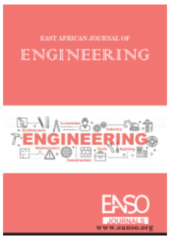


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*Original Article*

# Pavement Performance Testing of the Newly Constructed Port Reitz and Moi International Airport, Mombasa Access Road

*Mildred Akinyi Olang'o[1*], Prof. Sixtus Kinyua Mwea, PhD[1] & Prof. Francis J. Gichaga, PhD[1]*

[1] University of Nairobi P. O. Box 30197, GPO, Nairobi, Kenya.
* Author for Correspondence ORCID: https://orcid.org/0000-0003-2002-1477; Email: mildredkny@gmail.com

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*Inherent Risk,*
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*Pavement performance.*

## ABSTRACT

The 6.4 km long Port Reitz/Moi International Access Road project constructed under the design and build procurement method with an inherent risk of poor quality. A post-construction pavement performance evaluation is thus critical to evaluate the extent to which poor quality occurred. The International Roughness Index was measured using the Hawkeye-2000 Digital Laser Profiler with Pavement Logging Video Camera mounted on a calibrated vehicle and data was analysed using the Hawkeye Processing Toolkit Version 5.0.45, while the road roughness Rating was based on the Australian Road Research Board. The video record was analysed in blocks of equal lengths of 100 m for observation and assessment of the surface defects. The level of defects observed graded together with the IRI measurements gave the Present serviceability Index. Pavement Serviceability Index (PSI) was computed in compliance with ASTM 6433. The falling weight deflectometer equipment meeting the requirement of ASTM D4694 - 09 and ASTM D4695 used to measure pavement deflections under known load simulated the behaviour of the as-built pavement under loading, thus giving the pavement strength and the expected pavement life span. The deflection measurements were conducted on all lanes at intervals of approximately 100 m. The raw deflections (rd) data were converted to normalised deflection (nd) to simulate a standard pressure of 707 KPa from a dual-wheel assembly of 10-ton (100-kN). Back calculation of deflection data done using Rosy Design Software determined the layer strength and residual life. The analysis indicates that the road has residual life ranging from 20-6 years compared to 20-year design life consistent with the assumptions by Ogunsanmi (2019) that Design and Build contracts have an inherent risk of poor quality. In addition to incorporation and monitoring of quality through the design, construction and maintenance stages of the project, identification, evaluation, management, and monitoring of the inherent project risks are recommended for Design and Built Contracts in road projects.

 

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## INTRODUCTION

Kenya has a road network of about 177,800 km out of which only 63,575 km is classified. About 70% of the classified network are in good maintainable condition, while the remaining 30% require rehabilitation or reconstruction (East African Community, 2019). The road construction and maintenance projects in Kenya are traditionally packaged under the International Federation of Consulting Engineers (FIDIC) Red book conditions of contracts. Port Reitz/Moi International Airport, Access Road project was packaged as a Design and Build (Yellow book) FIDIC 1999 contract, a deviation from the tradition. The Design and Build (Yellow book) FIDIC 1999 contract; is an efficient contract delivery method, especially where the client does not have sufficient road data and designs, however has an inherent risk of quality (Ogunsanmi, 2019).

The initial design capacity of a pavement affects its structural strength and the maintenance regime adopted over the pavement design life (Gichaga, 1993). The depth of the pavement thickness, critical in the distribution of the applied traffic load to the subgrade, is a fundamental criterion in pavement design. For the pavement to sustain the traffic load over the design life, the resultant traffic loading deformation at the time of load application and cumulative over the pavement design life should not exceed the pavement own structural capacity (Mwea, 2001).

This study presents an evaluation of the post-construction pavement performance of the 6.4 km long Port Reitz and Moi International Airport access road along Changamwe- Magongo- Moi International Airport and Magongo – Mombasa Port with regards to its capacity to sustain the projected traffic loading over the two-year design life and compares the result with the initial design capacity expectations. The road under study is part of the Lagos – Mombasa of the Trans-Africa Highway Network.

## STUDY METHODOLOGY

The study entailed a review of design and construction data to establish the pavement thickness, pavement layer characteristics, design base year traffic, actual base year traffic, and design growth rates; traffic survey and analysis to determine the current traffic loading and traffic growth rate since construction; roughness measurements to obtain the pavement IRI; detailed pavement condition survey to determine the pavement PSN and rutting depth and structural testing to determine the pavement structural number and pavement deflections. The data thus obtained were analysed to determine pavement

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performance with a further deduction on quality risk occurrences.

## RESULTS AND DISCUSSION

### Pavement Layer Thickness and Material Characteristics

A review of the as-built pavement drawings and engineering design report indicated that Changamwe – Magongo (A109L) was constructed with a wearing course of 10/14 mm single seal; binder course of 75 mm asphalt concrete type I (0/25); base course of 175 mm DBM (0/30) and Subbase of 200 mm cement improved gravel (CBR ≥ 160%). The Port-Reitz Road (P81_Mombasa) was constructed with wearing course of Single seal of 10/14 mm; binder course of 75 mm asphalt concrete binder course; base course of 175 mm DBM (0/30) base, and a Subbase of 200 mm cement improved gravel subbase quality (CBR ≥160%).

The service roads on C110 and access to Port-Reitz Road were constructed with wearing course of single seal of 10/14mm; binder course of 75 mm asphalt concrete binder course; base course of 175 mm DBM (0/30) base and Subbase of 200 mm cement improved gravel (CBR ≥160%). The Changamwe – Airport Road (C110) has Wearing course of Single seal of 10/14 mm, 50 mm asphalt concrete binder course, 150 mm cement improved gravel base and 125 mm cement improved gravel subbase quality (CBR ≥160%). The Port-Reitz Loop Road (P161_Mombasa) has Single seal of 10/14 mm; 50 mm asphalt concrete binder course; 125 mm DBM (0/30) base, and 200 mm cement improved gravel subbase quality (CBR ≥160%).

### Design and Actual Base Year Traffic

A review of the traffic report indicated a design base year traffic of mean ESA 27,591 for A109 and service roads, mean ESA 1,378 for Airport access C110 road, mean ESA 18,194 for Port-Reitz and service road, and Mean ESA 8,566 for Port-Reitz loop road. *Table 1* provides a summary of the as-built road pavement and design traffic.

**Table 1: Summary of as-built pavement**

| No. | Lane | Mean ESA | Wearing course | Binder Course | Base Course | Subbase |
|---|---|---|---|---|---|---|
| 1 | A109 and Service Road | 27591 | 10/14 SS | 75 mm AC | 175 mm DBM | 200 mm Cement Improved gravel |
| 2 | Airport Access C110 | 1378 | 10/14 SS | 50 mm AC | 150 mm Cement Improved gravel | 125 mm Cement Improved gravel |
| 3 | Port-Reitz and Service Road | 18194 | 10/14 SS | 75 mm AC | 175 mm DBM | 200 mm Cement Improved gravel |
| 4 | Port-Reitz Loop Road | 8566 | 10/14 SS | 50 mm AC | 125 mm DBM | 200 mm cement improved gravel |

(**Source**: Author)

### Traffic Survey and Traffic Loading Analysis

The traffic survey and analysis were undertaken as per the Guide to Axle Loads Surveys and Traffic counts for determining traffic load on the pavement (TRL Limited, 2004).

A 5-day 16 hour and 2 days 24 hour classified manual traffic counts at Changamwe round-about, A109L/C110 junction and at C110/Port-Reitz junction was carried out, and data was analysed to obtain the average annual daily traffic presented in *Figure 1*.

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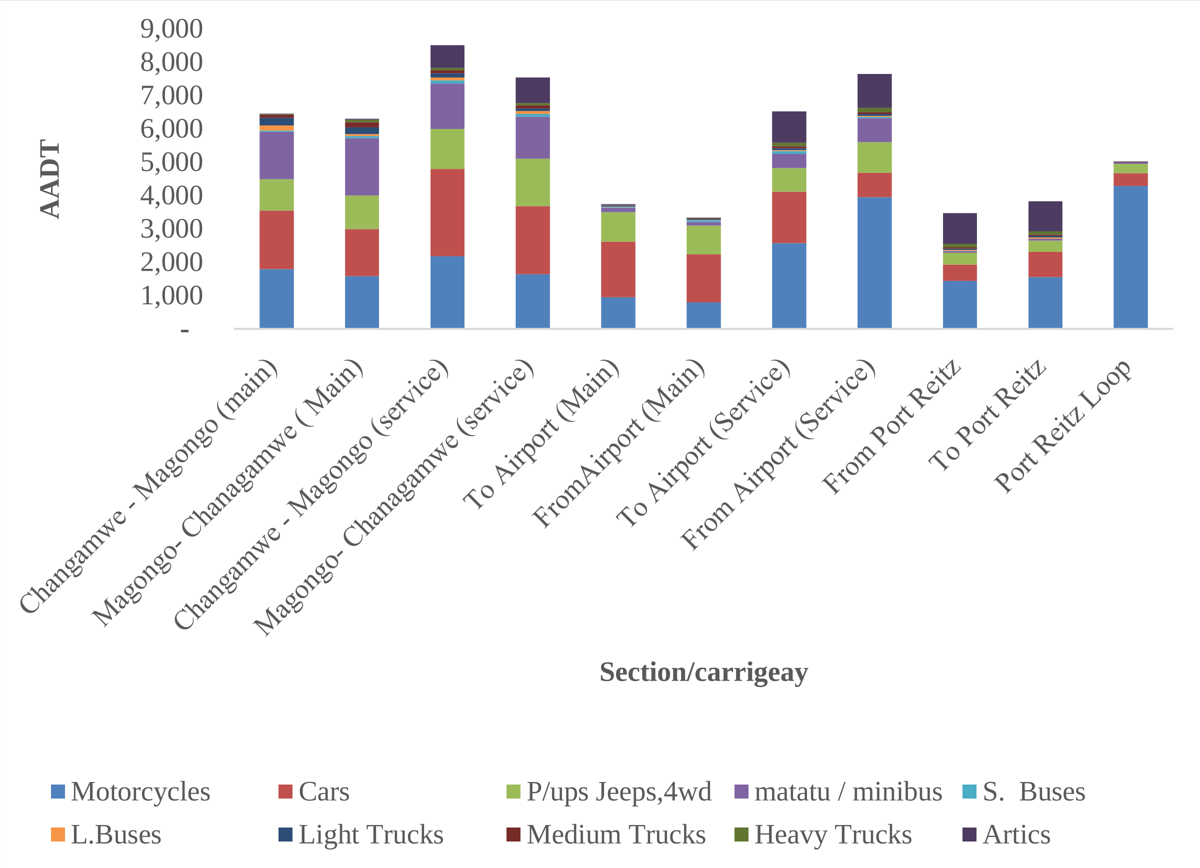
**Figure 1: Average Annual Daily Traffic in the Year 2019**




**Source**: Author

The two days axle load test carried out using a portable weighbridge data was analysed compared to the legal load equivalent factors. The equivalent standard loads were calculated by converting the various traffic spectrums into a unit standard equivalent load of 80 kN using Liddle's formulae expressed as follows; (Ministry of Transport and Communication, Republic of Kenya, 1987)

$$(L/80)^{n} \qquad \text{(i)}$$

Where: L = the load in kN on the single axle considered; n = the Equivalency factor with values ranging from 4-4.6.

For axles less than 130 kN, an EF of 4.5 can be used. However, the legal axle load equivalent factors range from 3.12 to 6.01 thus the Liddle's formulae was adjusted to reflect the Kenya legal axle load limits. The equivalent factor (n) tabulated in *Table 2* were applied.

**Table 2: Axle Load Equivalent Factor at Year 2019**

| Vehicle Category | Port Reitz Road | | | | Legal Axle Load Equivalent Factors | Adopted Axle Load Equivalence Factors for Design |
|---|---|---|---|---|---|---|
| | 80th Percentile | | Average | | | |
| | Direction of Travel | | Direction of Travel | | | |
| | To Port Reitz | From Port Reitz | To Port Reitz | From Port Reitz | | |
| LGV | | 0.01 | | 0.02 | 3.12 | 3.12 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| MGV | 0.1 | 0.1 | 0.07 | 0.15 | 3.12 | 3.12 |
| HGV | 4.44 | 1.1 | 4.1 | 0.52 | 3.8 | 3.8 |
| Trailer | 8.07 | 5.55 | 4.52 | 2.41 | 6.01 | 6.01 |

**Source**: Author, 2019

Pavement damage due to repetitive loading over the design life was factored in by the use of cumulative number standard axle values using the equation:

$$T = 365t_1 \frac{(1+i)^N - 1}{i} \quad \text{(ii)}$$

Where T = Cumulative number of standard axles; $t_1$ = the average daily number of standard axles in the first year after opening; i = the annual growth rate expressed as a decimal fraction tabulated in *Table 3*; N = the design period of 20 years

The growth rates in *Table 3* were based on the annual average growth rate of historical traffic and the growth rate of major indicators of the level of usage of various categories of vehicles in the country and consequently along the project road. The major indicators considered included vehicle registration, road licenses, earnings from road traffic, fuel consumption, the performance of the port of Mombasa, and Moi international airport.

**Table 3: Adopted Growth Rates for the Project Period.**

| Vehicle Category | Growth Rate Over Entire Road Design Period (%) |
|---|---|
| Motorcycles | 8.00 |
| Cars, | 6.84 |
| Utilities, Vans, Pick-Ups etc. | 4.60 |
| Matatus | 4.37 |
| Buses & Minibuses | 6.30 |
| LGV, | 4.81 |
| MGV | 6.70 |
| HGV & Art. Trucks | 7.82 |
| Others | 3.38 |

**Source**: Author, 2019

The equivalent factors thus obtained and the growth rates were applied across the various traffic spectrum to obtain the mean equivalent standard axles (ESA) loading expected on the project road tabulated in Table 4.4.

**Table 4: Mean Equivalent Standard Axle.**

| Lane | Mean ESA |
|---|---|
| A109 | 27591 |
| Airport Access C110 | 1378 |
| Port-Reitz Road | 18194 |
| Port-Reitz Loop Road | 8566 |

**Source**: Author, 2019

### Roughness Measurements

The Hawkeye-2000 Digital Laser Profiler measurements had a Mean International Roughness Index (IRI) of 2.6 m/Km with high roughness values due to bumps, bridge joints retained and mean IRI of 2.5 m/Km upon their removal as presented in *Tables 5* and *6*. The A109 and C110 have a mean IRI of 2.7 m/Km as is on the road; Port-Reitz Loop Road has a mean IRI of 2.1 M/Km, while Port-Reitz Road has a mean IRI of 2.3 m/Km.

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**Table 5: Mean IRI on lanes of each road section as is on the road.**

| Lane | Points | Mean IRI Right | Mean IRI Left | Mean IRI Lane | Mean BI |
|---|---|---|---|---|---|
| Airport Road - 0L | 27 | 3.0 | 3.0 | 2.6 | 2169 |
| Airport Road - 1L | 27 | 3.0 | 3.1 | 2.7 | 2202 |
| Airport Road – 2L | 16 | 2.6 | 2.5 | 2.2 | 1788 |
| Airport Road - 3L | 16 | 3.1 | 3.2 | 2.8 | 2296 |
| Airport Road - 0R | 27 | 2.7 | 2.5 | 2.3 | 1838 |
| Airport Road - 1R | 27 | 3.0 | 3.2 | 2.7 | 2268 |
| Airport Road - 2R | 14 | 3.5 | 3.0 | 2.9 | 2376 |
| Airport Road - 3R | 15 | 3.6 | 3.2 | 3.1 | 2508 |
| Changamwe - Magongo - 0L | 13 | 2.9 | 3.2 | 2.7 | 2189 |
| Changamwe - Magongo - 2L | 12 | 3.1 | 2.9 | 2.6 | 2174 |
| Changamwe - Magongo - 3L | 12 | 3.4 | 3.2 | 2.9 | 2426 |
| Changamwe - Magongo-1L | 13 | 4.0 | 3.9 | 3.5 | 2946 |
| Magongo - Changamwe - 1R | 13 | 2.7 | 2.8 | 2.5 | 1975 |
| Magongo - Changamwe - 2R | 12 | 2.8 | 2.7 | 2.5 | 1953 |
| Magongo - Changamwe - 3R | 10 | 2.7 | 2.4 | 2.3 | 1812 |
| Magongo - Changamwe- 0R | 12 | 2.7 | 2.6 | 2.4 | 1888 |
| Port-Reitz Loop - 0L | 5 | 2.0 | 2.5 | 2.0 | 1589 |
| Port-Reitz Loop - 0R | 4 | 2.4 | 2.4 | 2.1 | 1704 |
| Port-Reitz Road - 0L | 21 | 2.5 | 2.3 | 2.1 | 1695 |
| Port-Reitz Road - 1L | 21 | 3.0 | 2.8 | 2.6 | 2085 |
| Port-Reitz Road - 0R | 21 | 2.3 | 2.3 | 2.0 | 1621 |
| Port-Reitz Road - 1R | 21 | 2.8 | 2.5 | 2.4 | 1896 |
| Mean | 359 | 2.9 | 2.9 | 2.6 | 2085 |

**Source**, Author, 2019

**Table 6: Mean IRI on lanes of road sections without bumps and other interruptions**

| Lane | Points | Mean IRI Right | Mean IRI Left | Mean IRI Lane | Mean BI |
|---|---|---|---|---|---|
| Airport Road - 0L | 24 | 2.7 | 2.7 | 2.4 | 1950 |
| Airport Road - 1L | 24 | 3.1 | 3.2 | 2.8 | 2270 |
| Airport Road - 2L | 15 | 2.6 | 2.5 | 2.2 | 1788 |
| Airport Road - 3L | 16 | 3.1 | 3.2 | 2.8 | 2296 |
| Airport Road - 0R | 24 | 2.7 | 2.5 | 2.3 | 1829 |
| Airport Road - 1R | 23 | 3.0 | 3.3 | 2.7 | 2276 |
| Changamwe - Magongo - 0L | 9 | 2.6 | 3.1 | 2.5 | 2041 |
| Changamwe - Magongo - 2L | 8 | 2.9 | 2.7 | 2.5 | 2006 |
| Changamwe - Magongo - 3L | 10 | 3.4 | 3.2 | 2.9 | 2426 |
| Changamwe - Magongo-1L | 9 | 3.9 | 3.7 | 3.3 | 2799 |
| Magongo - Changamwe - 1R | 9 | 2.8 | 2.9 | 2.6 | 2043 |
| Magongo - Changamwe - 2R | 7 | 2.9 | 2.6 | 2.5 | 1978 |
| Magongo - Changamwe - 3R | 8 | 2.7 | 2.4 | 2.3 | 1796 |
| Magongo - Changamwe- 0R | 10 | 2.9 | 2.6 | 2.5 | 1960 |
| Port-Reitz Loop - 0L | 5 | 2.0 | 2.5 | 2.0 | 1589 |
| Port-Reitz Loop - 0R | 4 | 2.5 | 2.5 | 2.1 | 1704 |
| Port-Reitz Road - 0L | 21 | 2.5 | 2.3 | 2.1 | 1695 |
| Port-Reitz Road - 1L | 21 | 3.0 | 2.8 | 2.6 | 2085 |

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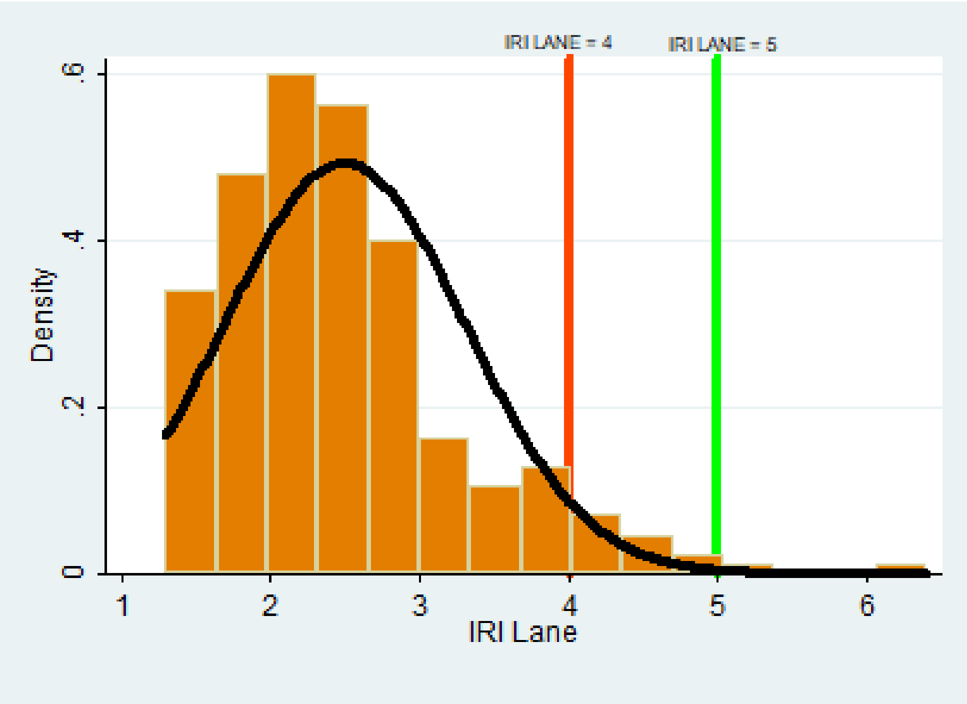
| Lane | Points | Mean IRI Right | Mean IRI Left | Mean IRI Lane | Mean BI |
|---|---|---|---|---|---|
| Port-Reitz Road - 0R | 21 | 2.3 | 2.3 | 2.1 | 1621 |
| Port-Reitz Road - 1R | 21 | 2.8 | 2.5 | 2.4 | 1896 |
| Mean | 289 | 2.8 | 2.8 | 2.5 | 2024 |

**Source**, Author, 2019

More than 80% of the population measured had an IRI value of less than 4 mm/km, while less than 2% of the population had an IRI of more than 5 mm/km consistent with the roughness quality requirement for the project road, as presented in *Figure 2*.

**Figure 2: A graph of IRI Lane against Density**




**Source**: Author, 2019

**Detailed Pavement Surface Condition Survey**

The analysis and grading of the video recorded by the pavement logging video camera mounted on the Hawkeye-2000 Digital Lase Profiler (DLP) and the IRI measurements gave a Mean PSI above 85 rated as Good in a scale of Failed (0) to Good (100). Less than 2% of the value analysed gave a satisfactory PSI at 83.2% and 84.6% indicating good pavement surface riding quality. *Table 7* presents a summary of the value of the pavement condition surveys.

**Table 7: Summary PSI Test Results.**

| Lane | PSI Values as is. | PCI Rating | PSI Values with high values due bumps, etc., removed | PCI Rating |
|---|---|---|---|---|
| Airport Road - 0L | 91.8 | Good | 94.9 | Good |
| Airport Road - 1L | 91.5 | Good | 90.3 | Good |
| Airport Road - 2L | 97.4 | Good | 97.3 | Good |
| Airport Road - 3L | 89.7 | Good | 89.6 | Good |
| Airport Road - 0R | 96.2 | Good | 96.3 | Good |

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| Lane | PSI Values as is. | PCI Rating | PSI Values with high values due bumps, etc., removed | PCI Rating |
|---|---|---|---|---|
| Airport Road - 1R | 91.1 | Good | 90.9 | Good |
| Changamwe - Magongo - 0L | 89.0 | Good | 92.8 | Good |
| Changamwe - Magongo - 2L | 86.8 | Good | 93.8 | Good |
| Changamwe - Magongo - 3L | 90.9 | Good | 88.6 | Good |
| Changamwe - Magongo-1L | 91.9 | Good | 84.6 | Satisfactory |
| Magongo - Changamwe - 1R | 88.6 | Good | 92.1 | Good |
| Magongo - Changamwe - 2R | 83.2 | Satisfactory | 93.2 | Good |
| Magongo - Changamwe - 3R | 93.0 | Good | 96.1 | Good |
| Magongo - Changamwe- 0R | 93.6 | Good | 93.2 | Good |
| Port-Reitz Loop - 0L | 96.1 | Good | 99.4 | Good |
| Port-Reitz Loop - 0R | 94.2 | Good | 98.2 | Good |
| Port-Reitz Road - 0L | 99.3 | Good | 97.7 | Good |
| Port-Reitz Road - 1L | 98.1 | Good | 92.1 | Good |
| Port-Reitz Road - 0R | 97.7 | Good | 98.8 | Good |
| Port-Reitz Road - 1R | 92.3 | Good | 94.7 | Good |
| Mean | 92.5 | Good | 93.4 | Good |

(Source: Author, 2019)

### Rutting Measurement

Hawkeye 2000 had a Laser Profiler Beam (LPB) that was used to measure 5-point transverse profile rutting and surface regularity compliant with requirements of ASTM E1703/ E1703M – 10 (2015). The road sections had a mean rut depth of 5.9 mm when the effect of bumps and bridge joints were not removed and 5.5 mm when the effect of bumps and bridge joints were removed. The road sections had a mean rut depth of 5.5 mm rut depth, which is below 6.25 mm the upper limit of surface regularity of a new road with asphalt surfacing as summarised in *Table 8***.**

### Pavement Deflection Measurement Analysis

Normalised deflections (nd1 to nd9 corresponding to nine consecutive geophone points of 0, 20,30,60,90,120,150,180, and 120 cm), obtained from the raw deflection simulating a standard pressure of 707 KPa from a dual wheel assembly of 50-kN, gave pavement deflection measurements as summarised in Table 9. The deflection back calculation by Rosy Design Software gave the layer strength and residual life summarised in *Table 9*

 

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**Table 8: Rutting measurements on Road sections**

| Road Section | Mean Rut Right with bump | Mean Rut Left with bump | Mean rut lanes with bump | Mean Rut Right with effect of bumps removed | Mean Rut Left with effect of bumps removed | Mean Rut Lane with effect of bumps removed |
|---|---|---|---|---|---|---|
| Changamwe – Magongo (A109L) | 5.5 | 6.4 | 5.9 | 5.2 | 5.6 | 5.5 |
| Airport Access Road (C110) | 5.3 | 6.3 | 5.8 | 5.1 | 5.6 | 5.4 |
| Port Reitz Loop (P161_Mombasa) | 5.4 | 7.1 | 6.2 | 4.9 | 5.7 | 5.5 |
| Port Reitz Road (P81_Mombasa) | 5.5 | 6.6 | 6.1 | 5.3 | 5.7 | 5.6 |
| Mean | 5.4 | 6.4 | 5.9 | 5.2 | 5.7 | 5.5 |

**Source**: Author, 2019

**Table 9: FWD data on homogenous sections**

| Lane | Mean nd1 | Mean nd2 | Mean nd3 | Mean nd4 | Mean nd5 | Mean nd6 | Mean nd7 | Mean nd8 | Mean nd9 |
|---|---|---|---|---|---|---|---|---|---|
| A109 | 168 | 132 | 117 | 72 | 55 | 42 | 34 | 30 | 23 |
| 0L | 211 | 159 | 134 | 73 | 51 | 37 | 30 | 26 | 20 |
| 0R | 120 | 99 | 92 | 61 | 50 | 39 | 31 | 27 | 21 |
| 1L | 320 | 223 | 177 | 96 | 69 | 51 | 40 | 34 | 27 |
| 1R | 145 | 121 | 113 | 75 | 60 | 46 | 38 | 33 | 26 |
| 2L | 153 | 120 | 103 | 59 | 46 | 35 | 29 | 26 | 20 |
| 2R | 147 | 124 | 116 | 78 | 62 | 47 | 37 | 32 | 25 |
| 3L | 124 | 104 | 96 | 62 | 49 | 38 | 32 | 29 | 22 |
| 3R | 137 | 115 | 108 | 74 | 60 | 46 | 37 | 32 | 25 |
| Airport Access C110 | 318 | 233 | 186 | 90 | 58 | 41 | 32 | 29 | 22 |
| 0L | 392 | 282 | 219 | 99 | 57 | 39 | 30 | 27 | 21 |
| 0R | 396 | 273 | 209 | 93 | 55 | 38 | 30 | 26 | 21 |
| 1L | 432 | 305 | 233 | 101 | 58 | 40 | 32 | 28 | 22 |
| 1R | 418 | 298 | 230 | 103 | 62 | 43 | 33 | 29 | 23 |
| 2L | 130 | 109 | 101 | 63 | 49 | 37 | 30 | 26 | 20 |
| 2R | 157 | 133 | 122 | 76 | 57 | 43 | 35 | 31 | 24 |
| 3L | 211 | 168 | 145 | 80 | 57 | 43 | 34 | 30 | 24 |
| 3R | 179 | 154 | 142 | 90 | 67 | 49 | 39 | 34 | 26 |

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| Lane | Mean nd1 | Mean nd2 | Mean nd3 | Mean nd4 | Mean nd5 | Mean nd6 | Mean nd7 | Mean nd8 | Mean nd9 |
|---|---|---|---|---|---|---|---|---|---|
| Port-Reitz Road | 135 | 114 | 105 | 65 | 49 | 37 | 29 | 26 | 19 |
| 0L | 120 | 101 | 94 | 56 | 43 | 32 | 25 | 23 | 17 |
| 0R | 133 | 112 | 103 | 61 | 45 | 33 | 26 | 23 | 17 |
| 1L | 126 | 107 | 100 | 63 | 50 | 38 | 31 | 28 | 21 |
| 1R | 158 | 136 | 126 | 79 | 59 | 44 | 34 | 30 | 23 |
| Port-Reitz Loop | 235 | 196 | 174 | 103 | 70 | 50 | 39 | 33 | 27 |
| 0L | 258 | 216 | 191 | 111 | 73 | 50 | 39 | 34 | 27 |
| 0R | 212 | 176 | 157 | 95 | 68 | 49 | 39 | 33 | 26 |
| Mean | 233 | 178 | 149 | 80 | 56 | 41 | 32 | 29 | 22 |

**Source**: Author, 2019

**Table 10: Mean pavement and subgrade moduli on homogenous sections**

| Lane | Mean ESA | Mean Residual Life Now (years) | Mean Required Overlay (mm) | Mean Critical Layer | Mean Surfacing Moduli MPa | Mean Base Moduli MPa | Mean Subbase Moduli MPa | Mean Subgrade Moduli MPa |
|---|---|---|---|---|---|---|---|---|
| A109 | 27591 | 19 | 8 | 3 | 10044 | 7986 | 4365 | 240 |
| 0 | 27591 | 20 | 0 | 3 | 9252 | 9645 | 5390 | 258 |
| 1 | 27591 | 18 | 8 | 3 | 7359 | 7593 | 3390 | 207 |
| 2 | 27591 | 17 | 22 | 3 | 8875 | 6360 | 2999 | 263 |
| 3 | 27591 | 19 | 4 | 3 | 14395 | 8190 | 5499 | 230 |
| Airport Access C110 | 1378 | 11 | 45 | 2 | 9709 | 2610 | 1814 | 237 |
| 0 | 1378 | 6 | 67 | 2 | 8459 | 900 | 1046 | 244 |
| 1 | 1378 | 6 | 72 | 2 | 8285 | 1048 | 1255 | 235 |
| 2 | 1378 | 20 | 0 | 3 | 12610 | 5263 | 2427 | 253 |
| 3 | 1378 | 19 | 7 | 3 | 11486 | 5682 | 3520 | 211 |
| Port-Reitz Road | 18194 | 19 | 6 | 3 | 12633 | 6713 | 4057 | 265 |
| 0 | 18194 | 20 | 0 | 3 | 12443 | 6950 | 4446 | 295 |
| 1 | 18194 | 18 | 10 | 3 | 12787 | 6521 | 3743 | 240 |
| Port-Reitz Loop Road | 8566 | 9 | 56 | 3 | 10371 | 2350 | 1205 | 183 |
| 0 | 8566 | 9 | 56 | 3 | 10371 | 2350 | 1205 | 183 |
| Mean | | 15 | 27 | 3 | 10433 | 4907 | 2944 | 241 |

(**Source**: Author, 2019)

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The deflection test was done at completion of the project, considering 20-year pavement design life, the project road had a mean residual life of 15 years against 20 years expected residual life. On average 27 mm overlay would be required for the pavement to serve the expected residual life. There were discrepancies in pavement strength within the various lanes of the same road link and also within the various links of the project road. The analysed test results indicate that A109 link had an average residual life of 19 years with the outer lane being the strongest pavement with 20 years residual life and lane 2 being the weakest layer with 17 years residual life. Port-Reitz Road link had an average residual life of 19 years with outer lane being the strongest with 20 years residual life and lane one being the weakest with 18 years residual life. Port-Reitz loop road link had an average 9 years residual life. Airport Access C110 road link had an average 11 years residual life with lane two being the strongest with 20 years residual life and lane 0 and 1 being the weakest with 6 years residual life.

Fundamentally, besides giving the driver a virtual impression of the vertical and horizontal alignment of the road, the road pavement should be able to carry the traffic loading over the design life. With the residual design life varying from 20 years to 6 years, the test analysis infers that the road pavement may not be able to carry the traffic loading over the design life of 20 years (Fred, 2013).

The initial design capacity of a pavement affects its structural strength and the maintenance regime adopted over the pavement design life (Gichaga, 1993). The depth of the pavement thickness, critical in the distribution of the applied traffic load to the subgrade, is a fundamental criterion in pavement design. For each pavement layer to sustain the traffic load over the design life, the resultant traffic loading deformation on the pavement layer at the time of load application and cumulative over the pavement design life should not exceed the pavement layer's own structural capacity (Mwea, 2001). Based on the analysed test results, the cement improved gravel (CBR $\geq$ 160%) layer thickness and characteristics was found to be most unstable layer both as base and Subbase in all the road link it was constructed. Moreover, may not be able to carry the pavement loading over the design life.

This instability in the cement improved gravel layer could be attributed to a combination of several factors (Mwea, 2001) such as inadequate design methods; non-compliance to design material specification in the actual construction process, inadequate maintenance of the constructed pavement, pavement subjected to axle load beyond the magnitude allowed in the design.

In his study by Mwea (2001) indicated that inadequate maintenance of the constructed pavement is a possible cause of instability in road pavement layer. However, since the testing was done at completion of the road pavement construction, the possibility of the instability of the road pavement being caused by inadequate road maintenance can be eliminated in this study.

In his study, Mosissa (2018) concluded that Kenya Design Manual pavement options are structurally unsustainable through the design period unless overlaid. The design for the project road was done in accordance with Kenya road design manual part III (Ministry of Transport and Communication, Republic of Kenya, 1987). The design pavement layer thickness and material characteristics were consistent with the design manual specifications. However, test on completion analysis indicates that varied overlay thickness would be required for the road pavement to serve its intended residual life. Thus, the study infers that the instability in the road pavement observed could possibly be attributed to inadequate design methods used.

There's also possibility of the project road being subjected to axle load beyond the magnitude allowed in the design. On average 25-50% of the axles are overloaded on Mombasa-Nairobi traffic (Ministry of Transport and Communication, Republic of Kenya, 1987). The project road is a total of 6.4 km long with part of the network having T1 traffic class. Considering that the Airport Access Road have only Asphalt Concrete surfacing on a quality gravel base and Subbase, the strains induced on the pavement by a single overloaded axle can subject the pavement to permanent deformation. Thus, the study infers that the instability in the road pavement observed could possibly be attributed to the layer being subjected to construction traffic axles loaded beyond the magnitude allowed in the design.

The project under study was a design and build contract. The contractor was responsible for designing the road as well as construction, with minimal input from the client at a fixed contract price and time (Castro, 2019). The Design and Build Contracts especially have an inherent risk of poor quality, cost, and time overrun and it is paramount there be an established system of checking and verifying the work output before the road Client approves the works (Ogunsanmi, 2019). The established system for checking and verifying the work output within the project under study was limited to the minimal strength requirement provisions in the Employer's requirement and pavement testing on completion. Whilst the test at completion presented herein highlight residual pavement life less than the anticipated residual life specified in the Employer's requirement. The system failed to take into account that as-built road pavements structure varies considerably with a wide range of values of material properties within particular specifications and considerable variability during the construction process (Ethopian Roads Authority, 2013). The project documents did not provide for system for controlling the variability during the construction process. Thus, the study infers that the instability in the road pavement observed could possibly be attributed to non-compliance to design material specification in the actual construction process.

## CONCLUSION

From the traffic survey and traffic loading analysis over the design life, it can be concluded that the project road mean equivalent standard axles was 27,591, 1,378, 18,194, and 8,566 for the A109, Airport Access, Port Reitz Road, and Port Reitz loop road respectively.

From the non-destructive field tests carried out, it can be concluded that the pavement properties for the newly constructed Port Reitz and Moi International Airport, Mombasa Access Road were of flexible pavement consistent with definition of flexible pavements (Lanham, 2019); those whose structure may temporarily or permanently deflect when subjected to loading. The pavement consisted of several layers of material differing in structural strength with the top most layer being the strongest and the subgrade layer being the weakest.

However, the assumption that pavement failure manifestation can be established through a detailed road condition survey using visual inspection and failure width and depth measurements summarised and presented, as surface condition rating may not be applicable for new pavements as the manifestation of the instability in the pavement was not apparent in the study. The study observed that a detailed road condition survey using visual inspection, failure width, and depth measurements for newly constructed road pavements may suggest a good riding quality pavement surface even though the road pavement may not be able to carry the traffic loading over the design life hence the need for pavement deflection measurements.

Based on the IRI and PSI analysis, the pavement had good riding quality performance. More than 80% of the population measured had an IRI value of less than 4 mm/km while less than 2% of the population had an IRI of more than 5 mm/km consistent with the roughness quality requirement. Less than 2% of the value analysed gave a satisfactory PSI at 83.2% and 84.6% indicating good riding quality pavement surface signifying savings in vehicle operating cost.

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Based on the deflection and traffic loading analysis, the deterioration model of the road pavement signifies that the road pavement may not be able to carry the traffic loading over the design life of 20 years with the analysed residual design life varying from 20 years to 6 years. Study by Flamarz (2017) suggest that instability in any of the pavement layers as a result of structural distress eventually causes pavement failure and that pavement failure can manifest itself in the form of alligator cracking, block cracking, longitudinal cracking, traverse cracking, shoving, depression, corrugation, edge drop, edge break, ravelling, and potholes. The Kenya National Highways Authority needs to monitor the pavement failure manifestation as suggested by Flamarz (2017). The study conclude that the resultant pavement performance was of poor quality.

**Recommendation**

The government of Kenya through the Road Agencies are rolling out several capital-intensive road projects using the Design and Build FIDIC form of Contact. While this study has pointed out the occurrence of the inherent risk associated with this form of Contracts. The Kenya National Highways Authority need to take into consideration these inherent risks while packaging future Design and Built Contracts.

There is need for establishment of system for checking and verifying the work output particularly to take into account as-built road pavements structure variability of material properties within particular specifications and considerable variability during the construction process to avert pavement instability attributable to non-compliance to design material specification in the actual construction process.

The study recommends further study on the possible cause of the instability of the new pavement including inadequacy in the design methods used, construction traffic axle load trends and its impact on pavement performance, and design material specification compliance during construction.

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