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Implementation of Mechanistic Approach to Design Of Highway Pavements In Nigeria - Utilizing The Nigerian Highway Manual

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Abstract
Highway Pavement Design in Nigeria has been primarily based on the empirical approach. Most of the roads designed using this method failed soon after construction by either fatigue cracking or rutting deformation or both. In 2013, the Nigeria Road Sector Development Team of the Federal Ministry of Works published a review of the 1973 Nigerian Highway Manual, with a view to develop a design method in Nigeria that is based on mechanistic approach in which, properties and thickness of the pavement layers are selected, so that stress and strain produced by traffic loading do not exceed the capabilities of any of the materials in the pavement. This paper presents an overview of the implementation of a mechanistic procedure termed "NEMPADS" as provided in the 2013 Nigerian Highway Manual for design of highway pavements in Nigeria. The paper illustrates the procedure for pavement material characterization, traffic analysis and environmental conditions as inputs to mechanistic design. Application of fatigue and rutting analysis as contained in the Manual was illustrated for typical highway pavements. The paper concluded that implementation of the NEMPADS design framework would go a long way in minimizing the frequent early pavement failure in Nigeria and recommended the need for a funded research for the development of a design tool that would incorporate design and analysis procedure for implementation of the NEMPADS framework.

***Keywords**: Nigerian Highway Manual, Mechanistic Approach, Design, Highway Pavement*

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I. INTRODUCTION

Pavement design is a complex field requiring knowledge of both soil and paving materials, and especially, their responses under various loadings and environmental conditions. Pavement design methods can vary, and have evolved over the years in response to changes in traffic and loading conditions, construction materials and procedures. Over the years, design methods have progressed from rule-of-thumb methods, to empirical methods and at present, towards a mechanistic approach.

Before the 1920s, pavement design consisted basically of defining the thickness of layered materials that would provide strength and protection to a soft subgrade. Pavements were designed against subgrade shear failure, Engineers used their experience based on successes and failures of previous projects. As experience evolved, several pavement design methods based on subgrade shear strength were developed. Ever since, there has been a change in design criteria as a result of increase in traffic volume.

In many developed countries, there has been emerging new technology termed "rational", "mechanistic-empirical", or "mechanistic" term used to describe new approaches to pavement analysis and design. Most of these are based on elastic layered representation of the pavement structure and have become powerful tools for the highway engineers. In this approach, adequate control of the pavement layers 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 the life of the pavement.

Road failures in most developing tropical countries have been traced to common causes which can broadly be attributed to any or combination of geological, geotechnical, design, construction, and maintenance problems [2]. Several studies have been carried out to trace the causes of early road failures in Nigeria; studies were carried out by researchers on the geological [2], geotechnical, [16], construction [9] and maintenance [5] factors. However, the design factor has not been given adequate attention.

Highway Pavement Design in Nigeria has been primarily empirical. An empirical approach is one which is based on the results of experiments or experience or both. This means that the relationship between design inputs and pavement failure were arrived at through experience, experimentation or a combination of both. The mechanistic approach involves selection of proper materials and layer thickness for specific traffic and environmental conditions such that certain identified pavement failure modes are minimized. The mechanistic approach involves the determination of material parameters for the analysis, at conditions as close as possible to what they are in the road structure.

1.1.1 Federal Highway Manual Design Procedure (1973)

Basically, highway pavement design methods in Nigeria have been derived from methods developed in the United Kingdom. The 1973 Nigeria Federal Highway Manual Pavement Design curves [11] have been taken from the UK Road Research Laboratory Note No. 29 [17]. The design procedure requires estimation of the daily traffic in terms of vehicles heavier than 29.89KN (3 tons) loaded weight and determination of the subgrade and base qualities in terms of the CBR. The selection of the pavement structure is made from design curves, depending on the expected loading, recommended minimum asphalt pavement thickness is then given as:-

Light Traffic	-	50mm (2 inches)
Medium Traffic	-	75mm (3 inches)
Heavy Traffic	-	100mm (4 inches)

This method uses the California Bearing Ratio and traffic volume as the sole design inputs. Most of the roads designed using the CBR method failed soon after construction by either fatigue cracking or rutting deformation or both [8, 7]. The CBR method was abandoned in California 90 years ago [3] for the more reliable mechanistic-empirical methods (Layered Elastic Analysis or Finite Element Methods). It is regrettable that this old method is still being used by most designers in Nigeria and has resulted in unsatisfactory designs, leading to frequent early pavement failures.

The Nigeria Road Sector Development Team in 2005 proposed a review of the Nigerian Highway Manual with a view to develop a design method in Nigeria that is based on analytical or structural approach in which properties and thickness of the pavement layers are selected so that stress and strain produced by traffic loading do not exceed the capabilities of any of the materials in the pavement.

The purpose of this paper is therefore, to present an overview of the implementation of a mechanistic procedure as provided in the 2013 Nigerian Highway Manual [12] for use in the design of highway pavements in Nigeria.

II. MATERIALS AND METHOD

2.1 Input Parameters To Mechanistic Design Approach

The mechanistic design approach for highway pavements requires the use of carefully select input parameters:

(i) Representative modulus and Poison’s Ratio for each of the pavement layers.
(ii) Traffic loading
(iii) Environmental conditions

Developing conceptual procedures for each of these processes is further complicated due to the interaction between them. For instance, due to stress sensitivity of base, subbase and upgrade materials, different modulus values have to be used for these layers for different load magnitudes. Therefore, the load conditions should be considered when selecting modulus in the mechanistic design approach. In order to develop a conceptual procedure for determining design considerations, the approach recommended is to consider variations in one subsystem (modulus of layers) assuming the other subsystems (traffic and environment) to remain constant.

2.1.1 Material Properties

Representative Layer Modulus and Poison’s Ratio

In the mechanistic design approach, the material properties which must be determined are the elastic modulus, resilient modulus and Poisson’s ratio of each layer.

2.1.2 Elastic Modulus

The elastic modulus can either be determined in the laboratory or correlated with conventional tests. In any case where there is need for laboratory testing, the method of testing the modulus should reproduce field conditions as accurately as possible. For this purpose, dynamic triaxial test is becoming widely accepted. There are several versions of this test with the dynamic modulus, diametric resilient modulus and indirect tensile tests generally used for asphalt concrete and stabilized materials.

2.1.3 Subgrade Resilient Modulus

The elastic properties of subgrade soils and unbound granular materials for base and subbase courses can be measured directly by the resilient modulus test using a triaxial test device capable of applying repeated dynamic loads of controlled magnitude and duration. The resilient modulus of subgrade can be determined in accordance with the AASHTO Guide [1]. To reflect actual field conditions, it is recommended that subgrade samples be collected for a period of twelve (12) months (four samples per month) in order to accommodate the effect of seasonal subgrade variation on resilient modulus of subgrades.

The resilient modulus (M_r) can be determined using correlation with CBR as follows[10]:

M_r (psi) = 1500 CBR (1)

In accordance with AASHTO Guide [1], determine the relative damage per month using equation (2)

$$u_f = (1.18 \times 10^8) M_R^{-2.32} \quad (2)$$

From equations 1 and 2

$$u_f = (1.18 \times 10^8) x (1500 CBR)^{-2.32} \quad (3)$$

Where,

u_f = relative damage factor

CBR = California Bearing Ratio (%)

Therefore, over an entire year, the average relative damage can be determined as follows:

$$\overline{u_f} = \frac{u_{f1} + u_{f2} + \ldots + u_{fn}}{n} \quad \text{Where, n = 12.} \quad (4)$$

Hence from equation 3.0, the average CBR is given by

$$\text{CBR} = \frac{(0.847\, x \bar{u}_f\, x 10^{-8})^{-0.431}}{1500} \quad (5)$$

For Minimum design CBR, Table 8.2 of the Manual [12] could be used.

2.1.4 Poisson's Ratio

The Poisson's ratio μ is defined as the ratio of lateral strain ε_L to the axial strain ε_a caused by a load parallel to the axis in which ε_a is measured. Values of Poisson's ratio are generally estimated, as most highway agencies use typical values as design inputs in elastic layered analysis as shown in Table 1.

Table 1: Poisson's Ratio Used by Various Agencies [6]

Material	Original Shell Oil Co.	Revised Shell Oil Co.	The Asphalt Institute	Kentucky Highway Dept.
Asphalt concrete	0.05	0.55	0.40	0.40
Granular Base	0.50	0.53	0.45	0.45
Subgrade	0.50	0.35	0.45	0.45

For Nigeria conditions, resort could be made to values used by established agencies such as Asphalt Institute [12]

2.2 Traffic

The deterioration of paved roads caused by traffic, results from the magnitude of the individual wheel loads, the contact tyre pressure and the number of times these loads are applied (load repetitions). For the purpose of structural design, cars and smaller-sized vehicles can be ignored and only the axle loading of the heavy vehicles that will use the road during its design life need to be considered.

2.2.1 Structural Design Period (SDP)

The Structural Design Period (SDP) is the period during which the road is expected to carry traffic at a satisfactory level of service, without requiring major rehabilitation or repair work. Presented in Table 2 are typical structural design periods for various road categories [12]

Table 2: Typical design periods for various road categories

Road Category	Design Period
A	20
B	20
C	15
D	10

2.2.2 Design Traffic

In Nigeria, the standard axle load is 80kN (Legally permissible axle load is 8.2 tonnes). The cumulative damaging effect of all individual axle loads is expressed as the number of equivalent 80kN single axle loads (ESAs or E80s). The ESAs thus represent the number of standard loads that would cause the damage to the pavement, as the actual traffic spectrum of all axle loads. ESAs is determined as follows:

1. Determine Annual Average Daily Traffic (AADT)

The AADT is defined as the total annual traffic summed up for both directions and divided by 365. It should be noted that for structural design purposes, the traffic loading in one direction is required. It is recommended that traffic counts to establish Annual Daily Traffic (ADT) at a specific site conform to the following:

i. The counts are for seven consecutive days

ii. The counts on some of the days are for full 24 hours, with preferably one 24hour count on a weekday and one during week end. On the other days, 12hour count should be sufficient with the 24hour counts used to determine an appropriate ratio to estimate the 24hour counts from the 12hour counts.

iii. Counts are avoided at times when travel activity is abnormal for short periods, for example, month-end, public holidays, etc.

iv. If possible the seven day count should be repeated several times through the year.

2. Determine Average Daily ESAs (ADE)

The traffic loading is calculated by converting the ADT to ADE. This is done by converting the volume traffic of each vehicle class (Table 3) into Equivalent Standard Axles (ESAs).

Table 3: Vehicle Classification (Source: Oguara, 2005)

Class	Description (Nanda, 1981)
1	Passenger cars, taxis, landrovers, pickups, and mini-buses.
2	Buses
3	2-axle lorries, tippers and mammy wagons
4	3-axle lorries, tippers and tankers
5	3-axle tractor-trailer units (single driven axle, tandem rear axles)
6	4-axle tractor units (tandem driven axle, tandem rear axles)
7	5-axle tractor-trailer units(tandem driven axle, tandem rear axles)
8	2-axle lorries with two towed trailers

The ADE is thus calculated as the sum of the product of the ADT per vehicle class, and the average ESA per vehicle class

$$ADE = \sum ADTj \ x \ E80\,j \qquad (6)$$

Where,

ADE = Average Daily ESAs

ADTj = Average Daily Traffic per vehicle class j

E80j = Average ESA per vehicle class j

ESAs per heavy vehicle used for design should be as shown in Table 4. In the Nigerian situation, overloading is considered in analysis [12].

Table 4: Typical ESAs per Heavy Vehicles [12]

Load-Control Situation	Range of ESAs per HV
No overloading	1.0 – 2.5
Overloading	5.5 – 23.0

3. Calculate Cumulative Equivalent Standard Axle Loading

The pavement design process requires the estimation of the average daily number of ESAs on one lane at the opening of the new road to traffic, which is then projected and cumulated over the design period to give the design traffic loading. This is done as follows:

i. Determine the basic average daily traffic for each class of vehicle

ii. Determine the one-directional traffic flow for each vehicle class expected over the design life and convert to ESAs using appropriate equivalency factors.

iii. Project the ADE at a selected growth rate, cumulating the total over the design period to determine the design traffic load.

The cumulative ESA per lane may be calculated from:

$ESA_{total} = ADE_{initial} \times f_y$ (7)

Where,

f_y = cumulative factor from Table 5

y = structural design period

2.2.3 Traffic Analysis Example

The traffic data for a proposed 4-lane highway during:

(i) Buses = 257 veh/day
(ii) 4-axle trailer unit trucks = 60veh/day
(iii) 6-axle tractor-trailer trucks = 64 veh/day
(iv) Annual growth = 6%,
(v) Design period = 20 years

Solution:

Buses

ESAL per Heavy vehicle (No overloading) = 1.75

4-axle trailer unit trucks

ESAL per Heavy vehicle (Overloading) = 14.25

6-axle tractor-railer Trucks

ESAL per Heavy vehicle (Overloading) = 14.25

Table 5: Traffic Growth Factor [12]

	Traffic Growth Factor, f_y I (% per annum)								
DESIGN PERIOD, y (years)	2	4	6	8	10	12	14	16	18
4	1 534	1 612	1 693	1 776	1 863	1 954	2 048	2 145	2 24
5	1 937	2 056	2 181	2 313	2 451	2 597	2 750	2 912	3 08
6	2 349	2 518	2 699	2 892	3 098	3 317	3 552	3 801	4 06
7	2 768	2 998	3 248	3 517	3 809	4 124	4 465	4 833	5 22
8	3 195	3 498	3 829	4 193	4 592	5 028	5 506	6 029	6 60
9	3 632	4 017	4 446	4 923	5 452	6 040	6 693	7 417	8 22
10	4 077	4 558	5 100	5 711	6 399	7 174	8 046	9 028	10 1
11	4 530	5 119	5 793	6 562	7 440	8 444	9 589	10 895	12 3
12	4 993	5 704	6 527	7 481	8 586	9 866	11 347	13 062	15 0
13	5 465	6 312	7 305	8 473	9 846	11 458	13 352	15 575	18 1
14	5 947	6 944	8 131	9 546	11 232	13 242	15 637	18 491	21 8
15	6 438	7 601	9 005	10 703	12 757	15 240	18 243	21 873	26 2
16	6 939	8 285	9 933	11 954	14 434	17 478	21 213	25 796	31 4
17	7 450	8 996	10 916	13 304	16 279	19 984	24 599	30 346	37 5
18	7 972	9 735	11 957	14 763	18 308	22 790	28 459	35 625	44 6
19	8 504	10 504	13 062	16 338	20 540	25 934	32 859	41 749	53 1
20	9 046	11 304	14 232	18 039	22 996	29 455	37 875	48 852	63 1
21	9 599	12 136	15 473	19 877	25 697	33 398	43 594	57 091	74 9
22	10 163	13 001	16 788	21 861	28 668	37 815	50 113	66 650	88 8
23	10 739	13 900	18 183	24 004	31 937	42 762	57 545	77 737	105 3
24	11 326	14 836	19 661	26 319	35 532	48 302	66 018	90 598	124 6
25	11 925	15 809	21 227	28 818	39 486	54 507	75 676	105 517	147 5

$$f_y = 365 \times (1+0.01i) \times [(1+0.01i)^y - 1] / (0.01i)$$

2.3 Environmental Condition

The two environmental parameters that influence pavement performance are temperature and moisture. Temperature conditions for the particular site have to be known to properly design an asphalt pavement, hence the test temperature should be selected so that the asphalt concrete modulus in the test matches with that in the field [3]. Influence of temperature can be accounted for by characterization of asphalt concrete at the pavement temperature. In the Asphalt Institute design method, pavement temperature can be correlated with air temperature [19] as follows:

$$MMPT = MMAT\left[1+\frac{1}{(z+4)}-\frac{34}{(z+4)}+6\right] \quad (8)$$

Where,

MMPT = mean monthly pavement temperature
MMAT = mean monthly air temperature
Z = depth below pavement surface (inches)

The effect of moisture (seasonal variation) was accounted for by calculating a weighted average subgrade resilient modulus based on the relative pavement damage over a one year period.

2.4 Mechanistic Design Failure Criteria

Mechanistic approach to pavement design requires models for relating the output from elastic layered analysis such as stress, strain etc to pavement behaviour such as cracking, rutting, etc. Most of the principles in the mechanistic design of highway pavements are based upon limiting horizontal tensile strains in the asphalt bound layer (fatigue analysis) and vertical compressive strain at the top of the subgrade(rutting) as shown in Figure 1.

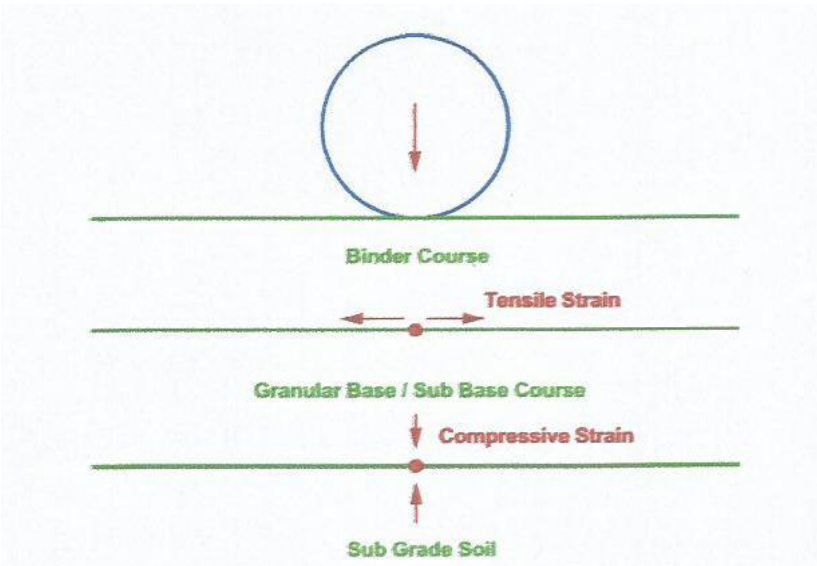

Figure 1: Critical Strains in Pavement Layer

The 2013 Nigerian Highway manual provided for the Nigerian Empirical Mechanistic Pavement Analysis and Design System (NEMPADS) as a framework for the implementation of mechanistic-empirical design of pavement for tropical climate in Nigeria. In the development of NEMPADS, nine (9) fatigue distress models and seven(7) rutting models were evaluated for the Nigerian environment. The study concluded that that Transport and Road Research Laboratory pavement performance model for fatigue is a good predictor for NEMPADS while the Indian model was used as predictor for NEMPADS pavement performance model for rutting for the fact that's that the environmental condition of Nigeria is similar to that of India

2.4.1 Fatigue Failure Criterion

Fatigue cracking is a phenomenon which occurs in pavements due to repeated applications of traffic loads. Accumulation of micro damage after each pass on a bituminous pavements leads to progressive loss of stiffness and eventually, to fatigue cracking. Repeated load initiate cracks at critical locations in the pavement structure, i.e. the locations where the excessive tensile stresses and strains occur. The continuous actions of traffic cause these cracks to propagate through the entire bound layer. The fatigue criterion in mechanistic design approach is based on limiting the horizontal tensile strain on the underside of the asphalt bound layer due to repetitive loads on the pavement surface, if this strain is excessive, cracking (fatigue) of the layer will result.

The Nigerian Empirical Mechanistic Pavement Analysis and Design System (NEMPADS) used the following model for fatigue analysis

$$N_f = 1.66x10^{-10}(\varepsilon_t)^{-4.32} \quad (9)$$

Where,

N_f = Allowable repetitions in term of fatigue

ε_t = Horizontal tensile strain at the bottom of asphalt layer

2.4.2 Rutting Failure Criterion

Permanent deformation or rutting is a manifestation of both densification and permanent shear deformation of subgrade. As a mode of distress in highway pavements, pavement design should be geared towards eliminating or reducing rutting in the pavement for a certain period. Rutting can initiate in any layer of the structure, making it more difficult to predict than fatigue cracking. Current failure criteria are intended for rutting that can be attributed mostly to weak pavement structure. This is typically expressed in terms of the vertical compressive strain (ε_v) at the top of the subgrade layer.

The Nigerian Empirical Mechanistic Pavement Analysis and Design System (NEMPADS) used the following model for rutting analysis:

$$N_r = 2.56x10^{-8}(\varepsilon_v)^{-4.5337} \quad (10)$$

Where,

N_r = Allowable repetitions in terms of rutting

ε_v = Vertical compressive strain on top of subgrade

2.4.3 Nigerian Highway Manual Mechanistic Structural Design Procedure

The design procedure involves the determination of the minimum thickness of the asphalt layer that will adequately withstand the horizontal tensile strain at the bottom of the asphalt layer and the vertical compressive strain at the surface of the subgrade [12].

The design procedure consists of the following steps:

STEP 1 – COMPUTE EXPECTED TRAFFIC

$ESAL_s\ (N_i) = ADE_{initial}\ x\ f_y$ (11)

Where,

ESAL = N_i = Expected number of repetitions or expected design traffic

f_y = Cumulative factor from Table 5

y = Structural design period

STEP 2 – EVALUATE MATERIAL PROPERTIES

- Determine elastic modulus of asphalt concrete
- Determine elastic or resilient modulus base material
- Determine resilient modulus of subgrade

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

M_r (MPa) = 10.342 * CBR (12)

M_r (lb/in.^{2}) = 1500 * CBR (13)

Table 6 presents base and subbase material requirement [12]

Table 6: Base and Sub-base Requirements

Parameter	Requirements	
	Sub-base	Base
CBR, minimum	20	80
Liquid Limit, maximum	25	25
Plasticity Index maximum	6	NP
Passing No. 200 Sieve, maximum	12	7

(ii) The designer is free to select either an asphalt concrete surface or an emulsified asphalt concrete surface, along with an asphalt concrete base, an emulsified asphalt base, or an untreated aggregate base and sub-base for the underlying layers. This will depend on the material that is economically available.

(iii) Mean annual temperatures in Nigeria are generally high, with temperatures ranging between 23^0C - 31^0C at the coast, and getting as high as 44^0C inland. 60/70 pen and 40/50 pen bitumen is therefore recommended for use in Nigeria [12]

STEP 3 – COMPUTE TRIAL PAVEMENT THICKNESS

NEMPADS recommend the use The Asphalt Institute design charts for the following types of pavements:

- **Asphalt Concrete Surface and Emulsified Asphalt Base**

These pavements have asphalt concrete as surface material and emulsified asphalt as the base material. Three mix types of emulsified asphalt base are used in this design and they are defined as:

Type I Emulsified asphalt mixes made with processed, dense-graded aggregates

Type II Emulsified asphalt mixes made with semi-processed, crusher-run, pit-run, or bank-run aggregate

Type III Emulsified asphalt mixes made with sandy or silty sands

Tables 7 presents minimum asphalt concrete surface for Type I & II Base.

Table 7: Minimum Asphalt Thickness for Type I & II Base [12]

Traffic Level ESALs	Type II and Type III (mm)
10^4	50
10^5	50
10^6	75
10^7	100
$>10^7$	130

- The Asphalt Institute also recommends that the base course be not less than 150 mm thick.

Table 8 gives the minimum recommended thickness for the asphalt concrete surface over the untreated aggregate base.

Table 8: Minimum Asphalt Thickness over Untreated Base

Traffic Level ESALs	Traffic Condition	Minimum Thickness of Asphalt Concrete
10^4	Lightly trafficked rural roads	75 mm
10^4 - 10^6	Medium truck traffic	100 mm
Above 10^6	Medium to heavy truck traffic	125 mm

STEP 4: COMPUTE PAVEMENT RESPONSE

- Compute horizontal tensile strain at the bottom asphalt layer and vertical compressive strain at top of subgrade using structural models
- NEMPADS [12] recommends the use of ELSYM5 programme for this purpose
- EVERSTRESS programme is also recommended

STEP 5: COMPUTE ALLOWABLE REPETITIONS

$$N_f = 1.66x10^{-10}(\varepsilon_t)^{-4.32} \quad \text{(Fatigue Criterion)} \quad (14)$$

$$N_r = 2.56x10^{-8}(\varepsilon_v)^{-4.5337} \quad \text{(Rutting Criterion)} \quad (15)$$

STEP 6: DETERMINE IF DESIGN IS SATISFACTORY

(a) Allowable repetitions must be greater than Expected repetitions for both fatigue and rutting criterion

(b) Determine Damage Factor to assess economical design

(i) $D = \dfrac{N_i}{N_f} < 1$ - fatigue criterion

(ii) $D = \dfrac{N_i}{Nr} < 1$ - rutting criterion

(c) (i) When D is greater than 1, design is unsatisfactory

(ii) When D is less than 1, design is satisfactory

(iii) When D is far less than 1, pavement is under designed

III. RESULT AND DISCUSSION

3.1 Implementation of Nigerian Highway Manual Design Model

Having established procedures for material characterization and traffic estimation, stresses and strains that satisfy both fatigue and rutting criteria can be computed. Figure 2 is a flow diagram of the mechanistic design procedure of the Nigerian Empirical Mechanistic Pavement Analysis and Design System (NEMPADS).

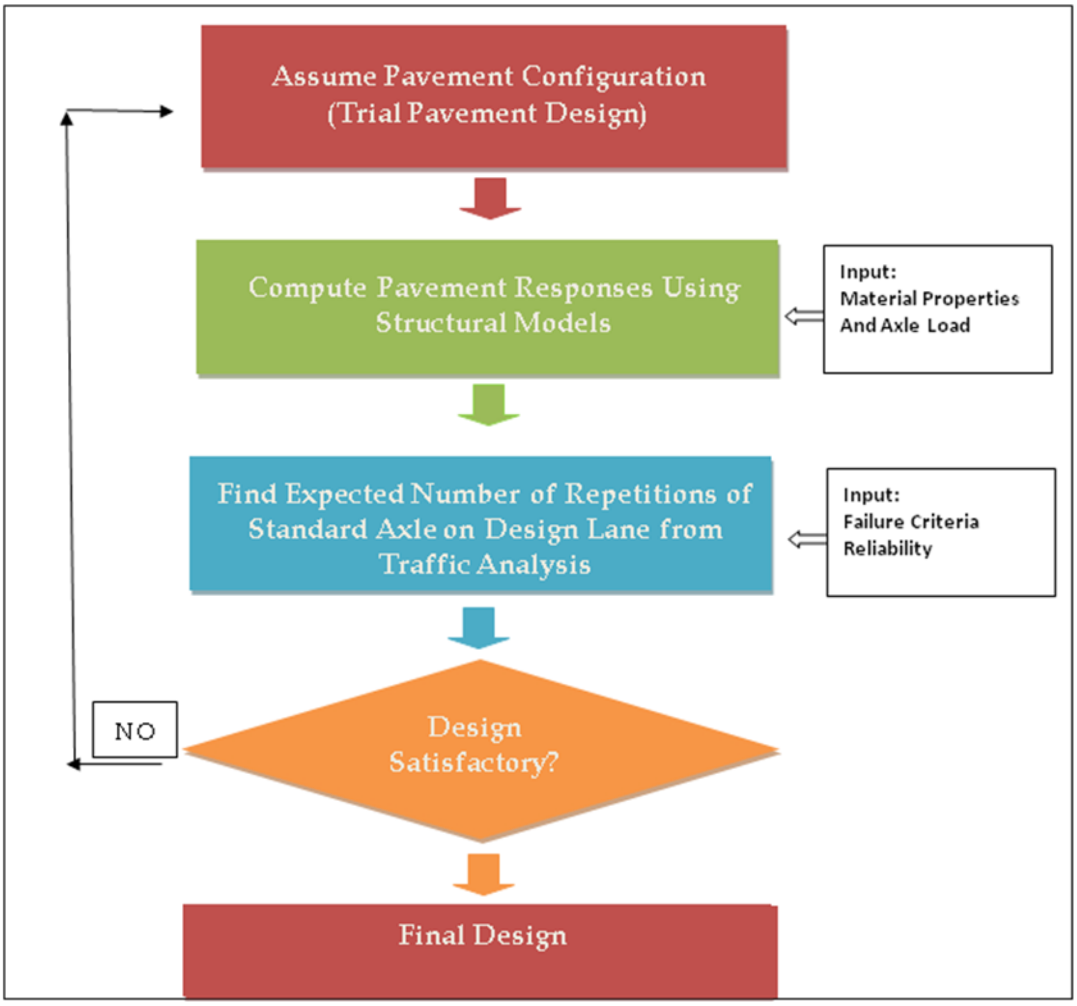

Figure 2: Flow Chart for NEMPADS Mechanistic Design Procedure

The implementation of the procedure require the use of computer programme. Several computer programmmes currently available for performing stress/strain calculations in Pavements. These include ELSYM5 (University of California Berkely), EVERSTRESS (Washington State Department of Transportation), CHEV 5L (Chevron Research Co.) BISTRO and BISAR (Shell Oil Co.), ELSYM5 CRANLAY (Australia OSIRO) programmes. All the programmes have the capability of solving stresses, strains and deflections for multi-layer systems.

3.1.1 Design Example 1

A highway flexible pavement was designed using the thicknesses and material properties in Table 9. The Nigerian CBR procedure was adopted in the pavement thickness trial design [7].

Table 9: Pavement Thickness and Material properties

Layer No.	Material	CBR (%)	Thickness of Layer (mm)	Elastic/Resilient Modulus (Mpa)	Poison's Ratio
1	Surface (Asphalt Concrete – gap graded)	-	100	5,000	0.35
2	Base (granular material)	80	210	824	0.40
3	Subbase(stabilized)	30	120	309	0.45

4	Subgrade	8	-	82.4	0.45
Expected traffic = ESAL = 3.2×10^7					

The layered elastic analysis programme *EVERSTRESS* was used in the analysis of the pavement with the defined inputs as shown in Table 9. The programme was used to compute stresses and strain due to 80 KN single axle load by analyzing the effects due to 40 KN single wheel loads spaced 305mm centre to centre, each having a tyre pressure of 690.78 KPa. Result of the analysis showed that the maximum horizontal tensile strain at the bottom of the asphalt layer and vertical compressive strain at the top of the subgrade were 371.91µЄ and -774.25µЄ respectively.

Applying NEMPADS fatigue distress model:

Allowable repetitions $N_f = 1.66x10^{-10} (\varepsilon_t)^{-4.32} = 1.66x10^{-10}\ x\ (371.91x10^{-6})^{-4.32}$

$N_f = 108{,}597$

= 1.1×10^5 Allowable ESAL repetitions

Damage Factor $D = \dfrac{N_i}{N_f} = \dfrac{3.2x10^7}{1.1x10^5} = 2.9x10^2 >>>>1$

The expected traffic repetition of 3.2×10^7 is greater than the allowable and Damage factor is far greater than 1, this implies that the pavement is not satisfactory and will fail by fatigue.

Similarly, applying NEMPADS distress model for rutting:

$N_r = 2.56x10^{-8} (\varepsilon_v)^{-4.5337} = 2.56x10^{-8} (774.25x10^{-6})^{-4.5337}$

N_r = 3,259,261.49

= 3.3×10^6 Allowable repetitions to failure

Damage factor $D = \dfrac{N_i}{N_r} = \dfrac{3.2x10^7}{3.3x10^5} = 97 >>>>1$

The allowable ESAL of 3.3×10^6 is less than 3.2×10^7 expected traffic repetition of 3.2×10^7 and Damage factor is far greater than 1, this implies that the pavement will fail by rutting deformation.

The structural design and analysis of the above pavement showed that the pavement will fail by fatigue cracking and rutting deformation, it is therefore necessary to carry out a redesign by adjusting pavement thickness and the entire design and analysis process repeated.

3.1.2 Design Example 2

Table 10: Pavement Thickness and Material properties (Oguara, 1985)

Layer No.	Material	CBR (%)	Thickness of Layer (mm)	Elastic/Resilient Modulus (Mpa)	Poison's Ratio
1	Surface (Asphalt Concrete)	-	76	5,000	0.35
2	Base (Cement Treated)	-	76	2480	0.40
3	Subbase(untreated laterite)	-	50	175	0.45
4	Subgrade	6	-	60	0.45
Expected traffic = ESAL = 6×10^5 axle repetitions					

The CHEV 5L computer programme was used to analyze the programme. The programme was used to compute stresses and strain due to 80 KN single axle load by analyzing the effects due to 20 KN single wheel loads spaced 305mm centre to centre, each having a tyre pressure of 520 KPa. The layered elastic analysis gave

the maximum horizontal tensile strain at the bottom of the asphalt layer and vertical compressive strain at the top of the subgrade as 137µЄ and 600µЄ respectively.
Applying NEMPADS fatigue distress model:

Allowable repetitions $N_f = 1.66 x 10^{-10} (\varepsilon_t)^{-4.32} = 1.66 x 10^{-10}\ x\ (137 x 10^{-6})^{-4.32}$

$N_f = 8{,}118{,}490$

= 8.1 x 10^6 Allowable ESAL repetitions

Damage Factor $D = \frac{N_i}{N_f} = \frac{6 x 10^5}{8.1 x 10^6} = 0.074 < 1$

Similarly, applying NEMPADS distress model for rutting:

$N_r = 2.56 x 10^{-8} (\varepsilon_v)^{-4.5337} = 2.56 x 10^{-8} (600 x 10^{-6})^{-4.5337}$

N_r = 10,354,655

= 1.0 x 10^7 Allowable repetitions to failure

Damage factor $D = \frac{N_i}{N_r} = \frac{6 x 10^5}{1 x 10^7} = 0.06 < 1$

In design example 2 above, the expected traffic repetition of 6 x 10^5 is less than the allowable repetition and Damage factor is less than 1 for both fatigue and rutting criteria. This implies that the pavement is satisfactory and will not fail by fatigue or rutting.

IV. CONCLUSION

This paper presented an overview of the implementation of mechanistic design of pavement in Nigeria based on NEMPADS framework. The procedure utilizes actual material properties and wheel load. The procedure also allow for changing design conditions. A major advantage of the mechanistic approach is the ability to predict pavement life and identify satisfactory pavement sections.

In consideration of the increasing wheel loads of vehicles in Nigerian roads, the implementation of the NEMPADS design framework would go a long way in minimizing frequent early pavement failure in Nigerian, hence, the paper recommends further research for the development of a design tool that would incorporate design and analysis procedures for implementation of NEMPADS framework.

REFERENCES

[1]. AASHTO (1993) American Association of State Highway and Transportation Officials, AASHTO. "Guide for Design of Pavement structures", Washington, D.C.

[2]. Ajayi, L. A., (1987) "Thoughts on Road Failures in Nigeria", The Nigerian Engineer, Vol. 22, Issue 1, Pp. 10-17

[3]. Brown, S. F. (1997) "Achievement and Challenges in Asphalt Pavement Engineering", International Society for Asphalt Pavement Lecture series in Seattle, Available at: http:/www.asphalt.org (Accesses: 2 August 2008)

[4]. Burmister, D. M., (1945) "The General Theory of Stresses and Displacement in Layered Systems" Journal of Applied Physics.

[5]. Busari, M.A.O. (1990) "Case Studies of Highway Deterioration, Maintenance, and Road Safety in a Developing Country", The Nigerian Engineer. Vol. 25, Issue 3, Pp. 45-54.

[6]. Edwards, J. M. & Valkering, C. P. (1974) "Structural Design of Asphalt Pavements for Road Vehicles – the influence of high temperatures", Highway and Road Construction.

[7]. Ekwulo, E. O, & Eme, D. B. (2009) "Fatigue and Rutting Strain Analysis of Asphalt pavements Designed Using CBR Methods", African Journal of Environmental Science and Technology, Vol. 3, Issue 12: pp. 412-421.

[8]. Emesiobi, F. C. (2004) "Comparative Analysis of Flexible Pavement Design Methods Using CBR Procedures in Evaluating Critical Fatigue and Rutting Strains", Journal of Agricultural and Environmental Engineering Technology, Vol. 1, Issue 2, Pp. 232-242

[9]. Eze-Uzomaka, O. J. (1981) "An Appropriate Technology Solution to Problems of Nigerian Road Industry", ICE London: Pp. 21-23

[10]. Heu Kelom, W. & A. J. Klomp, (1962) "Dynamic Testing as a Means of Controlling Pavements During and after Construction", Proceedings of the First International Conference on the Structural Design of Asphalt Pavements, 667

[11]. Highway Manual-Part 1 (1973) "Design", Federal Ministry of Works and Housing, Lagos.

[12]. Highway Manual-Part 1, 2013, "Design", Pavement and Material Design, Federal Ministry of Works

[13]. Nanda, P. K (1981) "A Simplified Approach to the Estimation of Equivalent Single Axles", Proceedings, Conference on Material Testing, Control and Research, Federal Ministry of Works: Pp. 30-51.

[14]. Oguara, T. M. (1985), "Mechanistic Approach to Design of Highway Pavements in Nigeria", ISSMFE Golden Jubilee Geotechnical Practice in Nigeria, NSE Lagos: Pp. 139-154.

[15]. Oguara, T. M. (2005) "Highway Engineering, Pavement Design, Construction and Maintenance", Treasure Communications Resource Limited, Yenagoa.

[16]. Oyediran, A. T. (2001) "Primary Cause of Highway Failures in South Western Nigeria and Lasting Solutions", NSE Technical Transactions, Vol. 36, Issue 3, Pp. 54-60.

[17]. Road research Laboratory (1970) "A Guide to the Structural Design of Pavements for New Roads", Road Note 29" 3rd Edition, Dept. of Environment, HMSO, London

[18]. Westergaard, H. M. (1926) "Stresses in Concrete Pavements Computed by Theoretical Analysis" Public Roads, Vol. 7, Issue 2, Pp. 25 – 35.

[19]. Witczak, M. W. (1972) "Design of Full Depth Asphalt Airfield Pavements", proceedings, Third International Conference on the Structural Design of Asphalt Pavements, Vol. 1. Pp 550-567.