THE INTERNATIONAL JOURNAL OF SCIENCE & TECHNOLEDGE

# Comparison of Four Design Methods on Rehabilitation of Flexible Pavements: For Nakuru - Nyahururu Road in Kenya

**Michael Abera Mosissa**
Student, Department of Civil and Construction Engineering, University of Nairobi, Kenya
**Sixtus K. Mwea**
Professor, Department of Civil and Construction Engineering, University of Nairobi, Kenya
**Paul K. Matheri**
Lecturer, Department of Civil and Construction Engineering, University of Nairobi, Kenya

***Abstract:***
*This paper looks at the need of finding structurally sustainable and economical design methods among the usual Kenyan Road Design Manual Part- III & IV (1987), Tanzanian Design Manual (1999), AASHTO 1993 and South African mechanistic-empirical Pavement Analysis Design Software (mePADS).The paper is based on the design of rehabilitation of flexible pavement on Nakuru – Nyahururu road in Kenya.*
*Due to under design; roads are dilapidating before their design period is reached. The result is the need of the reconstruction or excessive maintenance which is going to make road construction industry uneconomical.*
*Comparison of pavement structures obtained by use of Tanzanian Design Manual 1999, AASHTO 1993 and mechanistic-empirical Pavement Analysis Design Software of South Africa (mePADS) was made. The most economical pavement structure was designed. The research looked in to the sustainability of the pavement structure and for how long? If the project doesn't reach the design period, further design is needed in order to match with the design period for comparison with other design methods.*
*On the aspect of structurally sustainable pavement, pavement designed by use of Tanzanian design manual (1999) is safe when analyzed through the mechanistic-empirical Pavement Analysis Software (mePADS) whereas the pavement designed by use of the Kenyan design manual fails to reach half way the design period. AASHTO 1993 pavement reaches its service life one or two years before the design period.*

***Keywords**: AASHTO 1993, flexible pavement, falling weight deflectometer, homogeneous section, mechanistic-empirical pavement analysis design software, international roughness index, structural number, sub-grade.*

## 1. Introduction

Flexible pavement is composed of a bituminous material surface course and underlying base and sub-base courses. The bituminous material is more often asphalt whose viscous nature allows significant plastic deformation. Most asphalt surfaces are built on a gravel base, although some 'full depth' asphalt surfaces are built directly on the subgrade. According to Russel (2011), developing a rehabilitation design generally requires extensive investigation into the condition of the existing pavement structure, performance history, and laboratory testing of materials to establish suitability of existing and proposed materials for use in the rehabilitation design.

The study area Nakuru – Nyahururu road diverts from A109 Highway in Nakuru town passes through mountainous escarpments and covers a total distance of 60 kilometers.

In order to meet the demand of rehabilitating of the road in the stretch there was need to find most cost effective as well as structurally sustainable method of designing a road which will last its design period. This paper tries to provide a cost effective and sustainable pavement design methods by consideration of design manuals from South Africa, Tanzania, Europe and America. This was meant to design a cost effective pavement structure.

## 2. Methodology

The traffic survey data was collected along the project road to give the traffic loading. The alignment soil was collected according to Kenyan Design Manual Specification at an interval of 500 meters. Falling Weight Deflectometer testing was done with an interval of 100 meters in a staggered way from both directions. Additionally, Roughness (Bump Integrator) was done with an interval of 100 meters in a staggered manner from both directions.

*2.1. Alignment Soil Investigation*

The subgrade field property tests are summarized in the Table 1

| Date Tested | Location | Right Way | Layer Thick (mm) | FDD $Kg/m^3$ | Field Moisture (%) | Max. Dry Density $Kg/m^3$ | OMC (%) | Relative Compaction (%) | Subgrade DCP-CBR (%) |
|---|---|---|---|---|---|---|---|---|---|
| 25.11.16 | 3+000 | RHS | 185 | 1361 | 11.8 | 1651 | 13 | 101 | 19 |
| 25.11.16 | 6+000 | LHS | 160 | 1404 | 19.6 | 1427 | 22.6 | 98 | 14 |
| 25.11.16 | 9+380 | RHS | 173 | 1109 | 34 | 1107 | 34 | 100 | 13 |
| 25.11.16 | 12+580 | LHS | 150 | 1335 | 25 | 1307 | 24.7 | 102 | 28 |
| 25.11.16 | 17+550 | RHS | 160 | 1453 | 21 | 1286 | 15 | 101 | 32 |
| 25.11.16 | 22+250 | LHS | 155 | 1205 | 19 | 1200 | 18 | 100 | 12 |
| 25.11.16 | 25+880 | RHS | 150 | 1159 | 33.3 | 1262 | 13.5 | 92 | 5 |
| 20.11.16 | 28+850 | LHS | 165 | 1450 | 20 | 1512 | 20 | 102 | 37 |
| 25.11.16 | 32+350 | RHS | 156 | 1460 | 18 | 1512 | 14.5 | 101 | 38 |
| 25.11.16 | 35+200 | LHS | 150 | 1372 | 23.3 | 1368 | 25.2 | 100 | 30 |
| 25.11.16 | 40+400 | RHS | 170 | 1459 | 24 | 1489 | 16 | 101 | 34 |
| 25.11.16 | 55+820 | LHS | 151 | 1389 | 25.5 | 1389 | 25.1 | 104 | 40 |
| 25.11.16 | 59+000 | RHS | 150 | 1089 | 29.8 | 1192 | 31.4 | 91 | 36 |
| 25.11.16 | 60+000 | LHS | 149 | 1352 | 23.4 | 1313 | 23.2 | 103 | 38 |

*Table 1: Test results of Subgrade*

*2.2. Falling Weight Deflectometer*

The deflections were carried out according to the ASTM D4694 - 09 Standard Test Method for Deflections with a Falling-Weight-Type Impulse Load Device. This test method covers the determination of pavement surface deflections as a result of the application of an impact and impulse load to the pavement surface. The resulting deflections are measured at the Centre of the applied load and at various distances away from the load and in this case at nine consecutive geophone points of 0, 200, 300, 600, 900, 1200, 1500, 1800, and 2100 mm. To obtain sufficient data for statistical analysis, measurements were taken at intervals of approximately 100 m as shown in Figure 1.

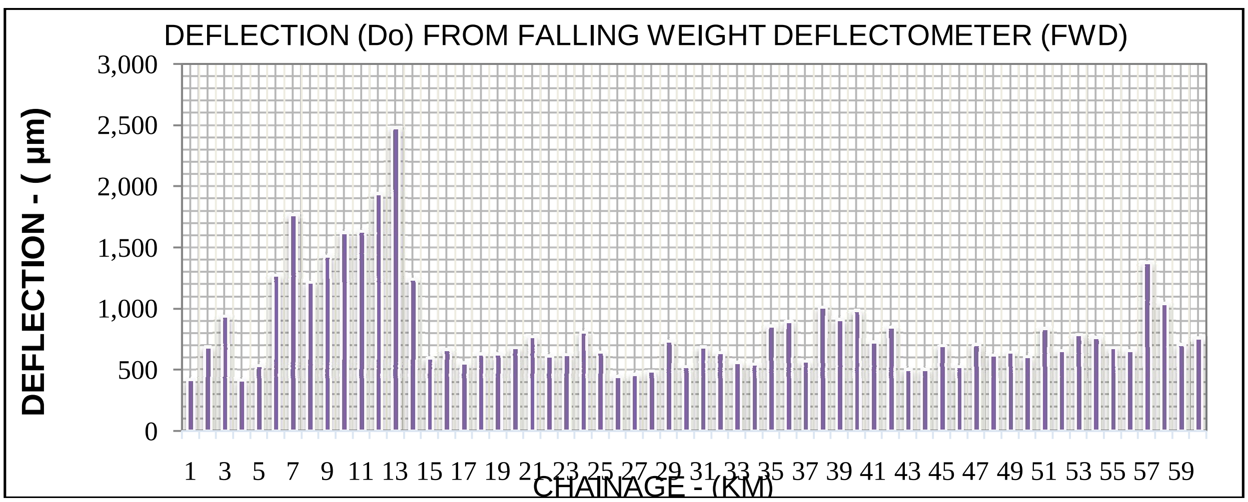


*Figure 1: Deflection measurement of ($D_0$) of FWD from Nakuru - Nyahururu*

*2.3. Classification of Project road Into Homogeneous Sections*

Sections were classified as homogeneous by CUSUM (Cumulative Sum) method where the deflection at the center $D_0$ of the FWD (Falling Weight Deflectometer) has a mean value and that mean value is deducted from each deflection ($D_0$).The cumulative sum of the result is plotted against the chainage of the road section as indicated on Figure 2 below. The first two homogeneous sections (HS-1 and HS-2) the last two homogenous sections (HS-4 and HS-5)were summarized as one homogeneous section HS-I and HS-III respectively.

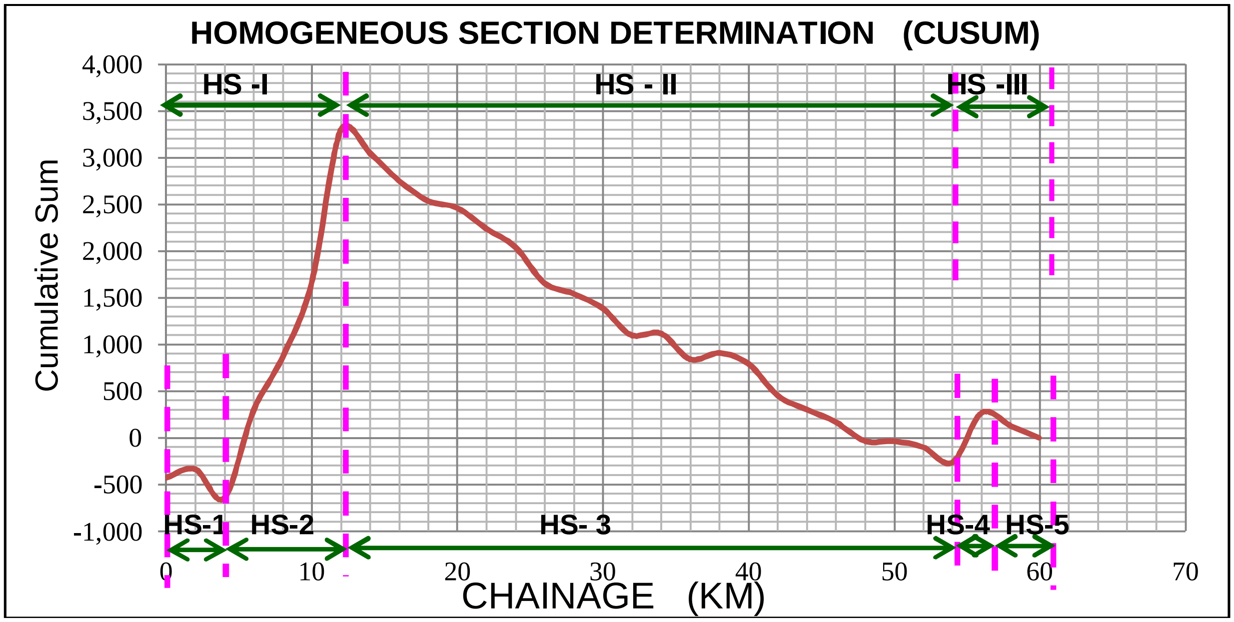

*Figure 2: Homogeneous section on Nakuru – Nyahururu road*

*2.4. Calculation of Cumulative Standard Axle and Traffic Classes*

The traffic class and sub-grade classification is shown in Table 2.Homogeneous section I & II are categorized under traffic class T 1 and the third homogeneous section HS- III is classified in T 2.

| **HOMOGENEOUS SECTION** | **HS-I** | **HS-II** | **HS-III** |
|---|---|---|---|
| Cumulative Number of Standard Axle | 29Millions | 26 Millions | 23 Millions |
| Subgrade Class | S4 | S3 | S6 |
| Traffic Class | $T_1$ | $T_1$ | $T_2$ |

*Table 2: Traffic Class and Sub-grade classification of each homogeneous section*

*2.5. Characteristic Deflection, $D_{90}$*

Due to a large number of factors affecting deflection, irrespective of the length of the road, variation in deflection from point to point was expected. The distribution of deflections in homogeneous section is expressed by Normal or Gaussian distribution Equation 1as calculated in Table 3.

$D_{90}$= d +1.3 x σ……………………………………………………………......Eq.1

| **Section** | **Homogeneous Section** | **From:** | **To:** | **Characteristic Deflection $D_{90}$** | **Pavement Condition** |
|---|---|---|---|---|---|
| 1 | HS - I | 0+000 | 13+250 | 1,688.06 | Severe |
| 2 | HS - II | 13+250 | 54+000 | 1,024.87 | Severe |
| 3 | HS - III | 54+000 | 60+000 | 1,198.53 | Severe |

*Table 3: Pavement condition based on characteristic condition, $D_{90}$*

*2.6. Characteristic Radius of Curvature (RoC)*

The magnitude of deformation is a function of the radius of curvature of the deflection bowl. In effect, the greater the flexural rigidity of pavement the larger the radius of curvature of the deflected shape for a given load and the smaller the strain. It is expressed in Equation 2 and pavement condition rating calculated as in Table 4.From the tabulated results the all homogeneous sections needed pavement reconstruction.

$$RoC = \frac{L^2}{2Do\left(1-\frac{D_{200}}{Do}\right)} \dots\dots\dots\dots\dots..\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots Eq.2$$

Where:-

L - 200mm for FWD i.e. position of second geophone;

$D_0$ - Deflection at Central geophone

$D_{200}$- Deflection at 200mm away from the central geophone

| NO | Section | From | To | Radius of Curvature (RoC) | Pavement Condition Rating |
|---|---|---|---|---|---|
| 1 | HS – I | 0+000 | 13+250 | 51 | Severe |
| 2 | HS – II | 13+250 | 54+000 | 61 | Severe |
| 3 | HS – III | 54+000 | 60+000 | 51.8 | Severe |

*Table 4: Pavement condition rating using radius of curvature*

## 3. Pavement Design Techniques (Methods)

### *3.1. Designing Using Kenyan Road Design Manual*

The road section between Nakuru and Nyahururu is of a mountainous and, rolling terrain. The road is an extension of Aberdare's mountain range in Kenya with a lot of small to medium rivers. The area had much gravel and quarry stone sites. The construction costs in Kenya Shillings for the pavement options were shown on Table 5.

| Homogeneous Sections | Subgrade Class | Traffic Class | Type Options | Surfacing | Base | Sub-Base | Cost / Km | Selected Options |
|---|---|---|---|---|---|---|---|---|
| Homogeneous Section (I) | $S_4$ | $T_1$ | Type 4 | AC - 75 | CSG -200 | GCS-225 | 25 M | TYPE 5 |
| | | | Type 5 | AC - 75 | CSG -150 | CLIM-200 | 19 M | |
| | | | Type 8 | AC -100 | GCS -150 | CLIM-125 | 25 M | |
| | | | Type 11 | AC -50 | DBM-125 | CLIM-175 | 42 M | |
| Homogeneous Section (II) | $S_3$ | $T_1$ | Type 4 | AC -75 | CSG -200 | GCS-275 | 36 M | TYPE 5 |
| | | | Type 5 | AC-75 | CSG -150 | CSG-225 | 18 M | |
| | | | Type 8 | AC-100 | GCS-150 | CSG-150 | 26 M | |
| | | | Type 12 | AC-50 | DBM-125 | GCS-225 | 47 M | |
| Homogeneous Section (III) | $S_6$ | $T_2$ | Type 4 | AC-75 | CLIM -200 | GCS-125 | 21 M | TYPE 4 |
| | | | Type 11 | AC-50 | DBM-125 | CLIM-100 | 40 M | |
| | | | Type 12 | AC-50 | DBM-125 | GCS-100 | 42 M | |
| | | | Type 13 | AC-50 | Conc.-150 | NG-100 | 46 M | |

*Table 5: Economical options from the design catalogue*

CLIM = Cement (Lime) Improved Materials; DBM = Dense Bitumen Macadam; AC = Asphalt Concrete; NG= Natural Gravel; Conc. = Lean Concrete

#### 3.1.1. Designing Using Tanzanian Design Manual (1999)

Tanzanian design manual is limited in options. These are specific to only some Base course types: - Granular, Cemented, Bituminous Mix and Penetration Macadam. Additionally the subgrade materials are all supposed to be greater than CBR 15% (>15%).

Homogeneous Section – I, II&III

The traffic volume was 29.05M, 25.60M & 22.7 Million for homogeneous sections I, II & III respectively. This fell in between 20-50 million E80, and classified as TLC 50 according to Tanzanian manual and is indicated in Table 6.

| Homogeneous Sections | Traffic Class | Base Options | Surfacing | Base | Sub-Base | Cost/ Km | Selected Options |
|---|---|---|---|---|---|---|---|
| Homogeneous Section I,II & III | TLC 50 | BM | AC-50mm | DBM-200mm | CM -250mm | 43 M | BM |
| | | PM | AC-100mm | PM -125mm | CM -300mm | 48 M | |

*Table 6: Options of Tanzanian Design Manual*

BM=Bituminous Macadam; PM= Penetration Macadam; CM= Cement Material; TLC= Traffic Load Class

#### 3.1.2. Analyzing the Kenyan Road Design Manual Options using of mePADS

In order to analyze the Kenyan options by use of the South Africa (mePADS), 3 layers were identified that are due to two layers of cement in the layer structure (Base and Sub-Base). The climate is taken Wet;as a rut depth of 20mm according to Kenyan design manual was adopted.

Using category "B" which is 90% for the Nakuru - Nyahururu road and the standard design load for South Africa is a 40kN dual wheel load (Based on the legal axle load of 80 KN allowed on public roads) at 350mm spacing between centers and a uniform contact pressure of 520kPa was set on the software.

i. -Homogeneous Section – I&II

Pavement type – 5 from the Kenya road design manual was selected. This was due to material availability and minimum construction cost. The selected pavement structure was as follows:-

- SURFACING : AC - 100mm
- BASE : Cement Stabilized Gravel-150mm
- SUB-BASE : Cement(Lime) improved material – 200/225mm

Putting the above data to the software (mePADS), the result of the analysis is shown as in Figure 3.From the Figure for type "B" road category, 90% of the road will reach its serviceability lifetime within 3-4 years after construction is complete.

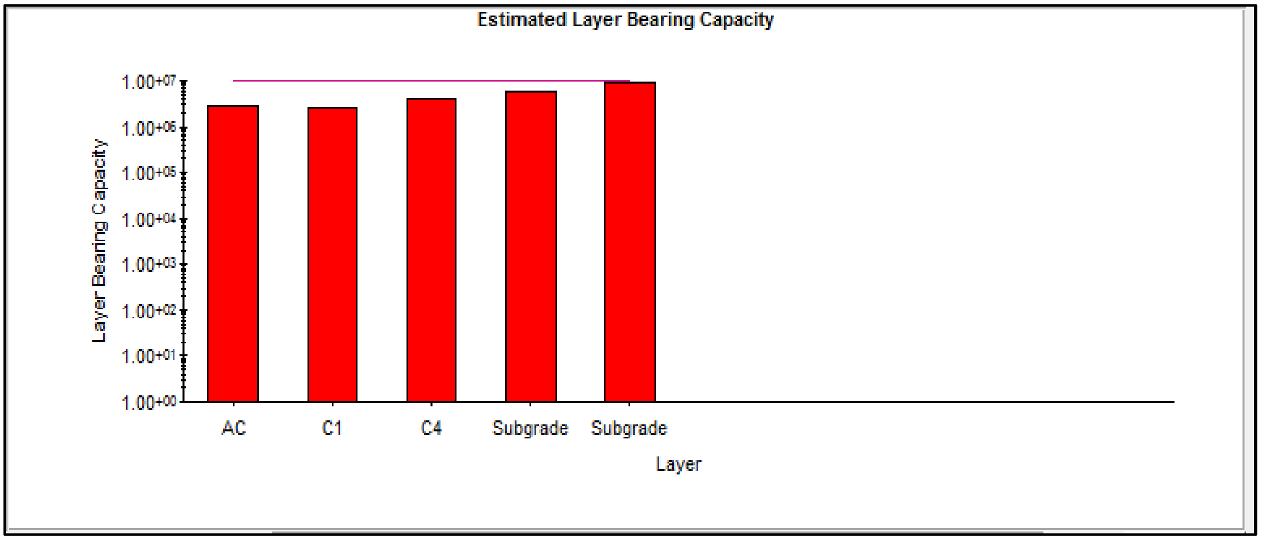


*Figure 3:Homogeneous sections- I & II analyzed by mePADS*

ii. -Homogeneous Section – III

Homogeneous Section –III has Subgrade class of S6 and traffic class of T2, among all options Type-4 was selected as minimum construction cost. Keeping all other parameters the same as those of homogeneous section I& II, the pavement structure for homogeneous section III was:-

| | |
|---|---|
| Surfacing | : AC – 75mm |
| Base | : Cement Stabilized Gravel – 200mm |
| Sub-base | : GCS (Base quality) – 125mm |

From the analysis shown in Figure 4, where the subgrade CBR is greater than 30 % but the surfacing, Base and Sub-base do not reach the minimum axle load range of the software which is 10 Million. The serviceability of the road with category "B" at 90% serviceability will last up to 7 years after construction. The analysis shows that an overlay for the three homogeneous sections for the remaining design period required when MePADS is used to check the pavement structures obtained from the Kenya Road Design Manual.

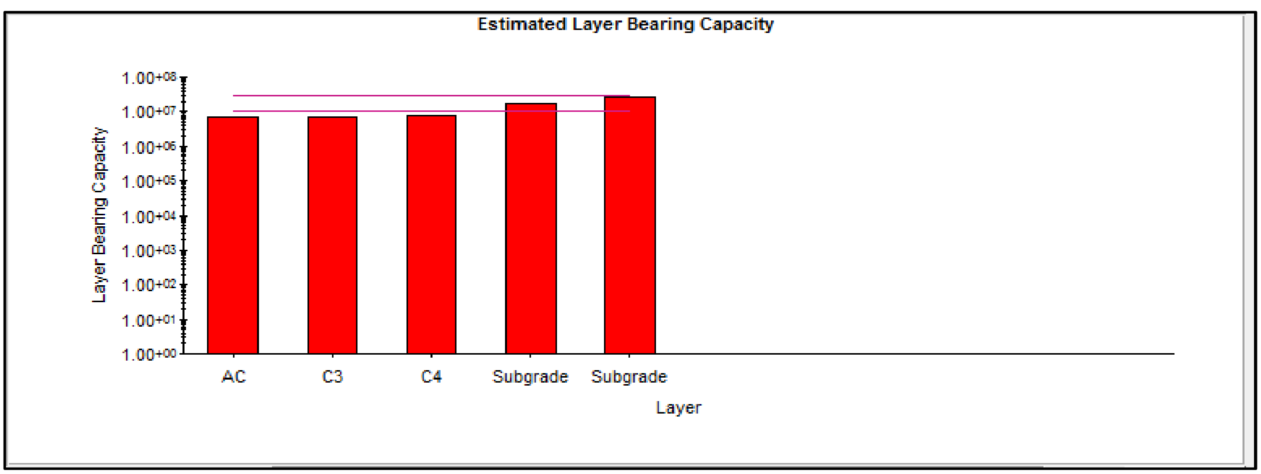


*Figure 4: HS-III being analyzed with mePADS software*

*3.2. Analyzing Tanzanian Design Manualusing mePADS*

i. - Homogeneous Section I, II and III

By use of the Tanzanian Design Manual the Table 7 shows the selected pavement structure. From the Figure 3 shown below, it was found that the AC was intact within the design range. The base, sub-base and subgrade layers could safely last the design life with a serviceability of B and reliability of 90%. Therefore; Tanzanian option was found safe after being analyzed by the mePADS with no need of overlaying during the design period.

| Layers | Description | Thickness |
|---|---|---|
| **Surfacing** | AC | 50 |
| **Base** | Bituminous Mix | 200 |
| **Sub-base** | Cemented Material (CM+CM) | 250 |

*Table 7: Selected pavement for homogeneous section I, II and III*
*Source: Tanzanian manual, 1999*

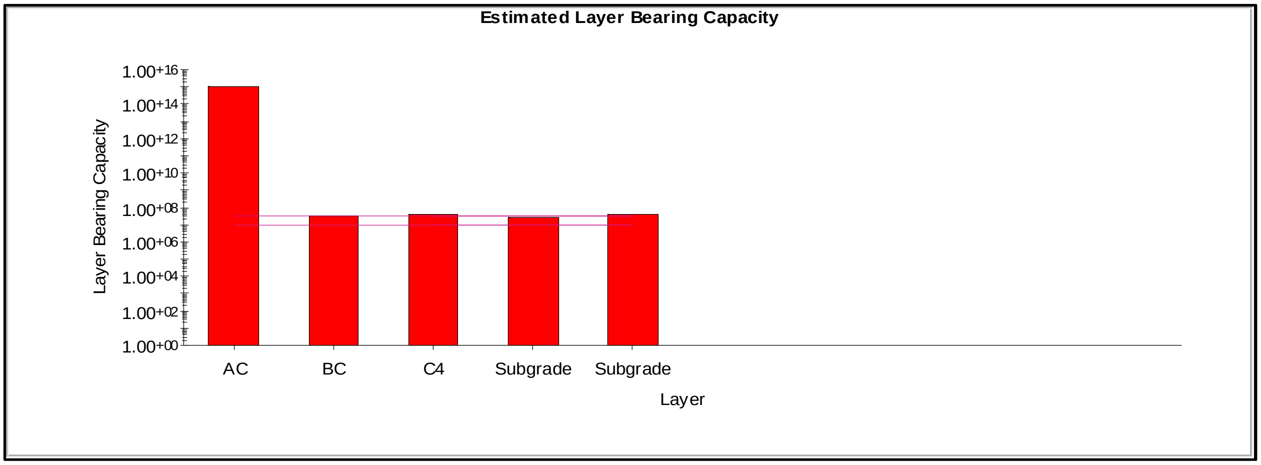


*Figure 5: Tanzanian options analyzed by mePADS*

*3.3. Overlaying for the Remaining Design Periods (Kenyan RDM)*

For comparison of the economical option over the design period it was necessary to design the overlay which would extend the pavement to the design period with the selection of Kenya Road design manual pavement structure. The existing structural number of the pavement and the Structural Number required for carrying the cumulative axle load on the road within the design period can be calculated by the Equation 3:-

$SN = a_1d_1m_1 + a_2d_2m_2 + a_3d_3m_3$……………………………………….……………….Eq. 3

Where;

SN=Structural Number

$m_i$= Drainage Coefficient

$d_i$= Thickness of pavement layer

An AC of 50 mm and a bituminous thickness of 130mm overlay so as to the pavement reach the remaining years of design period was used for further analysis.

*3.4. Design using mePADS of South Africa*

In order to design using MePADS, a surfacing of Asphalt Concrete (AC), a Base of Dense Bitumen Macadam and Sub-base of a Cement Improved Gravel pavement structure was assumed for the project road. The three homogenous sections I, II & III sectionhad subgrade values of 13, 10, & 36 and cumulative traffic load of 22.3 million, 19.6 million & 17.4 million respectively which lie in the E30 traffic category (TLC 10-30). A summary of the pavement sections for the three homogenous sections is now presented.

Homogeneous Section – I

$W_{18}$= 29.05 million,

From the analysis the pavement structure consisted of the following layers-

- Surfacing of AC - 30mm,
- Base Course of DBM - 200mm and
- Sub-base of Cement improved Gravel - 300 mm, as shown in Figure 4.Two layers of subgrade;

It was recommended that the lower subgrade be milled from the existing asphalt, base and sub-base layers. The milled subgrade would have which has a CBR of more than 30%. The upper subgrade was designed with a subgrade class of $S_6$.

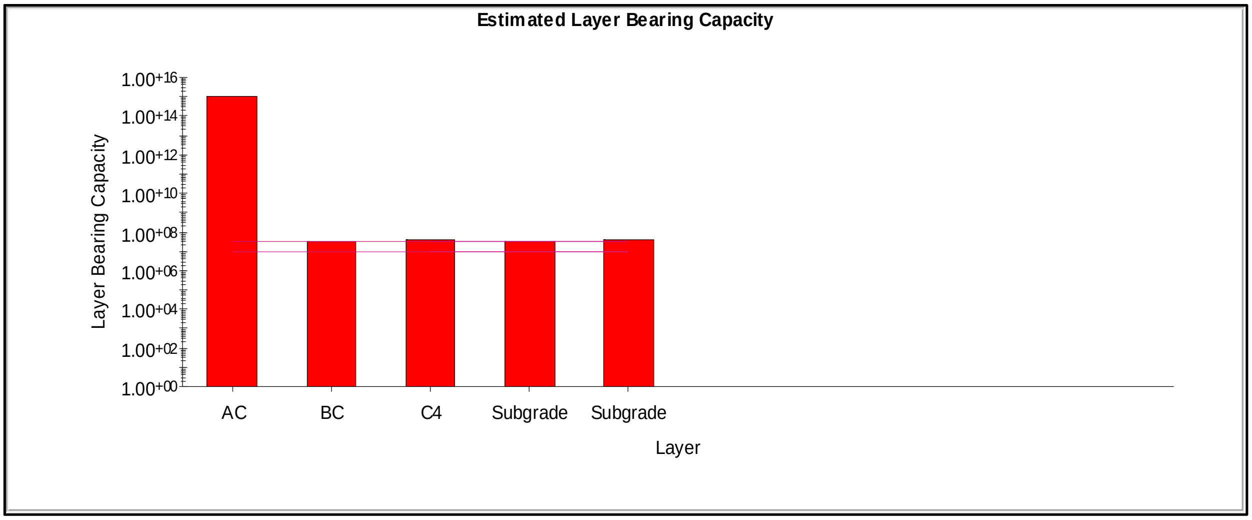


*Figure 6: mePADS analysis for homogeneous section -I*

Homogeneous Section –II

The design traffic of the homogeneous section which was 25.60M and the subgrade class was raised to a modulus of 250 MPA which has a CBR of more than 30%. From the analysis the pavement structure consisted of the following layers

- Surfacing: AC- 30mm
- Base Course: DBM – 190mm
- Sub Base Course: CM – 275mm (CM- Cement modified Gravel).

The Output of MePaDS for this pavement structure is shown in Figure 7.

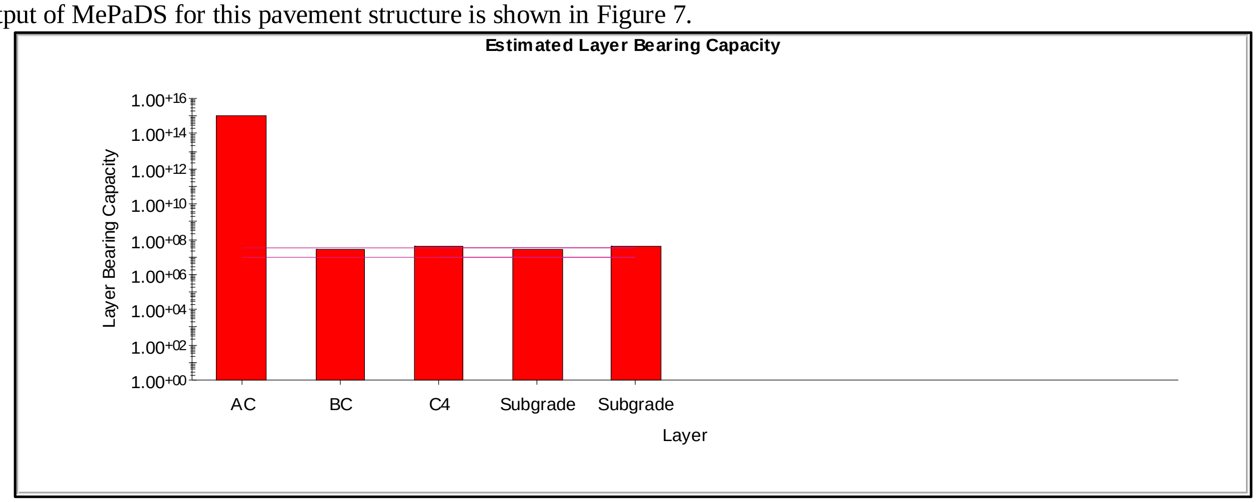


*Figure 7: mePADS analysis for homogeneous section -II*

Homogeneous Section –III

With a traffic loading of w18= 22.7 million, and following the same procedure the pavement structure is shown below while the MePADS results are shown in Figure 6: -

- Surfacing of AC of 30 mm and
- Base of DBM 190 mm and
- Sub-base of cement improved material of 250 mm is sufficiently in the range.

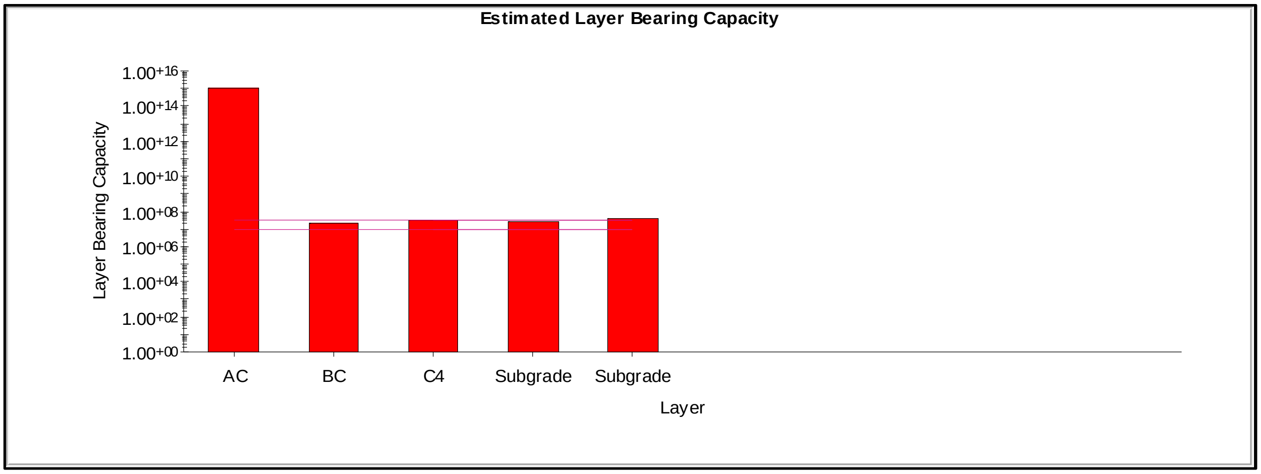


*Figure 8: mePADS analysis of HS-III*

*3.5. Design Using AASHTO 1993 Empirical Method*

Even though AASHTO 1993 method was developed in America; with an American soil characteristics & Climatic condition it was used with appropriate modifications as reference for this study. The results of all homogeneous sections are summarized in Table 8 below.

| With So = 0.45, ΔPSI = 4.5-2.5= 2, R=80%, m1=1.0 | | | |
|---|---|---|---|
| Homogeneous Sec. | Surfacing | Base | Sub-base |
| HS – I (W 29.05M) | AC=200 mm | DBM= 75 mm | CLIM =100 mm |
| HS – II (W 25.60M) | AC =175mm | DBM = 100mm | CLIM = 130 mm |
| HS – III (W 22.70M) | AC =175mm | DBM = 90mm | CLIM = 150mm |

*Table 8: AASHTO 1993 options for all homogeneous sections*

*3.6. Cost Comparison of Each design Methods*

In order to compare the pavement structures the following costs were added

- The initial construction cost
- Periodic maintenance envisaged after every 5 years
- Routine maintenance will done after new construction or periodic maintenance

The Cost comparison of the presented design techniques are shown in Figure 9.

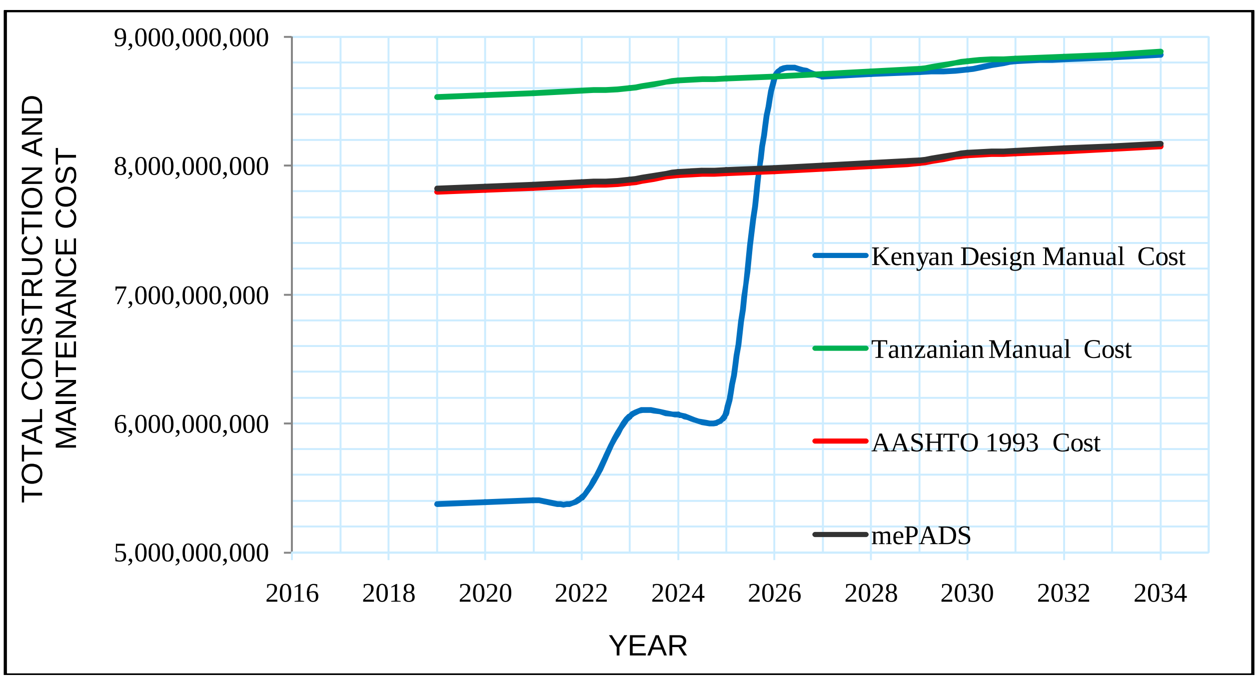


*Figure 9: Cost comparison of each design techniques*

**4. Conclusions**

After carrying out a pavement design by use of road design manuals from Kenya and Tanzania, AASHTO-1993 and South African software mePADS (mechanistic empirical Pavement Analysis Design Software) with a design period of 15 years the construction and maintenance costs were compared.

1. Designing using the Kenyan manual is not economical in the long run due to strengthening needed before the end of the design period. There is need of urgent revision of the Kenya Design Manual.
2. Using mePADS and AASHTO 1993 was found more economical than the Kenyan as well as Tanzanian design manual when the long term cost of maintenance over the design period is taken into account.
3. Kenyan RDM, 1987 pavement was found to be structurally insufficient when analyzed by mePADS.

**5. References**

i. AASHTO (1993), Guide for Design of Pavement structures. American Association of State Highway and Transportation Officials, Washington D.C USA.
ii. Liddle Wallace J. (1962) Application of AASHO Road Test Results to the Design of Flexible Pavement Structures, U.S. Bureau of Public Roads. Manual of Contract Documents for Highway Works (MCHW), Volume 3.
iii. Ministry of Roads Design Manual (1987): Pavement Design, Part III. The Republic of Kenya.
iv. Pavement and Materials Design Manual (1999): Ministry of Works, the United Republic of Tanzania.
v. RDM, (draft 2009). Overlay design and asphalt pavement rehabilitation. Design manual for roads and bridges, Ministry of Roads, Kenya.
vi. Road Design Manual Vol.3 (2005); Pavement Design Part I: Flexible Pavements, Ministry of Works, Housing and Communications, the republic of UGANDA.
vii. Russel W. Lenz (2011).”Pavement Design Guide”. Texas Department of Transportation, Texas, USA.