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AN OPTIMISED FLEXIBLE PAVEMENT DESIGN PROCEDURE

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ABSTRACT

The portion of the highway most obvious to the motorist is the road pavement, the surface of a road on which vehicles will travel. The road pavement provides traction for vehicles to travel as well as transfer normal stresses from the vehicle to the underlying soils (subgrade). This study developed an optimized flexible pavement design procedure that is based on fundamental properties of the pavement materials, environmental impacts, loading and pavement response. The study consisted of the determination of traffic volume on Akure – Ilesha Expressway. Established equations were used to obtain soil-cement stiffness, soil-cement tensile strength, allowable soil strain, subgrade stiffness and lateritic material constant from resilient modulus. Soil support values, layer co-efficient, serviceability index, structural Number, Regional Factors, cracking and No-cracking values as environmental factors were sourced from Design Manuals, Literatures Journals and test results. The load from the design traffic and resulting contact pressure were used to calculate the developed pavement stresses and strains at critical points of the pavement. Artificial Neural Network (ANN) was used to analyze the strains and stresses induced as responses to the pavement loading. The stresses and strains from ANN analysis were compared to the maximum permissible stresses and strains at the critical points of the pavement to select those that are less than the safe working stresses and strains at those points. The constraints equations were solved to produce the different layer thickness. Inserting the layer thicknesses produced the total cost of pavement in Naira per square meter when converted from US dollars. The results show 4.47 x 10^5 as Equivalent Axle load for twenty (20) years. The preliminary layout ranges between 425 mm to 550 mm while the optimum layout ranges between 600 mm and 625 mm. And the cost per square meter of the optimum layout ranges between ₦47,797.80 and ₦48,585.00. The proposed procedure produced an optimal layout that can sustain overloaded traffic (which is a basic design problem in Nigeria) through the design life. However, further studies should be undertaken on more additional different additives on lateritic soil to obtain optimal layout with this developed procedure

Keywords: Optimization, Design Procedure, Flexible Pavement, Artificial Neural Network, Layout, Equivalent Axle load

1.0 INTRODUCTION

There are multiple means of transportation such as water transport, air transport, road transport, train transport, etc. Transportation through roads are one of the most widely used means for transportation and cover the maximum population. The reasons for its wider acceptability are many. Some of them are like; the service could reach any individual to the door of their houses, hospital, schools, market or any other places that people use to visit on daily basis. It also allows the liberty of speed and time taken to visit a place. It has yet another advantage in terms of economics too. The construction cost along with maintenance cost is low in comparison to the number of people getting benefitted out of it. A larger part of credit goes to the technology and material that is getting in the construction of roads (1).

The portion of the highway most obvious to the motorist is the road pavement, the surface of a road on which vehicles will travel. Natural ground cannot support the wheel loads of vehicles- particularly when wet. The road pavement provides traction for vehicles to travel as well as transfer normal stresses from the vehicle to the underlying soils (sub-grade) (2). The pavement reduces the stresses on the subgrade to such a level that the subgrade does not deform under the action of traffic. At the same time, the pavement layers themselves need to be strong enough to tolerate stresses and strains to which the layer is exposed (3). Pavement are complex structures affected by many factors and stochastic processes such as traffic volume and load, material properties, environment, change of road bed soil support, pavement aging process, construction practices, and maintenance procedures. Uhlmeyer et al. (4) 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.

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 (5).

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, (6) and Ekwulo and Erne, (7), through a Comparative analysis of flexible pavements designed using the CBR procedures. Their result indicated that the pavements designed by the CBR-based methods are prone to both fatigue cracking and rutting deformation. Persistent pavement failures, limitation of current design method, performance issues with existing pavement and Nigeria desirous of having a change from the past and under-design practice call for optimized design procedure.

Therefore, there is a need to develop an optimized approach in order to improve and augment the procedure involved in the design of a flexible pavement in order to mitigate the effect of the aforementioned lingering problems, of which this study is hinged upon achieving

2.0 Methods

Traffic Analysis

Pavement structural design requires a quantification of all expected loads that pavements will encounter over its design life. This quantification is done using Equivalent single Axle loads (ESALs). This converts wheel loads of various magnitude and repetitions (mixed traffic) to an equivalent number of "Standard" or "Equivalent" loads. The distribution of the different types of vehicles plying the road was obtained from results of classification counts that was taken on Akure-Ilesha Expressway. The traffic census data collected were analyzed. Traffic census was analyzed into group under single and tandem axles This resulted into the number of vehicle in a group and the factor which when multiplied with the vehicle number became Equivalent Single Axle. The total sum of these become Total Equivalent Single Axle (TESA). TESA was imputed into an equation 1.0 for Equivalent Axle load (EAL) and the 20 years EAL was gotten as the load repetitions of the standard axle load(E80).

It was this that was compared with the standard as specified by AASHTO Design Manual.

$$EAL_O = \frac{TESA}{100}(\text{Truck }\%)\frac{ADTm}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 1.0$$

$$EAL_{20} = \frac{EAL_O(365)\{(1+i)^n - 1\}}{\text{Log}_e(1+i)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.0$$

EAL =Equivalent Axle Load

EAL_O = Initial daily EAL on the day traffic is opened on the road

EAL_n = EAL at any year n

i = rate of traffic increase expressed as a percentage per year.

TESA = Total Equivalent Single Axle

ADTmean = Average Daily Traffic mean

Material Characterization

The fundamental properties of lateritic soils, both stabilized and unstabilized were sourced from laboratory test results on laterite borrow pit materials. The laboratory test results on laterite borrow pit materials were also considered. The lateritic soils were categorized under base, sub-base and subgrade materials. The stabilization of the sub-base materials to upgrade them as base materials was considered. The additives used were cement and lime. The effects on the strength, compaction and Atterberg Limits of the sub-base material when different percentages of cement and lime were added were considered.

The fundamental properties of bituminous and asphaltic materials such as modulus of elasticity (E) and Poisson's ratio (μ) used were obtained from past reports and Journals of Civil Engineering. The modulus of elasticity of the stabilized laterite base especially that of the soil-cement was estimated from an equation developed by Otte, (8) relating the unconfined compressive strength to the average modulus of elasticity (E_b) of cement-treated materials. The representative stiffness or modulus of elasticity of the subgrade was estimated from the approximate relationship as follows.

E = KCBR

Where

E is Subgrade stiffness

CBR is California bearing ratio of the subgrade materials

K is Constant which ranges between 5 and 20

The Poisson's ratio adopted for the asphalt, stabilized laterite, unstabilized laterite was 0.4, 0.35 and 0.4 respectively. The equation relating the tensile strength of a soil-cement to its unconfined compressive strength of soil-cement given by Otte, (8) was used to estimate the tensile strength of the soil-cement. For the resilient modulus of untreated and treated lateritic soils, the equation relating the resilient modulus (M_R) of the material to the axial deviator stress (σ_d), the recoverable axial strain (ϵ_a), the bulk stress (Θ) and the regression constants (K_1 and K_2) from the $\log M_R$ versus $\log\sigma$ plot was considered. The $\log M_R$ versus $\log\sigma$ was plotted to evaluate the regression constants (K_1 and K_2) of the base material. As for the lime stabilized lateritic soil, the factors influencing its resilient properties were considered. The cyclic data on lateritic soil, soil-lime and soil-cement obtained were used to plot a graph of resilient modulus as a function of applied stress (deviator stress). Resilient modulus decrease with the increase of the bulk and deviatoric stress in constant confining pressure.

Environmental Factors

Environmental factors such as soil Support Values, Layer Coefficient, Serviceability Index, Structural Number, Regional Factors, Cracking and No-Cracking Values were sourced from AASHTO Design Manual (9), Literatures, Journals and test results.

Loading And Pavement Response

The load from the design traffic and resulting contact pressure were used to calculate the developed pavement stresses and strains at critical points of the pavement in connections with the preliminary combination of pavement materials and layer thicknesses. The developed values of stresses and strains were compared with the safe working values for the materials.

Artificial Neural Network for Pavement Design

An Artificial Neural Network (ANN) was developed, trained and deployed for the rapidly analyzing and designing pavements. The ANN technique has the unique advantage of being fast, consuming less computational resources, eliminating cumbersome mathematical equations as well as being re-trainable and customizable.

Figure 1 shows the graphical processes involved in developing the ANN for pavement design. The ANN was deployed by linking it with a designed Graphical User Interface (GUI) for pavement design.

Figure 2 shows the Neural Network Architecture that featured six input nodes and four output nodes.

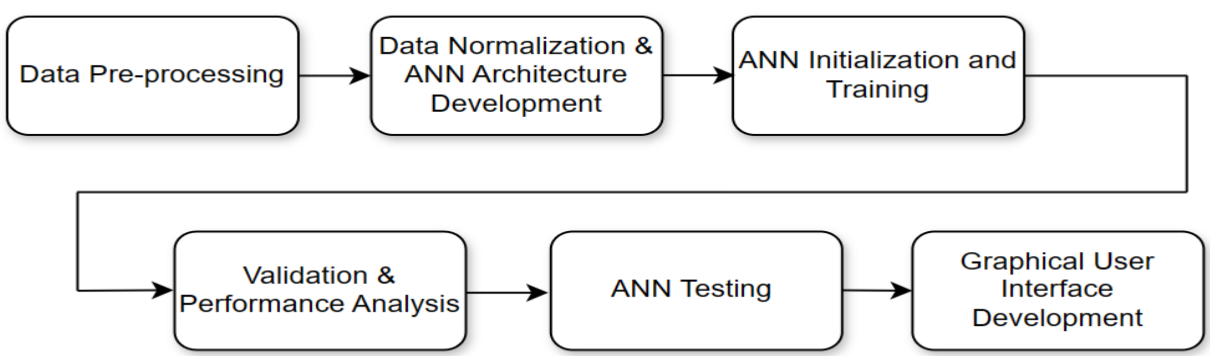

Figure 1: The processes involved in developing the ANN for pavement design

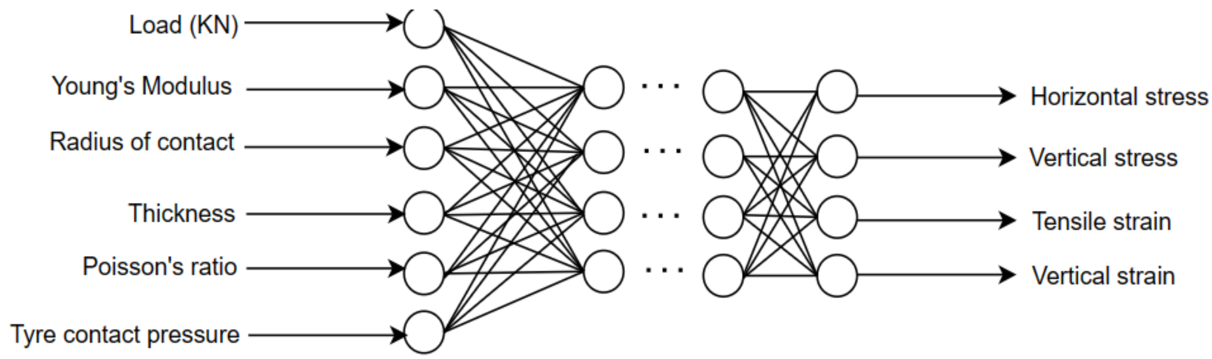

Figure 2: The Neural Network Architecture

Pavement layout and costing

The stresses and strains from ANN Analysis were compared with the maximum permissible stresses and strains at the critical points of the pavement to select those that are less than the safe working stresses and strains at those points. The layout of the pavement was selected by using modified Hejal *et al (*10*)* minimization equation given thus:

$MinS = 7.598h_1 + 0.750h_2 + 0.489h_3$ (after modification)

Subject to the following constraints

$a_1h_1 + a_2h_2 + a_3h_3 \geq SN$

$h_1 + h_2 + h_3 \geq Hmin$

$h_1 \geq 1''$ (25min)

$h_2 \geq 8''$ (200min)

$h_3 \geq 8''$ (200min)

$h_1 \leq 4''$ (100min)

$h_2 \leq 20''$ (500min)

$h_3 \leq 8''$ (200min)

$h_1, h_2, h_3 \geq 0''$

Where S = total cost of pavement system in dollars per square foot

SN = weighted structural number

a= layer coefficients

h= thickness of layers (inches)

Constraints equation were solved to produce the different pavement layer thicknesses including the optimal layer thickness Inserting the layer thicknesses (h_1, h_2, h_3) produced the total cost of pavement in Naira per square meter when converted.

3.0 Results and Discussion

Traffic Analysis Results

Table 1 shows the axle load distribution and the equivalent (80kN) single and tandem axle computation that gave Total Equivalent Single Axle (TESA). From the table it is seen that TESA per 100 trucks on Akure – Ilesha road is 47.26 out of which tandem axle is 10.03 (about 21.22%). The implication of this is that heavy vehicles (Trucks) do not ply the road with the same frequency as light vehicles.

The traffic along the road were classified with passenger cars having 79.62%, with trucks taking 20.38%. Out of this 20.38%

trailers take 9.41% while 2-axle load vehicles take the remaining 10.97%. The ,table also shows Equivalent Axle Load (EAL) computation using TESA from table 1 with a design period of 20 years and with 7% vehicle growth rate. The computation shows that from the 2023 EALo of about 28.89. The EAL20, twenty years after will be 4.47 x 10^5 . The figures (28.89 and 4.47 x 10^5) imply that all vehicular loads on Akure – Ilesha road in 2023 and those in the year 2043 all other things being equal were and will be 28.89 and 4.47 x 10^5 repetitions of the standard axle load (E80).

Table 1.0: Axle Load Distribution and Total Equivalent Axle Load Computation for 2023 Traffic Census Along Akure-Ilesha Road. (Pt = 2.0 and SN = 4)

Axle load (KN)	Single Axles per 100 Trucks			Tandem Axles per 100 Trucks		
	Number	F	N x F	Number	F	N x F
Under 3	69.5	0.0002	0.0139			
3-5	31.9	0.002	0.0638			
5-7	87.9	0.01	0.879			
7-9	3.1	0.03	0.093			
9-11	2.4	0.08	0.192			
11-13	4.1	0.18	0.738			
13-15	1.2	0.35	0.42	0.3	0.03	0.009
15-17	8.2	0.61	5.002	0.31	0.05	0.0155
17-19	10.0	1.00	10.0	1.1	0.08	0.088
19-21	7.0	1.55	10.85	2.0	0.12	0.24
21-23	2.3	2.31	5.313	2.3	0.17	0.391
23-25	1.1	3.33	3.663	3.1	0.25	0.775
25-27				5.1	0.35	1.785
27-29				6.1	0.48	2.928
29-31				2.0	0.64	1.28
31-33				1.1	0.84	0.924
33-35				0.4	1.08	0.432
35-37				0.2	1.38	0.276
37-39				0.21	1.72	0.3612
39-41				0.1	2.13	0.213
41-43				0.12	2.62	0.3144
TOTAL			37.23			10.03

Total Equivalent 80KN Single Axle (TESA) per 100 trucks on Akure-Ilesha Expressway

= 37.23 + 10.03 = 47.26

<u>Computation of Equivalent 80KN Single Axle Loads for 2023 Traffic Census along Akure-Ilesha Expressway Road for 20years period</u>.

Average daily traffic mean (ADTmean) for the year = 600

Directional split in two lane = 50% and 50%

Percent of trucks on road = 20.38%

EAL per 100 trucks on road = 47.26

Design period = 20years

Traffic growth rate, i = 7%

The initial daily equivalent 80KN single-axle loads is

$$\sum EAL_o = \frac{47.26}{100}(0.2038)\frac{600}{2} = \mathbf{28.89}$$

The natural log of (1 + i) = (1.07) is equal to 0.0677

$$\sum EAL_{20} = \frac{(28.89)(365)[(1.07)^{20} - 1]}{0.0677}$$

$$= \mathbf{4.47 \times 10^5}$$

Classification of Traffic on Akure-Ilesha road (2019)

Passenger cars = **79.62%**

Trucks = **20.38%**

Two axle = **10.97%**

Trailers = **9.41%**

Materials Characterization Result

The natural geo-technical properties of the lateritic soils used are shown in Table 2. It is seen from the table that the pavement materials are grouped as base material (A), sub-base materials (B) and the subgrade material (C). The table shows materials (B) and (C) as A-2-7 soil while material (A) is an A-2-4 soil meaning that (A) is the best out of the three pavement materials. It has a CBR of 92%. Materials B and C satisfy some of the specifications for materials for road base in the tropics. Because of this, the summary of results on the stabilization of material B is presented in Tables 3 and 4.

Table 3 shows the percentage cement added to the lateritic soil material (B) as ranging from 2 to 8 while table 4 shows the percentage of lime added to the same soil using the same range (2% to 8%). From table 4, the CBR of the soil increased from 56% at 2% cement to 300% at 6% cement and dropped to 128% at 8% cement. The table shows the maximum dry density (MDD) of the soil decreasing from 1869KN/M^3 at 2% cement to 1585KN/M^3 at 8% cement with the optimum moisture content increasing from 15% at 2% cement to 18% at 8% cement.

Table 2: Natural Geotechnical Properties of the Lateritic Soils

No	Material	GEOTECHNICAL PROPERTIES							
		L.L (%)	P.L (%)	P.I (%)	Gs	CBR (%)	Classification	% Clay L.L	% Clay P.I
A	Base	22	15	7	2.67	92	A-2-4	110	35
B	Subbase	44	26	18	2.70	29	A-2-7	264	108
C	Subgrade	44	29	15	2.42	20	A-2-7	308	105

Table 3: Summary of Results on Soil-Cement

Cement Content (%)	RESULTS						
	CBR (%)	MDD (KN/m³)	OMC (%)	LL (%)	PL (%)	PI (%)	UCS (N/mm²)
0	-	-	-	-	-	-	-
2	56	1869	15	43	29	14	0.711
4	163	1727	19	41	30	11	0.749
6	300	1685	18	41	31	10	0.973
8	128	1585	18	40.5	33	7.5	1.160

Table 4: Summary of Results on Soil-Lime

Lime Content (%)	RESULTS						
	CBR (%)	MDD (KN/m³)	OMC (%)	LL (%)	PL (%)	PI (%)	UCS (N/mm²)
0	-	-	-	-	-	-	-
2	59	1870	15	41.5	31	10.5	1.123
4	78	1780	19	39	33	6	1.384
6	78	1700	22	36	35	1	1.385
8	45	1650	24	34	38	-	1.122

Similar trends, as shown in Table 3, also occur in Table 4. Initially, the addition of lime (2%) increased the CBR of the soil even more than that of cement (2%), but subsequent additions do not show appreciable increase in the CBR. Similarly, lime content inhibits the effectiveness of the compactive effort, though to a slightly less degree. The unconfined compressive strength of soil-lime increases more appreciably from 1.123 N/mm² at 2% to 1.385 N/mm² at 6% before dropping to 1.122 N/mm² at 8% lime. From the results of unconfined compressive strength tests, it can be seen that lime impacts more shear strength on the lateritic soil than cement especially at the lower contents of the additives. The resilient properties of soil-cement and soil-lime where the soils are laterites are influenced by such factors as stress intensity, cement or lime content, moisture content, age of curing and the number of load repetitions.

Tables 5 to 7 show the cyclic test data on laterite, soil-lime and soil-Cement. The soil-cement has the highest resilient modulus from the three soil samples. This is followed by soil-lime especially at the lower applied stresses. At the higher stresses, lateritic soil has higher resilient modulus than soil-lime. At an applied stress of 280 kpa, laterite and soil-lime have the same resilient modulus, the value of which is 240 x 10^3 kpa. For all the soils, the resilient modulus decreases as the applied stress increases.

Table 5: Cyclic Test Data for lateritic soil

Cell pressure	Deviator stress (Kpa) σ_d	Recoverable strain (Micron) ϵ_a	Resilient Modulus (M_R) (Kpa)	Bulk Stress (Kpa) θ
0	85.5	205	416.529	85.5

40	128.3	381	336.545	248.3
80	248.3	845	294.005	488.0
180	408.3	1576	259.084	918.3

Table 6: Cyclic Test Data for soil-Lime

Cell pressure	σ_d	ϵ_a	M_R	θ
0	80.3	127	632.780	80.3
40	128.3	312	412.243	248
130	388.2	1454	266.976	778
170	488.0	2009	242.871	998

Table 7: Cyclic Test Data for soil-Cement

Cell pressure	σ_d	ϵ_a	M_R	θ
0	84.2	39	2,134.525	84
50	134.7	125	1,076.923	285
100	243.4	324	750.602	543
130	359.9	574	626.885	749
170	522.5	998	523.602	1033

The fundamental properties of bituminous and asphaltic materials, treated and untreated lateritic soils are based on previous studies. The stiffness (E) characteristics of bituminous mixtures depend on temperature and rate of loading. One loading rate corresponding to a vehicle speed of 80-100km/hr is adopted. A temperature range of between 0^0c and 40^0c is also adopted. Using all these a stiffness of 5000Mpa and a Poisson's ratio of 0.4 are used for bituminous and asphaltic materials. For the treated lateritic soils, the modulus of elasticity used ranged between 500Mpa and 4,500Mpa. Based on previous research, the Poisson's ratio used for both of them is 0.35. The relationship given by Otte, (1978) between the unconfined compressive strength and the average stiffness of a soil-cement is used to generate the stiffness of the soil-cement used here as shown on Table 8. Another relationship by the same author is used to estimate the tensile strength of the soil-cement used for this study as it is also shown on Table 8. From the table, it is observed that increasing the cement content does not give appreciable increase on both the average modulus of elasticity and tensile strength of the soil-cement. This however is a carryover effect from the value of the unconfined compressive strength of the soil-cement.

Table 8: Summary of the parameters calculated for soil-cement

Cement content (%)	(1) UCS (Mpa)	(2) Average Stiffness (E_b) (Mpa)	(3) Tensile Strength (Mpa)	(4) Fatigue Strength Ratio	(5 = 3x4) Tensile Stress (Mpa)
2	0.711	1102	10.18	0.35	3.563
4	0.749	1102	10.20	0.35	3.570
6	0.973	1103	10.30	0.35	3.605

8	1.160	1104	10.38	0.35	3.633

Safe Working Stresses and Strains of Pavement Materials

Table 9 shows the maximum permissible strain values for failure analysis. It shows the standard load repetitions (T) and the corresponding permissible tensile strains for asphaltic concrete materials with 5000 Mpa stiffness. It also shows the number of equivalent repetitions (E80) and the permissible vertical compressive strain in the subgrade soil corresponding to each of these loads.

For the treated materials especially the soil-cement, the allowable tensile strains (ϵ) depend on the strain at break (ϵ_b) of the material and the number of load repetitions (N_f). Otte *et al* (11) developed a relationship between these parameters. Figure 3 shows the relationship of elastic modulus and strain at break (ϵ_b) for a soil-cement. In case of a preliminary design, design values of strain at break (ϵ_b) could be obtained from the figure. It is seen from the figure that the strain at break (ϵ_b) decreases as the modulus of the soil-cement increases. This implies that soil-cement with high modulus of elasticity will have a low value of strain at break. Strain at break is that strain value of soil-cement at which the materials fails under the applied load. Table 10 shows the design traffic for different types of pavement materials excluding soil-lime. Limiting values of stresses and strains of materials including soil-lime are shown in Table 11. The allowable tensile and compressive strains for the load repetition for this study are estimated

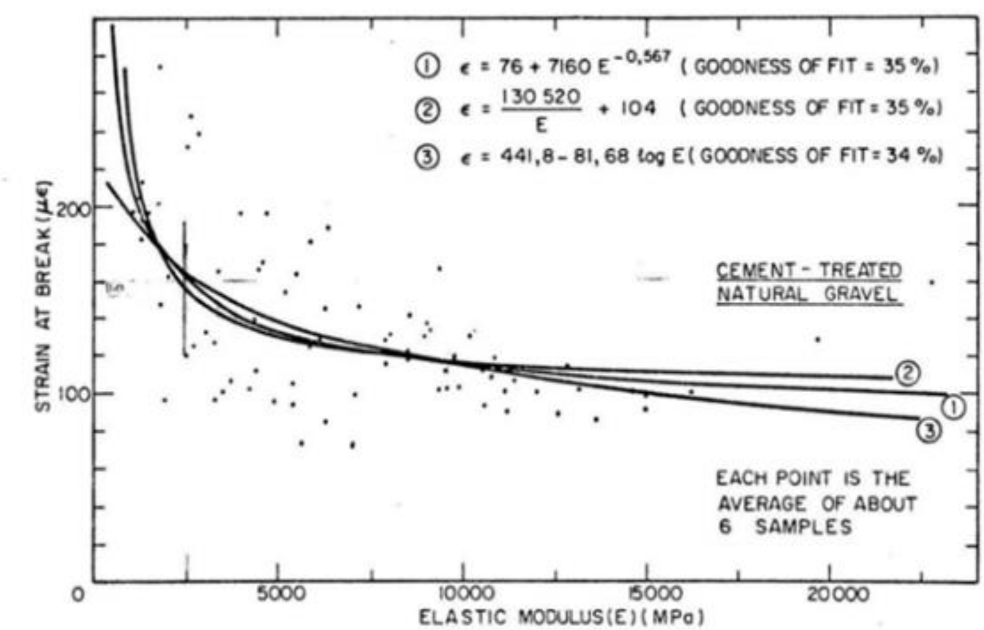

Figure 3: Relationship of Elastic Modulus and Strain at Break for Cement-Treated Materials.

Table 9: Maximum Permissible strain values for failure analysis

Number of standard load repetitions (T)	Permissible Tensile strain	Number of equivalent repetitions (E80)	Permissible vertical compressive strain in

	(x 10^{-6}mm/mm) (E_1 = 5000Mpa 9% void in mix)		**subgrade soil (x 10^{-6}mm/mm)**
10^3	-880	1 x 10^5	1000
10^4	-580	3 x 10^5	830
10^5	-360	1 x 10^6	650
10^6	-240	3 x 10^6	570
10^7	-150	1 x 10^7	460
10^8	-100	> 10^7	400

Table 10: Design Traffic for different types of pavement materials

Materials type	**Design traffic**
Bituminous materials	Total number of axle repetitions, T. (e.g. 5 x 10^6)
Soil-cement	Number of heavy wheel load (e.g. 5000 of 40KN)
Untreated and subgrade	Number of equivalent 80KN axles (E 80) (e.g. 10^6)

Source: Otte *et al.* (11)

Table 11: Limiting values of stresses and strains for pavement materials including soil-lime

Pavement layer	**Load repetition (T)**	**σ_H (Mpa)**	**Limiting ϵ_t**	**Stresses and strain (x 10^{-6}mm/mm) ϵ_z**
Surfacing	10^8		58	260
Base	10^6	(Weak) 0.3 (Strong)	140	650
Subgrade	10^5		230	1050

Table 12: Summary of allowable tensile and compressive strains

Material	**Strains (x 10^{-6}mm/mm)**	
	ϵt	**ϵ_C**

Asphaltic concrete surfacing	200
Soil-cement	
base or sub-base	
E= 500, 750, 1100, 3000, 4500Mpa	154, 119, 95, 89, 82
Soil-lime	
base or sub-base	140
Subgrade	969

from the relationship between the safe working tensile strain(ϵ), strain at break(ϵ_b) and the number of load repetitions(N_f) of cement-treated material given by Otte et al, (11) as shown in Table 12. The safe working strains for the asphaltic concrete and subgrade materials are obtained by interpolating for the values 5 x 10^6 repetitions and 4.47 x 10^5 E80 for surfacing and subgrade respectively. The value (4.47 x10^5 Es80) for the subgrade is the one estimated for Akure-Ilesha Expressway traffic census for a design life of 20years.

From table 12, it is observed that the allowable tensile strain of soil-cement on the average is less than that of soil-lime. It is therefore reasonable to deduce that soil-cement is more vulnerable to distress than soil-lime when used in pavement. The implication of this is that soil-lime can carry more load than soil-cement. This assertion is supported by tables 10 and 11 where the number of load repetitions "carriable" by soil-cement and soil-lime are 5 x 10^3 and 10^6 respectively. The asphaltic material as observed on the table has the highest allowable tensile strain because it is the most ductile material amongst the three. This is why it can carry as much as 5 x 10^6 axle repetitions (see table 10)

Environmental Effects

The effects of the environment considered were enumerated via the AASHTO design guide with a view to correlating theory with an established internationally accepted road test. Table 13 shows the estimated values from AASHTO nomographs as adapted to Nigerian environment with the conditions stated under the table. From the table, the soil support values for the soaked subgrade and sub-base materials are 3.6 and 4.8 respectively; while those of the unsoaked soil-cement and soil-lime base materials are 9 and 8,5 at CBR OF 163% and 78% respectively. The weighted structural number (SN) for both subgrade and sub-base for the two soils are 4.10 and 3.50 respectively. The weighted structural numbers for the bases of soil-cement and soil-lime are 1.9 and 2.10. These values implied that soil-lime is structurally stronger than soil-cement. The layer co-efficient shown for the sub-base are for soaked CBR 5% and 10% and the one for the base are for Moduli 1100 and 3000 Mpa respectively. The layer coefficient for surfacing is for a modulus of 5000 Mpa. The nomographs for estimating the values on table 13 are in accordance to AASHTO 2003.

Table 13(a): Estimated Values from AASHTO design guide as adapted to Nigerian Environment for treated base

Pavement layer	CBR (%)	Soil support values		Weighted structural Number (SN)		Layer coefficient (a)	
		S-C	S-L	S-C	S-L	S-C	S-L

Subgrade	5(soaked)	3.6	3.6	4.10	4.10	--	--
Sub-base	5, 10(soaked)	4.8	4.8	3.50	3.50	0.06(a_3)	0.07(a_3)
Base	163, 78(unsoaked)	9	8.5	1.9	2.10	0.14(a_2)	0.27(a_2)
Surfacing	-	-	-	-	-	0.44(a_1)	0.44(a_1)

<u>Conditions</u>

Present serviceability index (PSI) = 2.5

Regional factor (subgrade soaked) = 2.5

Modulus of surfacing (E_1) = 5000Mpa

Daily equivalent 18-kp single axle

load application for 20 years = 4.47×10^5 (E80)

S-C = Soil-cement

S-L = Soil-Lime

Table 13(b): Estimated values from AASHTO Design guide as adapted to Nigerian Environment for treated sub-base

Pavement layer	CBR (%)	Soil support values		Weighted structural Number (SN)		Layer coefficient (at)	
		S-C	S-L	S-C	S-L	S-C	S-L
Subgrade	5(soaked)	3.6	3.6	4.10	4.10	--	--
Sub-base	5,10 (soaked)	9	8.5	1.90	2.10	0.14(a_3)	0.27(a_3)
Base	163,78 (unsoaked)	8.5	8.5	2.10	2.10	0.11(a_2)	0.11(a_2)
surfacing	-	-	-	-	-	0.44(a_1)	0.44(a_1)

<u>Conditions</u>

Present serviceability Index (PSI) = 2.5

Regional factor (subgrade soaked) = 2.5

Modulus of surfacing (E_1) = 5000Mpa

Daily equivalent 18-kip single axle

load applications for 20 years = 4.47×10^5 (E80)

Optimal Layout and Costing Result

It is observed from table 14 that the optimal layout value is generally more than any of the preliminary layout values. This is so because all the values obtained as preliminary layout are theoretical in nature and do not account to a large extent for the practical situation of proposed site.

The inclusion of serviceability index, soil support values, subgrade condition as regional factor help in making the pavement layout more realistic as it is shown by optimal layout values. It is seen from the table that a sub-base with a lower CBR value has a higher optimal value. This is why it is observed from the table that a CBR of 5% has an optimal layout of 625mm compared to 600mm for a CBR of 10%. The table also shows that the subgrade modulus values have effects on the values of preliminary layouts. These effects are however neutralized by the condition of sub-base and this is the reason why the optimal value for E4 = 100Mpa and 5% CBR and E4 =200Mpa and 5% CBR are the same. The same thing when E4 =100Mpa and 5% CBR with E4 =200Mpa and 5% CBR. This implies that subgrade condition has an important role to play in pavement design. Other layers of the pavement also have their contributory roles. When the calculated layer thicknesses were imputed into the modified minimization equation, the cost per m² was got in dollars and was converted to Naira per m² as shown in the table.

Table 14: Preliminary Versus Optimal Layout of Pavement Sections for Soil-Cement Base with Respect to Cracking Criterion

Subgrade Modulus E_4	Sub-base CBR (%)	Base Modulus E_2	Preliminary Layout (mm)	Optimal layout (mm)	Optimal cost (N/m²)
100	5(soaked)	1100	475 500 525 550	h_1=100 625h_2 = 325 h_3 = 200	48,585.00
100	10(soaked)	1100	475 500 525 550	h_1=100 600h_2 = 300 h_3 = 200	47,797.80
200	5(soaked)	1100	425 450 475 500	h_1=100 625h_2 = 325 h_3 = 200	48,585.00
200	10(soaked)	1100	425 450 475 500	h_1=100 600 h_2 = 300 h_3 = 200	47,797.80

4.0 CONCLUSION

- The equivalent axle load calculated for the year 2043 (EAL20) was used as the subgrade design traffic for the procedure
- The resilient deformation of the treated soils increases as the applied load increase.
- The proposed procedure proved that it has the potential to improve and provide more reliable design.
- The procedure provide the pavement design engineers with tools to evaluate the performance of the pavement

component when comparing with other pavement design methods

- The procedure provide criteria to examine the effect of stabilized lateritic soil in pavement performance
- AASHTO design guide could be used to simulate the effects of environment on the design parameters thereby correlating theory with practice.
- The tensile stresses and strains at the bottom of asphaltic surface Increase as the thickness of the surface increases.
- The tensile stresses and strains at the bottom of treated layer decrease as the layer increases and the compressive stresses and strains at the top of subgrade also decrease as the depth increases.
- The tensile strain is a function of the stiffness of the treated layers as well as their thicknesses.
- The design for no-cracking criterion are more conservative than design for cracking criterion.
- The pavement layout selected from comparing maximum developed stresses and strains with the allowable stresses and strains could best be described as a preliminary pavement layout.
- The most efficient (optimal) layout can be obtained from the preliminary layouts by using optimization method as explained by civil engineering systems analysis
- The proposed procedure compares favorably and at times better than the procedures by Road Note 31 and CBR method by Una, Oto-Obong (2011) meant for tropical environment.
- The proposed procedure produced an optimal layout that can sustain overloaded traffic (which is a basic design problem in Nigeria) throughout the design life.
- Soil-lime base and sub-base gives better optimal layout than soil-cement base and sub-base.

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