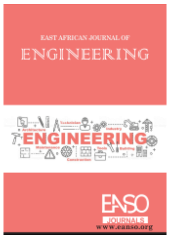

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Original Article

Evaluation of Performance of Pavement Founded on Reinforced Earth Sections along Outer Ring Road, Nairobi

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ABSTRACT

There are no existing local design manuals and construction guidelines for reinforced earth structures in Kenya. The objective of this study was to evaluate the performance of the pavement found on reinforced earth sections along Outer Ring Road. Structural evaluation was determined from deflection measurements using Falling Weight Deflectometer (FWD), while functional evaluation was by visual condition survey, roughness, and rut depth measurements. Classified traffic counts and axle load surveys were undertaken. It was established that the design traffic would be exceeded in year 10 after opening the road. The surface condition survey indicated that the pavement surface for the entire road was generally in good condition. The roughness rating for the entire road was rated "Good", while ten sections of reinforced earth embankment were rated "Fair". The characteristic rut depths on the reinforced earth sections were higher than the lane characteristic rut depth for the entire road. Three sections of the reinforced earth showed low severity, while the rest had no rutting. The PCI for the pavement on reinforced earth sections were lower than pavement on other sections of the road due to a higher International Roughness Index (IRI). The FWD deflections were higher on reinforced earth sections. It was found that the mean pavement moduli for surfacing and base, crack relief and subbase layers at reinforced earth sections were lower than for the pavement in other sections hence requiring thicker overlays. The overall residual life of the road was 17 years, while for the reinforced earth sections was 15 years. Based on the findings, monitoring of the traffic and performance of pavement on the reinforced earth embankments is vital for interventions to prevent premature pavement failure. There is a necessity to develop a design manual and construction guidelines for reinforced earth structures based on the local conditions in Kenya.

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INTRODUCTION

The Kenya Road Design Manual, Part III for materials and pavement design of new roads provides a guide on the factors that affect the design and cost of road embankments. The manual is silent on the use of reinforced earth on embankments despite the many benefits. Major roads in Kenya such as Thika Superhighway, Outer Ring Road, Nairobi Eastern bypass, and Kisumu bypass have reinforced earth embankments on most of their interchanges.

The study evaluates the performance of pavement found on the reinforced earth embankments on Outer Ring Road and determines when the design traffic will be exceeded during the operation of the road.

Problem Statement

Kenya lacks local design manuals and construction guidelines on reinforced earth structures such as road embankments. This has resulted in reinforced earth not being considered a preferred solution even in the cases where it would present the most economical civil engineering solution possibly due to a lack of confidence by the local engineers and contractors in the performance of pavements founded on them. In the Thika Superhighway project, it was observed that pavement founded on reinforced earth embankments exhibited signs of distress a few years after commissioning (Materials Testing and Research Division, 2014).

There has been a significant increase in traffic on major urban roads in Kenya leading to an unexpected increase in traffic loading on the pavements despite traffic projections during the design stage. Increased traffic loading has a significant direct impact on pavement performance, thus the need to monitor the existing traffic on the road against the projected traffic growth considered during the design stage. In addition, there is no integrated pavement performance management system to adequately monitor and evaluate the performance of pavements founded on reinforced earth embankments in the country.

METHODOLOGY

To achieve the objectives of the study, desktop studies, traffic surveys, and pavement structural and functional condition evaluation was undertaken on Outer Ring Road based on local manual guidelines and recognised international standards. The project road was subdivided into homogenous sections;

normal construction, bridge deck and reinforced earth embankments

Desktop Study

Secondary data was collected for Outer Ring Road through a detailed analysis of the design and construction reports of the project, which was critical in providing the project details relevant to this study.

Traffic Surveys

Classified traffic counts were conducted to determine the existing traffic on the road, while an axle load survey was conducted to determine Vehicle Equivalence Factors (VEF) for the derivation of axle loading (Ministry of Transport and Communication, 1987) and (Transport Research Laboratories, 2004) in addition, the current traffic loading was a crucial input parameter in the back analysis of pavement deflection data for the structural condition evaluation of the pavement.

The selected traffic count stations were at the following sections; between Thika road and Juja road, between Kangundo road and Jogoo road and between Jogoo road and Airport North Road. The axle load survey was undertaken at a section approximately 320 metres from the Kangundo roundabout towards the Jogoo road intersection, which presented an adequate space and safe location for the axle load survey exercise. A portable axle load survey equipment was used for the survey.

Functional Evaluation

Functional evaluation was by visual condition survey, roughness and rut depth measurements using Hawkeye 2000 Pavement Surface Profiler (PSP). Identification, measurement of intensity and determination of the severity of surface distress was made in accordance with Kenya's road manual for pavement rehabilitation and overlay design and standard practice for determination of roads and parking lots' pavement condition (ASTM International, 1999).

Roughness data was collected based on the standard practice for determination of IRI to quantify the roughness of pavements prescribed in AASHTO PP 37 – 04 (American Association of State and Highway Transportation Officials, 2019) and standard test method for measuring the longitudinal profile of travelled surfaces with an accelerometer established inertial reference on a profile measuring vehicle (ASTM International, 1998). The Australian Road Research Board (ARRB) Group rating scale was used to rate the roughness data and measured the average IRI for each delineated homogenous section (ARRB Transport Research, 1996).

The rut depth test was conducted in compliance with the standard test method procedure for the measurement of the depth of a rut at a chosen location on a pavement surface using Pavement Surface Profiler in compliance with ASTM E1703 - 10(2015). The pavement condition index (PCI) was calculated to rate the condition of a given road surface based on ASTM D6433-15.

Structural Evaluation

Pavement deflection measurements were conducted using Falling Weight Deflectometer (FWD) equipment that meets the requirements of ASTM D4694 – 09 (ASTM International, 1996) and ASTM D4695 – 03 (ASTM Intenational, 2008). The deflection measurements were analysed using Rosy design software to determine the residual strength of the existing pavement and to establish pavement maintenance intervention measures to preserve the structural integrity of the pavement.

RESULTS AND DISCUSSIONS

Outer Ring Road Project Design Data

Outer Ring Road Project Pavement Design Traffic

Pavement traffic class T2 was adopted for the design of Outer Ring Road pavement. The VEF adopted was 0.25 for buses and 1.54 for medium and heavy goods vehicles. The adopted growth rates were 2.6%, 3.5% and 4.4% for low, medium, and high growth rates, respectively. The pavement design traffic data for Outer Ring project is presented in *Table 1*.

Table 1: Outer Ring Road pavement design traffic

Road Section	Avg Daily No. of Std Axles -1 yr after opening (February 2018)			20 yr Cum No. of Std AXLES (x10^6) January 2037		
	Growth rate			Growth rate		
	Low (2.6%)	Medium (3.5%)	High (4.4%)	Low (2.6%)	Medium (3.5%)	High (4.4%)
Airport north- Jogoo Rd	1301	1313	1324	9.83	10.84	11.97
Traffic Class				T3	T2	T2
Jogoo Rd -Kangundo Rd	2347	2367	2387	17.72	19.54	21.58
Traffic Class				T2	T2	T2
Mumias South - Juja Rd	2001	2018	2035	15.11	16.66	18.40
Traffic Class				T2	T2	T2

Outer Ring Road Typical Pavement Structure

The pavement structure for Outer Ring Road project was the standard pavement structure type 11 based on Kenya Road Design Manual, Part III, suitable for the corresponding design traffic class T2 and design subgrade of strength S4. The pavement layers are shown in *Table* 2 below.

Table 2: Outer Ring Road typical pavement structure

Pavement Layer	Description
Surfacing	50mm thick, 19mm super pave (AC type)
Base (Main Carriageway and Service road)	125mm thick, 37.5mm super pave (AC Type) DBM in one layer
Anti-Crack layer	125mm thick 2% cement improved 0/30mm GCS Class A, compacted to 98% MDD
Subbase	175mm thick 4% cement improved gravel material of base quality with minimum CBR 160% Compacted to 95% MDD
Subgrade	300/350mm improved subgrade material of S4 quality (min. CBR 14%) compacted to 100% MDD in layers of 150mm each.

Reinforced Earth Sections of Outer Ring Road

Based on the design and construction drawings, the reinforced earth sections of Outer Ring Road project are shown *Table 2* below.

Table 3: Reinforced Earth Sections of Outer Ring Road

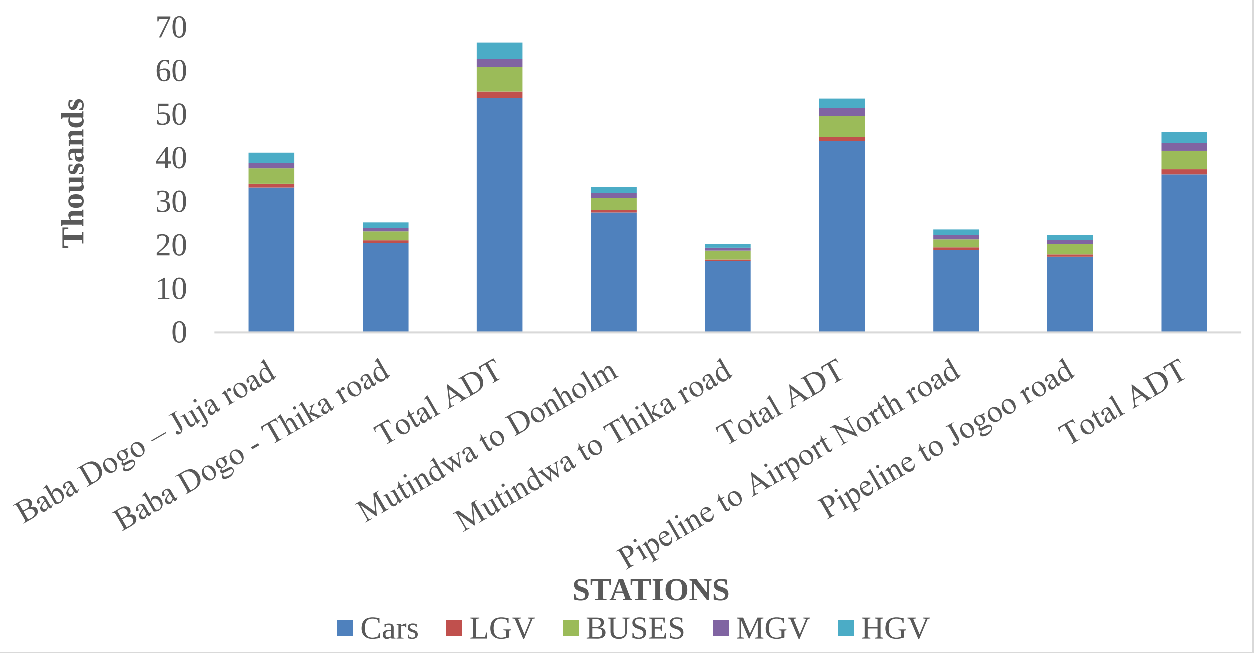
Description	Section from	Section to	Total Length (m)
Mathari River	1+300	1+482	182
	1+550	1+700	150
Kangundo Flyover	3+660	3+908	248
	4+864	4+995	970
Pipeline Flyover	9+750	9+831	81
	10+175	10+225	50

Traffic Survey

Traffic Volume in ADT – 2021

Baba Dogo station recorded the highest Average Daily Traffic (ADT) for each direction and for the two directions combined, while Pipeline station recorded the lowest. It was established that the traffic volume towards the Airport North Road (Eastern bypass) direction was higher than traffic towards Thika roadside for all stations. The traffic volume is displayed *in Figure 1***.** below.

Figure 1: Traffic volume in ADT – 2021



Cars recorded the highest volume in all stations followed by buses and the least was light goods vehicles. Heavy Goods Vehicles (HGV) had a significant contribution to commercial vehicles. The increase in heavy goods vehicles on the road after upgrading the project road is attributable to reduced travel time and smooth road surface hence reduction in vehicle operating costs and more comfortable rides to the drivers (Chandra & Kumar, 2021).

Vehicle Equivalence Factor (VEF)

The calculated average VEF for each vehicle class based on the axle load survey data is summarised in *Table 4***.**

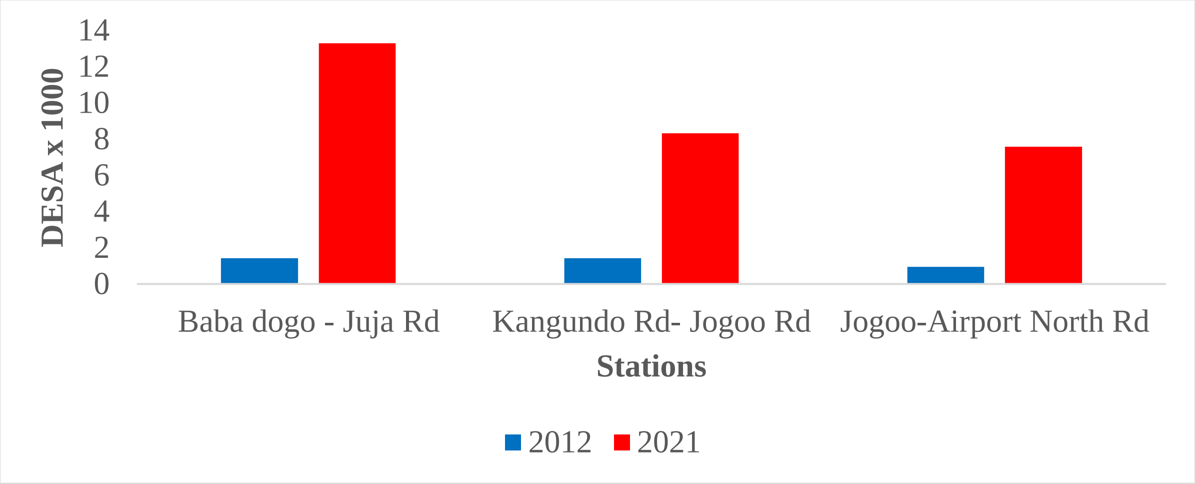
Table 4: Vehicle Equivalence Factor

Vehicle Type	Average VEF
Bus	0.48
Medium Goods Vehicles (MGV)	1.15
Heavy Goods Vehicles (HGV)	4.19

Daily Equivalent Standard Axles (DESA)

Upgrading of the road resulted in a significant increase in traffic loading, confirmed by the growth rates, which are higher than the projected rates during the design year. The comparison of DESA between the project design year (2012) and 2021 is illustrated in *Figure 2* below.

Figure 2: Comparison of 2012 and 2021 DESA



A typical long-term growth curve is a combination of an exponential growth rate followed by a linear growth rate and, lastly, a declining growth rate. The exponential growth rate is usually 5 years after the opening of the road, while linear growth rate goes to around 10 years, and in the last 5 years, the growth rate declines (Oregon Department of Transportation, 2022). Therefore, Outer Ring Road is currently experiencing an exponential growth rate that is expected to normalise with time to achieve a linear growth rate. This calls for close monitoring of the traffic on the road to get the actual growth rates with time which may be influenced by micro or macro factors. Traffic monitoring is of paramount importance to an effective pavement maintenance strategy as it establishes the actual year the anticipated design traffic will be reached and appropriate interventions to be undertaken to ensure the road is serviceable through the design period.

Cumulative Equivalent Standard Axle (CESA) loads

The adopted growth rates during the project design were 2.6%, 3.5% and 4.4% for low, medium, and high growth rates, respectively. It was established that the mean traffic growth rate for Outer Ring Road for the first three years of operation was 25%. To determine the cumulative standard axle loading for the remaining design life years, a conservative growth rate of 5% was adopted (Kenya Urban Roads Authority, 2022). The axle load increased exponentially in all three traffic survey stations by an average growth rate of 25.3%. The calculated CESA are shown in *Table 5* below.

Table 5: CESA on Outer Ring Road project

Target year	**Design CESA -2012**		
	Stations		
	Baba Dogo	**Mutindwa**	**Pipeline**
Base year (2018)	2,035	2,387	1,324
Design year (20 years)	18,400,000	21,580,000	11,970,000
CESA based on 2021 traffic survey			
Year 2021	13,288	8,328	7,580
ESA based on a 5% Annual Traffic Growth Rate			
Year 10 (2028)	39,488,234	24,749,050	22,525,410
Year 15 (2033)	77,197,072	48,382,873	44,035,793
Year 20 (2038)	125,324,168	78,546,285	71,489,099

It was established that the pavement has not yet carried traffic loading above the design loading as of the year 2021, but the design traffic will be exceeded in year 10 after opening the road, that is, in 2028.

Visual Condition Survey

The surface condition survey indicated that the pavement surface condition is generally good except at Km 5+329 and Km 7+177 which were observed to have mild rutting at LHS and RHS, respectively, as shown in *Figure 3*.

Figure 3: Pavement surface condition

Survey: OUTERING ROAD_LHS_1L
Camera: 1 BASLER BIP2-1600-25C (21397646)
Frame No: 552
Chainage: 5.329 km
SubChainage: 5.129 km
Vehicle location: Lat: -1.2848682 Lon: 36.8839053 Alt: 1626.9
Road name: OUTERNG ROAD
From: 2 ALLSOAPS
To: 3 DONHOLM

Survey: OUTERING ROAD_RHS_0R
Camera: 1 BASLER BIP2-1600-25C (21397646)
Frame No: 730
Chainage: 7.177 km
SubChainage: 3.540 km
Vehicle location: Lat: -1.2653481 Lon: 36.8795923 Alt: 1607.1
Road name: Road name
From: 2 DONHOLM OV 1
To: 3 NAIROBI RIVER

The distress could have resulted purely from poor construction at these specific sections and/ or in combination with high traffic. The sections call for immediate maintenance intervention measures and monitoring to prevent further deterioration of the pavement.

Roughness Measurement

Based on the statistical analysis of the IRI data, it was noted that the average IRI for the entire road ranged from 2.03 to 2.14 m/Km, which is rated as "Good". Despite the overall rating of the entire road indicating that the road condition is rated good, specific measurements at the reinforced earth sections showed varying conditions. It was observed that based on the characteristic IRI for the reinforced earth sections, ten sections rated "Good" and "Fair". The analysis of IRI at the reinforced earth sections is shown in *Table 6*.

Table 6: Distribution of IRI at the reinforced earth sections

Lane	Chainage	Min of IRI Lane, m/Km	Average of IRI Lane, m/Km	Max of IRI Lane, m/Km	Std Dev	Characteristic IRI (Ave.+1.3SD)	IRI Rating
Outer Lane (LHS)	1+300-1+482	1.47	3.06	4.62	2.23	5.94	Fair
	4+864-4+995	1.84	2.7	3.55	1.21	4.27	Fair
	9+750-9+831	4.11	4.11	4.11	0	4.11	Fair
Inner Lane (LHS)	1+300-1+482	2.77	3.01	3.24	0.33	3.44	Good
	3+660-3+908	2.69	3.35	3.82	0.59	4.12	Fair
	4+864-4+995	2.75	2.87	2.99	0.17	4.63	Fair
	9+750-9+831	4.63	4.63	4.63	0	4.63	Fair
	10+175-10+225	0	1.54	3.08	2.18	4.37	Fair
Outer Lane (RHS)	1+300-1+482	1.63	2.81	3.99	1.67	4.98	Fair
	9+750-9+831	4.64	4.46	4.64	0	4.64	Fair
	10+175-10+225	0	1.43	2.86	2.02	4.06	Fair
	10+175-10+225	0	1.7	3.39	2.4	4.81	Fair

Table 7: Average rut depths at the reinforced earth sections

Lane	Chainage	Min Rut mm	Average rut, mm	Max Rut, mm	Std Dev	Characteristic Rut (Ave.+1.3SD)	Rut rating
Outer Lane (LHS)	1+300-1+482	2.16	2.62	3.07	0.65	3.46	No rutting
	1+550-1+700	2.39	2.73	3.08	0.49	3.37	No rutting
	3+660-3+908	1.04	1.83	2.37	0.70	2.74	No rutting
	4+864-4+995	2.07	2.59	3.11	0.73	3.55	No rutting
	9+750-9+831	1.78	1.78	1.78	0.00	1.78	No rutting
	10+175-10+225	1.92	2.70	3.47	1.10	4.12	No rutting
Inner Lane (LHS)	1+300-1+482	1.59	2.01	2.44	0.60	2.79	No rutting
	1+550-1+700	1.19	1.31	1.44	0.17	1.54	No rutting
	3+660-3+908	1.60	2.42	3.94	1.32	4.13	No rutting
	4+864-4+995	5.22	6.21	7.20	1.40	8.02	Low severity
	9+750-9+831	2.41	2.41	2.41	0.00	2.41	No rutting
	10+175-10+225	1.76	3.74	5.72	2.80	7.38	Low severity

Lane	**Chainage**	**Min Rut mm**	**Average rut, mm**	**Max Rut, mm**	**Std Dev**	**Characteristic Rut (Ave.+1.3SD)**	**Rut rating**
Outer Lane (RHS)	1+300-1+482	1.27	1.58	1.88	0.43	2.14	No rutting
	1+550-1+700	1.65	1.68	1.71	0.04	1.73	No rutting
	3+660-3+908	1.31	1.54	1.90	0.31	1.95	No rutting
	4+864-4+995	2.06	2.10	2.13	0.05	2.16	No rutting
	9+750-9+831	2.57	2.57	2.57	0.00	2.57	No rutting
	10+175-10+225	0.00	0.97	1.93	1.37	2.74	No rutting
Inner Lane (RHS)	1+300-1+482	1.68	3.35	5.02	2.37	6.42	Low severity
	1+550-1+700	1.58	1.86	2.14	0.39	2.37	No rutting
	3+660-3+908	1.11	1.41	1.83	0.37	1.89	No rutting
	4+864-4+995	1.02	1.22	1.42	0.28	1.58	No rutting
	9+750-9+831	2.57	2.57	2.57	0.00	2.57	No rutting
	10+175-10+225	0.00	0.84	1.67	1.18	2.37	No rutting

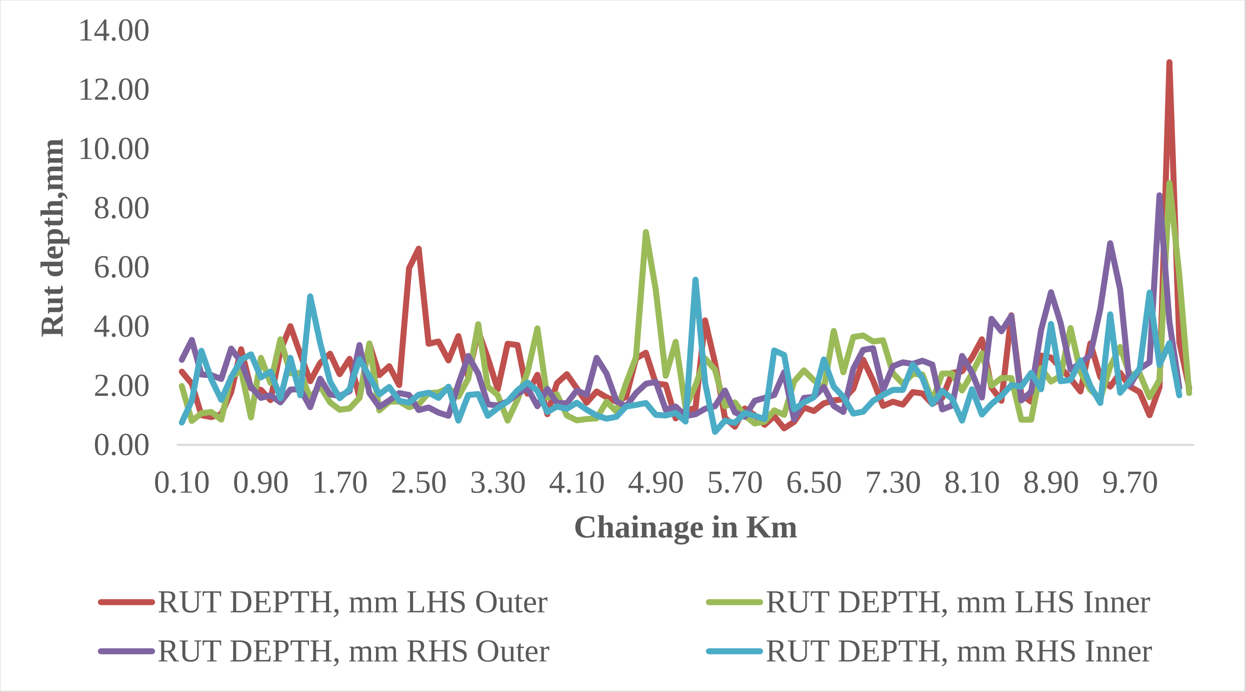
Roughness is an indicator of pavement surface deformation. Pavement deformation is a result of weakness in any of the pavement layers that has experienced movement after construction. Such deformation may result in cracking and any surface distortion is a traffic hazard. Many researchers concur that possible causes of pavement deformations are insufficient compaction or inadequate strength of the subbase layer, insufficient fill compaction, slip, or groundwater. Therefore, the sections that rated fair were a result of secondary compaction on the reinforced earth sections on the premise that the entire road was provided with a similar pavement structure and within the same environmental conditions. This could also arise due to inadequate compaction during the construction of the road.

The roughness evaluation criteria in Kenya, which is based on TRRL recommendations, state that IRI above 2.8mm/Km requires resurfacing on trunk roads (Ministry of Roads and Public Works, 1988). Most IRI values at the reinforced earth sections are above the minimum allowable roughness hence requiring resurfacing to restore the surface smoothness. A strengthening overlay layer is more appropriate based on the function of the road and the current traffic volumes.

Rut Depth Measurements

Rut depth measurements were taken for the entire road length, and it was established that all the sections had characteristic rut depths less than 6mm, hence rated as 'No rutting'. This implies that the entire road is generally in good condition. The graphical representation of the rut depth measurements for the entire road is shown in *Figure 4* below.

Figure 4: Rutting along the Outer Ring Road



It was observed that the characteristic rut depths on the reinforced earth sections were generally higher than the general lane characteristic rut depth for the entire road. Three sections of the reinforced earth showed low severity, while the rest had no rutting.

The average rut depths at the reinforced earth sections are presented in *Table 7*.

The deterioration mechanism of rutting based on the Kenya road design manual is densification which can occur in the subgrade and or other pavement layers, particularly the subbase and base. The possible causes are insufficient stability of the base and/or subbase, insufficient base thickness or insufficient subgrade compaction (Sharad & Prof.Gupta, 2013) (Ministry of Roads and Public Works, 1988). The pavement for the entire road is uniform and constructed in the same period; it is apparent that the cause of rutting would arise from insufficient compaction of the backfill material of the embankment.

Pavement Condition Index (PCI)

The calculations and analysis of PCI results established that the average PCI for the lanes were 72 and 73 for the LHS and RHS, respectively. The rating was thus "Satisfactory" for the two lanes.

The PCI indicated that most reinforced earth sections have lower values compared to the normal road sections. The PCI at the reinforced earth sections ranged from 45 to 92, with the following number of sections rated as "Good", "Satisfactory", "Fair", and "Poor", being three, eight, ten and one, respectively. The sections with a rut depth rating of low severity recorded pavement condition rating of "Fair" to "Poor". The PCI and the rating for the reinforced earth section are presented in *Table 8.*

Table 8: Pavement Condition Index for reinforced earth sections.

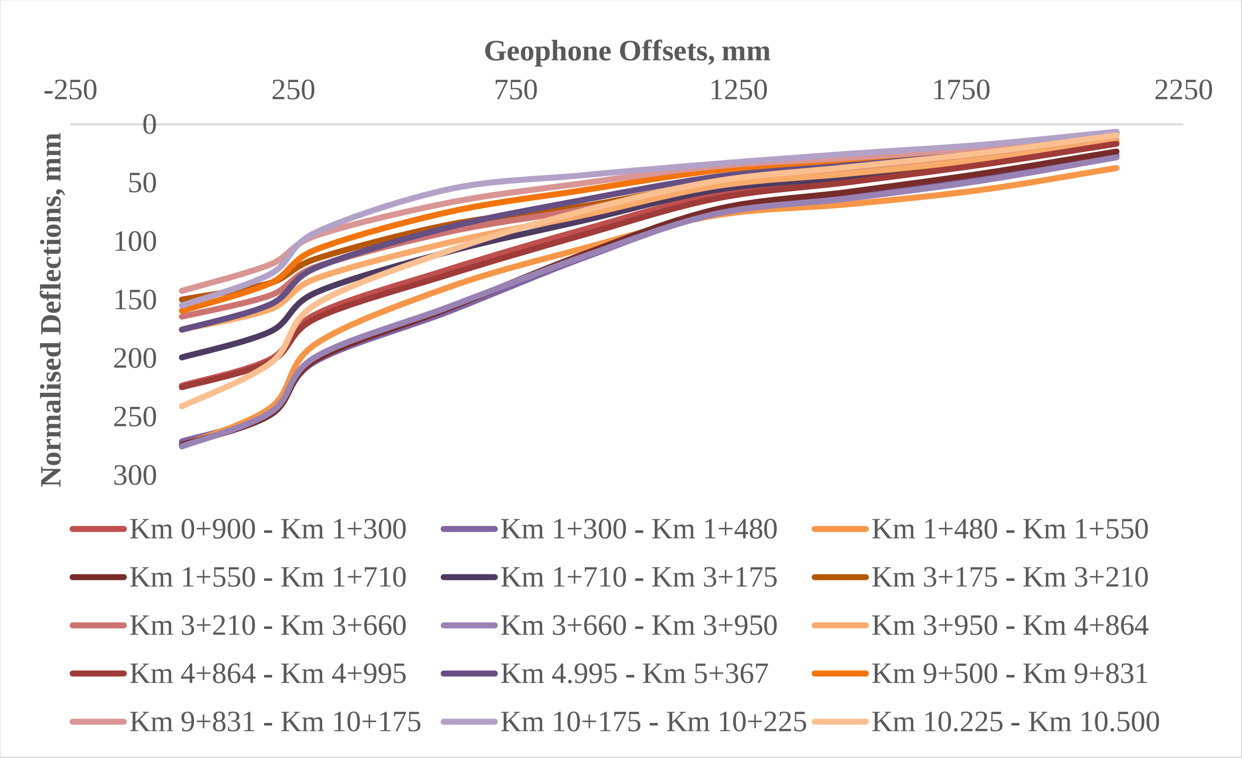
Lane	Chainage	Average rut, mm	Rutting rating	PCI	Pavement Condition rating
Outer Lane (LHS)	1+300-1+482	2.62	No rutting	66	Fair
	1+550-1+700	2.73	No rutting	65	Fair
	3+660-3+908	1.83	No rutting	77	Satisfactory
	4+864-4+995	2.59	No rutting	66	Fair
	9+750-9+831	1.78	No rutting	78	Satisfactory
	10+175-10+225	2.7	No rutting	65	Fair
Inner Lane (LHS)	1+300-1+482	2.01	No rutting	74	Satisfactory
	1+550-1+700	1.31	No rutting	89	Good
	3+660-3+908	2.42	No rutting	68	Fair
	4+864 - 4+995	6.21	Low severity	45	Poor
	9+750-9+831	2.41	No rutting	68	Fair
	10+175-10+225	3.74	Low severity	56	Fair
Outer Lane (RHS)	1+300-1+482	1.58	No rutting	82	Satisfactory
	1+550-1+700	1.68	No rutting	80	Satisfactory
	3+660-3+908	1.54	No rutting	83	Satisfactory
	4+864-4+995	2.1	No rutting	72	Satisfactory
	9+750-9+831	2.57	No rutting	66	Fair
Inner Lane (RHS)	1+300-1+482	3.35	Low severity	59	Fair
	1+550-1+700	1.86	No rutting	76	Satisfactory
	3+660-3+908	1.41	No rutting	86	Good
	4+864 - 4+995	1.22	No rutting	92	Good
	9+750-9+831	2.57	No rutting	66	Fair

The lower values of PCI at the reinforced earth sections of the road are due to higher IRI values resulting from inadequate compaction of the backfill material of the embankment leading to secondary consolidation of fill layers after the opening of the road to traffic. The poor rating at section 4+864 - 4+995 is an alarm to the road maintenance management as this requires immediate intervention to prevent premature failure of the pavement.

Structural Condition Survey

It was observed that pavement deflections decreased with increasing geophone offsets from the centre, as graphically presented in the form of deflection bowls in *Figure 5*.

Figure 5: Deflection bowls of homogenous sections



The sections with the highest deflection measurements had the maximum characteristic deflection. It was also observed that pavement on reinforced earth embankments recorded higher deflections than the adjacent pavement on normal sections. The mean and characteristic deflections on reinforced earth embankment sections are shown in *Table 9*.

Table 9: Mean and characteristic deflections on the reinforced earth sections

Reinforced earth sections	Min nd1, µm	Mean nd1, µm	Max nd1, µm	Std. Dev.	Characteristic Deflection D90µm (nd1Mean+1.3SD)
Km 1+300 – 1+480	186	271	439	52	338
Km 1+550 – 1+710	182	274	363	52	342
Km 3+660 – 3+950	153	275	423	75	373
Km 4+864 – 4+995	119	225	392	77	325
Km 10+175 – 10+225	106	155	240	54	225

The high deflections on reinforced earth sections are a good indicator that the borrowed design manuals and construction guidelines are not addressing the local conditions for embankments materials and or construction methodologies and, therefore, not achieving the expected benefits of reinforced earth structures.

Analysis of Overlay Requirements and Residual Life

The pavement deflection data recorded was used for back calculation and analysis to determine the pavement layer moduli, which is a key parameter for the existing pavement structure for the entire road, and the following was established; the Asphalt Concrete and DBM in all sections had moduli above 4000 MPa which is attributable to Asphalt Concrete, the crack relief layer exhibited moduli above 2700 MPa attributable to design UCS of 1800 kN/m2 of GCS, the subbase layer did not meet the moduli requirement of cement stabilised gravel of 4000 MPa, and the subgrade did not meet the support requirement for cement stabilised gravel subbase of at least 1000 MPa.

It was found that the mean pavement moduli for surfacing and base, crack relief and subbase layers at reinforced earth sections were lower than for the pavement in other sections of the road. The Pavement Layers Moduli (PLM) for reinforced earth sections are summarised in *Table 10* below.

Table 10: Average pavement layers moduli on reinforced earth sections

Reinforced earth section	**Mean Moduli, MPa**			
	Surfacing and Base	**Crack relief**	**Subbase**	**Subgrade**
Km 1+300 – 1+480	4900	2063	916	128
Km 1+550 – 1+710	5036	2319	986	127
Km 3+660 – 3+950	3795	2116	703	140
Km 4+864 – 4+995	5308	3942	2568	151
Km 9+500 – 9+831	5449	4666	1811	238
Km 10+175 – 10+225	6019	5262	3087	398
Mean	5085	3395	1679	197

The average overlay requirement for the entire road was 17 mm, which is a minimal layer with an average residual life of 17 years. On the other hand, the average overlay requirement for the reinforced earth sections was 29 mm, with an average residual life of 15 years. The residual life and overlay requirements for reinforced earth sections are shown in *Table 11*.

Table 11: Analysis of overlay requirements

Reinforced Earth sections	**Critical layer**	**Residual life in years**	**Reinforcement, mm. (20 years design period)**
Km 1+300 – 1+480	4	15	25
Km 1+550 – 1+710	4	14	30
Km 3+660 – 3+950	4	11	50
Km 4+864 – 4+995	4	17	20
Km 9+500 – 9+831	4	19	5
Km 10+175 – 10+225	4	15	45
Mean	4	15	29

It was concluded that pavements founded on reinforced earth would deteriorate faster, resulting in larger overlay requirements. Therefore, there is a need for regular maintenance interventions, close monitoring and evaluation of the pavement sections in embankments.

CONCLUSIONS

The design traffic of Outer Ring Road has not been exceeded as of the year 2021 but will be surpassed in 10 years of the road operation, that is, in the year 2028.

The Outer Ring Road is in good surface condition, as indicated by the satisfactory Pavement Condition Index. However, there are minor surface irregularities though within tolerance levels. It was found that the average IRI for the entire road sections ranged from 2.03 to 2.14 m/Km, which is rated as "Good", and ten of the reinforced earth sections rated "Fair". The road is in good condition based on the average rut depth of less than 6 mm, rated as "No rutting." the reinforced earth sections were found to have higher rut depths, with three sections having a rating of "Low severity". The average PCI for the lanes was 72 and 73 for the LHS and RHS, respectively, rated as "Satisfactory", and reinforced earth sections had ten and one sections rated as "Fair" and "Poor", respectively.

The pavement as constructed was established to have a residual life ranging from 11 to 20 years with an average of 17 Years, while the mean residual life for the reinforced earth sections was 15 years which is three years less than the expected residual life. The overlay requirement of the pavement was concentrated on the reinforced earth embankments and was minimal over the design period. Regular and periodic maintenance interventions are adequate for pavement serviceability.

Recommendations

Regular road maintenance and nominal overlay before 10 years of opening the road to traffic are recommended to preserve the structural integrity of the pavement. Periodic monitoring and evaluation of the traffic, functional and structural performance of the pavement is of great importance for the formulation of an effective and efficient maintenance regime of the road.

There is a necessity to develop a design manual and construction guidelines for reinforced earth structures based on the local conditions in Kenya for the realisation of the benefits of reinforced earth structures.

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