Pavement Evaluation of the Nairobi Eastern By-Pass Road

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ABSTRACT

Pavement evaluation is fundamental in determining the functional and structural conditions of the pavement structure and its need for strengthening. Functional conditional pavement evaluation indicated that the pavement was not satisfactory owing to the high values of the pavement surface roughness measured in International Roughness Index (IRI) in some sections, which were in excess of the recommended minimum of IRI of 3.0 mm/m limit. Three traffic analysis scenarios were simulated and the RoSy analysis and design software was used in the analysis. The CUSUM method was used to plot the FWD pavement surface deflections. The Falling Weight Deflectometer (FWD) deflection measurements indicated that the pavement structure exhibits varying characteristics from strong pavement to moderate pavement as the deflections values fluctuated along the pavement length. The study established that the by-pass road has a remaining service life of more than fourteen (14) years in almost the entire study stretch. The study found out that the traffic loading influenced the performance of the pavements because as the traffic level increased from traffic scenario I to III there was a corresponding increase in the overlay thickness required and a decrease in the remaining service life. The elastic moduli of the pavement layers were stable and hence satisfactory to withstand the traffic loadings. To reduce the high pavement surface roughness a single seal of surface dressing with 10/14 class 1 chippings and 80/100 penetration grade bitumen binder for pavement surface treatment was recommended.

KEYWORDS: *FWD deflection testing, CUSUM method, IRI, Remaining service life, Elastic Moduli.*

1. INTRODUCTION

As part of a research at the University of Nairobi on the evaluation of flexible pavements in Kenya, the pavement structure of Nairobi Eastern By-Pass Road was assessed, by conducting traffic data collection and analysis, FWD deflection testing, measurement of rutting and roughness using the Road Laser Profiler, and review of the available design reports and as built drawings, to determine the functional and structural pavement conditions.

Flexible pavements are made of three main courses; surfacing course made of bituminous material, the base and the sub-base courses built on a natural or improved subgrade (Kadiyali & Lal, 2013). Ibrahim, (2012), noted that the deterioration rate of pavements is influenced by; the characteristics of engineering materials used in building, history of construction and maintenance, climatic influences and the intensity of traffic loadings. Rokade *et al*, (2010) averred that pavement deteriorations increase with the passage of time resulting in either structural pavement failure where the pavement fails to carry design loads or functional pavement failure where the pavement does not offer a smooth and comfortable riding surface hence increasing vehicle operating costs, travel time, and overall transportation costs.

It is vital that the performance of flexible road pavements is monitored and evaluated to; assess the rate of pavement damage, establish the renovation and maintenance needs, and perform proper planning of pavement maintenance and restoration activities. The pavement condition features used to assess pavement performance and the need for restoration entails: functional evaluation - pavement roughness (International Roughness Index-IRI); structural pavement evaluation - pavement surface deflections, pavement material cored samples and testing pits; evaluation of pavement surface condition - pavement defects; and evaluation of pavement safety which involves skidding resistance (Ibrahim, 2012).

The failure of flexible pavements has been prevalent in Kenya, a trend causing concern to both the government and road users. The failure of flexible pavements in Kenya results in discomfort among the road users, increased transportation costs of goods and services, increased vehicle operating costs, increased road crashes leading to loss of lives and properties, delayed cargo delivery to various destinations, long travel times as vehicles have to drive slowly on the failed sections of the pavement, high maintenance cost for vehicles; increased budgets and spending by government on pavement rehabilitation and maintenance.

2. METHODOLOGY

The steps that were followed in the evaluation of the Nairobi Eastern by-pass flexible pavement comprise of; review of existing as built drawings and project design documents, traffic survey and traffic data analysis, pavement functional and structural testing, data collection and analysis; and recommendation of maintenance and rehabilitation interventions based on the Kenya design standards and manuals.

2.1 Traffic Data Collection and Analysis

The determination of traffic loading on Nairobi Eastern by pass road was done by undertaking classified traffic counts at two stations (station A-near Thika road and Station B- near Kangundo road roundabout). The classified traffic counts were performed between 19th to 25th April 2017 at the overpass and underpass at Kangudo road (C98) at chainage EK 13+157m and at the underpass at the Nairobi-Thika Road at chainage EK 26+946m. The average daily traffic was computed from the data comprising of five-day 12-hr count and two-day 24-hr counts on 22nd April 2017 and 25th April 2017. The 12-hr counts were converted to 24-hr counts and the traffic counts were limited to commercial traffic only. The traffic data collected was analysed to determine the; Average Annual Daily Traffic (AADT), classification of the number of commercial vehicles, and Equivalent Standard Axle Load (ESALs).

Traffic data was converted into equivalent standard axles using legal limits of vehicle equivalence factors in Kenya. The cumulative ESALs were based on the average Gross Domestic Product (GDP) growth rate between 1961 and 2017. Traffic data was analysed for 14 years remaining life of the Nairobi Eastern by-pass road. Table 1 provides the three traffic scenarios that were simulated for use in assessing the performance of the flexible pavement road for different traffic loadings during the remaining design life (Infrastructure Department, 2017).

Table 1: Traffic Analysis Scenarios

Traffic Scenario	Scenario Description
I	The highest traffic loading in one direction (Lane Traffic Loading) (Station A)
II	80% of the total traffic in the two lanes (Station A)
III	100% of the total traffic in the in the two lanes (Station A)

2.2 FWD Pavement Deflections' Measurement and Analysis

The Primax Falling Weight Deflectometer (FWD) testing at the Nairobi Eastern by-pass road flexible pavement was carried out on both directions over the entire length at 100m intervals on 15th June 2017. The methodology for carrying out deflection measurements using FWD was in line with the Kenyan road design manual part V.

2.2.1 FWD Sensor Spacing

For this research, the spacing of geophones was: 0 mm, 200 mm, 300 mm, 600mm, 900 mm, 1200 mm, 1500 mm 1800 mm and 2100mm (Roads Department, 2009).

2.2.2 Surface Temperature Measurement

The pavement surface temperature was measured and recorded automatically to the FWD file. The monitoring of the surface temperature during testing was used to help the FWD operator in taking decisions to stop testing in case the pavement became very hot.

2.2.3 Analysis of Pavement FWD Deflection Data

RoSy Analysis and Design Software was used in the analysis of the FWD deflection data to determine the; pavement layers' Elastic Moduli (E), remaining service life of the pavement, and the required overlay thicknesses.

2.3 Pavement Distress Condition Survey

The Road Laser profiler was used to collect the surface distress features of the road section under study. The main distress that were monitored include: potholes, rutting, cracking, and fatigue failure. The type, severity and quantity of the distress was collected to aid in the assessment of rehabilitation needs (Roads Department, 2009).

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2.4 Pavement Surface Roughness Survey

Pavement surface roughness was measured using a Road Laser Profiler and results expressed through the International Roughness Index (IRI), in m/km, or mm/m.

2.5 Determination of Pavement and Subgrade Soil Properties

The pavement design reports and as-built reports and drawings of Nairobi by-pass road were reviewed to establish the; pavement material types, pavement layer thickness, and subgrade California Bearing Ratios CBRs.

3. DATA PRESENTATION AND ANALYSIS

3.1 Traffic Data Analysis

The total daily traffic loading in traffic count station A (direction Thika road to Kangundo Road, A to B) was 7,448 ESALs while the total traffic in the opposite direction (B to A) was 8,522 ESALs as provided in figure 1.

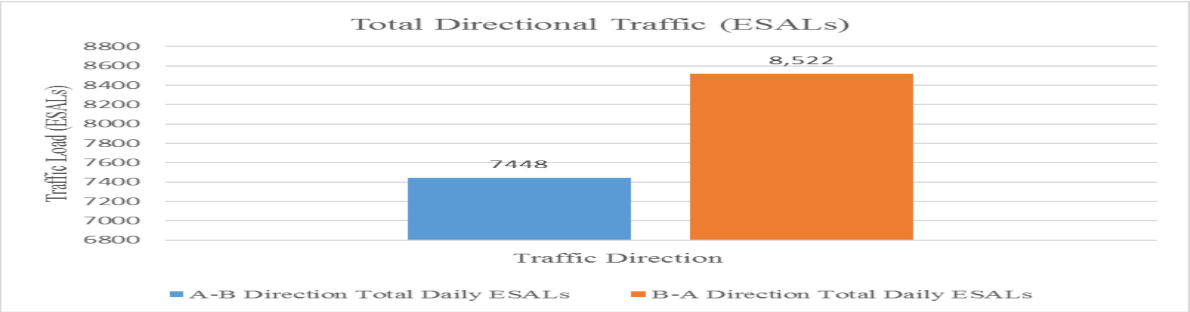

Figure 1 : Total Directional Daily Traffic Load (ESALs)

Table 2 shows the three traffic analysis scenarios (I, II and III) that were used in the analysis of the traffic influence on the performance of the pavement.

Table 2: Equivalent Standard Axle Load (ESAL) for Traffic Analysis Scenarios

Traffic Scenario	Scenario Description	Traffic: ESALs
I	The highest Traffic Loading in one direction (Lane Traffic Loading) - (Station A)	8,522
II	80% of the total traffic in the two lanes (Station A)	12,775
III	100% of the total traffic in the in the two lanes (Station A)	15,970

3.2 Type of Pavement Structure

The pavement structure of the Nairobi Eastern by-pass road is a standard pavement structure types 11. Tables 3 and 4 provides the details of the pavements structure and layers' moduli respectively.

Table 3: Pavement Structure of the Carriageway (CCC,2009)

10mm	Asphalt Surface Treatment (3/6)
50mm	Fine-Grained Asphalt Concrete (0-20)
150mm	Asphalt Crushed Stone (0-30) base
180mm	Cement Stabilized Crushed Stone (2-4% of Cement) subbase
300mm	MDD 100% below Pavement Structure Layer, improved subgrade
Total Thicknesses	**690mm**

Table 4: Pavement Layers' Moduli (Roads Department, 1987)

S/No.	Type of Pavement Material	Layer Moduli (Mpa)
1	Type I (High Stability) Asphalt Concrete (AC)	4000

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2	Dense Bitumen Macadam (DBM) Base/ Asphalt Crushed Stone (0-30) base	5000
3	Cement Improved Graded Crushed stone Subbase	300
4	Improved Subgrade	300

3.3 Pavement Condition of the Nairobi Eastern By-pass Road Flexible Pavement

3.3.1 Visual Surface Condition

A detailed visual condition survey was undertaken on each travelling lanes. Table 5 gives a summary of the visual data collected with respect to the various homogenous sections. The results show that none of the sections had visible pot holes, cracks or unchecked drainage. The average visual condition survey (VCS) index was 0.0 implying that the visual characteristic of the road was generally in a good condition and could be remedied through regular light maintenance. However, although there was no section with serious visible distresses, the averages of the speed among the sections differed significantly with some sections having average speed of as high as 63.0 kph for homogenous section 8 and as low as 31.8kph in section 12 of the road.

Table 5: Visual Surface Condition Summary

Homogenous section (HS)	Sections of the road	Average of VCS Index	PCI	No. of Potholes	No. of Cracks	Average of Speed kph	Shoulder rating	Drainage
1	13.0-14.0	0	85	None	None	40.5	Good	Good
2	14.1-17.2	0	85	None	None	56.9	Good	Good
3	17.3-17.6	0	85	None	None	57.5	Good	Good
4	17.7-17.9	0	85	None	None	45.5	Good	Good
5	18.0-18.6	0	85	None	None	48.2	Good	Good
6	18.7-19.1	0	85	None	None	55	Good	Good
7	19.2-22.0	0	85	None	None	61.2	Good	Good
8	22.1-23.5	0	85	None	None	63	Good	Good
9	23.6-24.0	0	85	None	None	62.4	Good	Good
10	24.1-24.8	0	85	None	None	44.3	Good	Good
11	24.9-25.8	0	85	None	None	48.1	Good	Good
12	25.9-27.8	0	85	None	None	31.8	Good	Good
Grand Total		**0**	**85**			**52.9**		

3.3.2 Pavement Rutting Index

Rutting of the pavement was measured using Road Laser profiler equipment. Pavement rutting index was calculated from chainage EK 13+157m to chainage EK 26+946m of the Nairobi Eastern by-pass on both lanes. Taking chainage EK 13+157m as the starting point, the average rutting index for the road on the left (vehicles moving towards Thika road) was 1.20 while the right (vehicles moving towards Kangundo road) had a rutting index of 0.76 implying that the road has more rut towards Thika road than from Thika road as shown in Table 6.

Table 6: Pavement Rutting Index

Average of Rut Lane	Average of Rut Right	Average of Rut left

1.73	0.76	1.20

3.3.3: Rutting along Sections of the Road

Figure 2 shows rutting along the road, from the graphical representation, it shows that rutting values were more for the Left side of the road (towards Thika road) compared to rutting on the right side of the road (from Thika Road).

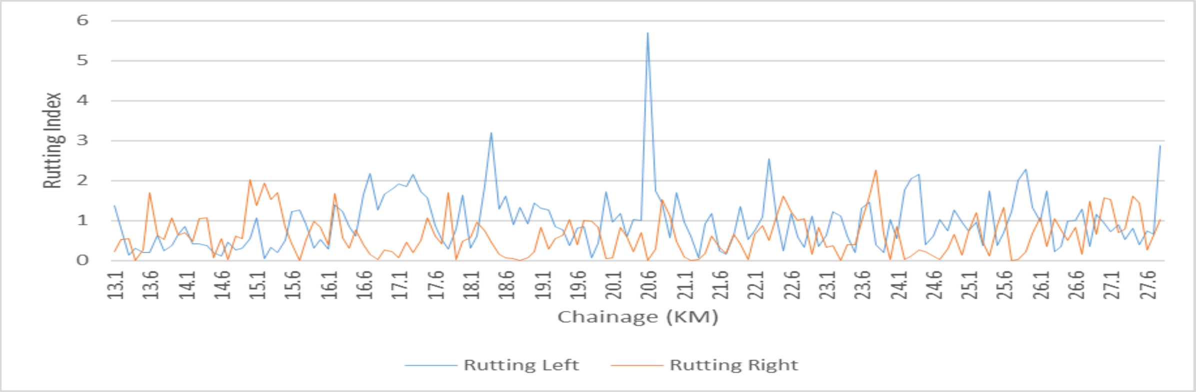

Figure 2 : Rutting along the Sections of the Road

The rutting values fluctuates across the road with some section of the road along the right side of the road having rutting index of close to 6.0 such as at chainage EK 20+100M to EK20+700M. The rutting values are less than 15mm so the pavement can be treated by dragging and brushing.

3.3.3 Pavement Surface Roughness

The roughness of the road was determined using a Road Laser profiler equipment. The equipment measured the International Roughness Index (IRI) for both the right and left lanes of the road. The average IRI for the left lane (towards Thika road) was 1.86 mm/m while the average IRI for the right lane (towards Kangundo road) was 1.19 mm/m. The average IRI for the road was 1.27mm/m as shown in Table 7.

Table 7: Pavement Surface Roughness (IRI) of the Road

Side of the Road	**Average of IRI Lane** (mm/m)
Left	1.86
Right	1.19
Average IRI of the Road	**1.27**

Figure 3 shows the pavement surface roughness along the Right and Left lanes of the road from chainage 13+157m to chainage 26+960m. The results show that left lane (A-B) had a higher roughness index compared to the right lane.

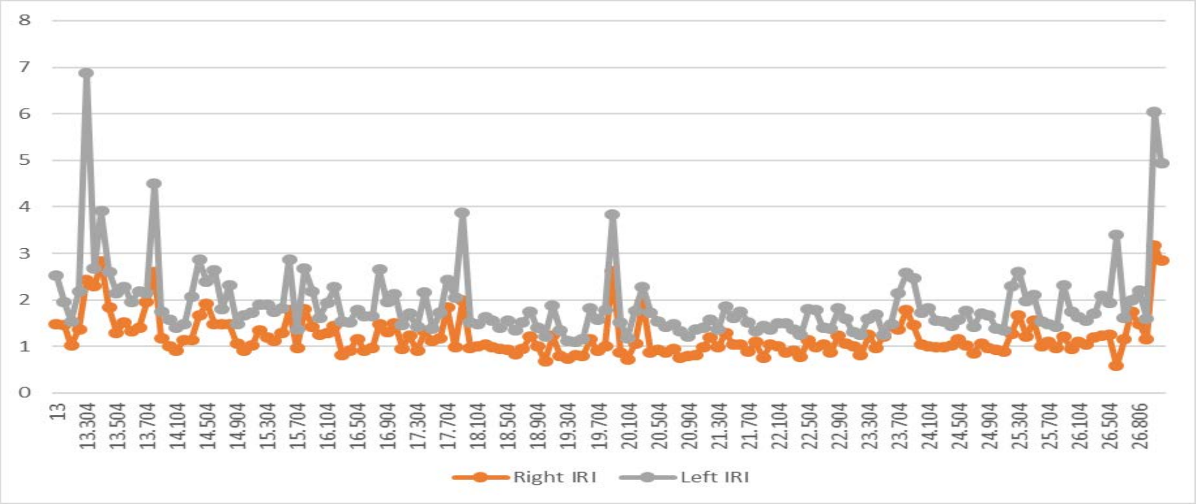

Figure 3: Pavement Surface Roughness (IRI) along the Road

Figure 3 shows a higher value of IRI of 6.87 mm/m occurred at around chainage EK 13+200m on the left lane, with IRI values ranging from 3.39 to 4.51 mm/m in some sections of the road. Therefore, the pavement requires strengthening by a thin overlay, patching and, or sealing of cracks.

3.3.4 CUSUM Curve and the Homogenous Sections

A Cumulative Sum Method (CUSUM) on FWD central deflection measurements (ND_1) was used to identify homogenous sections of the road as shown in Figure 4. A plot of the cumulative sum of the differences (CUSUM) of the FWD (ND_1) deflections from the mean deflection to get the sections which had same statistical trend was performed. After the plot, 12 homogenous sections were identified as shown in Figure 4. The section under study on Nairobi Eastern By-pass road has the same traffic level, the same pavement structure, subgrade type and surface conditions, therefore, the ND_1 deflections were used to classify the road into homogenous sections.

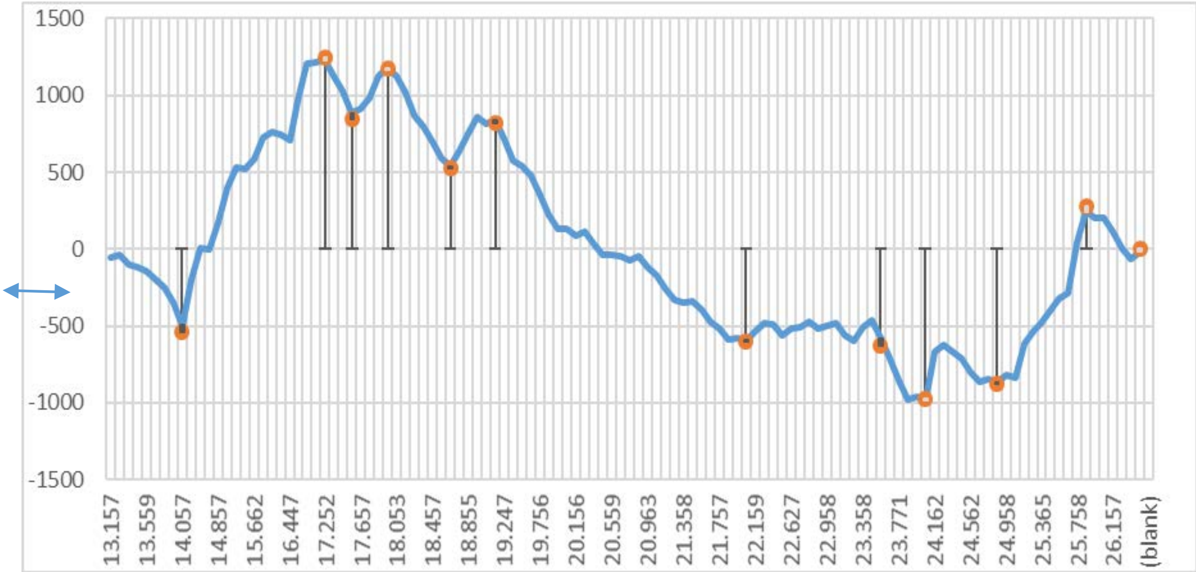

Figure 4: CUSUM Curve along the Nairobi Easter By-pass Road

3.3.5 Remaining Service Life of the Nairobi Eastern By-pass Road

The FWD deflection data, pavement characteristics mainly layer thickness and the material properties, and the traffic loading in ESALs, were used in the determination of the remaining pavement service life by using the RoSy pavement analysis and design software. The remaining service life of the Nairobi Eastern pavement structure was averagely 19.6, 19.1, and 18.7 years for traffic analysis scenarios I, II and III respectively.

The design life of the Nairobi Easter By-pass Road was 20 years. The road was opened to traffic in 2011, therefore, by 2017, the time of the study; it had given service for a period of six (6) years only. Therefore, the theoretical number of years the road should give service without major repairs is 14 years.

Therefore, generally the flexible pavement structure of the Nairobi Eastern By-pass is sufficiently strong and can give service to traffic usage for a period of 19.6, 19.1, and 18.7 years for traffic analysis scenarios I, II and III respectively provided that routine maintenance measures are carried out to preserve the pavement structure in good condition.

3.3.6 Pavement Layers Moduli

The thickness of each layer of the pavement structure was initially obtained from the design report and a comparison with the as built records, there was no significant difference, therefore the pavement layers' thickness obtained from design report were used in the backcalculation process with the RoSy software to determine the elastic moduli of the pavement structure layers.

The elastic moduli, of the 200mm thick asphalt concrete layer and the base course, which were made of the bituminous materials, ranges from 5,613.7Mpa to 14,936.2Mpa. In addition, the 180mm thick subbase layer that comprised of cement stabilized crushed stone (2-4% of cement content) has an elastic moduli ranging from 1,544.8 Mpa and 9,102.3Mpa. Finally, both the 300mm thick upper and lower subgrade have an elastic moduli ranging from 358.1 Mpa to 295,785.0 Mpa. When the elastic moduli of the pavement layers are compared to the values in Table 4, the pavement layers' elastic moduli are higher than the values in Table 4, thus showing that the pavement structure is stable. Table 8 provides the overlay thicknesses requirements in the various homogenous sections along the road for all the traffic analysis scenarios.

Table 8: Average Overlay Thickness along the Homogenous Sections

Homogenous Sections	Chainage in KM	Average Overlay Thickness (mm)		
		Traffic Scenario I: 8522 ESA	Traffic Scenario II:12775 ESA	Traffic Scenario III:15970 ESA
1.0	13.0-14.0	1.4	2.2	2.8
2.0	14.1-17.2	1.6	6.3	9.8
3.0	17.3-17.6	0.0	0.0	0.0
4.0	17.7-17.9	2.5	9.4	13.1
5.0	18.0-18.6	0.0	0.0	0.0
6.0	18.7-19.1	15.5	28.0	36.5
7.0	19.2-22.0	0.0	0.9	1.7
8.0	22.1-23.5	0.5	1.3	2.7
9.0	23.6-24.0	0.0	2.0	5.0
10.0	24.1-24.8	3.4	5.9	7.8
11.0	24.9-25.8	1.5	4.5	8.5
12.0	25.9-27.8	0.0	0.0	0.0
Average Overlay (mm)		**1.5**	**3.8**	**5.8**

The results show that the average overlay thickness required for traffic analysis scenario I, II, and III was 1.5mm, 3.8mm, and 5.8 mm respectively.

4. CONCLUSION

From this assessment functionally, the pavement was not satisfactory owing to the high values of the IRI in some sections, which are in excess of the recommended minimum of an IRI of 3.0 mm/m limit before any interventions are made. Therefore, the pavement requires strengthening by a thin overlay, patching and sealing of cracks.

The elastic moduli, of the 200mm thick asphalt concrete layer and the base course, which were made of the bituminous materials, range from 5,613.7Mpa to 14,936.2Mpa against a minimum of 4000Mpa. In addition, the elastic moduli for the 180mm thick subbase layer that comprised of cement stabilized crushed stone (2-4% of cement content) ranges from 1,544.8 Mpa and 9,102.3Mpa against a minimum of 300Mpa. Finally, both the 300mm thick upper and lower subgrade had an elastic moduli ranging from 358.1 Mpa to 295,785.0 Mpa against a minimum of 300Mpa. This shows that the pavement structure layers were stable and hence satisfactory to withstand the traffic loadings.

The results show that the average overlay thickness required for traffic analysis scenario I, II, and III was 1.5mm, 3.8mm, and 5.8 mm. However, looking at other factors like the state of the pavement structure layers that were stable and from the nature of the pavement surface deflections, the road pavement structure is stable and adequate, a single seal surface dressing of 10/14mm to reduce the high pavement surface roughness has been considered adequate.

5. RECOMMENDATION

The pavement structure was found to be stable and could largely serve for the remaining design life of the road. To reduce the high pavement surface roughness a single seal of surface dressing with 10/14 class 1 chippings and 80/100 penetration grade bitumen binder for pavement surface treatment will be suitable.

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