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Original Research Article

Pavement Evaluation of Kampi Ya Moto - Eldama Ravine - Kamwosor B77 Road

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Abstract: Assessment of pavement performance is essential in determining the serviceability and structural state of the pavement structure. Pavement failure and deterioration always commence immediately after the road has been opened to traffic. Several factors contributing to pavement failure and damage include traffic load, soil, environmental, economic, and stress distribution factor. Therefore, flexible pavement failure and deterioration are well-defined by alligator cracks, concentrated potholes, ruts, settlement, and localised depression. Pavement evaluation determines highway sections' functional and structural conditions for frequent monitoring or planning for maintenance. Kampi ya Moto-Eldama Ravine-Kamwasor (B77) road is a Kenya National Highways, Authority (KeNHA) class B road constructed in 2008. The length of the road is approximately 79.5 Km. However, the pavement had numerous distress features which developed even before the design life of the pavement was attained. The study, therefore, concentrated on evaluating the performance of the pavement to identify the type and level of severity of pavement distress; to establish a surface condition by measuring the level of roughness and rut depth and to perform a visual evaluation survey of the existing flexible pavement distresses; to identify the reason of structural and functional failures on Eldama Ravine-Kamwosor, and finally, to establish the residual structural strength of the existing flexible pavement and suggests the most viable maintenance intervention measures.

Keywords: Pavement evaluation, Deterioration, Deformation, failure, serviceability, Drainage layers, maintenance, flexible pavement, pavement structure.

1. INTRODUCTION

1.1 BACKGROUND

Kenya is a developed country with more than 10,000km of paved roads. Many roads within the country have pavement failures that must be either maintained or rehabilitated. The process of flexible pavement failure and deterioration of these roads commences immediately after they have been opened to traffic. It begins slowly in such a way that it may not be noticeable, and over time it hastens. To reduce early pavement failure and deterioration, it is essential to come up with the best method for road preparation, design, construction, and maintenance. This can be achieved by frequently testing and inspecting flexible pavement that has earlier deteriorated or failed.

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

1.2 Problem statement

Pavements Structure are very complex, and they have a mutual connection to the following: the

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specific area's environmental condition, construction style, traffic axle loads, maintenance process, and finances. Flexible pavements deteriorate because of increased traffic loading, poor construction styles, absence of quality drainage structures, environmental factors, and substandard design quality. Due to the dynamic nature of pavements of the road, the problem relating to pavement structures is composite. The components of the pavement of the road worsen slowly, and to keep these elements of the road pavement in an excellent motorable state, it requires funds to spend in terms of the maintenance process. But the maintenance process will only be perfect if the pavement evaluation of the road is well conducted.

1.3 Objectives

The general objective of this study is to establish the contributing factors of structural and functional failures on the existing pavement of Kampi ya moto- Eldama Ravine – Kamwosor Road, a stretch of 79.5 kilometres. To achieve the general objective, the following specific objectives were considered. They include:

i. To ascertain whether drainage condition contributes to pavement failure.
ii. To establish whether material properties contribute to pavement failure
iii. To determine whether annual traffic loading accelerates pavement deterioration.
iv. To scope maintenance work standards that will reinstate the road pavement.

2. LITERATURE REVIEW

2.1 Theoretical review of pavement performance

Pavement can decline its functionality majorly due to the occurrence of surface distresses like potholes, cracks, depressions, and ruts; it was stated that transportation engineers are required to identify the original cause of the failure of the flexible pavement before engaging themselves in maintenance actions. It has been established that failures and deterioration of flexible (bituminous) pavements are mainly engendered by reasons/groups of causes. It has been seen that other distresses of the pavement are always omitted when engaging in maintenance actions. In contrast, a few parameters, such as pavement cracking, pavement rutting, and unevenness index, are the only ones being considered.

2.2 General review of pavement performance

2.2.1 Sources of pavement deterioration

According to Woods and Adcox (2004), They considered that pavement failure might be characterised by the following: construction material failure, functional failure, structural condition failure, or unification of the above three factors. They define structural failure as the absence of the ability of pavement to support or carry loads. Further, they termed functional failure as the failure that may designate the deterioration of the pavement's actual function. Finally, materials failures transpired due to the ruin or loss of material on the road carriageway/pavement surface. Improper grading tests underneath pavement materials and unsuitable surfacing materials may lead to material failures.

Harischandra (2004) investigated and noted that pavement distresses such as cracks (alligators cracking), depressions, hanging road edges, potholes, ruts, and corrugation are significant for road pavement defects, and also stressed that road traffic, age of the pavement, geometry of the road, climate, drainage systems, quality of construction, materials of construction and maintenance strategies play a significant role in contributing of deterioration process of the road pavement.

S. K. Mwea, T. M. Nyang'au & P. K. Matheri (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 categorised bituminous pavement failures in Kenya as one of the discomforting things for road users. As a result of this discomfort, road users suffer an increase in vehicles operation costs, an increase in the price of transportation of goods and services, increased road accidents leading to people losing their lives and properties, delayed goods delivery to different destinations, delayed journeys 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) in his study stated that traffic loading, unsuitable drainage, heaving subgrade soils, and use of poorly graded materials in construction are the leading causes of failures of pavement. 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 minimise early pavement failures and deterioration.

Shiferaw, G. W, & Dessalegn, G. A. (2019) pointed out that the main pavement failures that frequently affect paved roads are cracks such as fatigue cracking and alligators 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.

2.2.2 Pavement layers

Sikdar *et al.*, (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 deformation of either surfacing, materials of the pavement; (subbase and base) or the underlying subgrade, or a combination of all these mentioned. To come up with 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 recognised, 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 depression caused. It also decreases road safety and road user comfort.

2.2.3 Advantage of drainage in pavement performance

Kaare, Kuhi, and Koppel (2012) 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. Tiza, M. T, Iorver, V & Iortyom, E (2016) emphasised 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 the excessive water content in the pavement underneath layers (base, sub-base, and sub-grade soils).

Magdi (2014), in his study, 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 4 number reasons that link to the premature deterioration 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 minimise road deterioration.

2.2.4 Causes of failures in Flexible Pavement (FP)

a) Use of substandard quality materials for construction
b) Application of hefty traffic on the wrong class of road.
c) Climatic changes
d) Poor drainage
e) Poor artistry and supervision during road construction
f) Maintenance policy
g) Frequent maintenance of road
h) Inadequate geotechnical tests

2.3 Synthesis of Literature review

Poor drainage, lack of proper maintenance, climate change, and excessive traffic loading are critical factors in pavement failure and deterioration. Suitable design and installation of drainage systems will assist in minimising the problem of pavement failures and damages. Rainwater that always stands or finds its way out of the drainage through the road carriageway due to improper drainage system installation will eventually flow freely to its final destination.

Proper maintenance of these paved roads is 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 will apply a different engineering way of taking care of the issue at hand. Also, without proper supervision and coordination between the teams undertaking maintenance exercises will result in substandard outcomes at the contract’s completion period. Therefore, once the problem of the existing pavement failure and deterioration is found through the process of pavement evaluation, a proper maintenance policy must be put in place to develop an efficient maintenance process. As for climate change, engineers should not assume the methods and materials that are supposed to be used when undertaking construction works in a different part of the country.

3. METHODOLOGY

3.1 Introduction

Various methods such as surface condition survey, determination of Pavement Condition Index (PCI), pavement structural condition surveys, and analysis of pavement evaluation were conducted based on the study’s objective.

3.1.1 Visual Survey

The visual survey was conducted to evaluate the road drainage systems and observe whether there are 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.

3.1.2 Surface Condition Surveys

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).

3.1.2.1 Collection and Quantification of Surface Distress Data

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

3.1.3 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 and establish the most viable maintenance intervention measures. The tasks under 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.

4. RESULTS AND DISCUSSION

4.1 Introduction

This chapter analyses the result obtained from the exercise following the method from the Chapter above.

4.2 Visual condition of the Study Area.

The minor distress observed that did not reflect on the structural state of the road included bleeding of the AC surface, as depicted in Figure 1. The primary structural distresses observed on the road have numerous potholes, eroded edges, block cracking, depression, deformation, rutting, and poor drainage, as depicted in Figure 2.

Figure 1: Minor distress and lack of drainage system on Kampi ya Moto-Kamwosor Road

Figure 2: Major distress and lack of defined system

4.2.1.1.1 Major distress associated with deformation

a) Roughness

In this research, International Roughness Index has been defined to be engendered from numerous apparatus. They include pavement structure deformation, cracking, rutting, potholes, and environmental aspect. These apparatuses, when combined, leds to the discomfort of the road user, especially the driver when using the road. This can be defined in equation (i) as follows.

$$IRI= RI_{(sc)}+ RI_{(c)} + RI_{(r)}+ RI_{(s)} + RI_{(e)} \text{ .... (i)}$$

Where:-$RI_{(sc)}$-: roughness index (Structural deformation cracking, $RI_{(c)}$-: Roughness index (cracking), $RI_{(r)}$-: Roughness index (rutting), $RI_{(p)}$-: Roughness Index (pothole), $RI_{(e)}$-: Roughness Index (Environmental)

From equation (i), it is clear that the road roughness is directly proportional to pavement structure deformation, cracking, rutting, potholes, and environment.

Road structure layers involve Surfacing, Base, Subbase, and Subgrade. In pavement, we are usually interested in the vertical change in position at the surface (e.g., due to a vehicle passing). In this view, Road pavement deformation results from the sum of all the vertical strains at every point beneath the surface. Deformation in an ideally elastic material is recoverable. The passage of a too-heavy wheel will tend to deform the pavement and thus return to its normal condition when the pressure is released. The continuous stress on the pavement will grow to change the vertical appearance of the road; therefore, permanent deformation of the pavement automatically outgrows. Strain is defined at a particular point, whereas deformation is defined as the change itself. Thus, in the flexible pavement, the stress and the strain will gradually move parallel since deformation will occur once the two are defined. This is illustrated in fig 3 as shown below.

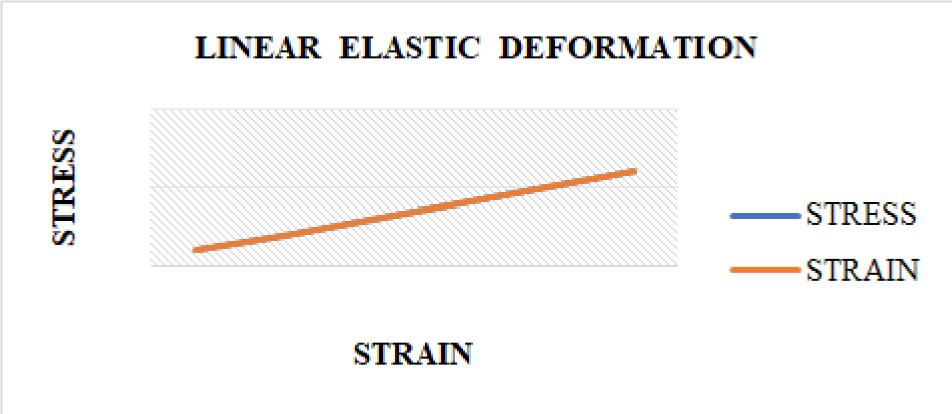

Figure 3: Illustrate that linear elastic deformation grows gradually in strain and stress

Once the pavement deformation is experienced, the user's road comfort is affected. Therefore, Road roughness structural deformation ($RI_{(sc)}$) results from all underneath layers being under stress. Thus $R_{(sc)}$ can be further broken down to the following as shown in equation (ii):

$RI_{(sc)}$ = SLD +BLD+ SBLD ……………………….. (ii)

Where:- SLD- Surface layer deformation BLD- Base layer deformation and SBLD- Sub-base Layer deformation

Numerous types of cracks will lead to pavement deformation thus, roughness. Some of the cracks include longitudinal and transverse cracking, corrugation and shoving, depression, and Potholes

b) Pothole Progression

Pothole progression on the carriageway is usually a result of cracks needing to be attended to on time. Therefore, potholes will tend to progress gradually in time unless repaired. This can be illustrated in Fig 4, as shown below.

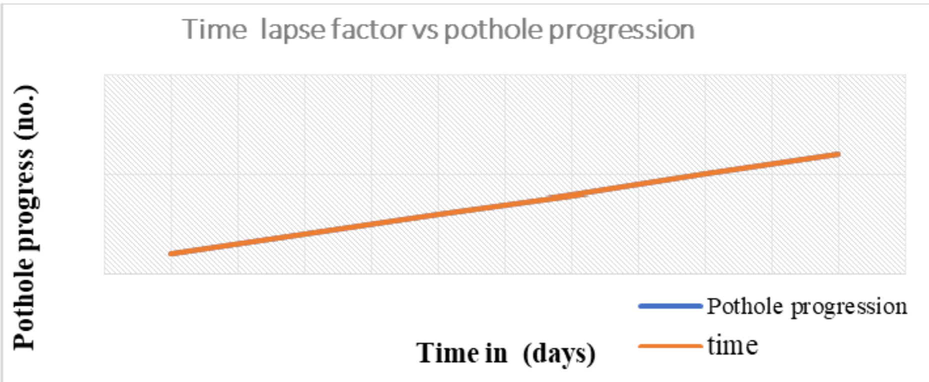

Figure 4: Pothole progression with time

The deformation, which is terms as Roughness caused by Potholes ($RI_{(p)}$), can also be represented in equation (iii) as follows.

$RI_{(p)} = A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9$ …… (iii)

Whereas

$A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8, A_9$:- $Pothole_1$, $Pothole_2$ …………………..

c) Rutting

Rutting is one of the significant components of the Roughness index. It is recognised as a minor depression along the wheel paths in a pavement. It is classified into two categories that is Mix rutting and Subgrade Rutting.

There are four components associated with the depth of rutting. They include Initial densification (RDO), Structural deformation (RDST), plastic deformation (RDPD), and wear from studded tires (RDW), which can be illustrated mathematically in the following equation (iv), as shown below.

RD=RDO+RDST+RDPD+RDW ……………… iv

From the survey undertaken on the study area, the rut depth was collected, and the measurement was noted down, as shown in Table 1. From the analysis, the road section means Rut was found to be 4.1mm; this indicates that the road is rated as being of Low Severity.

Table 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	4.1
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	

4.2.1.1.2 Roughness measurement

Roughness data collected in m/Km for the road sections are summarised in Table 2.

Table 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 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

From the summary of the data provided from the field, it was noted that the international Roughness of the entire road had an average IRI of 4.2 m/km. Therefore, the road roughness, according to the road roughness rating chart in table 3, is considered FAIR. This indicates that for the study road to be rated as fair, it is because some sections were less deformed compared to the other section. However, an IRI of 4.2m/km specifies that the entire road structures need to be improved for it to fit traffic of class 4.

4.3 Determination of Pavement Condition Index of the study road.

The Summary of PCI values and ratings for the Kampi ya moto-Eldama Ravine- Kamwosor road sections are presented in Table 5.

Table 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 5: Summary of Findings from Surface Condition Survey

Road Section	Average IRI	Average Rut	PCI Value	Rating
Kampi Ya Moto - Kamwosor (B77)	5.4	4.1	55	Fair

Table 5 above shows that the PCI value of the study road was 55, rated as FAIR. Therefore, the findings of the PCI of the study road were not sufficient for road class B.

4.4 Drainage Distress

Drainage distress will eventually be pronounced 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 parched from water, 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.
- Water seepage from attached sections.
- Filtration of Surface water through existing cracks and joints.
- Capillary action caused whereby moisture rises above the groundwater table.

4.5 Drainage Systems

Lack of subsurface drainage in the pavement structure can lead to secondary damage, such as the early formation of cracking or swelling of the flexible pavement materials. This will reduce the life span of the pavement that might have been designed to cover a certain period before any defects appear.

The research will concentrate on two water sources to ascertain the reason for pavement deterioration in the early stages of the pavement life cycle. These sources include infiltration and subterranean water. As far as pavement drainage is concerned, infiltration is the most crucial source that frequently leads to severe deterioration of most pavement structures. Furthermore, the study road has different climatic conditions in which the section experiencing cold weather have been characterised by a very high-water table of almost 55%. For instance, a round kilometre 38 to 63 of the research section is described by residential buildings and concentrated forests with an existing dam that tends to collect storm water for the population within the project area.

During the visual survey, there were some sections where water oozed through the pavement. This indicated that the water table was too high, thus making the pavement around that area unstable. Also, perched water in most places, especially between Kilometer 55 to 60, was industrialised under pavements due to the reduced water evaporation rate from the surface.

The visual survey analysis indicated that a significant problem of this pavement failure was the existence of improper drainage. In areas with a high-water table, there was a need to introduce a free-flow path underneath the pavement surface. In these areas, sub-drainage facilities are estimated to be very important. These sub-drainage facilities considered in this research that are to be introduced will enable the existing water trapped beneath the pavement surface to control the process of infiltration by either diverting or moving away water that will tend to enter the pavement surface through existing cracks, either when it is raining or surface flow. Furthermore, it will enable managing underground water movement by either reducing water moving into the pavement layers, including base, subbase and top/bottom subgrades, or lowering the water table, especially at the sections prone to the high-water table. Therefore, it is necessary to perform both sub-drainage functions regularly, and sometimes the two may be combined into a single sub-drainage system to achieve excellent performance regarding drainage.

For instance, Darcy's empirical Law expresses water flow through the soil. Furthermore, the Law states that the velocity of the flow of water is directly proportional to the hydraulic gradient, as shown in equation (i) below.

$v=ki$ ……………………………….……… (i)

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

$Q=kiA_2$ …………………………………… (ii)

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 soils and hydraulic slopes. Though, generous margins have been used to permit turbulent flow in emerging conditions for subsurface drainage. The requirements of these underground 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 that are prone to saturation with water on the pavement structure (drainage layers).

4.5.1 Factors influencing Permeability

i. Value/Rate of Permeability.
ii. Significance of pore fluid and temperature.
iii. Influence of grain size.
iv. Impact of void ratio.
v. Effect of structure and classification of pavement layers.

4.5.1.1 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 wrong 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.

4.5.1.2 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, when the base and subbase are saturated, excess rain tends to run off as surface drainage.

4.5.1.3 Frequency of Flow

For the adjusted drainage channel parallel to the paved surface of the road to be sufficient, it must be constructed/ created to handle the maximum flow rate possible. As for the project road, the side drains were not well-defined. As a result, water tends to cross over the road. Table 6 shows the suggested range of drainage factor values (DF) that one can use when evaluating the condition of the drainage.

Table 6: The suggested range of drainage factor values

Drain type	Drainage Condition	
	Excellent -DF_{min} (Defined drains)	Very poor-DF_{max} (Undefined drains)
Fully lined and linked	1	3
Surface lined	1	3
V-shaped -Hard	1	4
V-shaped – soft	1.5	5
Shallow-Hard	2	5
Shallow-Soft	2	5
No drain- but it is required	3	5
No drain –but not required	1	1

The drainage factor presented in Table 6 is a continuous variable whose values range between 1 to 5, representing excellent and very poor, respectively. Here the drain type is defined, and the condition of the drain is given in terms of factors. From the table, the drainage condition for excellent can be narrowed down to defined drains and very poor to undefined drains, which is tabulated in Table 7.

Table 7: Summary description of the drainage condition

Description	Drainage Condition
Defined Drains	Good
Undefined drains	Bad

From the visual survey, analysis shows that most of the road drainage was undefined. Thus, one could identify the change in the water path. As a result, most of the water was assumed to pass above the road carriageway. For an instant, the photographs attached above in figs 4-1 and 4-2 show the road carriageway with an undefined drain. However, as a result of the investigation obtained from the field works, it is clear that the road drains condition was categorised as BAD.

4.6 Structural Condition Survey

4.6.1 Design traffic loading

Based on historical information and Traffic studies carried out in the region, the estimated daily ESA and projected traffic loading are as per table 8.

Table 8: Design traffic loading for road sections

Daily ESA in 2020	Projected Cumulative ESA for seven years (2021-2027)	Projected Cumulative ESA for ten years (2021-2030)	Projected Cumulative ESA for 15 years (2021-2035)
134	0.4	0.6	1.1

4.6.2 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. Trenching was performed at various intervals**.** Below are the results data of the tests

Table 9: Trenching Intervals

Road Name	Length	Average Trenching Intervals (Km)
Kampi ya Moto – Kamwosor Road (B77)	79.1	16

Table 10: Trenching data

Road ID	Chainage	Layer Ref	PM	PI	CBR	SG class
Kampi Ya Moto – Kamwosor Road (B77)	Km 12+640 LHS	NSG	2001	23	7	S2
Kampi Ya Moto – Kamwosor Road (B77)	Km 36+500 RHS	NSG	1512	18	19	S5
Kampi Ya Moto – Kamwosor Road (B77)	Km 50+450 LHS	NSG	2304	24	6	S2
Kampi Ya Moto – Kamwosor Road (B77)	Km 65+400 RHS	TSG	1892	22	11	S3
Kampi Ya Moto – Kamwosor Road (B77)	Km 65+400 RHS	BSG	2231	23	6	S2

Table 11: Summarized Coring Test Results

Chainage	Average Core Thickness, mm	Average Core Density, GCC	Average Core air voids %	Average Binder Content %
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
65+400 RHS	50	2.2	4.8	5.8

Table 12: Logging Findings

Logging Points	Surfacing Material & Thickness, mm	Base Material & Thickness, mm	Subbase Material & Thickness, mm
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 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*

4.6.3 Subgrade Material Test Results

Tables 13 show the results of the existing subgrade layer.

Table 13: 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 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,*

4.6.4 Deflection measurement using FWD

4.6.4.1 Introduction to Deflection Measurement Using FWD

Deflection measurements in this report were conducted using Primax FWD, which meets the requirements of ASTM D4694 – 09: and the test method defined in ASTM D 4695-96. The deflection measurements were conducted on the Outer Wheel Path (OWP) at intervals of approximately 100 m. Readings were taken for nine geophones at each drop point.

4.6.4.2 FWD Data Normalisation and determination of homogenous sections

Normalisation 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 normalised 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 computation and graph. The mean normalised deflections for the homogeneous areas are shown in Table 14.

Table 14: Mean Normalized deflections for Homogeneous Sections on sub-network

HS	Length (Km)	nd1	nd2	nd3	nd4	nd5	nd6	nd7	nd8	nd9
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**

The computed CUSUM value is graphically presented in Figure 4-5. It 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

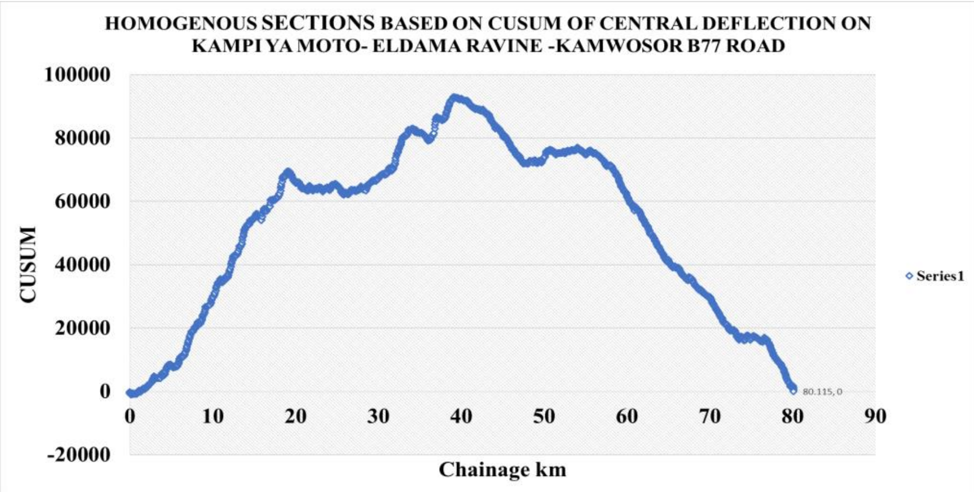

Figure 0-5: Cumulative Mean Difference from Mean (CUSUM) Values of Deflections on Bitumen Pavement of the Kampi ya mot- Eldama Ravine- Kamwosor (B77) Section

4.7 PAVEMENT ANALYSIS AND DESIGN

4.7.1 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.

4.7.2 Pavement and subgrade moduli

The pavement and subgrade moduli are shown in Table 15, while the overlay of the strengthening requirement is in Table 16.

Table 15: Pavement and subgrade layer Moduli for Homogeneous Sections on sub-network

HS	Surfacing Elastic Modulus (MPa)	Base Elastic Modulus (MPa)	Subbase Elastic Modulus (MPa)
Km 0-18	3668	575	175
Km 18-30	3512	595	137
Km 30-40	2705	647	170
Km40-80.1	4022	785	212
Mean	**3476**	**650**	**173**

Table 16: Overlay Requirements for Various Homogeneous Sections on sub-network

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

Generally, the Daily ESA for the road was found to be 134, as shown in the summary table 8, with a forecasted design traffic loading for a 15-year design period of approximately 1.1 million cumulative equivalent standard axles that follow in Class T4.

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.

5. CONCLUSION AND RECOMMENDATION

5.1.1. Recommendation for Industry

As per the assessment conducted for Kampi ya moto –Eldama Ravine- Kamwosor road, it is concluded that the road is structurally deficient for T4 traffic. Therefore, primary intervention is supposed to be prioritised to save the road from more damage, thus becoming unsuitable for motorised use.

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

a. 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.
b. Carry out repairs on potholes, shoulders, and failed sections as a short-term intervention
c. Lay 50 mm (0/20) asphalt concrete Type I binder course as a long-term intervention.
d. Apply single seal surface dressing 10/14 mm pre-coated chippings as routine maintenance.
e. Widening and reinstatement of shoulders, especially where the road is narrow and with no shoulders, respectively.

5.1.2 Recommendation for further research

From the results and analysis, drainage systems were seen to have more impact on pavement performance. Without good drainage channels on the paved road, all other components associated with the pavement structure get affected. Therefore, it is recommended that more emphasis be put across, and further research on the types and adequacy of drainage systems on the paved road in specific locations be conducted to ensure the pavement structure's durability.

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