



## Comparative analysis of structural methods of flexible pavement design: A case study of Igbara-Oke Akure road, Ondo State, Nigeria

OYEDEPO, O.J.<sup>1</sup> and FANILOLA, O.D.

Department of Civil Engineering, Federal University of Technology, Akure, Ondo State, Nigeria

**ABSTRACT:** Pavement materials respond to axle load that is influenced by stress, temperature, and moisture among others. These factors often cause functional or structural failure; which can be reduced through effective structural design methods. The primary aim of the research is to compare different structural methods of flexible pavement on the basis of the most economical using both construction and maintenance cost as the basis of evaluation; while other design factors are taking into consideration. Traffic volume count was carried out manually, while soil samples collected from selected locations were tested in accordance with BS 1377 to determine the parameters to be used for the structural design using both Empirical and Mechanistic- Empirical methods. An average value of 7 was obtained for the group index (GI) for the selected locations which indicates that the soil is fair to be used as subgrade; the soaked CBR test also yielded a value of 8% for the subgrade which is within specifications for Roads and Bridges as given by the Federal Ministry of Works in Nigeria (1997), while a total Equivalent Single Axle Load (ESAL) of  $1.39 \times 10^6$  was obtained for the expected average daily traffic. Pavement thickness of 475mm, 350mm and 600mm was obtained using Empirical method with no soil strength test (Group Index method), Empirical method with soil strength test (CBR method) and Mechanistic – Empirical method (AASHTO method) respectively. Using the prevailing rate in the study area, a total amount of N48.95million, N33.17million and N89.82million will be used to construct one kilometer of road using the GI, CBR and AASHTO methods respectively. Thus, from the comparative cost, CBR methods give the most economical at the construction stage while the AASHTO method will give the most durable pavement. However, the AASHTO method of design is hereby recommended for the design since it takes into consideration the stress-strain properties of the soil and also gives the minimum maintenance cost.

**Key Words:** Pavement, Axle Load, Pavement Failure, Design Methods and Comparative Cost

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### INTRODUCTION

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

<sup>1</sup>Correspondence to: Oyedepo, O.J., oyedepoo@yahoo.co.uk

(AASHTO, 1993); 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), etc.], 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, behavior, 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. 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.

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, the primary aim of this research is to compare varying structural methods of flexible pavement design discuss above for the study location on the basis of which is the most economical in terms of construction cost, strengthening and maintenance cost and durability.

Several approaches have been proposed to assist in selecting a pavement type that would best suitable for an area; while the choice of the type of road pavement was mostly made on an improvised basis. Also some typical designs were worked out for both rigid and flexible pavement based on standard practice and comparative cost studies; while considering the comparative costs, initial construction costs, strengthening and maintenance costs and cost of vehicle operation as key elements.

In 1985, an economic study conducted on South Africa recommended pavement types for heavy traffic of up to 75 million Equivalent Single Axle Loads (ESALs). The study concluded that the general policy followed by the National Transport Commission of specifying that 20 percent of the heavy-duty pavements should be concrete on top of cement stabilized sub-base, and 20 percent should be asphalt surfacing on top of a bituminous base and a cement stabilized sub-base. The remainder may be of asphalt surfacing on top of a crushed-stone base and a cement stabilized sub-base, the conclusions were based on a present worth of cost comparisons. The study considered 30 years for the analysis period while factors considered in the economic analysis for comparison of the pavement type included initial construction cost, the expected maintenance costs, road-user delay costs, and the expected salvage value at the end of the analysis period.

Pittman 1996 stated that the U.S. Army Corps of Engineers' thickness design procedures for rigid

and flexible pavements were deterministic in nature. The pavement design methods use only one value, typically the mean value, for each of the design parameters and essentially ignore the inherent variability of the design parameters

during the design process; while design parameters, such as the California Bearing Ratio (CBR) of the subgrade in flexible pavement design was taken into consideration.

### DESCRIPTION OF THE STUDY AREA

The fourteen kilometer Akure – Igbara Oke road was constructed in the year 1969 along with some other roads in the state, such as Ondo – Ore, Ifon – Okitipupa road by the then Western region. It links the South-Western States to both the South-East and Northern Nigeria. The overall pavement thickness was estimated to be 360mm with 150mm laterite base, 150mm laterite sub base, 30mm binder course and 30mm asphalt wearing course. The Federal Ministry of Works and Transport took over the control of the road in the year 1976 due to the new transport policy to enhance proper maintenance. Since then, various rehabilitation works has been carried out on the road, the recent one was undertaken

by the Federal Road Maintenance Agency (FERMA).

The road shown in Figure 1 below was designed to sustain light traffic in the late 60’s to 70’s, with the creation of Ondo state in 1976 having its capital in Akure, and increase in urban migration has led to increase in the movement of vehicles from different part of the state to Akure, and this has caused a tremendous increase in traffic volume on this road. Though, its lifespan is exceeded non- provision of asphalt overlay has stressed the existing pavement which led to both functional and structural failure on some sections of the road network.

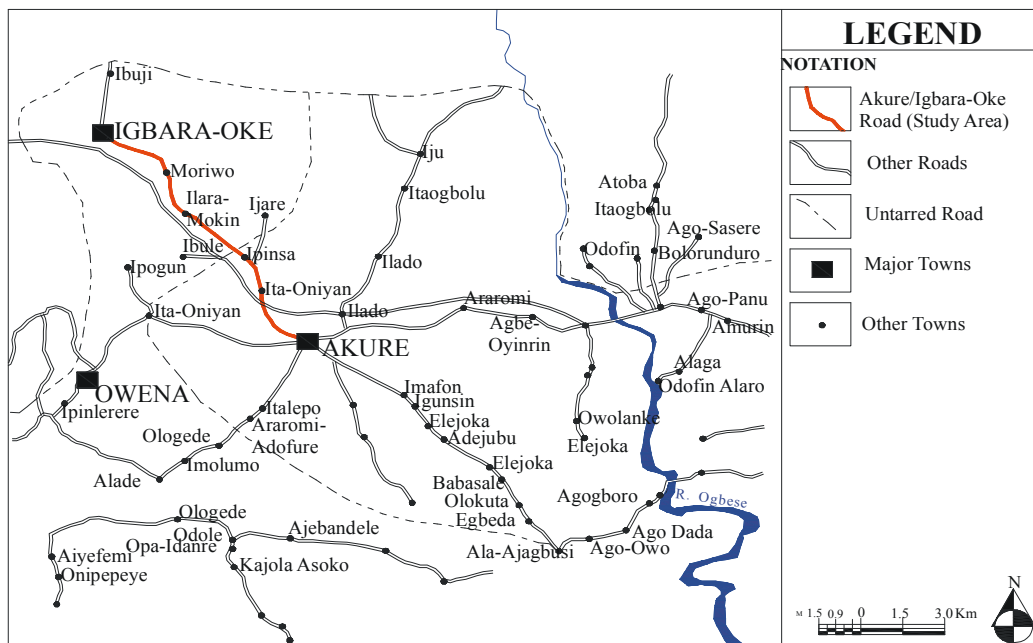


Figure 1: Administrative Map of Ondo State Showing Igbara-Oke/Akure Road

Source: Ifedore Local Government Area (2010)

## MATERIALS AND METHODS

The reconnaissance survey of the study area was conducted while the traffic volume count was done manually. However, disturbed soil samples were taken at three different locations for laboratory tests according to BS 1377 and

the Nigerian general specification for Roads and Bridges (1997) to evaluate soil parameters such as Atterberg limit, California Bearing Ratio, Soil classification and Resilient modulus among others.

## DATA ANALYSIS AND RESULTS

From the CBR test carried out, a lowest value of 8% was chosen to be used for designing as this gives the most critical condition the soil can ever be subjected to. Table 1 below shows the report of the in situ soil test conducted on the selected locations.

### Pavement Design

The following methods of structural methods of pavement design were used:

#### Group Index Method of Pavement Design

The group index of the soil samples are evaluated using equation 4.1 below while the summary of the values for the locations are given in table 4.7

$$G.I = 0.2a + 0.005ac + 0.01bd \quad \dots\dots\dots 4.1$$

Where:

a = that portion of the percentage passing the 75  $\mu$ m sieve greater than 35 and not exceeding 75 and expressed as a whole from the 0 - 40

b = that portion of the percentage passing the 75  $\mu$ m sieve greater than 15 and not greater than 55 expressed as a whole number from 0 – 40

c = that portion of the numerical LL greater than 40 and not exceeding 60 and expressed as a positive whole number from 0 – 20

d = that portion of the numerical PI greater than 10 and not exceeding 30 and expressed as a positive whole number from 0 – 20

#### For Sample 1

$$G.I(1) = 0.2 \times 20 + 0.005 \times 20 \times 5 + 0.01 \times 40 \times 5 = 6.5$$

say 7.0

Similarly, the Group Index for other soil samples was calculated in the same manner and the summary given in Table 2.

Using the design chart for the group index method, with a group index of 7 and expected average daily traffic volume of 532veh/hr, the value of each layer is obtained as follows:

From curve A, selected material sub base = 200 mm

From curve D, combined thickness of surface, base and subbase = 475 mm

Therefore thickness of base & surfacing = 475mm – 200mm = 275mm

Provide surfacing thickness of 75mm

Thickness of base = 275mm – 75mm = 200mm

However, the pavement layers are shown schematically in Figure 2.

#### Empirical Method Using Soil Strength Test

In this method, Road Note 31 design chart is used.

Calculation of the Equivalent Standard Axle Load (ESAL)

Passenger car (1000 lb/ Axle) = 38%

2 Axle single unit trucks (6000 lb/ Axle) = 5 %

3 Axle single unit trucks (10000 lb/ Axle) = 30%

Growth rate = 4%

Design period = 20 years

Growth factor = 29.97

Percent truck volume on design lane = 50

Load equivalency factors:

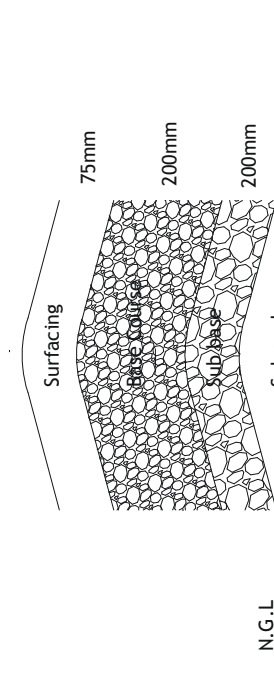
Passenger car (1000 lb/ Axle) = 0.00002 (negligible)

**Table 1: Report of In Situ Soil Test Carried Out**

Location	Pavement Layer															
	Subgrade					Sub Base					Base Course					
	% passing sieve 200	LL	PI	Soaked CBR (%)	Resilient Modulus N/mm2	% passing sieve 200	LL	PI	Soaked CBR (%)	Resilient Modulus N/mm2	% passing sieve 200	LL	PI	Soaked CBR (%)	Resilient Modulus N/mm2	unSoaked CBR (%)
1	15	28	6	8	12,000	23	26	8	22	33,000	27	22	14	71	106,000	71
2	12	26	6	9	13,500	20	22	7	19	28,500	24	21	12	68	102,000	68
3	18	32	7	13	19,500	23	19	9	36	54,000	29	18	11	70	105,000	70

**Table 2: Summary of Group Index values for the selected locations**

Sample	G.I	Remarks
1	7	Fair soil
2	7	Fair soil
3	7	Fair soil



**Figure 2: Schematic Diagram of the Pavement Thickness Using GI Method**

2 Axle single unit trucks (6000 lb/ Axle)=0.01043  
 3 Axle single unit trucks (10000 lb/ Axle)=0.0877  
 4 Axle single unit trucks (14000 lb/ Axle)=0.360  
 The ESAL for each class of vehicle is computed below

$$ESAL = f_d \times G_{ji} \times AADT \times 365 \times N_i \times F_{ei}$$

Where:

ESAL = equivalent accumulated 18000 lb axle load for truck category i

AADT = first year annual average daily traffic or vehicles in truck category i

$F_{ei}$  = truck factor for vehicles in truck category i

$G_{ji}$  = growth factor for a given growth rate j and design period t

$f_d$  = design lane factor

$$2 \text{ axle single unit truck} = 0.50 \times 29.78 \times 3190 \times 0.05 \times 365 \times 2 \times 0.01043 = 0.018 \times 10^6$$

$$3 \text{ axle single unit truck} = 0.50 \times 29.78 \times 3190 \times 0.3 \times 365 \times 3 \times 0.0877 = 1.37 \times 10^6$$

$$\text{Total ESAL} = 1.39 \times 10^6$$

For the purpose of design, the CBR value of 8% is used as this value is the most critical value of the soil strength.

Using Road Note 31 design chart, the pavement thickness obtained are:

Sub base thickness = 150 mm

Base thickness = 150 mm

Bituminous surfacing thickness = 50 mm

Total pavement thickness = 350 mm

However, the pavement layers are shown schematically in Figure 3.

**Mechanistic-Empirical Design Method (AASHTO Design Method)**

The main engineering property required for the subgrade is its resilient modulus, which gives the resilient characteristics of the soil when it is repeatedly loaded with an axial load. The recommended levels of reliability, standard deviation and structural layer coefficient ranges are as given in table 3.0.

AASHTO gives the conversion factor;  $M_r$  (N/mm<sup>2</sup>)= 1500CBR

Resilient modulus of asphaltic concrete = 450,000 (N/mm<sup>2</sup>)

CBR value of the base course material = 100,  $M_r$  = 31000 (N/mm<sup>2</sup>)

CBR value of the subbase course material = 22,  $M_r$  = 13500 (N/mm<sup>2</sup>)

CBR value of the subgrade material = 8

$M_r$  of subgrade = 8 x 1500 = 12000 N/mm<sup>2</sup>

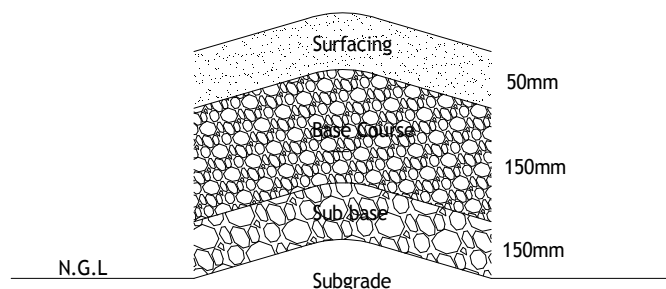
Reliability level (R) = 99%

Standard deviation (So) = 0.49

Initial serviceability index  $P_i$  = 4.5

Terminal serviceability index = 2.5

$$\square PSI = 4.5 \quad \square .5 = 2$$



**Figure 3: Schematic Diagram of the Pavement Thickness Using CBR Method**

**Table 3: Suggested Levels of Reliability, Standard Deviation and Structural Layer Coefficient for Various Functional Classifications**

Functional Classification	Recommended level of reliability				Standard Deviation, $S_o$		Structural Layer Coefficient			
	Urban		Rural		Flexible pavements	Rigid pavements	a1 Surface Course	a2 Untreated Base	a3 Sub base	
Interstate and other freeways	85	99-9	80	99-9	.40	.5	.30-.40	.17-.45	.05-.18	.05-.14
Other principal arterials	80	99	75	95						
Collectors	80	95	75	95						
Local	50	80	50	80						

Source: AASHTO Guide of Pavement Structures, Washington, D.C.(1993)

The basic design equation is given as;  

$$\log(W_{18}) = Z_R \cdot S_o + 9.36 \cdot \log(SN+1) - 0.20 + \frac{\log(\Delta PSI)/(4.2-1.5)}{0.4+1094/(SN+1)^{5.19}} + 2.32 \cdot \log(MR) - 8.07$$
 .....4.2

Where:

- $W_{18}$  = accumulated 18,000 psi equivalent single axle load for the design period
- $Z_R$  = reliability factor
- $S_o$  = standard deviation
- $SN$  = structural number
- $\Delta PSI$  = initial PSI – terminal PSI
- $M_R$  = subgrade resilient modulus
- The value of the structural number (SN) is gotten from the nomograph
- When  $ESAL = 2.44 \times 10^6$ ,  $SN = 4.4$

To determine the appropriate structure layer coefficient for each construction material,

- i) Resilient value of asphalt cement = 450000 N/mm<sup>2</sup>,  $a_1 = 0.44$
- ii) CBR of the base course material = 100,  $a_2 = 0.14$
- iii) CBR of the sub base course material = 22,  $a_3 = 0.10$

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  $SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$ , the SN value of 4.40 is used to obtain the several values of  $D_1, D_2$  and  $D_3$ .

To determine the SN above the subgrade, Using the appropriate value of  $M_r$  in the nomograph,  $SN_1 = 4.4$  and  $SN_2 = 3.8$   
 $M_r$  for base course = 31,000 N/mm<sup>2</sup>  
 Using this value in the nomograph,  $SN_1 = 2.6$  giving,

$$D_1 = \frac{2.6}{0.44} = 5.9 \text{ in (147.5 mm)}$$

Using 6 in (150 mm) for the thickness of the surface course,

$$D_1 = 6 \text{ in (150 mm)}$$

$$SN_1 = a_1 D_1 = 0.44 \times 6 = 2.64$$

$$D_2 e^{\frac{SN_2 - SN_1}{a_2 m_2}} e^{\frac{3.8 - 2.64}{0.14 - 0.8}} e^{\dots} 10.36 \text{ in} = 259 \text{ mm}$$

12 in (300 mm) is used

$$SN_2 = 0.14 \times 0.8 \times 12 + 2.64 = 1.34 + 2.64$$

$$D_3 = \frac{SN_3 - SN_2}{a_3 m^3} = 4.4 - \frac{(2.64 + 1.34)}{0.1 \times 0.8} = 5.25 \text{ in}$$

(131.25 mm)

6 in (150 mm) is used

$$SN_3 = 2.64 + 1.34 + 6 \times 0.8 \times 0.1 = 4.46$$

The pavement will therefore consist of 150 mm asphalt concrete surface, 300 mm base course, and 150 mm sub base. However, the pavement layers are shown schematically in Figure 4.

**Cost Estimate for 1km Length of Road Using the Prevailing Rate in Ondo State For Design Method Using GI**

Asphalt Thickness = 75mm; Lateritic Base = 200mm; Lateritic Subbase = 200mm

Volume of Asphalt for 1km length = 0.075 x 10.3 x 2000 = 1545 tonnes

Volume of Lateritic Base = 0.2 x 1000 x 10.3 = 2060m<sup>3</sup>

Volume of Lateritic Subbase = 0.2 x 1000 x 10.3 = 2060m<sup>3</sup>

Cost of Asphaltic surface = 1545tonnes @ N25,000/tonnes = N38,625,000.00

Cost of Stone Base = 2060m<sup>3</sup> @ N1500/tones = N3,090,000.00

Cost of Lateritic Subbase = 2060m<sup>3</sup> @N1350/tonnes = N2,781,000.00

Total	N44,496,000.00
Add 10% wastage	N4,449,600.00
Total Cost	N48,945,600.00

Similarly, the cost of construction for the other two design methods were determined in the same manner and shown in table 4.0 below.

**Remark:**

The total construction cost obtained is base on the prevailing rate in the study area and for relatively flat terrain; excavation in rock and road infrastructure such may increase the amount in relative proportion. Also, the construction cost using CBR method is most economical while AASHTO design method gives the highest value. However, only AASHTO design method takes into account the stress-strain which the soil is subjected to, a major factor contributing to pavement distress. Thus, the overall maintenance cost is reduced if pavement thickness obtained using AASHTO design method is used.

**Table 4: Cost Analysis of the Various Methods of Structural Design**

Pavement Layer	Material	Design Method / Thickness(mm)			Design Method/Construction Cost ₦ x 10 <sup>6</sup>		
		GI	CBR	AASHTO	GI	CBR	AASHTO
Surfacing	Asphalt	75	50	150	38.63	25.75	77.25
Base Course	Stone base	200	150	150	3.09	2.32	2.32
Subbase	Laterite	200	150	150	2.79	2.09	2.09
Total					44.50	30.15	81.65
Add 10% Wastage					4.45	3.02	8.17
Total Cost					48.95	33.17	89.82



## CONCLUSION

The total thickness obtained are 350mm, 475mm, and 600mm respectively using G.I, CBR and AASHTO method; while the total construction cost are N88.99m, N61.5m and N164.39m per km of road respectively. It is recommended that value

obtained using AASHTO design method be used since the method takes into account the stress-strain properties of the soil which subsequently gives minimum maintenance charges.

## REFERENCES

- AASHTO (1993)**. AASHTO Guide for Design of Pavements Structures, American Association of State Highway and Transportation Officials, Washington, DC.
- TRANSPORT AND ROAD RESEARCH LABORATORY (1998)**. A Guide to Road Project Appraisal, Overseas Road Note 5. Crowthorne, Berkshire:
- ATTOH-OKINE, N.O. (2002)**. "Uncertainty Analysis in Structural Number Determination in Flexible Pavement Design - A Convex Model Approach" *Construction and Building Materials*, 16(2):67-71.
- BS 1377 (1975)**. Methods of Testing Soil for Civil Engineering Purposes, British Standard Institute, BSF London, England.
- DEPARTMENT OF TRANSPORT, SCOTISH DEVELOPMENT DEPARTMENT (1990)**. Specification for Road and Bridge Works.
- FGN (1997)**. The Nigerian General Specifications for Road and Bridges, Volume II, Federal Ministry of Works.
- FEDERAL MINISTRY OF WORKS AND HOUSING MANUAL (1973)**. Highway Design Manual Part 1
- NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM (2004)**. Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, NCHRP Project 1-37A, National Research Council, Washington, DC.
- NUNN, M.E., BROWN, A., WESTON, D. and NICHOLLS, J.C. (1997)**. Design of Long-life Flexible Pavements for Heavy Traffic, TRL Report 250. Crowthorne, Berkshire: The Transport Research Laboratory,
- OWOLABIA.O (1996)**. Towards an Improved Road Network for the Survival of Nigerian Economy. Proceedings of the Maiden National Engineering Conference at Federal Polytechnic Bauchi, Nigeria pp 121-130
- Traffic assessment, HD 24/96, (1996): Design Manual for Roads and Bridges, Vol. 7, Section 2. London: The Department of Transport.
- WITCZAK, M.W. (2004)**. "Assessment of the Allowable Threshold Rut Depths by Layers in Asphalt Pavement Systems" Transportation Research Board, NCHRP 9-19, National Cooperative Highway Research Program, Washington, D.C.
- YODER J.E. and WITCZAK W.M. (1975)**. Principles of Pavement Design, 2<sup>ND</sup> Edition, Niley, England, pp 196 – 241.
- ZHANG, Z., LEIDY, J.P., KAWA, I. and HUDSON, W.R. (2000)**. "Impact of Changing Traffic Characteristics and Environmental Conditions on Flexible Pavements," Transportation Research Record 1730, Washington, DC, pp. 125-131.