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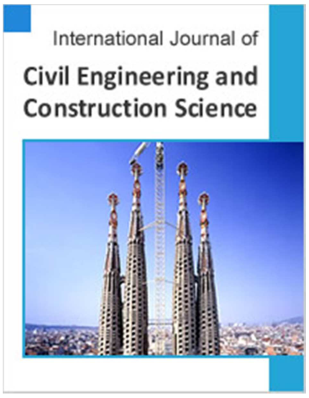

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A Comparative Study of Contemporary Flexible Pavement Design Methods in Nigeria Based on Costs

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Abstract

The choice of an appropriate design method from Group Index (GI), California Bearing Ratio (CBR), American Association of State Highway Officials (AASHTO) and Asphalt Institute design methods has a great potential on the cost effectiveness in pavement development. The aim of the research is to compare different structural methods of flexible pavement analysis and design on the basis of cost and long lasting serviceable structure. Traffic volume count was carried out manually, while soil samples collected from selected locations were tested to determine the parameters to be used for the structural design using both empirical and mechanistic- empirical methods. Average GI of 4 was obtained for the subgrade. The soaked CBR of 13% was determined and used for the design of a pavement structure to support a total Equivalent Single Axle Load (ESAL) of 5.5×10^6 AADT traffic for a design period of 10-20 years. Results showed that the pavement thicknesses were 400, 300, 500 and 560mm for GI, CBR, Asphalt Institute and AASHTO methods, respectively. The corresponding costs for development of the outcome structures are; ₦67,623,595.00; ₦61,701,412.00; ₦71,195,040.00 and ₦71,539,240.50 per kilometer of a standard two-lane carriageway. Thus, CBR method was recommended as the most economical while the Asphalt Institute and AASHTO methods the technically reliable and will provide most durable pavements. However, the Asphalt Institute and AASHTO methods of design are recommended for Nigerian flexible pavement construction, since they take into account the stress-strain properties of the soil and provide minimum maintenance cost.

1. Introduction

Pavement materials response to axle load imposed stress that is influenced by tyre pressure, temperature, and moisture, among others, whose individual and collective effects can be reduced through an effective structural design method. Several theoretical developments followed in the different parts of the world, In Europe, for flexible pavements, Shell adopted Burmister's theoretical work to model and analyze the pavement as an elastic layered system involving stress and strain [1]. In North America (USA), a comprehensive set of full-scale road tests were launched. The American Association of State Highway Official [2] introduced its first guide in 1972 which was revised in 1986 and 1993. From these two agencies, a conclusion can be drawn that the trend in pavement engineering was either empirical or a mechanistic method. An empirical approach is one which is based on the results of experiments or experience.

This means that the relationship between design inputs (loads, material, layer configuration and environment) and pavement failure were arrived at through experience, experimentation or a combination of both. The mechanistic approach involves selection of good quality materials and layer thickness for specific traffic and environmental conditions such that certain identified pavement failure modes are minimized. In mechanistic design, material parameters for the analysis are determined at conditions as close as possible to what they are in the road structure. The mechanistic approach is based on the elastic or visco-elastic representation of the pavement structure. In mechanistic design, adequate control of pavement layer thickness as well as material quality are ensured based on theoretical stress, strain or deflection analysis. The analysis also enables the pavement designer to predict with some amount of certainty in the life of the pavement.

It is generally accepted that highway pavements are best modelled as a layered system, consisting of layers of various materials (concrete, asphalt, granular base, sub-base and subgrade) resting on the natural subgrade. The behaviour of such a system can be analyzed using the classical theory of elasticity [3]. This theory was developed for continuous media, but pavement engineers recognized very clearly that the material used in the construction of pavements do not form a continuum, but rather a series of particular layered materials.

Pavement materials respond to axle loads in complex ways that is influenced by stress, temperature, moisture, time and loading rate among others. This makes the structural design of pavement to depend largely on empirical methods like the American Association of State Highway and Transportation Officials (AASHTO) guides for pavement design [2]; while several developments over recent decades have offered an opportunity for more rational and rigorous pavement design procedures. Flexible pavement design is manifested in mechanistic, or mechanistic-empirical (M-E) based design procedures that incorporate the treatment of life-cycle costs and design reliability. However, state-of-the-art practice methods, on the other hand, tend to rely more on empirical correlations with past performance, index-value-based characterizations of material properties [layer coefficient, R-value, California bearing ratio (CBR)], and engineering judgment for design strategy selection. The mechanistic design procedures refer to those methods that incorporate models based on fundamental engineering mechanics to evaluate the state of stress in a pavement and predict response, behaviour, and performance. On the other hand, empirical design approach is one that is based solely on the results of experiments or experience; some of them are either based on physical properties or strength parameters of the soil subgrade [4].

For flexible pavements, structural design is mainly concerned with determining appropriate layer thickness and composition, whose main design factors are stresses due to traffic load and the climate (temperature) variations. The two methods of flexible pavement structural design that are common today include empirical design and mechanistic empirical design [5].

An empirical analysis of flexible pavement design can be done with or without soil strength test. An example of design without soil strength test is by using Highway Research Board (HRB) soil classification system, in which soils are grouped from A-1 to A-7 and a group index is added to differentiate soils within each group. Examples with soil strength test use are McLeod, Stabilometer, California Bearing Ratio (CBR) test [6]. Mechanistic-empirical (M-E) methods represent one step forward from empirical methods; the induced state of stress and strain in a pavement structure due to traffic loading and environmental conditions is predicted using theory of mechanics. Mechanistic-Empirical (AASHTO) models link these structural responses to distress predictions. Thus, this study is to compare varying structural methods of flexible pavement design for the study location on the basis of which is the most economical in terms of construction cost, strength and maintenance cost and durability.

Embacher and Snyder [7] stated that, the costs of pavement construction, maintenance, and rehabilitation are primary factors considered by most local agencies in the selection of pavement type [hot-mix asphalt concrete (HMAC) or Portland cement concrete (PCC)] for new construction, according to them, the optimal use of agency funds for any given project can be determined only through an economic analysis of all associated agency costs and the performance of the pavement.

Embacher and Snyder [7] defines a road surface or pavement as a durable surface material laid down on an area intended to sustain vehicular or foot traffic, such as a road or walkway. They state that in the past, cobblestones and granite sets were extensively used, but these surfaces have mostly been replaced by asphalt or concrete. Such surfaces are frequently marked to guide traffic. They further state that, permeable paving methods are beginning to be used for low-impact roadways and walkways.

Uhlmeyer et al. [8] indicates that all hard surfaced pavement types can be categorized into two major groups, flexible and rigid. Flexible pavements are those which are surfaced with bituminous or asphalt materials. These can be either in the form of pavement surface treatments such as a bituminous surface treatment (BST) generally found on lower volume roads or, hot mix asphalt (HMA) surface courses generally used on higher volume roads such as the interstate highway network. These types of pavement are called flexible since the total pavement structure bends or deflect due to traffic loads. A flexible pavement structure is generally composed of several layers of materials which can accommodate the flexing.

Recently, there is a lot of variability in guide to design a pavement. Although all kinds of methods are available, pavement suffers damage which might have been caused by inadequate design thickness, among other factors. It is critical to determine the most appropriate pavement thickness for a given traffic level and subgrade condition. To overcome the problems, there is a need to study comparative pavement thickness analysis using pavement design methods and implied costs that will be most economical and appropriate in terms of durability [9].

In Nigeria, the only design method currently in use for asphalt pavement is the California Bearing Ratio (CBR) method. This method uses the California Bearing Ratio as the material and traffic volume as sole design inputs. The method, however, does not (i) account fully for damaging effects of heavier wheel loads and their frequency, (ii) consider whether the road is single or dual carriage and (iii) take in account the thicknesses of sub-base, base and surfacing separately [10]. The method was adopted by Nigeria as contained in the Federal Highway Manual [11]. Most, if not all of the major roads in Nigeria designed using the CBR method are the source of current unsatisfactory serviceability, as confirmed by Emesiobi [12] and [13], through a comparative analysis of flexible pavements designed using the CBR procedures. The result indicated that the pavements designed by the CBR-based methods are prone to both fatigue cracking and rutting deformation. The CBR method was abandoned in California 50 years ago [14] for the more reliable mechanistic-empirical methods, and Nigeria is desirous of having a change from the past and troublesome design practice. The study is therefore aimed to analyse the cost advantage of flexible pavement structure derived through different structural design methods.

The specific objectives are to:

(i) develop design parameters for structural pavement design methods in Nigerian highways,
(ii) design and cost a pavement for a selected movement corridor by the four most common design methods (CBR, GI, AASHTO and Asphalt Institute design methods)
(iii) compare the cost of structural design of the flexible pavement with the different methods and hence,
(iv) rate the contemporary pavement design methods in Nigeria that will be most comparable to the global best practices in pavement development.

2. Materials and Methods

Reconnaissance survey of the study area was conducted while the traffic volume count was done manually. Lateritic soil samples were collected, by method of bulk disturbed sampling, at a depth of 0.5 – 2.5 m after the removal of topsoil. They were stored and kept dry in bags in the soil laboratory for laboratory tests according to [15] and the Nigerian general specification for Roads and Bridges [16] was used to evaluate soil parameters such as Atterberg limit, California Bearing Ratio, Soil classification and Resilient modulus. Structural designs of flexible pavement were carried out using (i) California Bearing Ratio (CBR) Method, (ii) Group Index (GI) Method, (iii) Asphalt Institute design Method and (iv) AASHTO Design Method on a kilometre length of University of Ilorin road and sampled for costing and comparison.

3. Results and Analysis

3.1. Traffic Count Survey

The traffic survey results are shown in Table 1, From the Table, university approach have the highest percentage traffic composition of 19% on day 2 and the lowest percentage traffic composition of 5% was recorded on day 7.

Table 1. *Summary of traffic counts survey.*

	Cars and Taxis	Buses	Bikes	Trucks and lorries	Total vehicles (pcu)
Equivalent P.C.U.	1.0	2.8	0.75	2.0	
Monday	2,364	3382	8.25	204	5958.25
Tuesday	2477	3712.8	9.75	178	6377.55
Wednesday	2242	3670.8	10.5	240	6163.3
Thursday	2209	3410.4	8.25	288	5915.65
Friday	2179	3519.6	9	160	5867.6
Saturday	1130	1313.2	9	52	2508.2
Sunday	828	868	6	12	1714

Average of Daily Traffic (ADT) = 4929 pcu/hr/day

3.2. Soil Test Results

The summary of the engineering properties of the natural soil is presented in Table 2. The Group index value of the soil was found to be 4.

Table 2. *Engineering Properties of Natural soil samples.*

Sample number	A	B	C
Sample description	Reddish Brown	Reddish Brown	Reddish Brown
AASHTO classification	A-2-6	A-2-6	A-2-7
Natural Moisture Content (%)	10.70	10.65	11.91
Liquid Limit (%)	40.47	30.81	40.94
Plastic Limit (%)	21.33	15.05	21.21
Plasticity Index (%)	19.11	15.05	19.73
% Passing sieve No. 200(0.075 mm)	2.6	6.9	40
Group Index	0	0	4
Maximum Dry Density (mg/m$^{3)}$	1760	1800	1870
Optimum Moisture Content (%)	12.1	9.70	9.96
Unsoaked CBR (%)	32	42	25
Resilient modulus M_R (N/mm^2)	48000	55500	19500
Soaked CBR (%)	14	37	13
Resilient modulus M_R (N/mm^2)	21000	63000	37500

From the engineering properties presented in Table 2, the natural soil sample could be generally classified as Clayey Gravel soil and fall under group classification of A-2-6(0). This conforms to the report by [17] that, most lateritic soils for road construction fall within the A-2, A-6 and A-7 groups. It has significant clay material constituents, and there was presence of some sand and gravel materials constituents in the soil. The result showed that the soil samples have less percentage finer than 0.075 fractions (that is, % Passing 0.075 mm sieve < 35%), LL < 40% and PI > 11%. Hence, the soil classified as A-2-6(0) and the general rating as sub-grade in accordance with AASHTO [18] is excellent too good. The soil has significant constituent materials of mainly silty or clayey gravel and sand.

3.3. Flexible Pavement Design

The lowest soaked CBR value of 13% was obtained in Table 2 and was chosen to be used for design as this gives the most critical condition the soil can ever be subjected to. Table 3 shows the conversion factors applied on number of commercial vehicles to obtain the equivalent number of standard vehicles.

Table 3. *Conversion factor to obtain the equivalent number of standard axles from the number commercial vehicles.*

Type of road	No. of axles per comm. vehicle (a)	No. of standard axles per comm. vehicle (b)	No. of standard axles per comm. vehicle (a) x (b)
Motorways and truck roads designed to carry over 1000 comm. veh. /day in each direction at time of construction.	2.7	0.4	1.08
Roads designed to carry between 250 and 1000 commercial vehicle per day in each direction at time of construction.	2.4	0.3	0.72
All other public roads	2.25	0.2	0.45

Source: [19]

3.3.1. Group Index Method of Pavement Design

The group index of the soil samples are evaluated from equation (1). From the design chart of Figure 1a group index of 4, expected average daily traffic volume of 4929veh/hr and design life of 10 years, the value of each layer was obtained as follows:

$$G.I = 0.2a + 0.005ac + 0.01bd \quad (1)$$

where;

a = that portion of material passing 75 micro sieve (0.075mm) greater than 35 and not exceeding 75% (expressed as a whole number from 0 to 40).

b = that portion of material passing 75 micron sieve greater than 15 and not exceeding 55% (expressed as a whole number from 0 to 40)

c = that value of liquid limit in excess of 40 and less than 60 (expressed as whole number from 0 to 20)

d = that value of plasticity index exceeding 10 and not more than 30 (expressed as a whole number from 0 to 20).

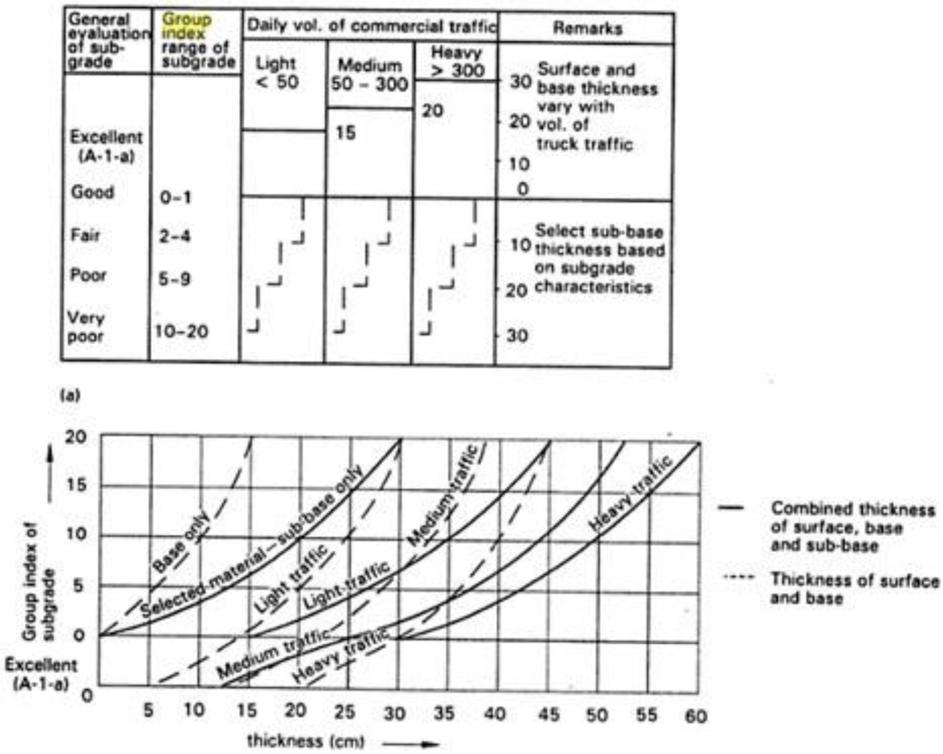


Figure 1. *Group Index Graphs. Source:[20].*

From curve A, selected material sub base thickness = 120mm

From curve D, combined thicknesses of surface, base and subbase = 400mm

Therefore; thickness of base and surfacing = 400mm – 120mm = 280mm

Provide surfacing thickness (Assume) 80mm

Thickness of base = 200mm

3.3.2. Empirical Method Using Soil Strength (CBR) Test

In this method, California Bearing Ratio (CBR) Method design chart is used (Figure 2), Table 4 shows the analysis period suggestsed by AASHTO and Asphalt Institute while Table 3 indicates the lane distribution factors and are used to determine thefollowing parameters;

Table 4. *Analysis Period Suggested by AASHTO and Asphalt Institute.*

Highway Conditions	Analysis Period (Years)
High volume, urban	30-50
High volume, rural	20-50
Low volume, paved	15-25
Low volume, aggregate surface	10-20

Source: [2]

1. Length of Road= 1km
2. Traffic intensity as worked out =4929Veh/day
3. Growth rate of traffic (assumed) = 7.5%
4. Total Period of Construction = one year
5. Design C.B.R. of Sub grade Soil=13.00% (Table 2)

CBR for sub-base material = 25% (Table 2)

CBR for base material = 100% (Assumed)

6. Design Period of the Road= 20 Years (Table 4)
7. Initial Traffic in the Year of Completion of Construction

$$A = P \times (1 + r)^{n+1} \quad (2)$$

where:

A = Traffic in the year of completion of construction CV/ Day

P = Traffic at last Count April 2016

r = Annual growth rate of traffic

n = Number of years between the last census and the year of completion of construction

I = design life of the highway

Therefore; traffic intensity is;

A = 22508 commercial vehicles per day.

From Figure 2 curve F,

The total flexible pavement to be placed on the sub-grade having a CBR of 13% = 300mm

a. Total thickness placed on sub base having CBR of 25% = 200mm
b. Total thickness on base having a CBR 100% = 75mm
c. Thickness of sub base material = 100mm
d. Thickness of base material =125mm
e. Thickness of surfacing = 75mm

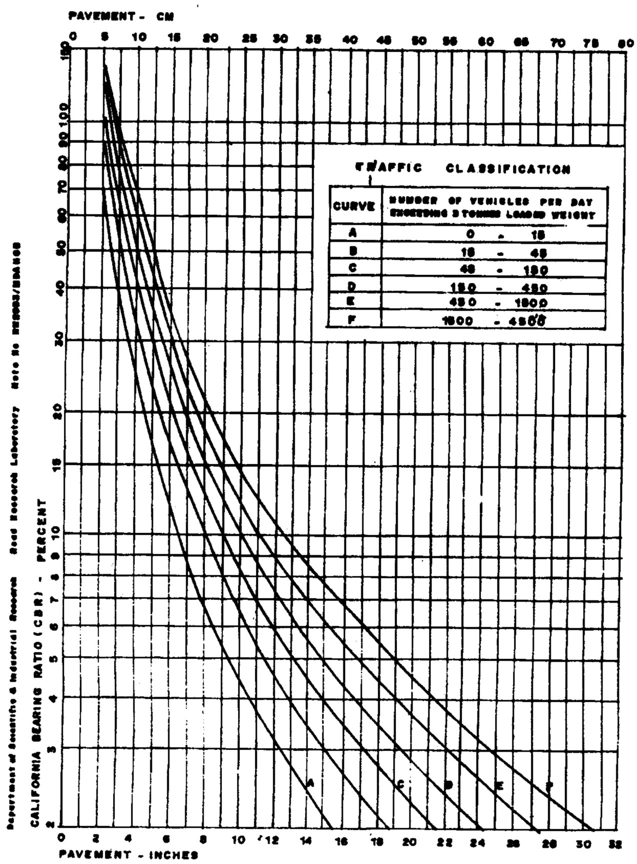


Figure 2. *The CBR Design chart: Source: [21].*

3.3.3. AASHTO Design Method

The design was done base on the 1993 AASHTO guide procedure.

AASHTO gives the conversion factor; Mr (N/mm^2)=1500CBR (Source: [2])

Resilient modulus of asphaltic concrete = 450,000(N/mm^2) (Table 2)

CBR value of the base course material = 100, Mr= 31000 (N/mm^2) (Source: [2])

CBR value of the sub-base course material = 22, Mr = 13500 (N/mm^2) (Table 2)

CBR of Sub-grade Soil: 13% (Table 2)

Design Life of Pavement: 20 years (Table 4)

Annual Growth rate: 7.5%

Distribution of Commercial vehicle for Single Lane: Double Lane

i. The present traffic is 4929 comm. vehicle per day per carriageway.
ii. During the 20 years design life, the slow lane will carry:
   a. Traffic on each lane 4929/2 = 2465 comm veh/day/lane
   b. Cumulative repetition at the end of 20 years (N)

$$N = (1 + r)^n \times A \times 365 \times n \quad (3)$$

where; N is the cumulative number of standard axles, r is the annual growth rate of commercial vehicle, A is the traffic on each lane and n is the design life in a year.

Therefore; N = 7.6 x 10^6 comm. Vehicle

The number of standard axles to be used for design purposes is 0.72 (from Table 3)

Equivalent standard axles load, (ESAL) = 5.5 x 10^6 standard axles (from equation 3)

Mr of subgrade = 19500 N/mm^2

Reliability level (R) = 99%

Standard deviation (So) = 0.49 (ranges from 0.4 to 0.5)

Initial serviceability index Pi = 4.5

Terminal serviceability index = 2.5

ΔPSI = 2

The value of the structural number (SN) is gotten from Figure 3.

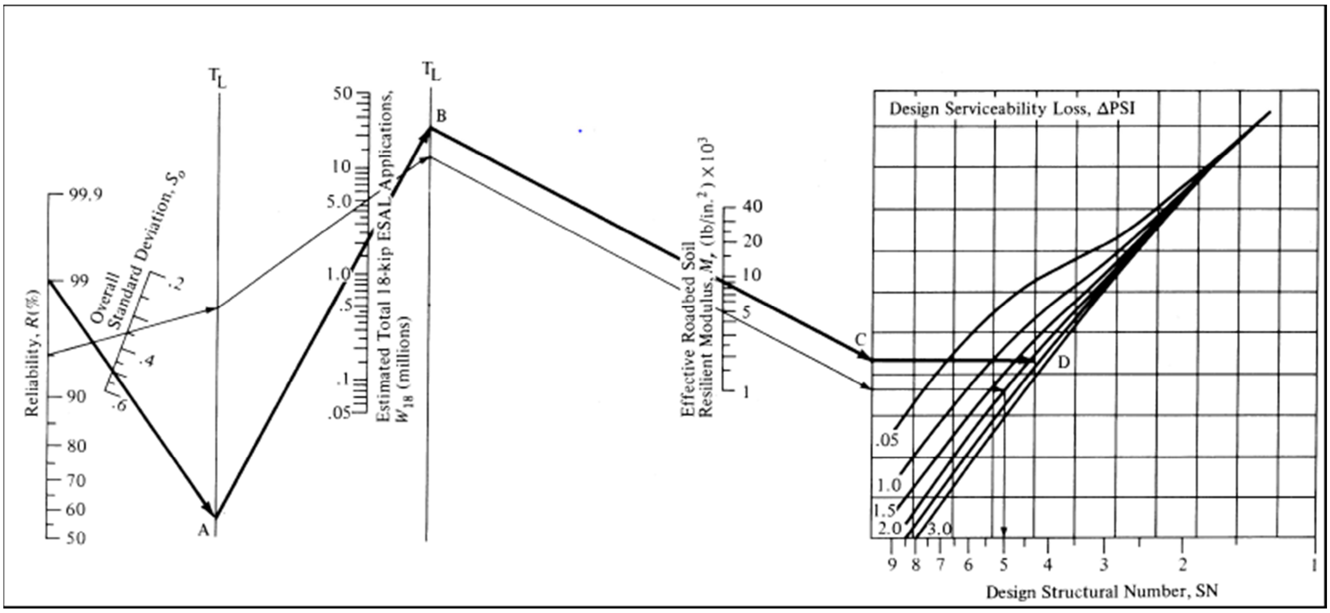


Figure 3. Design Chart for Flexible Pavements Based on Using Mean Values for each Input. Source: [2].

When ESAL = 5.5 x 10^6, SN = 3.6

Appropriate structure layercoefficients for each construction material are,

(i) Resilient value of asphalt cement =450000 N/mm^2, a_1 = 0.44

(ii) CBR of the base course material = 100, a_2= 0.14

(iii) CBR of the sub base course material =25, a_3= 0.11

To determine the drainage coefficient m_1, assume that the percentage of time pavement structure will be exposed to moisture levels approaching saturation = 30, m_1= 0.80. From;

$$SN = a_1D_1 + a_2D_2\, m_2 + a_3D_3m_3, \quad (4)$$

The SN value of 4.40 is used to obtain the values of D_1, D_2 and D_3.

Using the appropriate values for Mr in Figure 3, the SN value of 4.40 is used to obtain the values of D_1, D_2 and D_3

To determine the SN above the subgrade, Using the appropriate value of Mr in Figure 3, SN_3 = 4.4 and SN_2 = 3.8.

Mr for base course = 31, 000 N/mm^2 Using this value in the figure 3,

SN_1 = 2.6

Giving: $D1 = \frac{SN1}{a1} = 5.9\ in$ ~6 in (150mm) for the thickness of the surfacing course.

$SN_1 = a_1D_1$= 2.64

$D_2 \geq \frac{SN1-SN2}{a2m3} \geq 10.4\ in.(\ 260mm)$. SN_2= 3.84

$D_3 = \frac{SN3-SN2}{a3m3}$ = 6.0 in. (150 mm). SN_3= 4.40

The pavement will therefore consist of 150 mm asphalt concrete surface, 260 mm base course, and 150 mm sub base.

3.3.4. The Asphalt Institute Design Method

Conversion of CBR to Resilient Modulus (Mr) is done as follows:

$$Mr(MPa) = 10.342 * CBR \text{ (From 23)} \quad (5)$$

$$Mr(Ib/in.^2) = 1500*CBR \text{ (from 23)} \quad (6)$$

For CBR = 13%;

Mr(MPa) = 134.45Mpa

Mr (psi) = 19500 psi

Cumulative repetition at the end of 20 years = N = 7.6 x 10^6 comm. Vehicle (from equation 3)

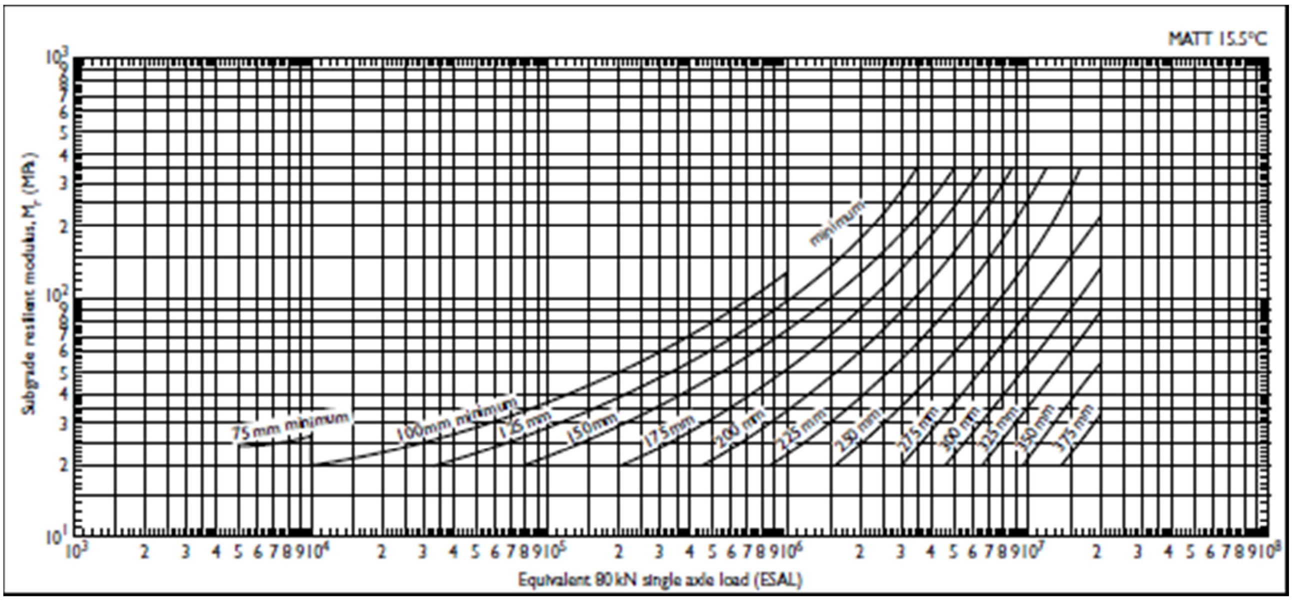
The number of standard axles to be used for design purposes is 0.72 from Table 4.

ESALs = 5.5*10^6 standard axles

Since the mean annual temperature in Nigeria are generally high, with temperatures ranging between 23 - 31°C and the design requests a 300mm untreated aggregate base, from Figure 5, for the full-depth, asphalt pavement will be used.

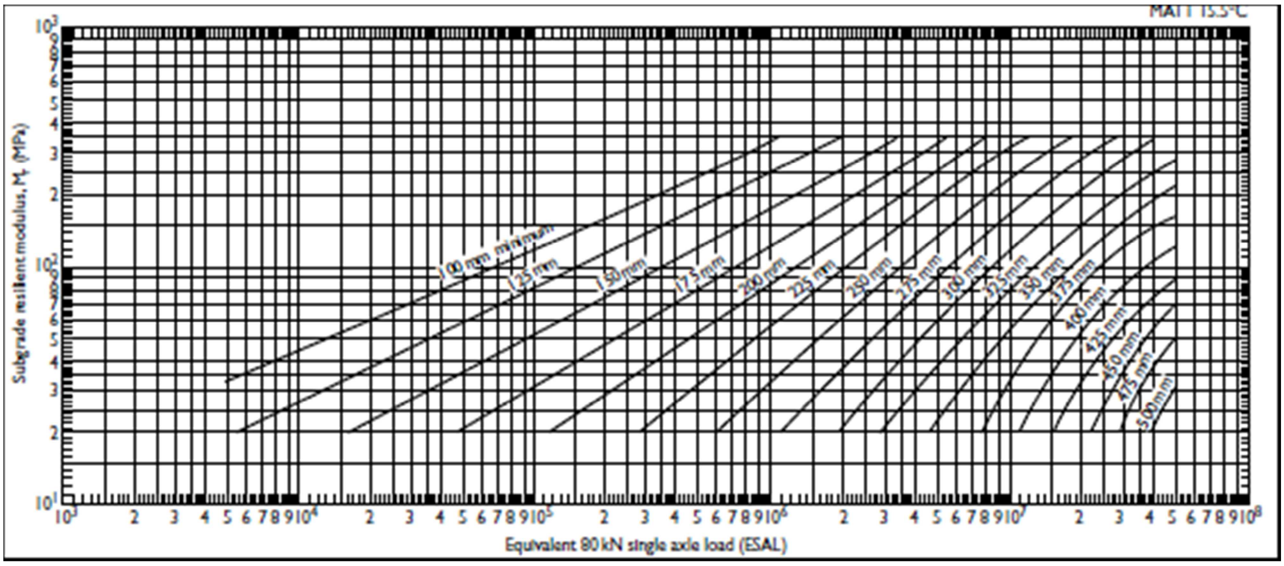
From Figure 4, the design thickness of the asphalt pavement portion is 200mm giving a total pavement thickness of 500mm.

The pavement will, therefore, consist of 200mm asphalt concrete surface and 300 mm untreated aggregate base courses.



Source: [22]; The Asphalt Institute; reprinted with permission.

Figure 4. *Untreated aggregate base, 300mm thickness.*



Source: [22] The Asphalt Institute; reprinted with permission.

Figure 5. *Full-depth asphalt concrete.*

3.4. Comparison of Pavement Layer Thicknesses

Four different methods of structural pavement design were used to determine the required thicknesses of the asphalt flexible pavement of a section of University of Ilorin road. The results are summarized in Table 5.

4. Discussion

Table 5 shows the comparison in pavement layer thickness of each flexible pavement design method. It was shown that CBR design method gave the thinner pavement layer compared to the others. The CBR design method has 75mm asphalt layer thickness, 125mm base course and 100mm sub-base course. However, the AASHTO method has 150mm thickness asphalt layer, 260mm base course and 150mm sub-base layer. 100mm thick asphalt layer, 300mm base course and 100 mm sub-base layer were obtained for the Asphalt Institute design method. For the Group Index design method a thickness of 80mm asphalt layer, 200mm road base and 120mm sub-base layer were obtained. AASHTO and Asphalt Institute methods produced thicker pavement layer. This leads to prevention of structural damage, such as fatigue or fatigue cracking, permanent deformation that result from the deformation of the soil subgrade and plastic deformation that may occur in the asphalt pavement layer, which enhance reduction in rehabilitation cost and prolong the pavement life.

Table 5. *Pavement layer thicknesses for each flexible pavement design methods.*

DESIGN METHOD / PAVEMENT LAYER	CBR	AASHTO	GROUP INDEX	ASPHALT INSTITUTE DESIGN
Asphalt Layer (mm)	75.0	150.0	80.0	100
Base Layer (mm)	125.0	260.0	200.0	300
Sub Base Layer (mm)	100.0	150.0	120.0	100
Total Pavement Layer Thickness (mm)	300.0	560.0	400.0	500

Figure 6 shows the graph of pavement thicknesses of the design methods and Table 6 presents the cost of pavement materials used in preparing the Bill of Engineering Measurement and Evaluation (BEME) for the design methods.

Figure 6, further confirms that AASHTO and Asphalt Institute methods are technically reliable, stable and durability which should be the first consideration in engineering, while the GI and CBR methods have financial advantage only. It also shows that AASHTO and Asphalt Institute design methods gave highest thicknesses such as 560 and 500 mm respectively. This is because they are based on the mechanistic-empirical design method, and account for stress-strain property of the pavement materials.

Table 6. *Price of Items.*

Items	Cost in 2016 (Naira)
Asphaltic Concrete (m^2)	4,500
Lateritic Soil (m^3)	2,000
Hard rock and hard pan Laterite (m^3)	4,000

Source: [23].

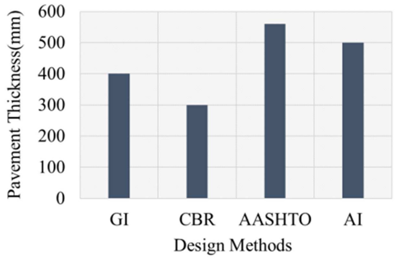


Figure 6. *Graph of Pavement Thicknesses of the Various Design Methods.*

The quantities are for 1km length and 8.2m wide two-lane Unilorin road. The rate in Table 6 were obtained from the Kwara state Ministry of works and transport, Ilorin Kwara state, Nigeria. The summarized BEME is presented in Table 7.

From Table 7, the costs of producing a kilometre stretch of road constructed using CBR, GI, are less cost than that of AASHTO and Asphalt Institute design methods respectively. This implies the GI and CBR design methods are financially viable as depicted in Figure 7.

Table 7. *Summary of BEME for the Four Design Methods.*

	Design Method	CBR	AASHTO	Asphalt Institute	G.I
Bill No.	Description	Amount (₦)	Amount (₦)	Amount (₦)	Amount (₦)
1	Earthworks	5,125,000.00	9,989,200.00	10,866,000.00	8,710,000.00
2	Road works	50,840,000.00	54,899,000.00	53,710,000.00	52,808,000.00
	SUB TOTAL	55,840,000.00	64,888,200.00	64,576,000.00	61,518,000.00
	Add 5% Contingency	2,798,250.00	3,244,410.00	3,228,800.00	3,075,900.00
	SUB TOTAL	58,763,250.00	68,136,610.00	67,804,800.00	64,593,900.00
	Add 5% VAT	2,938,162.50	3,406,663.50	3,390,240.00	3,229,695.00
	GRAND TOTAL	61,701,412.50	71,539,240.00	71,195,040.00	67,823,595.00

Figure 7 also shows a reasonable variation in costs of initial construction of the flexible pavement using various design methods, while Figure 8 shows the percentage composition of pavement cost analysis of the design methods.

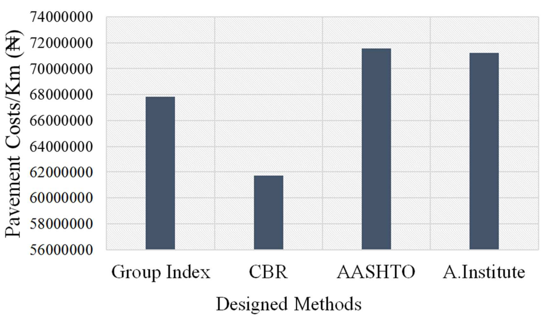


Figure 7. *Graphical comparison of Pavement Costs of the Various Design Methods.*

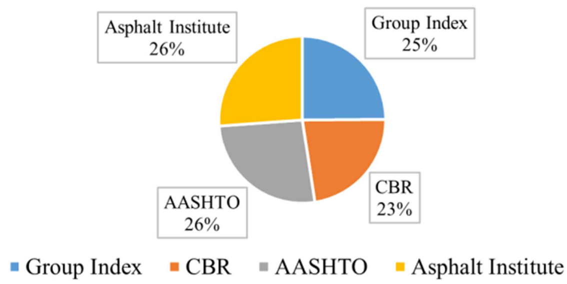


Figure 8. *Percentage Composition of Pavement cost Analysis of Various Methods.*

Figure 8 shows that, there is no significant difference in the costs obtained for the AASHTO and the Asphalt Institute methods, while the cost of producing a kilometer length of a road using the CBR design method is 2% low than that of constructing the same stretch employing GI design method.

Also pavement thickness affects the total cost of constructing a new pavement. An added advantage of AASHTO and Asphalt institute methods is that design periods of 20 years adopted is double the life span of pavement designed using CBR and Group index methods, which is 10 years.

5. Conclusion and Recommendations

5.1. Conclusion

Cost comparison of using empirical and mechanistic-empirical methods of flexible pavement showed that in terms of lifecycle cost, use of mechanistic-empirical method is cheaper while in terms of initial construction costs, empirical method is cheaper.

Four methods of designing flexible pavement layer thickness design were considered in this study and the following conclusions were drawn:

i. An average Group Index value of 4, Soaked CBR value of 13% and Equivalent Single Axle load (ESAL) of $5.5*10^6$ AADT were obtained and used for the design of a kilometer length of the pavement structure.
ii. The base/sub-base thicknesses produced by the GI, CBR, AASHTO and Asphalt institute design methods are 320, 225, 410 and 400mm respectively.
iii. Pavement thicknesses of 400, 300, 500, and 560mm were obtained for GI, CBR, AASHTO and Asphalt institute methods of design, respectively, while the corresponding costs of pavement per kilometre are ₦67, 823,595.00, ₦61, 701,412.50, ₦71, 539,240.00, and ₦71, 195,040.00.
iv. The CBR design method prove to be economical but not technically acceptable, while the AASHOTO and Asphalt Institute design methods prove reliable as they account for the stress-strain properties of the pavement material and in long run of the pavement structure it will be more economical because they have less maintenance charges.

5.2. Recommendations

The following recommendations are drawn:

i. AASHTO and Asphalt Institute design methods should be used since the methods are mechanistic-empirical. They take into account the stress-strain properties of the soil, which subsequently gives minimum maintenance charges and distinguishes between pavement structural damage.
ii. Further studies should be undertaken to compare the life cycle costs and benefits for the contemporary flexible pavement design methods in order to allow for comparison of the variation of design methods so as to select the best design procedure.

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