to the intensity and rainfall time. Therefore, the process should be considered on relatively low-intensity rains when designing the subsurface drainage facilities. This is because high-intensity rainfalls are estimated not significantly to increase the adverse effect of water on flexible pavement performance. Furthermore, excess rain runs off as surface drainage when the base and subbase are saturated. As a result, the saturated base and sub-base, at some point, get weaker and lose stability, leading to pavement deformation. In addition, the cracks in the pavement of the project roads contributed to the pavement sub-base and base being soaked with water as water penetrated the layers during rains by infiltration.

iv. **Period for drainage**.

After noticing water on the pavement layer, one might become anxious to know when it will drain out. The drainage systems in the pavement structure play a significant role in achieving this. To ensure that the water flows freely from the pavement structure to the nearest disposal destination, certain factors must be taken into consideration. These factors include the thickness of the pavement layers, the length of the drainage path, the gradient of the drainage path, and the penetrability of the pavement layers. Moreover, the pavement should be designed to facilitate speedy water drainage to prevent the pavement layer from soakage and saturation. This is because holding a large amount of water for an extended period can lead to the degradation of the pavement structure and reduce its lifespan.

v. Extent and slope of the drainage path.

Based on the discussion above, it is clear that the duration for adequate drainage is determined by achieving the appropriate gradient for the drainage path and attaining the desired length. These are the most critical aspects of the drainage system. Additionally, the size of the drainage system should be designed based on the flow's magnitude and regularly evaluated and monitored.

vi. Effect of vegetation on the drainage of the pavement structure

The presence of vegetation on the road edge or the drainage of the pavement structure will not only reduce the sight distance of the vehicle user but also promote the blockage of the road's drainage system. When the drainage system of the pavement structure is blocked, the flow of water is compromised; thus, the water forcefully tends to find its way over the carriageway of the flexible pavement. In case of the presence of pavement defect on the surface that will contribute to allowing water to penetrate the pavement layers, the expedition of the pavement deterioration occurs immediately.

vii. Effect of litter on the drainage of the pavement structure

Litter in the road reserve can be very inappropriate regarding pavement drainage. Furthermore, litter can be very unsafe as it can block side drains that usually enable the excessive water from the pavement surface during rains to flow freely to the nearest stream/ river. Sometimes, this litter, when stockpiled, vanishes the water path, thus making most of the drains undefined.

viii. Frequency of flow.

For the adjusted drainage channel parallel to the paved surface of the road to be considered sufficient, it must be constructed/ created to handle the maximum flow rate possible. Also, it must be frequently maintained to enable the free flow of water to the nearest disposal destination. As for the project road, the side drains and round culverts (access and cross) were not well-defined. As a result, water tends to cross over the road surface.

2.5 Type of pavement defects and their effects

(Neero. G.S, 2013) identified the types of pavement defects that affect the performance of the pavement structure. They include

a) Potholes

Potholes are severe pavement defects that pose a significant risk to road users. They occur when unattended cracks allow water to penetrate the pavement layer, leading to further deterioration. Potholes can cause extensive damage to vehicles, especially when drivers are unaware of their presence or travelling at high speeds. Additionally, they can compromise road safety by increasing the likelihood of accidents resulting in severe injuries or fatalities.

b) Patches

Patches are portions of the pavement surface that have been removed and replaced. They fix any pavement surface defects or cover an exposed trench. However, patched areas often end up incompatible with the surrounding pavement surface, leading to further damage and deterioration. Engineers view patches as a temporary solution to pavement repair and road safety. Still, they fail to realize that low-quality patches and inappropriate patching methods can lead to more damage and deterioration of the pavement surface before maintenance planning is finalized. Potholes are the main reason why engineers undertake patching processes. Although patches are considered temporary, they can last long if high-quality patches and a standard procedure are used. If the pavement surface deterioration comes from the underlying layers, then reconstruction is the most appropriate remedial practice, not patching.

c) Depression

The settlement of the underlying layers usually causes depression in the pavement. This may be due to inadequate compaction, particularly in the base, subbase, or surface layers. When a depression forms on the road, it can cause discomfort for road users and potentially lead to severe road deformation. Surface water may stagnate in the depression and lead to the formation of large potholes, which can cause severe accidents. If not addressed early on, this can result in road roughness.

d) Pavement cracking

Pavement cracking can cause a significant increase in water penetration through the road surface. Once the water has soaked through the pavement layers, it can cause damage to the layers underneath. If left unaddressed, continuous traffic loading on the weakened pavement layer can lead to the formation of potholes, which may result in severe accidents. Examples of these types of cracking include longitudinal, alligator, and transverse cracking.

e) Rutting

Over time, the excessive weight of heavy trucks or inappropriate base construction can cause a lined depression in a flexible pavement structure called rutting. The presence of ruts is hazardous as they can cause a vehicle to skid if filled with water, pulling the car towards the depression and potentially leading to a loss of control and severe accidents.

f) Roughness

Road roughness is a type of deformation that can affect the stability of a vehicle, as well as the drainage systems and channels of the road. It is measured in the International Roughness Index, or IRI (m/km). Road roughness is usually linked to other defects, such as rutting caused by permanent deformation within the pavement layers due to consistent wheel traffic. This can lead to a change in the pavement's vertical position, causing depressions. The International Roughness Index is typically obtained from a longitudinal road view.

Road roughness indicates that the road is deteriorating or has already deteriorated. When driving or riding on a rough road, especially in a motor vehicle, the user can experience discomfort. This is because roughness is often accompanied by other defects such as cracking, potholes, and environmental factors. The International Roughness Index measures how much these defects combine to cause discomfort for the road user.

g) Corrugations

Road corrugations are usually caused by insufficient compaction of the pavement layers, including the sub-base, base, and surface layers. These corrugations can make the road surface very rough, causing discomfort to road users. In some cases, vehicles travelling through such areas at high speeds may become unstable, leading to severe accidents.

h) Ravelling

Ravelling occurs due to loose debris on the flexible pavement structure, thus leading to road roughness that will eventually cause discomfort to the road user. Also, water collected in the ravelled locations may result in the vehicle Hydroplaning and loss of skid resistance.

i) Bleeding

Bleeding is a pavement defect that affects the skid-resistance element of a pavement design. This defect usually occurs in areas with high temperatures, especially during hot weather. When the bitumen's viscosity becomes lighter, the traffic tends to push the bitumen to the surface, causing bleeding.

j) Polishing

Pavement Polishing is when the protruding rough/angular particles of pavement aggregate become polished over time. When surface dressing a particular road, especially a high-trafficked highway, laying the aggregate is usually difficult (Tamrakar, 2019). The pavement will suffer polishing whenever the aggregates laid are subjected to excessive studded tire wear. The excessive and speedy traffic tends to remove the laid aggregate meant to lower surface friction, which is an essential component of the skid resistance of the flexible pavement, thus becoming unsafe.

k) Swell

A swell generally tends to raise the pavement surface upwards. The bulging of the pavement layers is usually caused by either frost heaving or by moisture. It always originates from the lowest layer of the pavement structure, which is the subgrade layer. Subgrades with a high plasticity index and too much clay soil can generally swell and heave. In order to repair such defects, especially when they are very extreme, the reconstruction process should be premeditated.

All these pavement defects mentioned above occur due to a single factor or combination of various factors discussed in this report.

2.6 Causes of failures in flexible pavement

(Sharad.S. Adlinge, 2013) state that Failure of the flexible pavement road transpires due to several factors, including water interference, stress from heavy vehicles loaded with goods, expansion and contraction from seasonal temperature changes, and exposure to heat from the sun. These factors were further broken into the following:

a. Use of substandard quality and inadequate materials for construction

The quality of materials used in the construction and maintenance of roads is crucial for their performance. Unfortunately, the use of low-quality materials such as substandard subgrade with low bearing strength or incorrect grading of base or subbase layers can reduce the road's lifespan. These low-quality materials can cause early failures and deterioration, especially in newly constructed or newly maintained paved roads. The absence of pavement failures and deterioration improves road users' safety comfort and prolongs the road pavement's life span. Also, when the pavement layers' thicknesses are inadequate, or the loads imposed on it have maximum loading that was not designed to hold, the excess stress developed due to surface forces can lead to pavement deformation or failures. Furthermore, if the subgrade material cannot provide stability, it may be due to improper compaction or material weakening caused by water infiltration. This can result in the transfer of pavement damage from the subgrade layer to the topmost layer, leading to more severe pavement reconstruction costs that cannot be avoided.

b. **Application of hefty traffic on the wrong class of road.**

Engaging heavy-loaded traffic on the pavement surface, especially on the wrong traffic class of the road, is another main factor that causes deformation/deterioration of the pavement surface. (Croney P, 1998) stated that pavement deterioration that arises from deformation is usually linked with cracking brought about by heavy vehicles. Failures such as cracking and depressions/ruts on pavement will automatically be increased due to heavy traffic loading. Thereafter, cracks or depressions will enable the surface water to penetrate the pavement surface or stagnate on the road surface. This contributes to the early development of potholes that expend the road deterioration to approximately higher levels.

c. Climatic changes

Rainfall and annual variations in temperature are some of the few climatic factors that significantly impact pavement failures and deterioration. The pavement layers' loss of strength and steadiness is always influenced by rainfall. Since most pavement structures around the country are designed based on a specific climate situation of a place or area, rain's effect on road pavements can sometimes be destructive and unfavourable. Also, rainfall is well recognized as one of the main factors contributing to soil erosion, raising the water table, especially on the roads constructed in swampy areas with no subs drainage systems, and infiltration especially in areas where paved roads are being developed without drainage structures or where the road have cracks which they have not been attended to on time. Long rains of low intensity are recognized to be more adverse compared to short rains. This is because, in the season of long rains, the moisture absorbed by the soil is superior during this condition than when there are short rains with high intensity.

d. Poor drainage

Drainage systems in pavement structures are always categorized as one of the main contributors to how long the pavement will last in a case recently constructed. Without the introduction of the drainage system, the life span of the pavement is usually wanting, thus, the design period is automatically reduced. Drainage structures within the paved roads must be well-designed, built/constructed, and well-maintained. When a road fails, the primary factor that is estimated to cause the failure is inadequate drainage systems. It is assumed that the absence of drainage systems in the pavement structure expedites the deterioration and failures of the pavement surface. Poorly designed and maintained drainage systems will sometimes channel water directly to the carriageway of the road or keep it at a standstill due to its incapability of free flow. Excess water standing on the road surface combined with traffic action led to pavement distress.

e. Poor workmanship and supervision during road construction and maintenance.

Effective supervision and quality workmanship are critical in ensuring that flexible pavements are durable and do not deteriorate quickly. This means that the design specifications must be consistently followed and met during the early stages of construction and maintenance. Failure to adhere to these specifications will result in premature failures and deterioration of the flexible pavement structures, which means that the design life of the road will not be achieved.

Engaging contractors who understand highway engineering quality work and promoting coordination between the supervisory and contractor's teams is essential. A policy on selecting eligible site agents should be documented in all road works, and regular, thorough training for the supervisory team should be considered and certified. By doing so, premature failures and deterioration of the flexible pavement will be minimized.

Regular site/field visits should also be promoted, especially in areas where maintenance and construction of paved roads have been done well. This will ensure that the supervisory team is well-equipped with the necessary skills and knowledge to promote the durability of the road.

f. Frequent maintenance of road

Routine maintenance should be carried out occasionally when the flexible pavement structure is new to ensure that the constructed pavement road meets its design life. For instance, a constructed road will need frequent checks to maintain its condition. It is considered that the cost of maintaining a road is usually significantly small compared to when the road has completely failed. However, many charges will be incurred for pavement reconstruction when it fails, with its attendant economic drain on the government. In Kenya, we have road agencies entitled to always provide safe, adequate and motorable roads throughout the years. Through these road agencies, the Kenya government regularly supports road infrastructure by providing them with enough monies to maintain all roads- paved and unpaved- within the country, frequently occurring each financial year. Also, new road maintenance programmes have been formulated within the country through road agencies. This maintenance programme includes the introduction of performance-based contracts (PBC)- hybrid performance-based contracts (HPBC) or pure performance-based contracts (PPBC), framework contracting contracts (FCC), and routine and periodic maintenance contracts. The programmes are categorized into long-term and short-term programs that care for paved and unpaved roads nationwide. This road maintenance programme enables the agencies to reduce the frequent occurrence of quick recurrence of these distresses that, when not attended to, lead to totally deforming the flexible pavement surface into terrible condition.

g. Inadequate geotechnical tests

A sound geotechnical investigation should be carried out before any construction work occurs. All the test results attained from the good geotechnical test on the soil samples obtained from several locations on the particular sites for flexible pavement construction should be trusted and used. In addition, all other relevant data needed from the site for flexible pavement construction should also be obtained and utilized. The outcome of a preliminary geotechnical examination of the project's lifespan cannot be over-emphasized.

h. Financial cost

A pavement cannot be completed if the cost of construction is not implemented. Flexible pavement roads constructed with no constraints in cost tend to have a high level of adequate performance and are considered very durable and attractive. In many cases, especially in some countries like Kenya where the prices of construction commodities tend to fluctuate from one period to another, the contractors who may have tendered the contract during a specific period when an item (for road construction) was less expensive when it comes to awarding of this particular contract the contractor tends to have difficulty in delivering the contract due to variation as mentioned above. The buying price of a specific commodity/item may have changed and become more expensive. For instance, the cost of bitumen in some regions of the world can be more accommodating than in other parts. Thus, those areas where the bitumen is cheap tend to perform excellent pavement road construction. Most contractors will want to see the profit that they will receive after completing the contract. Due to this, they will tend to produce a low standard of the product (low standard flexible pavement) that will sometimes lead to high repair costs. Also, regarding the reconstruction of the pavement layers, under-quoting of the different bill items leads to more substandard services that are usually identified at the end of the project. Financial costs in flexible pavement construction and maintenance are always more challenging factors that should be examined intently. As the engineers plan for the reconstruction or repair of a particular flexible pavement road or structure, they should keenly be more advanced in terms of how to compensate the client who is responsible for doing the work in case of price variations in order to produce an excellent flexible pavement structure that will cover its design period without the occurrence of any damages and failures.

2.7 Synthesis of literature review

2.7.1 Literature review summary

The above elaboration has shown that many variable factors cause pavement failure and deterioration, and if looked at keenly, a solution to these defects can be found.

Poor drainage systems/channels, lack of proper maintenance, and climate change are critical factors in flexible pavement failure and deterioration. For a specific pavement structure to survive and be able to achieve its maximum design period, the element of providing flexible survival techniques should be presented clearly, thus promoting its stability and durability. This will be achieved by providing suitable design and installation of adequate drainage systems in the pavement structure; thus, it will assist in minimizing the problem of pavement failures and damages. Rainwater that always stands or finds its way out to the drainage through the road carriageway in the process of infiltration due to improper drainage system installation will eventually flow freely to its final destination.

A well maintained and constructed flexible pavement structure is considered essential for both the social and economic development of communities. This means that it not only improves the livelihood of communities by reducing travelling times and reducing traffic delays, but it also ensures that the safety of the passengers is not compromised. However, a road with various pavement defects tends to increase vehicle operating costs compared to a well-maintained and constructed road free of defects. Therefore, propagating proper maintenance of these paved roads is always considered the best remedy for pavement failure and deterioration. Still, these maintenance operations are sometimes conducted differently, thus failing to meet the standards of maintaining a given road. For instance, engaging non-technical personnel to solve a problem of road deterioration and failures will apply a different way of taking care of the issue that may not have been documented or specified, thus promoting more early deterioration and failures of the pavement structure. Also, without proper supervision and coordination between the teams undertaking maintenance exercises, it will result in substandard outcomes during the contract's completion period. In order to achieve the above, it is important to understand how all the flexible pavement deformation and defects occur so as to recommend the most appropriate formula/way of planning and implementing the process of construction and maintenance to reduce any emerging risks of early deterioration. As discussed in this chapter, the government of Kenya has supported road infrastructure by formulating road agencies whose mandate is to provide adequate, safe roads for the public to use. One way of fulfilling these agencies' input is through the government's help, ensuring that all the roads are taken care of, be it temporary or permanent repairs.

An inventory road survey usually assists road engineers in familiarizing themselves with the previous and current condition of the specific road. The recorded condition, when integrated, enables them to come up with the correct intervention procedure that will assist them in scoping maintenance work of that particular road.

Therefore, once the problem of the existing pavement failure and deterioration is found through the process of pavement evaluation, a proper maintenance policy must also be put in place to develop an efficient maintenance process. As for climate change, engineers should refrain from assuming the methods and materials that are supposed to be used when undertaking construction works in a different part of the country. For instance, the material used for construction in the western and central parts of Kenya is sometimes not eligible in regions like the North-eastern and northern parts of the country. This is because areas in the central and west experience a lot of long rains with high intensity, and the water table within these areas is too high, unlike regions in the northern and north-eastern, which experience short showers with low intensity and the water table is too low.

As per the above discussion and citations, pavement defects in my project areas, such as concentrated potholes, depression, pavement cracking (longitudinal, transverse, and alligator cracking), settlements, ravelling, ruts, and corrugation, will be severely minimized if the factors affecting the pavements will be taken care of accordingly.

Therefore, pavement evaluation should be addressed even if done on a particular road or area. Thus, consistent assessment of the pavement performance should be conducted to help expand the knowledge of providing the best planning procedure for adequate maintenance and construction action.

2.7.2 Literature gap

A flexible pavement structure comprises multiple layers compacted to a specific designed thickness depending on the pavement type. This structure is placed on top of the natural or improved subgrade and is responsible for spreading, distributing, or transferring the vehicles' weight to the subgrade layer. To be considered excellent, a pavement structure should provide a comfortable riding surface, satisfactory skid resistance, and minimal noise pollution. (Ashfaq Majeed Naik, 2018)

It has been noticed that pavement evaluation has been conducted on many paved roads all over the world. However, most results show that pavement layers deteriorate because of weather, construction materials, and lack of adequate and suitable drainage systems. Also, generalizing the intervention process by estimating the maintenance process has led to a need to solve the problem of pavement deterioration and failures. It is, therefore, better to concentrate on the issues affecting pavement failure and damage to make the process of pavement evaluation more effective and valuable. Thus, the research will focus on the pavement evaluation of Kampi ya Moto- Eldama ravine- Kamwosor B77 road, a stretch of 79.5km. The type and level of severity of pavement distress will be identified, its structural and functional condition will also be determined, and the possible cause of this failure and provision of effective treatment and maintenance type will be determined and proposed in this process.

3 METHODOLOGY

3.1 Introduction

This chapter discusses the methods used to evaluate pavement on Kampi Moto- Eldama Ravine-Kamwosor B77 Road. It concentrated on various methods such as visual and surface condition surveys, determination of Pavement Condition Index (PCI), pavement structural condition surveys, and analysis of pavement evaluation based on the study's objectives.

3.2 Visual survey

The visual survey was conducted on 5th June 2020 to evaluate the road drainage systems and observe whether they were working. Also, the road carriageway and shoulders were visually surveyed to determine the type of distress within the project road. The activity was conducted by walking and driving slowly throughout the project road. Visual survey of Kampi ya Moto Eldama Ravine -Kamwosor road involved taking photographs of the identified distresses and the condition of the drainage of the road.

3.3 Surface condition surveys

A surface condition survey was conducted on 5th June 2020 to assess road riding quality and document surface distress. A surface condition survey is usually based on roughness measurements, rutting and surface irregularity tests, and surface distress determination. My research used laser technology to determine road roughness. In addition, rutting and surface distress were collected using automatic and manual methods.

The Hawkeye-2000 Digital Laser Profiler (DLP) that was used in this survey was automatic equipment that performed roughness and rutting measurements using Laser Profiler Beam (LPB) and pavement surface distress logging using Pavement Logging Video Cameras (PLVC).

(i) Roughness measurement

Roughness data was collected using the Hawkeye-2000 Digital Laser Profiler, which met the requirements of (AASHTO, 1996) PP 37-04 and ASTM E950 -98. The roughness measurements were in m/km.

(ii) Rut measurement

Rutting tests were conducted with the Digital Laser Profiler in compliance with ASTM E1703 / E1703M – 10 (2015). The average rut measurements were in mm.

(iii) Collection and quantification of surface distress data

The Hawkeye 2000 has four (4) pavement and asset logging video cameras (PLVC), namely the pavement, center, driver on the right, and guide. The road surface distress data were collected using pavement and center cameras. Identification, measurement of intensity, and determination of the severity of surface distress were made under RDM_V, 1988, and ASTM D 6433 -07.

(iv) Determination of pavement condition index (PCI)

The pavement condition index (PCI) is usually a calculated value obtained from the surface distress for a precise pavement section, which is attributed to pavement surface condition. It was determined based on the type and level of severity of distress and the number of pavement distress observed.

Below are the steps followed when finding the pavement condition index (PCI) value;

i. Through visual survey and manual measurement of identified sections with distress, the type, extent of existing distresses, and severity level were integrated and noted down accordingly.
ii. The densities of each type of distress identified were then calculated. Then, using a set of curves proposed by the ASTM, the density values calculated were interpreted into deduct value and corrected deduct value.
iii. Calculating the pavement condition index (PCI) value was also done in an iterative process (aiming at achieving the desired result), which was further analysed by a numerical value between 0 and 100. In this case, 0 represents the **failed or possible bad condition,** and 100 represents the **good or best possible condition**.

A direct survey was considered to be performed in the case of a tiny pavement section. Radom-selected areas were surveyed for the extensive paved sections;

i. The entire selected section of the pavement surveyed was characterized into sample units.
ii. The test was done on a certain number of selected units based on the number of sample units in the flexible pavement section.
iii. The type, extent, and level of severity distress of the pavement in each section were noted using the ASTM Standard D6433 method.
iv. The pavement condition index (PCI) of each tested sample unit was calculated using the method defined in the standard D 6433 method. Note that the amount of distress and the densities of the distress for each tested section were involved in this calculation. Determination of deducting value was found using the value originating in the above. Whereby the values were minus from one hundred (100) to attain the pavement condition index (PCI) value.
v. The PCI of the pavement system was expected to be equivalent to the PCI of the sampled areas in the case where the samples surveyed are representative of the general section

ASTM D6433-98 provides a systematic method for calculating the PCI value related to the pavement condition, as shown in Table 3-1

Table 3-1: Pavement Condition Index (PCI) Scale

PCI Range scale	Pavement Condition
85-100	Good
70-85	Satisfactory
55-70	Fair
40-55	Poor
25-40	Very Poor
10-25	Serious

PCI Range scale	Pavement Condition
0-10	Failed

Note[*] code from (ASTM D 6433-98)

3.4 Pavement structural condition surveys and analysis

The pavement structural condition survey and analysis were conducted to determine the residual structural strength of the existing pavement structure and establish the most viable maintenance intervention measures. The tasks under the structural condition survey included deflection measurement, traffic surveys and analysis to develop design loading, pavement and subgrade logging, material sampling, and laboratory testing used to establish the layer thickness, strength, and structural condition analysis.

3.4.1 Traffic surveys

The design traffic loading forms a crucial input parameter in the back analysis of deflection data for the structural evaluation of the pavement. Traffic surveys can be done in different ways but will depend on the availability of various factors to determine which method will be the best to adopt. Factors that one is to consider when choosing a suitable method include the availability of budget to perform that exercise, availability of personnel, availability of instruments, and magnitude of the traffic on the project road. Traffic surveys can either be done manually or automatically.

In the case of my research, secondary traffic data was obtained from Kenya National Highways Authority to assist in getting daily equivalent standard axles (DESA). The traffic survey involved carrying out classified traffic counts to determine the nature of traffic in terms of volumes and composition. It also involved an origin-destination survey that was used to determine the equivalence factors of adopted categories of vehicles.

This project's classified manual traffic count was conducted at one census point at Nyaru (Chepketeret) from 16th October 2018 to 22nd October 2018. ***Appendix 1*** shows the summary of traffic count data.

i. Data collection method

All vehicles were manually counted and recorded. The two lanes were considered together since the carriageway was 6.5 m wide.

ii. Traffic classification

Traffic classification was necessary to enable the determination of the levels of utilization of the project road and the distribution and supply of traffic. Therefore, the adopted traffic classification is given in Table 3-2. This classification was based on that of the MOR with additional classes as deemed necessary on-site.

Table 3-2: Classification of Motorized traffic

Vehicle Category	Description
Motorcycles	All mopeds and other motorcycles
Cars	Saloon cars and station wagon passenger cars.
Pick-ups, Jeeps, 4WDs, Vans,	All pick-ups, 4 WD cars, and private vans
Matatus and Minibuses	All public service matatus and minibuses with a seating capacity of between 14 to 33
Buses	All public service buses with a seating capacity of more than 33
Medium Goods Vehicles (MGV)	All trucks with two axles
Heavy Goods Vehicles (HGV_R)	All trucks with 3 - 4 axles
Heavy Goods Vehicles (HGV _A)	All trucks with 5 - 6 axles
Other Vehicles	Tractors, construction equipment, etc.

The vehicle category and description in Table 3-2 were modified to fit the project study. This was based on the vehicle type that passed the project road.

iii. Traffic survey station

Due to the minimal traffic along the project road that was caused by the condition of the road, the traffic survey station that was more effective was at Nyaru area, a place known as Chepketeret, as shown in Table 3-3.

Table 3-3: Locations of Traffic Census Station and Types of Survey Carried Out

Road Ref. No.	Location	Type of Survey
B77	B77 at Chepketeret (Nyaru-along Nyaru -Kapi ya Moto road)	• 24-hour junction counts for seven days • Axle load surveys for seven days. • O-D Studies for seven days.

iv. Traffic counts

Day and night traffic counts were conducted from 7:00 a.m. to 7:00 p.m. and 7:00 p.m. to 7:00 a.m., respectively. In addition, the traffic passing the survey station from each direction was continuously recorded through manual tally counting.

Traffic analysis was carried out from the census station, and the results were used to describe traffic characteristics along the project road. First, the Average Daily Traffic (ADT) was calculated as the average flow for the seven-day counts and then adjusted to 24-hour flows using 24/12-hour traffic flow factors determined from the night counts. Next, a seasonal variation factor of 1.0 was applied to the ADT to estimate the Annual Average Daily Traffic (AADT) as the fundamental factor for the project area could not be determined due to a lack of automatic counts data for major roads in the area.

v. Origin -Destination Surveys

O-D surveys were conducted simultaneously with the traffic counts at the locations shown in Table 3-3 (for seven days from 7:00 a.m. to 7:00 p.m.) to determine the existing "quantities" of travel between various locations and relationships between the quantities and types of travel.

The roadside Interview Method was selected for the surveys as it could supply detailed and accurate information since it was gathered directly from motorists without needing to infer anything from their behaviour. The following information was collected from them: -

- Vehicle type and number of axles
- Trip origin, destination, and purpose
- Number of vehicle occupants

- Types of commodities conveyed, particularly for trucks
- Vehicle loading capacity and utilization.

The survey data obtained from the station were analyzed.

vi. Axle Load Surveys

- **Axle Load Measurements**

Seven-day axle load surveys were conducted at O-D stations to estimate the number of equivalent standard axles currently using the project road. A portable weighbridge was used to measure the axle loads for different vehicle categories, and the data obtained was processed to determine the 85th percentile equivalence factor for each vehicle type.

- **Equivalence Factors**

The EF values for each axle were summed for each vehicle category and used with AADTs to compute the Equivalent Standard Axles (ESA) on the project road. The cumulative frequency distribution of the axle loads for each vehicle category in each direction, as shown in *Appendix 2* of this report, was plotted. The 85th percentile load was determined, which gives the best compromise for design since it is only exceeded by 15% of the axle loads on the road.

$$EF = (LS \div 80)^{4.5}$$

Where EF- Is the Equivalent Factor of the single axle considered

LS –Is the Load in KN on the single axle considered

vii. Adopted growth rate

- **Growth Rate**

Using the economic survey reports of 2013, 2014 and 2019 by the Kenya National Bureau of Statistics, the indicators, including registration of vehicles fuel consumption and transport demand elasticity approach, together with the past trend in traffic growth on the project road, were considered and used to arrive at plausible figures for traffic growth rates.

viii. Design traffic loading

The traffic loading – Cumulative Standard Axles (CSA) was obtained based on the estimated daily equivalent standard axle (DESA) and the adopted growth rate. The following Equation 3.1 was used

$$CSA = 365\, t_b \frac{(1+r)^n - 1}{r} \quad \text{……………………………………Equation 3.1}$$

Where,

tb = Daily Equivalent Standard Axles

r = Growth rate (%)

n = Number of years

3.4.2 Pavement coring, trenching, logging sampling, and material testing

The existing pavement structure was established by conducting coring, trenching, logging, sampling, and material testing. The samples were collected for laboratory testing to determine the strength of the bond between the base layer and assess the pavement's drainage characteristics.

Logging was conducted to determine the thickness of the pavement layers.

Trenching was performed at various intervals of approximately six (6) of the entire road**.** Trenching and coring were concentrated on areas where the pavement had wholly deteriorated and sections with less deterioration.

A coring machine was used to extract cylindrical samples of road-based materials from the pavement. The machine drills a hole into the pavement and extracts a cylindrical sample of the material, which was then transported to a laboratory for testing and analysis.

Coring a roadway was done to verify the existing pavement structure conditions and depths. This information was then used to select an appropriate treatment or confirm the adequacy of a proposed resurfacing method. Cores were taken in areas with numerous defects and without defects, and the procedure in the field was carried out in the carriageway of the project road.

3.4.3 Deflection measurement using FWD.

Deflection measurement is usually conducted with various equipment: stationary, impact, vibratory, or impulse load type. Deflection measurements in this report were performed using Primal FWD with nine geophones that meet the requirements of ASTM D4694 – 09 and the test method as defined in ASTM D 4695-96. (ASTM, 2009).

The deflection measurements were conducted on 31/05/2020 on outer lanes at intervals of approximately 100 m on the outer wheel path (OWP) at an offset of about 0.7m from the edge of the carriageway. At each drop point, readings were taken for the nine (9) consecutive geophone points of 0, 20, 30, 60, 90, 120, 150, 180, and 200 cm.

A summary of the deflection measurement is attached in ***Appendix 3*** of this report.

(i) Preliminary analysis by normalising

The target load during testing was 50 KN, which resulted in a standard pressure of 707 KPa. In the field, attempts are made to test at this pressure as much as possible. Due to the gradient and the nature of the road surface, the resultant pressure is slightly lower or above this pressure in most cases. The FWD deflection data were normalized to a standard pressure of 707 KPa using the linear *equation 3.2*.

$$\boldsymbol{d_n} = \{\boldsymbol{d_i} \times \boldsymbol{L_t}\}/\{\boldsymbol{L_i}\} \quad \text{..} \quad \textit{Equation 3.2}$$

Where:

- d_i is the deflection reading for the sensor located *i* mm from the centre.
- $\boldsymbol{d_n}$ is the normalized deflection reading for the sensor located i mm from the centre.
- L_i is the load level applied during the test
- L_t is the target load level of 707KPa based on the standard axle of 10-ton

Further, the normalized deflections were used to establish homogenous sections using the cumulative sum of difference from mean (CuSUM) method of the central deflections.

(ii) Pavement analysis parameters and criteria

The deflection data was analysed using RoSy Design Software. The necessary input parameters and the criteria for analysis of the outputs were as follows.

a. Pavement analysis parameters

The following design parameters were considered during data input for RoSy Design analysis:

i. Existing road lane width of 3.25 m with a carriageway width of 6.5m
ii. Pavement design temperature of 30^0C.
iii. Existing pavement as established from as-built records.
iv. Fatigue laws as presented in RDM Part III.
v. Daily ESA as established from the traffic surveys and
vi. Pavement analysis for 7, 10, and 15 years design period.

b. Pavement Analysis Criteria

The pavement analysis was carried out under conditions in RDM part III and V and, therefore, compared to elastic moduli in section 8.2.3 of Road Design Manual Part III for Material as follows:

i. Asphalt concrete type II – 2500MPa;
ii. Cement-treated Graded Crushed Stone as a base – 4000 MPa;
iii. Cement improved gravel (base quality) as Subbase – 2000 MPa;
iv. Subgrade Strength S4 – 125 MPa.

Additionally, the pavement was checked for residual life and strength, critical layer and overlay requirements for each homogenous section as the basis for maintenance, rehabilitation/strengthening intervention recommendations.

4 RESULTS ANALYSIS AND DISCUSSION

4.1. Introduction

This chapter analyses and discusses the results obtained from the exercise following the methods from Chapter Three above.

4.2.Visual condition/ distress survey

Visual observations made during the reconnaissance visit were recorded in picture format. The distresses on the pavement's surface were captured as shown in Figures 4-1, 4-2 and 4-3.

4.2.1. Visual condition for Kampi ya Moto –Eldama Ravine –Kamwosor Road

The minor distress observed that did not reflect on the structural state of the road included bleeding of the asphalt concrete (AC) surface, as depicted in Figure 4-1. The road also exhibits several major distresses, including potholes, eroded edges, block cracking, depression, rutting, lack of shoulders, and poor drainage, as illustrated in Figures 4-2 and 4-3.

Figure 4-1: Minor distress (bleeding) and lack of drainage system on Kampi ya Moto-Kamwosor Road (source from the field)

Figure 4-2: Major distress and lack of defined system. (source from the field)

Figure 4-3:Major distress on Kampi ya Moto - Kamwosor Road (source from the field)

Based on field observations, as shown in Figures 4-1, 4-2, and 4-3, it was concluded that the surfacing distresses were caused mainly by drainage issues. There were sections noted with water oozing through a poorly bonded pavement layer. The visually surveyed surfacing distresses were found at kilometres 3, 14, 55 to 67, and 72 to 79.5.

4.2.2. Drainage distress

The non-existence of drainage structures was considered the primary defect observed along the entire project road. It was assumed that emerging potholes within the asphalt concrete were evidence that they were formed due to lack of proper drainage systems. The drainage distress will eventually be created when the road lacks surface and sub-surface drainage.

Once the road drainage is generated, it is supposed to be maintained to prevent the flow of surface water to the pavement layers, thus causing the pavement to deteriorate. In addition, surface drainage will tend to preserve the road surface from water parches, collect the drained-off water from the road surface, increase road stability and carry collected water by using the gravitational force into the nearby river. Likewise, sub-surface drainage will tend to prevent and control the moisture content of the road sub-grade, maintain the bearing capacity of the sub-grade soil by restricting the entry of water into it, and reduce the capillary rise because sometimes, due to capillary action, the water rises into the sub-grade from the groundwater.

Factors that increase the sub-soil moisture content are:

- Increase in the groundwater table in the pavement structure.
- Water seepage from attached sections.
- Filtration of Surface water through existing cracks and joints.
- Capillary action caused whereby moisture rises above the groundwater table.

After conducting a visual and surface condition survey, it was discovered that the road lacked proper drainage, which was deemed necessary. The drainage condition for the entire road was found to be very poor and was therefore labelled as undefined. During the visual survey, certain sections were observed to lack longitudinal drainage, which caused water to alter its course and flow above the road carriageway. This resulted in water seeping into the pavement structure, weakening the underlying layers. Figure 4-4 depicts the undefined drain condition of the road carriageway as a result of the investigation conducted in the field. The road's drain condition was categorized as BAD, which likely contributed to the deterioration of the pavement structure.

Figure 4-4: Sections with no drainage channels (Sourced from the field)

4.3. Surface condition surveys

A survey was done to assess the quality of the road surface and identify any damage. This helped determine the severity of pavement distress by measuring road roughness and rutting. The results were used to calculate the pavement condition index.

Based on the observations made during the study, it was noted that some parts of the road were in good condition, while others had visible pavement damage. Despite the localized damage in certain areas, the road remained stable, especially in the sections where repairs had been carried out. The shoulder of the road was worn out throughout the entire study area. Furthermore, a large number of sections had a hanging edge that was about 200mm deep.

a) Rutting measurements

Based on the survey conducted on the project road, rut depths were measured and recorded. Data analysis revealed that the average rut depth for the road section was 4.1mm, indicating a **low severity rating** for the road. Table 4-1 shows the summary of rut depth measurement.

Table 4-1: Summary Rut depth measurements

Road Sections / Lanes	Lane	Points	Min Rut Value	Max Rut Value	Mean Rut Value	Road Section Mean RUT
Kampi Ya Moto - Kamwosor (B77)	LHS	121.0	0.7	11.0	4.6	
Kampi Ya Moto - Kamwosor (B77)	LHSb	23.0	0.5	7.7	3.7	
Kampi Ya Moto - Kamwosor (B77)	RHS	648.0	0.2	18.7	4.0	4.1

b) Roughness measurement

Roughness data was collected and noted in m/Km, summarized in Tables 4-2 and 4-3, which detail the International Roughness Index (IRI) and rating description of road roughness, respectively.

Table 4-2: Roughness measurements

Road Sections / Lanes	**Lane**	**Points**	**Min IRI Value**	**Max IRI Value**	**Mean IRI Value**	**Road Section Mean IRI**
Kampi Ya Moto - Kamwosor (B77)	LHS	515.0	1.6	13.4	4.5	4.2
Kampi Ya Moto - Kamwosor (B77)	RHS	464.0	1.5	9.6	4.1	
Kampi Ya Moto - Kamwosor (B77)	LHS	798.0	1.6	19.1	4.1	

Table 4-3: Road Roughness Rating

RATING, m/km	RATING Description
0-2	Very Good
2-4	Good
4-6	Fair
6-10	Poor
Above 10	Bad

Sourced from highway development & management(Bituminous roads deterioration) 2015; modified to fit my study section

Based on the data summary, it was found that the average International Roughness Index (IRI) of the entire Kampi ya Moto Eldama Ravine Kamwosor road was 4.2 m/km. According to the road roughness rating chart in Table 4-3, this indicates that the road was in fair condition. This suggests that some parts of the road were less damaged than others. However, it is essential to note that an IRI of 4.2m/km means improvements are needed to restore the road's rideability.

c) Determination of pavement condition index of the study road.

The PCI (pavement condition index) is a numerical rating calculated based on the level of surface distress of a particular pavement section. It is a helpful indicator that shows the condition of the pavement surface, ranging from 0 (Failed) to 100 (Good). The value was calculated based on the type and level of distress present, which is closely linked to the material properties of the pavement. When the pavement's material properties are compromised, stability is lost, and the pavement becomes weaker. In this report, ASTM D6433-98 was used to determine the PCI values, which were rated according to Table 4-4. Table 4-5 summarizes the PCI values and ratings for the Kampi ya moto-Eldama Ravine-Kamwosor road section.

Table 4-4: PCI Rating Scale & Colours: Code (ASTM D 6433-98)

PCI Range scale	Rating colour	Pavement Condition
85-100		Good
70-85		Satisfactory
55-70		Fair
40-55		Poor
25-40		Very Poor
10-25		Serious
0-10		Failed

Table 4-5: Summary of Findings from Surface Condition Survey

Road Section	**Average IRI**	**Average Rut**	**PCI Value**	**Rating**
Kampi Ya Moto - Kamwosor (B77)	4.2	4.1	55	Fair

Table 4-5 displays a PCI value of 55 for the study road, rated as **fair**.

In summary, it was generally seen that the surface distress observed was bleeding of the AC surface. In contrast, structural distresses observed on the road included numerous potholes, eroded edges, block cracking, depression, rutting, and poor drainage. In addition, the road width was too narrow. As a result, the road had an average IRI of 4.2 m/Km, rated as **Fair**, a mean rut depth of 4.1 mm, rated as being of **Low Severity,** and a mean PCI of 55, rated as **Fair.**

4.4. Structural condition surveys

4.4.1. Traffic analysis

The traffic data collected were recorded and analysed as follows;

a) AADT findings

Based on the traffic count results, the AADT of the type of vehicles along the project road was obtained and presented in a graph, as shown in Figure 4-5.

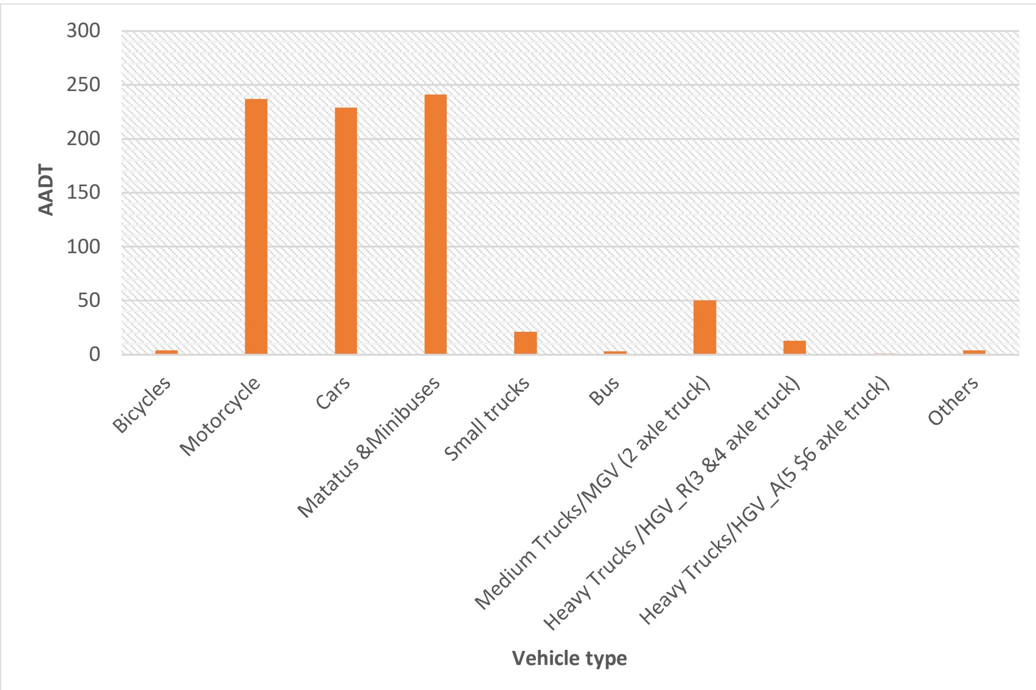

Figure 4-5: AADT of various vehicles along the project road

From Figure 4-5, the highest AADT was the matatus, followed by the motorcycles and cars, with 241,237 and 229, respectively. The high number of Matatus and minibuses in this section was due to the trend of public drivers offering public transport services to people living within the project road. The lowest were bicycles, buses and heavy trucks/HGV_A, with 4, 3 and 1, respectively.

Table 4-6 shows the project road's Annual Average Daily Traffic (AADT).

Table 4-6: Annual Average Daily Traffic (AADT) on Project Road - Both Directions

Survey Station	Direction movement	Bicycles	Motorcycle	Cars	Matatus & Minibuses	Small trucks	Bus	Medium Trucks/MGV (2-axle truck)	Heavy Trucks /HGV_R(3 &4 axle truck)	Heavy Trucks/HGV_A (5 & 6 axle truck)	Others
At Chepketeret along Nyaru Kamwosor	To Nakuru via Eldama ravine	2	125	106	123	10	2	22	5	0	2
	From Nakuru via Eldama ravine	2	113	123	118	12	2	29	9	1	1
	Total AADT	**4**	**237**	**229**	**241**	**21**	**4**	**51**	**14**	**1**	**4**

**Data source from Kenya National Highways Authority (KeNHA)*

Based on Table 4-6, the AADT within the project road was low due to the poor road condition that discourages motorists from using this section.

b) **O-D survey findings**

(i) **Categories of Vehicles in O-D Interviews**

The numbers of motorists interviewed for each vehicle category are shown in Table 4.7.

Table 4-7: Summary of motorists interviewed for each vehicle category during the O-D survey

Station	Vehicle Category				
	Buses	MGV	HGV_R	HGV_A	Total
Chepketeret	3	100	60	3	166
Total	3	100	60	3	166

(ii) **O-D Matrices**

The O-D matrix of the data collected at the survey station for the major town (concentrating on the project road) was given in Table 4.8.

Table 4-8: O-D Matrix of Chepketeret Station

	Destination												
	Town Name	**Nairobi**	**Nakuru**	**Eldama ravine**	**Torongo**	**Kamwosor**	**Metkei**	**Nyaru**	**Chepkorio**	**Kaptagat**	**Biwott**	**Eldoret**	**Others**	
Origin	**Nairobi**	0	0	0	0	0	0	0	0	1	0	0	1	2
	Nakuru	0	0	0	0	0	0	0	0	1	0	2	1	4
	Eldama Ravine	0	0	0	0	0	0	1	0	1	0	17	0	19
	Torongo	0	0	0	0	0	0	1	0	0	0	2	0	3
	Kamwosor	0	0	0	0	0	0	3	0	0	0	14	2	19
	Metkei	1	0	0	0	0	0	2	0	0	0	1	0	4
	Nyaru	1	0	3	0	2	1	0	0	0	1	0	2	10
	Chepkorio	1	0	0	0	2	0	0	0	0	0	0	1	4
	Kaptagat	1	0	1	0	0	0	0	0	0	0	0	0	2
	Biwott		0	0	0	0	0	2	0	0	0	0	1	3
	Eldoret	1	10	20	1	27	1	0	0	0	1	0	5	64
	Lodwar	0	0	1	0	0	0	0	0	0	0	0	0	1
	Chepsikor	0	0	0	0	1	0	0	0	0	0	0	0	1
	Others	3	1	0	0	5	0	1	0	1	3	4	12	30
	Total	8	11	25	1	35	2	10	0	4	5	40	25	166

***Note**: The table shows the number of trucks (Buses, MGV, HGV_R and HGV_A) passing the project roads*

(iii) O-D Matrices for Vehicles interviewed at Chepketeret B77

From the O-D matrix, the highest percentage of truck type was the MGV at 60.24%, followed by HGV_R at 36.14% and finally HGV_ A and bus at 1.80%

(iv) Trip Purposes

The trip-generating activities were basically trade/business.

(v) Type of Goods

The percentage compositions of goods transported by vehicles intercepted at the O-D stations are shown in Figure 4.6.

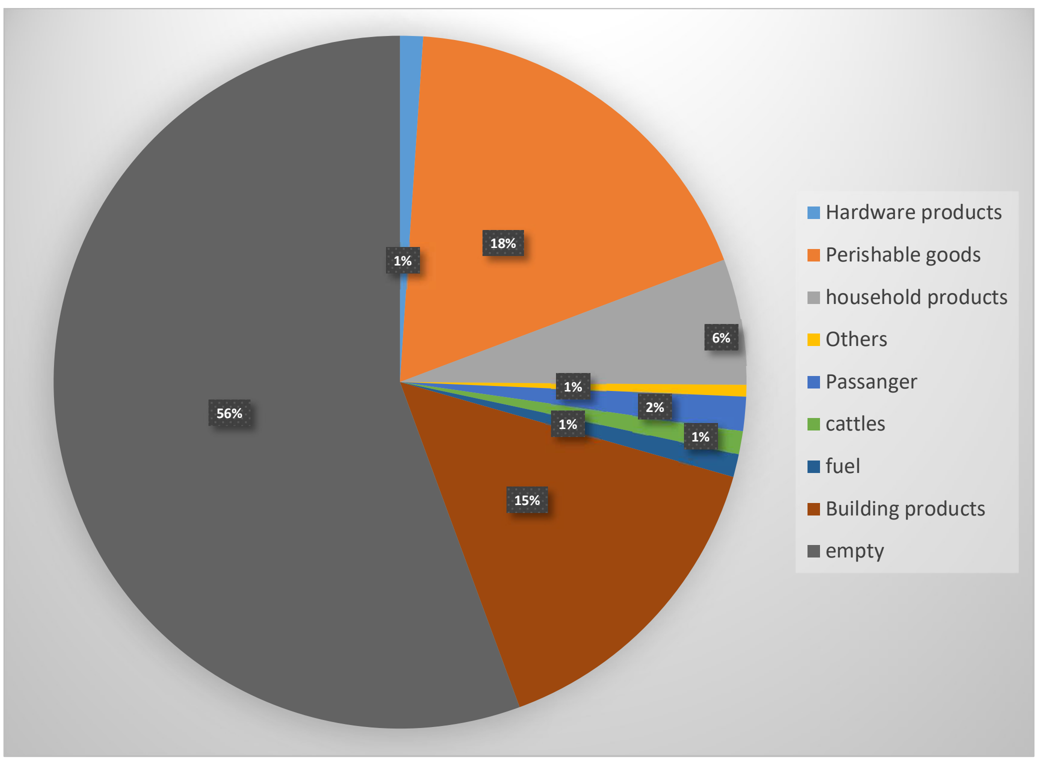

Figure 4-6:Types of Goods/Products Transported/Identified for each sampled vehicle at long the project road.

The pie chart recorded that the empty trucks surveyed were the highest at 56%, followed by the trucks carrying perishables goods at 18%, and finally, the building products such as Stones, timbers and poles at 15%. The remaining products have the lowest percentage, ranging from 1% to 6%.

c) Equivalent factor

The number of vehicles measured are as shown in Table 4-9. Cumulative frequency distribution of the axle loads for each vehicle category in each direction was plotted and the 85th percentile load, which gives the best compromise for design since it is only exceeded by 15% of the axle loads on the road, was determined.

$$EF = (LS \div 80)^{4.5}$$

Where EF- Is the Equivalent Factor of the single axle considered

LS –Is the Load in KN on the single axle considered

Table 4.9 below gives a summary of the adopted 85th percentile axle loads and corresponding equivalence factors (minimum, maximum, median) for each vehicle category.

Table 4-9:Equivalence Factors for the Project Road

Vehicle Category	No. of vehicles	Equivalence Factor			
		Minimum	Maximum	Median	Adopted
Bus	3	0.31	0.67	0.62	**0.62**
MGV	100	0.00	15.94	1.54	**1.54**
HGV 1	60	0.00	19.80	3.24	**3.24**
HGV 2	3	5.63	13.72	8.54	**8.54**

**Source of primary data: KeNHA.*

Based on the cumulative frequency distribution of the axle loads for each vehicle category in each direction, the median was identified as the adopted equivalence factor. This was determined by taking the 85th percentile load into account, as it is only exceeded by 15% of the axle loads on the road. This approach provides the best compromise for design purposes.

d) Adopted growth rate

The growth rates of the various categories of vehicles were derived based on the following.

- **Historical Traffic Growth**

For this analysis, the historical traffic data of the project and adjacent roads was fitted to the geometric model, and growth rates for the various categories of vehicles at low (L), medium (M), and high (H) levels which were obtained from the Kenya National Highways Authority are shown in Table 4.10.

Table 4-10 - Historical Traffic Growth Rates of Project and Adjacent Roads

Road	Historical Growth Rates of Vehicles (%) at Low (L), Medium (M), and High (L) Levels														
	Cars			LGV			MGV			HGV			Buses		
	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
B77 Eldama ravine-Nyaru	5	6	7	4	5	6	6	7	8	5	6	7	5	6	-
Adopted	5.	6	7	2	5	6	6	7	8	5	6	7	5	6	-

**Source of Primary Data: KeNHA*

- **Economic Indicators of Traffic Growth at the National Level**

(i) **New Registration of Motor Vehicles**

The average annual growth in new vehicle registrations between 2008 and 2018, as indicated in the Economy Survey 2013, 2014 and 2019, is shown in Table 4.11.

Table 4-11: Average Annual Growth in New Vehicle Registrations for the 2014 - 2018 Period

Vehicle type	Saloon Cars	station wagons	Pickups	trucks/ lorries	Buses & coaches	Minibuses /matatu	trailers	Wheeled tractors	Others
2008	18686	24747	8983	6691	1243	5206	2100	1262	797
2009	16930	27599	7120	6037	1057	4483	2883	1115	2575
2010	16165	37553	6975	4924	1264	3600	2379	1161	3648
2011	11026	31199	7442	5247	1662	451	2556	1179	2724
2012	12985	39862	7945	7821	1638	78	3761	1386	1753
2013	16343	48662	9819	9570	2062	235	3973	1902	1451
2014	15902	53542	12568	10681	2210	213	2925	2032	2533
2015	14369	54120	13878	13785	2342	581	3905	2259	2522
2016	12490	46123	12722	9632	1765	516	2829	2478	1618
2017	11376	55322	9866	7460	1072	459	1953	2703	860
2018	10504	64179	11220	6514	1065	812	2083	4040	1619

**Provisional; Source of Primary Data: Economic Survey 2013,2014 and 2019 prepared by KNBS*

The number of newly registered motor vehicles increased by 5.2% from 282,672 in 2017 to 297,289 in 2018, mainly due to higher registration of motor station wagons. New registration of motor vehicles increased by 12.0 % from 91,071 units in 2017 to 102,036 units in 2018. The number of newly registered station wagons rose for the second consecutive year to 64,179, while panel vans and pick-ups increased by 13.7% in 2018. Similarly, newly registered trailers increased by 6.7% to 2,083 units, while wheeled tractors rose by 49.5% to 4,040 units in 2018. The number of new mini-buses registered almost doubled from 459 in 2017 to 812 in 2018. The registration of saloon cars continued to decline, with 10,504 units registered in 2018. In addition, the number of newly registered lorries, trucks, buses, and coaches declined for the third year to 6,514 units and 1,065 units, respectively, in 2018. The general decline in new registration of buses, lorries and trucks is partly explained by the availability of rail freight and passenger services since 2017.

(ii) **Fuel Consumption**

Table 4.12 shows the annual growth rates of motor spirit and light diesel consumption. The positive increase in the consumption of these products indicates an increase in traffic and vehicle trips in the country.

Table 4-12: Domestic Petroleum Demand for the 2013 - 2018 Period

Survey Year	Fuel Consumption '000 in Cubic Metres	Growth Rate %
2008	1701.1	
2009	2141.7	25.90
2010	2012.5	-6.03
2011	1955.7	-2.82
2012	1879.1	-3.92
2013	2071.5	10.24
2014	2343	13.11
2015	2476	5.68

2016	2715	9.65
2017	2845.2	4.80
2018	3140.4	10.38
		6.70

**Provisional; Source of Primary Data: Economic Survey, 2013,2014 & 2019 prepared by KNBS*

- **Transport Elasticity Coefficients**

Econometric experience indicates that demand for transport tends to move with the economic growth rate as measured by GDP but at a slightly higher rate than the aggregate national or regional GDP values. This relationship is generally referred to in transport economics as the income elasticity of demand for transport over time measured by a change in transport demand due to changes in income. Analysis of the growth rate in transport and storage correlated with changes in GDP in the last ten years from 2008 to 2018 in Kenya is shown below in Table 4-13:

Table 4-13: Percentage changes in GDP

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
GDP at market prices	1.5	2.8	5.8	4.4	4.6	4.7	5.4	5.7	5.9	4.9	6.3	*4.7*
Transport and storage	3	7	6.2	4.7	4	6.6	5.5	8	6.5	7.2	9.9	*6.2*
Elasticity for transport & storage versus GDP	*2.0*	*2.5*	*1.1*	*1.1*	*0.9*	*1.4*	*1.0*	*1.4*	*1.1*	*1.5*	*1.6*	*1.4*

Source of primary data: Economic Survey 2013,2014, and 2019. Prepared by KNBS

The average elasticity for transport and storage versus GDP was 1.4, as shown in Table 4-13. This means that for every 1% growth in GDP, the transport sector grew by 1.4 % between 2008 and 2018. Therefore, the expected traffic growth rate for the project road was estimated from the product of average elasticity for transport and storage and GDP growth rates, assuming transport elasticity 1.4 persists at the same value in the foreseeable future.

The future adopted growth rates for various categories of vehicles were derived from linear regression analysis. The adopted growth rates scenarios were categorized as Low, Medium and High, as shown in Table 4-14:

Table 4-14: Adopted Traffic Growth Rates

Period	**Vehicle Category**	**Growth Rate**		
		Low	**Medium**	**High**
2019-2023	Cars	5.2	7.4	9.6
	Vans&Pick-ups	5.2	7.2	9.1
	Matatus	2.7	4.1	5.4
	Minibus	2.7	4.1	5.4
	Bus	2.7	4.2	5.4
	LGV	6.1	8.4	10
	MGV	6.1	8.4	10
	HGV	4.3	7.6	11.1
	M/Cycles	4.3	7.6	11.1
2023 - 2033	Cars	4.3	6.1	8.6
	Vans&Pick-ups	3.8	5.9	7.9
	Matatus	1.5	2.7	6
	Minibus	1.5	2.7	6
	Bus	3.7	5.9	9.1
	LGV	3.7	5.9	9.1
	MGV	3.8	5.9	9.1
	HGV	3.6	4.9	8.5
	M/Cycles	3.6	5.8	9
2034-2039	Cars	3.4	4.5	5.4
	Vans&Pick-ups	3.2	4.4	6.5
	Matatus	3.8	5.4	6.5
	Minibus	2.8	4.5	5.6
	Bus	2.5	4.5	5.6
	LGV	3.3	4.6	5.3
	MGV	3.3	4.6	5.3
	HGV	2.7	2.7	3.2
	M/Cycles	3.6	4.9	5.2

**Sourced from KeNHA-(Elasticity of transport demand is assumed to remain constant throughout the analysis period).*

For the study, the growth rates for the ten (10) years between 2023 – 2034 were adopted as the representative growth rates for the road during the design period.

e) Daily equivalent standard axle

Based on the equivalent factor obtained, the estimated daily equivalent standard axle (DESA) of Kampi ya moto- Eldama ravine- Kamwosor road is as per Table 4-15.

Table 4-15: Daily Equivalent Standard Axle

TRAFFIC CLASS.	AADT	EF	DESA
BUS	4	0.62	2.48
MGV	51	1.54	78.54
HGV1	14	3.24	45.36
HGV2	1	8.34	8.54
		Totals	**134.92**

f) Design traffic loading

To obtain the traffic class for the road, the cumulative equivalent standard axle for the road for 15 years was calculated, as shown in Table 4.16. The following formulae was used.

$$CSA = 365\, t_b \frac{(1+r)^n - 1}{r}$$

Where,

tb = Daily Equivalent Standard Axles

r = Growth rate (%)

n = Number of years

Table 4-16: Cumulative equivalent standard axle

TRAFFIC CLASS.	DESA	CSA
BUS	2.48	20,909.62
MGV	78.54	662,194.31
HGV1	45.36	354,586.18
HGV2	8.54	66,758.51
	134.92	**1,104,448.62**

After analysing the data, it was determined that the daily equivalent standard axle was 134.92. Based on the data obtained, the cumulative standard axle for the project road was 1.1*10^6 CSA. According to RDM Part III, the project road falls under traffic class T4.

4.4.2. Pavement coring, trenching, logging sampling, and material testing

Coring, trenching, logging, sampling, and material testing were conducted to establish the existing pavement structure and sample materials for laboratory testing.

i. Logging findings

The thickness of each pavement layer, starting from surfacing material, base material and subbase material, was recorded as shown in Table 4-17.

Table 4-17: Logging Findings

Road Section	Logging Points	Surfacing Material and thickness, mm	Base Material & Thickness, mm	Subbase Material & Thickness, mm
Kampi ya Moto – Kamwosor Road (B77)	Km 12+ 640	70 mm AC	120 mm GCS	200 mm HIG
	Km 36 + 500	50 mm AC	100 mm GCS	150 mm HIG
	Km 50+ 450	50 mm AC	100 mm GCS	120 mm HIG
	Km 57+150	120mm AC	150mm GCS	100 mm GCS
	Km 65+400	50 mm AC	100 mm GCS	125 mm HIG

**AC: Asphalt Concrete, GCS: Graded Crushed Stones, NG: Natural Gravel, HIG: Hydraulically Improved Gravel*

According to the sample taken from the field, the thickest asphalt concrete (AC) was found at km 57+150 with a thickness of 120mm. On the other hand, the thinnest AC was recorded at km 36+500, 50+450, and 65+400 with a thickness of 50mm. The 120mm thickness of AC could be due to repeated maintenance programs carried out in that section. The base and subbase material thickness ranged from 100mm to 150mm and 100mm to 200mm, respectively. The subbase material varied along the road, with improved gravel found at

12+640, 36+500, 50+450, and 65+400, while graded crushed stones were located at km 57+150.

ii. Subgrade material test results

Trenching was performed at various intervals, as shown in Table 4-18.

Table 4-18: Trenching Intervals

Road Name	Length	Average Trenching Interval (Km)
Kampi ya Moto – Kamwosor Road (B77)	79.5	6

The trenching intervals at specific chainages for the subgrade layers, including native subgrade, top subgrade and bottom subgrade layers, were recorded. The analysis of the data obtained from the laboratory test was recorded in terms of the plasticity modulus, plastic index, maximum dry density (MDD), optimum moisture content (OMC), California bearing ratio (CBR) and subgrade class as indicated in Table 4-19.

Table 4-19: Subgrade Properties

Section	layers							Atterberg Limits					Compaction T 99			
		20 mm	10 mm	5 mm	2 mm	425 µm	75 µm	LL (%)	PL (%)	PI (%)	LS (%)	PM	MDD (Kg/m^3)	OMC (%)	4 days soak	Swell
		KAMPI YA MOTO - KAMWOSOR B77 ROAD														
Km 12+640 LHS	NSG	100	97	96	91	87	79	46	23	23	11	2001	1445	21.4	7	0.2
Km 36+500 RHS	NSG	100	95	92	88	84	75	37	19	18	9	1512	1490	20.8	19	0.1
Km 50+450 LHS	NSG	100	99	98	97	96	92	48	24	24	12	2304	1155	25.4	6	0.3
Km 57+150 RHS	TSG	-	-	100	97	84	71	77	40	37	18	3108	1291	33.3	5	0.6
Km 65+400 RHS	TSG	100	98	95	93	86	78	55	33	22	11	1892	1325	18.4	11	0.2

Km 65+400 RHS	BSG	100	99	99	98	97	96	58	35	23	12	2231	1110	20.0	6	0.3

The above-existing subgrade layers are summarized in Table 4-20.

Table 4-20: Summarized Subgrade Properties

Road ID	Chainage	Layer	PM	PI	CBR	SG class
Kampi Ya Moto – Kamwosor Road (B77)	Km 12+640	NSG	2001	23	7	S2
Kampi Ya Moto – Kamwosor Road (B77)	Km 36+500	NSG	1512	18	19	S5
Kampi Ya Moto – Kamwosor Road (B77)	Km 57+150	TSG	3108	1291	5	S2
Kampi Ya Moto – Kamwosor Road (B77)	Km 50+450	NSG	2304	24	6	S2
Kampi Ya Moto – Kamwosor Road (B77)	Km 65+400	TSG	1892	22	11	S4
Kampi Ya Moto – Kamwosor Road (B77)	Km 65+400	BSG	2231	23	6	S2

**TSG: Top Subgrade, BSG: Bottom Subgrade, NSG: Native Subgrade,*

Based on the results obtained, the plastic index (PI) was satisfactory, but the subgrade materials' California Bearing Ratio (CBR) differed from one section to another. The CBR of the subgrade properties ranged from 5 to 19, with 5% being the minimum and 19% being the maximum. According to the RDM Part III, the CBR of subgrade ranging from 5 to 10 belongs to the Subgrade class S2, as indicated in Table 4-20. The lower CBR shows that the subgrade layer had a lower bearing strength, which cannot support the upper layers sufficiently. Therefore, the subgrade material was rated as inadequate for the study road.

iii. Pavement coring test results

Table 4-21 represents the pavement coring test from the recovered aggregate obtained from the site. The core thickness, density, core air void and the percentage grading test for sampled chainages were recorded. Table 4-22 shows the summarized coring test results.

Table 4-21: Coring Test Results

Road Name	Sampling Location	Core Thickness, mm	Core Density, gcc	Max. Theoretical Density, gcc	Core air voids %	Binder Content %	% pass. 28	% pass. 20	% pass. 14	% pass. 10	% pass. 6.3	% pass. 4	% pass. 2	% pass. 1	% pass. 0.425	% pass. 0.3	% pass. 0.15	% pass. 0.075
Kampi Ya Moto- Kamwosor B77 Road	12+640	60	2.191	2.380	7.9	5.4	100	100	100	84	75	73	58	31	14	11	7	5
	36+500 LHS	50	2.287	2.397	4.6	5.4	100	100	98	77	60	48	37	25	14	11	7	5
	50+450 LHS	50	2.241	2.396	6.5	5.6	100	100	86	64	39	30	25	21	17	13	8	5
	57+150 RHS	90	2.045	2.265	8.3	5.0	100	100	98	82	67	50	29	16	8	5	3	1
	65+400 RHS	50	2.237	2.351	4.8	5.8	100	100	98	73	46	33	25	18	11	10	7	5

Table 4-22:Summarized Coring Test Results

Road Name	Chainage	Average Core Thickness, mm	Average Core Density, GCC	Average Core air voids %	Average Binder Content %
Kampi ya Moto – Kamwosor Road (B77)	12+640	60	2.2	7.9	5.4
	36+500 LHS	50	2.3	4.6	5.4
	50+450 LHS	50	2.2	6.5	5.6
	57+150 RHS	90	2.1	8.3	5.0
	65+400 RHS	50	2.2	4.8	5.8

Based on the result of 5 tests performed, the core air void percentage of the four sections were sufficient, thus ranging from 3 to 8%. At km 57 +150, the core air void percentage was too high beyond the upper limit specification for type II pavement.

iv. Pavement material properties analysis

Pavement material properties are one of the most significant elements in the pavement structure. From the field test, the materials' layers varied based on the material type and thickness at specific sections. In some areas where the pavement was stable, it was noted that the layers were adequately laid in the proposed thickness, and the level of compaction was well-defined. Whereas the sections with defects when the coring test took place, the base and sub-base thickness and particle size distribution were compromised. In this section, visually, it was noted that the surfacing layer had numerous cracks. This allowed water to penetrate, thus affecting the stability, which also led to an assumption that the compaction level was inadequate during the laying process, especially when doing the maintenance program of the project road. For instance, in some areas, especially at Km 57+150, the grading per cent passing of sieve 0.0075 was 71%. This means that there were too many fines thus, making it insufficient. Furthermore, water in the pavement promoted saturation of the underneath base and sub-base layer, thus lowering the strength of the layers designed to support the abutting topmost layer.

Surfacing thickness varied from section to section. Also, from the coring and trenching test, it was noted that the material properties were varying; that is, the grading of the pavement base and subbase layers were porous; thus, voids were formed that allowed water to weaken these layers, leading to diminishing support provision to the surfacing layer.

4.4.3. Deflection measurement using FWD

i. FWD data normalisation and determination of homogenous sections

Normalization was conducted on FWD data from the test load to the standard load of 50 KN, equivalent to an average pressure of 707 KPa. The normalized central deflections were used to establish homogenous sections on road sections using the Cumulative Sum of Difference from the mean Method (CUSUM). The roads were divided into homogenous sections from the CUSUM computations and graphs, as presented in Figure 4-7

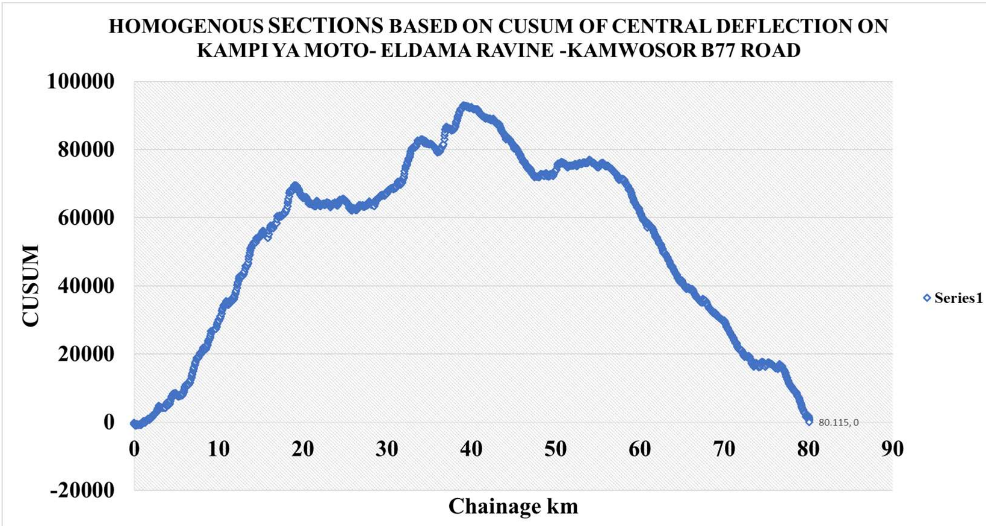

Figure 4-7: Cumulative Mean Difference from Mean (CUSUM) Values of Deflections on Bitumen Pavement of the Kampi ya mot-Eldama Ravine- Kamwosor (B77) Section

The computed CUSUM value is graphically presented in Figure 4-7, indicates that the existing bitumen pavements on the project road have the following homogeneous sections: -

- Km 0+000 - Km 18+000
- Km 18+000 - Km 30+000
- Km 30+000 - Km 40+000
- Km 40+000 - Km 80+100

The FWD data is summarized in homogenous sections, as shown in table 4-23.

Table 4-23: Deflections data for Homogeneous Sections on sub-network

HS	Length (Km)	d1	d2	d3	d4	d5	d6	d7	d8	d9
Km0-18	18.0	958	701	540	232	128	86	65	55	47
Km18-30	12.0	804	574	429	170	95	66	50	44	35
Km30-40	10.0	911	657	493	204	118	81	62	54	45
Km40-80.1	40.1	667	434	303	117	79	60	49	43	36

The mean normalized deflections for the homogeneous section were calculated, and the results are shown in Table 4-24

Table 4-24: Mean Normalized deflections for Homogeneous Sections on sub-network

Road ID	HS	Length (Km)	nd1	nd2	nd3	nd4	nd5	nd6	nd7	nd8	nd9
B77	Km0-18	18.0	943	6356	4238	821	8	78	511	427	46
	Km18-30	12.0	792	5205	3369	600	6	60	397	337	35
	Km30-40	10.0	897	5954	3871	721	7	75	495	418	44
	Km40-80.1	40.1	657	3930	2377	412	5	55	385	331	35
	Mean		**822**	**5361**	**3464**	**638**	**6**	**67**	**447**	**378**	**40**

Based on the mean normalized deflections for homogenous sections of the project road, higher mean defections were encountered between km 0 – 18 and the least at km 40-80.1. This means the road was weaker between km 0-18 compared to km 40-80.1.

ii. Characteristic Deflection, D90

The characteristic deflection, D_{90}, is a required input for calculating the existing pavement's Equivalent Modulus, Eq. This deflection was determined using the expression given below: -

$$D_{90} = D_m + 1.3s$$

Where:

D_m is the mean deflection, and

s is the standard deviation.

The characteristic deflection of the homogenous sections of bitumen pavements on the project road is shown in Table 4-25.

Table 4-25: Characteristic Deflections, D_{90}, of Homogeneous Sections of Bitumen Pavements on Project Road

Homogenous Section (Km - Km)	Length Km	Mean Deflection, D_m (µm)	Standard Deviation (µm)	Characteristic Deflection, D_{90} (µm)
Km0-18	18.0	1492	494	2134
Km18-30	12.0	1200	426	1754
Km30-40	10.0	1387	472	2001
Km40-80.1	40.1	910	260	1248

The deflection levels for km 0-18 and km 30-40 were too high, with 2134 µm and 2001 µm, respectively. This was followed closely by 1754 µm and 1248 µm, represented in km 18-30 and 40-80.1. The higher deflection means a poor surface condition. Thus, the structure design of the project road was inadequate.

4.4.4. Pavement analysis and design

(i) Introduction to pavement analysis and design

Pavement analysis was carried out to determine pavement structural response parameters such as pavement and subgrade moduli, critical pavement layers, and overlay requirements. The required pavement analysis parameters included the existing pavement structure derived from pavement logging and design traffic loading in determining the above parameters.

(ii) Pavement and subgrade layer moduli

The daily equivalent standard axle (DESA) obtained from the traffic surveys and other design parameters, as aforementioned in chapter three, were considered during data input for RoSy design analysis for pavement and subgrade moduli calculation, and the results were tabulated in Table 4-26, as shown.

Table 4-26: Pavement and subgrade layer Moduli for Homogeneous Sections on sub-network

Road Section	**HS**	**Surfacing Elastic Modulus (MPa)**	**Base Elastic Modulus (MPa)**	**Subbase Elastic Modulus (MPa)**	**Subgrade Elastic Modulus (MPa)**	**Critical pavement layer**
Kampi Ya Moto - Kamwosor Road (B77)	Km 0-18	3668	575	175	110	3
	Km 18-30	3512	595	137	159	3
	Km 30-40	2705	647	170	132	3
	Km 40-80.1	4022	785	212	393	3
	Mean	**3476**	**650**	**173**	**199**	**3**

The results showed lower elastic modulus between km 0-18, km 18-30, and km 30-40. The decrease in the stiffness modulus resulted in pavement damage. In addition, the subbase elastic modulus was also found to be too low across the homogeneous sections, indicating that the subbase material could not provide sufficient support to the upper layers. Similarly, the subgrade material was found to have a lower elastic modulus between km 0-18.

The critical pavement layer of the entire road was 3, as indicated in table 4-26. From the Elastic modulus, the overlay requirements for various homogenous sections to strengthen the road surface were obtained and tabulated in Table 4-27

Table 4-27: Overlay Requirements for Various Homogeneous Sections on sub-network

Road ID	HS	7 -Year Overlay	10- Year Overlay	15-Year Overlay
B77	Km0-18	55	70	85
	Km18-30	75	90	105
	Km30-40	75	90	105

Road ID	HS	7 -Year Overlay	10- Year Overlay	15-Year Overlay
	Km40-80.1	80	90	110

Note: For thicknesses more significant than 60 mm, the overlay material is DBM; for thicknesses less than 60 mm, the overlay is Asphalt Concrete Type I.

The AC surfacing had moduli values that conform to AC type II. In contrast, Moduli values for the GCS base and HIG subbase did not meet the minimum threshold indicated in Road Design Manual Part III. Therefore, the native subgrade material lies mainly in subgrade class S2. The minimum and maximum overlay requirements for a 7-year design period were 55 and 80 mm, respectively, with an average of 73 mm. For a 15-year design period, the minimum and maximum overlay requirements were 85 and 110 mm, respectively, with an average of 103 mm.

Despite numerous maintenance activities within the project road, the analysis has shown that the pavement structure along Kampi ya Moto - Eldama Ravine – Kamwosor has reached a point where a severe rehabilitation process is highly needed. This is based on the results of the residual life of the pavement that varies from section to section, with the lowest having zero. From the visual survey, it was noted that most of the sections on the carriageway were damaged, thus characterised by defects like concentrated potholes, emerging cracks, and hanging shoulders that lead to the narrowing of the pavement surface. It was also noted that the drainage channels were undefined, and where the drainage system was identified, they were not well maintained.

Further, it was observed that in some sections, especially along the Eldama ravine – Kamwosor, the trenching results showed that the CBR of the subgrade was found to be lesser than the required subgrade CBR, which is supposed to be 8% and above.

It is now confirmed that the lack of a defined drainage system abundantly contributed to the deterioration and failure of the pavement of the study road. Also, the discussion on inadequate drainages has been extensively elaborated in many research documents; thus, one of the significant interventions to be considered to enable pavement life to achieve its purpose is to provide adequate drainage channels.

Despite well-graded pavement material satisfying appropriate pavement properties needed in a specific area/section, water significantly contributes to pavement failure. No matter what transpires, it largely affects the existing material properties of the pavement layers, thus leading to fast deterioration even before the pavement structure serves its purpose. Therefore, the provision of suitable materials that may fit the specific area or section of the road, based on the availability of the material and climate of the site, should be made as one of the most prioritised aspects in road construction, rehabilitation and maintenance.

Therefore, it is necessary to provide adequate interventions to maintain the road's serviceability function and promote safety.

In summary, the daily equivalent standard axle for the road was found to be 134.92, as shown in Table 4-15. The calculated design traffic loading for a 15-year design period was approximately 1.1 million cumulative equivalent standard axles, which, according to RDM Part III, falls in class T4. The proposed pavement structure type for the project road for future rehabilitation is Type 7, considering subgrade S2 as the native subgrade, while the top and bottom are to be improved to S4 with a thickness of 300mm. The base and subbase layers are GCS of 150mm and cement-improved material of 150mm, respectively.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

As per the assessment conducted for Kampi ya moto –Eldama Ravine- Kamwosor road, it is concluded that:

i. The project road exhibits various types of pavement distress, including potholes, cracks, depressions and edge damage. The severity of the distresses was assessed based on road roughness, rutting and pavement condition index, rated as fair.

ii. The leading cause of pavement damage was inadequate drainage, which raised the moisture levels in the underlying layers. This led to the weakening of these layers and a subsequent reduction in their ability to provide adequate support to the upper layers.

iii. The lower elastic modulus in homogeneous sections indicates that the pavement has deteriorated. Therefore, the proposed intervention will prioritize the homogeneous sections with much damage. An excessive maintenance rate is proposed for the project road based on the homogeneous sections to restore the road to its functional and structural condition.

5.2. Recommendation from this study

As per analysis, the recommended intervention based on a 7-year overlay design will be proposed for implementation as follows:

a. Carry out repairs on potholes, shoulders, and failed sections as a short-term intervention
b. Maintain all the existing drainage, and in a case where the drains are not defined, drainage should be designed to enable the free flow of water.
c. Based on overlay requirements, the proposed long-term intervention is to lay a 50 mm (0/20) asphalt concrete Type I binder course.
d. Apply single seal surface dressing 10/14 mm pre-coated chippings as routine maintenance.

5.3. Recommendation for further research

Based on the results and analysis, it is evident that drainage systems significantly impact the performance of pavement. All the other components associated with the pavement structure are affected without proper drainage channels. To ensure the durability of the pavement structure, it is highly recommended to emphasise the types and adequacy of drainage systems on paved roads in specific locations.

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APPENDICES

APPENDIX 1: TRAFFIC COUNT DATA

Census Station	Lane	Road Name	Date	Time	bicycles	Motorbikes	cars	matatu	Small trucks	bus	MGV	HGV R	HGV A	OTHERS
Chepketeret	LHS	Nyaru-Kamwosor	16/10/2018	Day	0	23	66	33	9	1	16	1	0	1
Chepketeret	LHS	Nyaru-Kamwosor	17/10/2018	Day	1	99	73	106	22	1	32	3	1	2
Chepketeret	LHS	Nyaru-Kamwosor	18/10/2018	Day	2	137	78	123	14	2	34	4	0	6
Chepketeret	LHS	Nyaru-Kamwosor	18/10/2018	Night	0	10	35	21	1	0	4	1	0	0
Chepketeret	LHS	Nyaru-Kamwosor	19/10/2018	Day	1	149	103	133	4	1	21	7	0	1
Chepketeret	LHS	Nyaru-Kamwosor	20/10/2018	Day	5	146	158	177	5	4	16	8	0	4
Chepketeret	LHS	Nyaru-Kamwosor	20/10/2018	Night	0	20	33	9	0	0	0	0	0	0
Chepketeret	LHS	Nyaru-Kamwosor	21/10/2018	Day	1	140	104	108	6	1	10	2	0	0
Chepketeret	LHS	Nyaru-Kamwosor	22/10/2018	Day	3	149	90	151	6	1	18	7	0	3
Chepketeret	RHS	Nyaru-Kamwosor	16/10/2018	Day	1	48	33	36	11	2	11	1	1	0
Chepketeret	RHS	Nyaru-Kamwosor	17/10/2018	Day	3	108	91	73	20	1	44	4	3	1
Chepketeret	RHS	Nyaru-Kamwosor	18/10/2018	Day	2	141	89	136	14	2	42	8	1	2
Chepketeret	RHS	Nyaru-Kamwosor	18/10/2018	Night	0	14	23	10	8	0	8	0	0	0
Chepketeret	RHS	Nyaru-Kamwosor	19/10/2018	Day	2	130	131	139	5	0	28	14	2	1
Chepketeret	RHS	Nyaru-Kamwosor	20/10/2018	Day	3	15	187	174	9	4	25	18	1	1
Chepketeret	RHS	Nyaru-Kamwosor	20/10/2018	Night	0	24	30	14	0	0	0	1	0	0
Chepketeret	RHS	Nyaru-Kamwosor	21/10/2018	Day	0	139	175	105	9	4	18	5	0	1
Chepketeret	RHS	Nyaru-Kamwosor	22/10/2018	Day	4	169	102	137	6	0	26	9	0	2
Total					**28**	**1661**	**1601**	**1685**	**82**	**24**	**353**	**93**	**9**	**25**

APPENDIX 2: AXLE LOADING DATA

Section ID	TYPE	Count of Index	Avarage of 1st Axle	Avarage of 2nd Axle	Avarage of 3rd Axle	Avarage of 4th Axle	Avarage of 5th Axle	Avarage of 6th Axle	Total Axle	Min Equivalent Axle Load factor	Max Equivalent Axle Load factor	Avarage Equivalent Axle Load factor
Nyaru-Kamwosor	Bus	3	4337	6890					11227	0.31	0.67	0.62
	MGV	100	3588	5823					9411	0	15.94	1.54
	HGV R	60	4896	6054	5656				16606	0	19.8	3.24
	HGV A	3	6160	9097	9080	5943	9203	6705	46188	5.63	13.72	8.54

APPENDIX 3: FWD DATA

Road No.	RoadFromChainage	RoadToChainage	Lane	Section	IRS	Chainage (m)	Reinforcement	7 Yr Overlay	10 Yr Overlay	15 Yr Overlay	DESA	Measurement Date	ResLifeNow (Years)	Reinforcement (mm)	Critical Layer	Air Temp.	Surface Temp.	Pavement Temp.	Pressure(Kpa)	Layer Th.1	Layer Th.2	Layer Th.3	Surfacing (Elastic Modulus)	Base(Elastic Modulus)	Subbase(Elastic Modulus)	Subgrade (Elastic Modulus)	nd1	nd2	nd3	nd4	nd5	nd6	nd7	nd8	nd9	Chainage (m)	CUSUM
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]