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Development of design tool for Nigerian (CBR) design of flexible pavement

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ABSTRACT

As a result of the inconsistencies in the result of structural thickness design of flexible pavements, arising from individual differences in sight and judgment in the use of design charts and tables, a study on the development of a computer program for the design of flexible pavement was carried out. The study was based on the Nigerian (CBR) design method for flexible pavement. The thickness above layer for each pavement material was obtained by interpolation at 1% CBR interval. Using the data obtained, equations for curves A to F were developed. Using the developed equations, Algorithm and codes were written in accordance with the Nigerian (CBR) designs procedure. The results of developed program, N-Flex-Pave were validated by comparing it results with that of the conventional procedure (CBR design curve). Results show that structural thickness design using N-Flex-Pave compared favorably with the conventional procedure with a minimum ratio of 0.97 and a maximum ratio of 1.10. Calibration of N-Flex-Pave-calculated and Design Curve-measured results were compared using linear regression analysis and the results were found to be good with minimum coefficient of determination R^2 of 0.996 and maximum R^2 of 0.999 indicating that N-Flex-Pave is a good estimator of pavement layer thickness using the Nigerian (CBR) design procedure. Result also indicated that design can be completed in few seconds when compared to the time spent when conventional procedures are employed. A conclusion was made that N-Flex-Pave is capable of carrying out structural thickness design for the Nigerian (CBR) method and should be recommended for use by pavement engineers in Nigeria.

Key words: Computer Program, CBR, Flexible Pavement, Design.

INTRODUCTION

In Nigeria, the only developed and most common method of flexible pavement design is the Nigerian (CBR) method. In this method, the determination of structural thickness of the pavement is made using design charts and Tables. In most cases, no two individual obtains the same result even when the same design information is used. The Nigerian (CBR) method is an empirical procedure which uses the California Bearing Ratio and traffic volume as the sole design inputs. The method was originally developed by the U.S Corps of Engineers, modified by the British Road Research Laboratory [1] and adopted by Nigeria as contained in the Federal Highway Manual [2]. The Nigerian (CBR) design method is a CBR-Traffic volume method, the thickness of the pavement structure is dependent on the anticipated traffic, the strength of the foundation material, the quality of pavement material used and the construction procedure adopted. The method considers traffic in the form of number of commercial vehicles/day exceeding 29.89kN (3 tons). To determine the no of vehicles/day exceeding 3 tons loaded weight, the anticipated traffic is adjusted using the traffic adjustment factor in Table 1 and percentage of trucks in the design lawne in Table 2. The selection of pavement structure is made from design curves as shown in Figure 1. The thickness of the pavement layers is dependent on the expected traffic loading. The recommended minimum asphalt pavement surface thickness is considered in terms of light, medium and heavy traffic as follows:

Light traffic	-	50mm
Medium	-	75mm
Heavy	-	100mm

The inconsistencies and variations in the result of structural thickness design of pavements arising from individual differences in sight and judgment in the use of design charts and tables have become a matter of concern for pavement designers. Hence, the need to develop a more precise and accurate design tool that will enable pavement designers produce uniform structural thickness design results. There is no existing computer program for the design of flexible pavement for the Nigerian (CBR) design method. The purpose of this paper is to develop the design tool, N-Flex-Pave, for the Nigerian (CBR) design of flexible pavement. This will ease design process and provide a uniform flexible pavement structural design result using the Nigerian (CBR) procedure.

Prior to the invention of the computers, pavement designs were solely carried out using design charts, Tables and nomographs. In contemporary times with the invention of computers, pavement design could be carried out using computer programs. Several computer programs have been developed for the design of pavements. The programs are either empirical, layered elastic analysis or finite element programs.

The American Association of State Highway and Transportation Official AASHTO [3] developed its empirical design utility for flexible and rigid pavement. The program solves the 1993 AASHTO Guide basic empirical design equation for flexible and Rigid pavements. It also provides information on variable descriptions, typical values and equation precautions.

A number of computer programs based on layered elastic theory [4] have been developed for layered elastic analysis. The program CHEV [5] developed by the Chevron Research Company can be applied to linear materials, however, CHEV program was modified to account for material non-linearity and called DAMA [6]. The DAMA computer program can be used to analyze a multi-layered elastic pavement structure under single or dual-wheel load, the number of layers cannot exceed five. In DAMA, the subgrade and the asphalt layers are considered to be linearly elastic and the untreated subbase to be non-linear. Instead of using iterative method to determine the modulus of granular layer, the effect of stress dependency is included by effective elastic modulus computed according to equation 1.0.

$$E_2 = 10.447 h_1^{-0.471} h_2^{-0.041} E_1^{-0.139} E_3^{-0.287} K_1^{0.868} \quad (1.0)$$

Where, E_1, E_2 and E_3 are the modulus of asphalt layer, granular base and subgrade respectively; h_1 and h_2 are the thicknesses of the asphalt layer and granular base. K_1 and K_2 are parameters for K-θ model with $k_2 = 0.5$. ELSYM5 developed at the University of California is a five layer linear elastic program for the determination of stresses and strains in pavements [7; 8]. The KENLAYER computer program developed at the University of Kentucky in 1985 incorporates the solution for an elastic multiple-layered system under a circular load. KENLAYER can be applied to layered system under single, dual, dual-tandem wheel loads with each layer material properties being linearly elastic, non-linearly elastic or visco-elastic. The Everstress [9] layered elastic analysis program from the Washington State Department of Transportation was developed from WESLEA layered elastic analysis program. The pavement system model is multilayered elastic using multiple wheel loads (up to 20). The program can analyze hot mix asphalt (HMA) pavement structure containing up to five layers and can consider the stress sensitive characteristics of unbound pavement materials. The consideration of the stress sensitive characteristics of unbound materials can be achieved through adjusting the layer moduli in an iterative manner by use of stress-modulus relationships in equations 2.0 and 3.0;

$$E_b = K_1 \theta K_2 \text{ for granular soils} \quad (2.0)$$
$$E_b = K_3 \sigma_d K_4 \text{ for fine grained soils} \quad (3.0)$$

Where,
E_b = Resilient modulus of granualar soils (ksi or MPa)

E_s = Resilient modulus of fine grained soils (ksi or MPa)
θ = Bulk stress (ksi or MPa)
σ_d = (Deviator stress (ksi or Mpa) and
K_1, K_2, K_3, K_4 = Regression constants

K_1, and K_2, are dependent on moisture content, which can change with the seasons. K_3, and K_4 are related to the soil types, either coarse grained or fine-grained soil. K_2 is positive and K_4 is negative and remain relatively constant with the season.

The ILLI_PAVE 2D computer program (10) developed at the University of Illinois at Urbana-Champaign treats the pavement system as an axi-symmetric solid domain. The resilient modulus is stress-dependent and failure criteria for granular material and fine-grained soils are incorporated in ILLI_PAVE. The principal stresses in the subbase and subgrade layers are updated iteratively. The Mohr-Coulomb theory is employed as a criterion to ensure the principal stresses do not exceed the strength of the material. When the base or subgrade layer is divided into several layers, the minor stresses in the upper layer may be very small or become tensile in the lower layers. Therefore, the replacement of the small or negative stress by a large positive stress results in a higher, modulus. The MICH_PAVE 2D [11] finite element computer program is very similar to ILLI_PAVE. It uses the same methods to model granular material and soils and the same Mohr-Coulomb failure criteria. MICH_PAVE uses a flexible boundary at a limited depth beneath the surface of subgrade instead of a rigid boundary at a large depth below the surface. MICH_PAVE is capable of performing both linear and non-linear finite element analysis of flexible pavements. It assumes axi-symmetric loading condition and computes an equivalent resilient modulus for each pavement layer that is obtained as the average of the moduli of the finite elements in the layer that lie within an assumed 2:1 load distribution zone. For non-linear material, MICH_PAVE employs the stress dependent K-θ model to characterize the resilient modulus of soils through a stress dependent modulus and constant Poisson's ratio. ABAQUS, a commercially available 3D FE program has been used in the structural analysis of pavement systems. The program has the ability to accommodate both 2D FE analysis and 3D FE analysis and use reduced integration elements (3D) to reduce the total computational time [12].

MATERIALS AND METHODS

The following data for five (5) different pavement sections were use for typical pavement design examples for the development of N-Flex-Pave program:

Traffic and Material Parameters for Structural Thickness Design
No. of Lanes = 4 lane highway
No. of vehicle exceeding 3 tons = 1600
Traffic growth rate = 6%
Design period = 20yrs
For a design period of 20yrs, and traffic growth rate of 6%,
Traffic Adjustment factor from Table 1 = 1.84
∴ Anticipated traffic = 1600 x 1.84
= 2944 veh/day
From Table 2, for a 4-lane highway, use 100% of vehicles on design lane

$$\frac{100}{100} \times 2944 = 2944 \text{ veh/day}$$

Traffic category - Heavy traffic
∴ Use Curve F

Pavement Sections and Material CBR:

	Section 1	Section 2	Section 3	Section 4	Section 5
Subgrade	2%	3%	4%	5%	6%
Sub-base	20%	23%	25%	28%	30%
Base	80%	83%	85%	88%	90%

The following procedures were adopted in the development of the N-Flex-Pave program:

Step 1: Generating Design Curve Data
To generate the design curve data for curves A, B, C, D, E and F, interpolations were carried out at intervals of 1% CBR on the CBR-Pavement thickness chart. The interpolations produced the "thicknesses above layer" and the corresponding CBR for curves A to F.

Step 2: Developing Curve Equations from Curve Data
The data generated in step 1 was modeled using the Microsoft Office Excel Program (Power Option) with "CBR" as X-axis and "Thickness above layer" as the Y-axis to obtain the curve equations. The curve equations for curves A to F are as presented in Equations 4.0 to 9.0

$Y = (1625x)^{-1.82}$ - Curve A (4.0)
$Y = (1984x)^{-1.73}$ - Curve B (5.0)
$Y = (2874x)^{-1.52}$ - Curve C (6.0)
$Y = (3546x)^{-1.81}$ - Curve D (7.0)
$Y = (3660x)^{-1.76}$ - Curve E (8.0)
$Y = (3998x)^{-1.73}$ - Curve F (9.0)

Where,
X = CBR (%) and

Y = T = Thickness above layer (mm) (10.0)

Step 3: Developing Program Algorithm.
The following connotations where used in developing the program algorithm.
Traffic Data :

A = Number of vehicle exceeding 3 tons.
B = Traffic growth rate
C = Traffic adjustment factor
D = Percentage of vehicle in the design lane
E = Anticipated daily traffic in terms of No of Veh. exceeding 3 tons.
= No of Veh. Exceeding 3 tonnes x Traffic Adjustment Factor x % of Veh. in design lane
∴ E = A x C x D
F = The Curve equation to be used for pavement thickness determination.
T = Thickness above layer

If $0 \le E \le 15$, T = $\left(\frac{CBR}{1625}\right)^{-0.55}$ for Curve A

If $15 \le E \le 45$, T = $\left(\frac{CBR}{1984}\right)^{-0.56}$ for Curve B

If $45 \le E \le 150$, T = $\left(\frac{CBR}{2879}\right)^{-0.55}$ for Curve C

If $150 \le E \le 450$, T = $\left(\frac{CBR}{3546}\right)^{-0.55}$ for Curve D

If $450 \le E \le 1500$, T = $\left(\frac{CBR}{3660}\right)^{-0.55}$ for Curve E

If $1500 \le E \le 4500$, T= $\left(\frac{CBR}{3998}\right)^{-0.57}$ for Curve F

Thickness Description:

T_1	=	Total thickness
T_2	=	Thickness of base and surface
T_3	=	Thickness of surface = $T_{surface}$
$T_2 - T_3$	=	Thickness of base = T_{base}
$T_1 - T_2$	=	Thickness of sub-base = $T_{subbase}$

Recommended Thickness of Surface:

Light traffic;	$T_3 \geq 50$
Medium traffic;	$T_3 \geq 75$
Heavy traffic;	$T_3 \geq 100$

Step 4*:* Creating Interface on Visual Basic Package

a) Creating Textbox**:** Pick text box on the tool box, set property name;
b) Creating Label**:** Pick label on the toolbox, click caption then reset the name property.
c) Set board style
d) Insert name property
e) Name property: This is where the calculated output is being displayed
f) Pick command button, go to caption and type in text calculate, then go to name property and say cmd calc.
g) Form addition: go to project and say add form.

Step 5*:* Code Writing

The codes were written in Visual basic 6.0 [13]. The following codes were written in line with the program algorithm;

i. Codes to Determine Traffic Parameters
ii. Codes to evaluate the various thicknesses
iii. Codes for thickness adjustment
iv. Codes for the cross section of the designed pavement

Executing the N-Flex-Pave Program

The N-Flex-Pave is a user-friendly program, it is simple to use and easy to run. The program is applicable to four-layered (Surface, base, subbase and subgrade) flexible pavement system. When all the necessary design input parameters have been made, the program can run successfully in less than 30 seconds. The following traffic and material parameters are required as inputs in N-Flex-Pave;

i. Traffic Data: Number of vehicles exceeding 29.89kN(3 tons), traffic growth rate, Number of lanes, and design lane.
ii. Material Properties: CBR of subgrade, subbase and base material.

Four (4) steps are required to carry out a complete design of a flexible pavement using N-Flex-Pave;
Step 1 of 4(Figure 2):

This window takes Traffic data input; No. of veh/day exceeding 3tons, traffic growth rate, design period, No. of lanes and design lane, click next to go to step 2 of 4 - the "material parameter" window.

Step 2 of 4(Figure 3):
This window takes the material parameters input, click next to get to step 3 of 4 - the "thickness above layer" window,.

Step 3 of 4(Figure 4):
At step 3 of 4, the program displays computed "thickness above layer" for subgrade, subbase and base, click next for step 4 of 4 - the "thickness of layer" window.

Step 4 of 4(Figure 5):
On this window, the thickness of layer is automatically computed and displayed. Click Finish to end design. At this stage if the computed surface thickness is less than the recommended minimum for light, medium or heavy traffic,

the program propmts the warning message “Surface thicknes is less than the recommended value, do you want to carry out an adjustment”. The user has an option of clicking Yes, No or Cancel. If the user clicks Yes, the program automatically adjust the thickness in accordance with design procedures as shown in Figure 6. The user may also view the cross section of the pavement by clicking “View Site” as shown in Figure 7.

RESULTS AND DISCUSSION

The results of structural thickness design using N-Flex-Pave are as presented in Tables 3a to 3e while the results using conventional Design curves are presented in Tables 4a to 4e. Also, Tables 5a to 5e show the comparison of the results using N-Flex-Pave and Design curves.

The results as presented in Table 5a to 5e show that the using the N-Flex-Pave program, the actual thicknesses of layers for section 1 are 100mm, 115mm and 546mm for surface, base and sub-base respectively, section 2 are 100mm, 120mm and 405mm for surface, base and sub-base respectively, section 3 are 100mm, 105mm and 311mm for surface, base and sub-base respectively, section 4 are 100mm, 100mm and 278mm for surface, base and sub-base respectively while the thicknesses for section 5 are 100mm, 110mm and 217mm for surface base and sub-base respectively.

Similarly, using the conventional Design Curves, the actual thicknesses of layers for section 1 are 100mm, 113mm and 550mm for surface, base and sub-base respectively, section 2 are 100mm, 120mm and 400mm for surface, base and sub-base respectively, section 3 are 100mm, 100mm and 320mm for surface, base and sub-base respectively, section 4 are 100mm, 110mm and 265mm for surface, base and sub-base respectively, while section 5 are 100mm, 110mm and 220mm for surface base and sub-base respectively. This shows that the result of structural design using N-Flex-Pave compare favorably with that of convention design curves.

VALIDATION OF N-Flex-Pave PROGRAM RESULTS

The N-Flex-Pave results were validated by comparing pavement thicknesses computed by the N-Flex-Pave and measured thicknesses using the Design Curves. Results presented in Table 6a show that the average ratio of N-Flex-Pave-calculated and Design Curve-measured thickness above layer are; base – 1.05, 0.97, 1.00, 1.06 and 1.10 for sections 1, 2, 3, 4 and 5 respectively; sub-base – 0.98, 0.98, 1.01, 0.97, 1.04 for sections 1, 2, 3, 4 and 5 respectively, and subgrade – 0.99, 1.01,0.92, 1.00 and 0.99 for sections 1, 2, 3, 4 and 5 respectively.

Similarly, Table 6b shows that the average ratio of N-Flex-Pave-calculated and Design Curve-measured thickness of layer are; surface – 1.0, 1.0, 1.0, 1.0, 1.0 and 1.0 for sections 1, 2, 3, 4 and 5 respectively; base – 1.02, 1.00, 1.05, 0.91 and 1.00 for sections 1, 2, 3, 4 and 5 respectively, and sub-base – 0.99, 1.01, 0.97, 1.05 and 0.99 for sections 1, 2, 3, 4 and 5 respectively.

Table 1: Initial Traffic Adjustment Factor

Design Period Years (n)	Annual growth Rate, Percent (r)				
	2	4	6	8	10
1	0.05	0.05	0.05	0.05	0.05
2	0.10	0.10	0.10	0.10	0.10
4	0.21	0.21	0.22	0.22	0.23
6	0.32	0.33	0.35	0.37	0.39
8	0.43	0.46	0.50	0.53	0.57
10	0.55	0.60	0.66	0.72	0.80
12	0.67	0.75	0.84	0.95	1.07
14	0.80	0.92	1.05	1.21	1.40
16	0.93	1.09	1.28	1.52	1.80
18	1.07	1.28	1.55	1.87	2.28
20	1.21	1.49	1.84	2.29	2.86
25	1.60	2.08	2.74	3.66	4.92
30	2.03	2.80	3.95	5.66	8.22
35	2.50	3.68	5.57	8.62	13.55

The N-Flex-Pave-calculated and Design Curve-measured layer thicknesses were calibrated and compared using linear regression analysis as shown in Figures 8a, 8b, 8c, 9a and 9b for thickness above base layer, thickness above sub-base layer, thickness above subgrade layer, base thickness and subbase thickness respectively. The coefficient of determination, R^2 were found to be very good. The calibration of N-Flex-Pave-calculated and Design Curve-measured layer thicknesses resulted in R^2 of 0.990, 0.996, 0.999, 0.987 and 0.998 for thickness above base layer, thickness above sub-base layer, thickness above subgrade layer, base thickness and subbase thickness respectively. This result indicates that N-Flex-Pave is a good estimator of pavement layer thickness using the Nigerian (CBR) flexible pavement design procedure.

Table 2: Lane distribution factors on multilane roads

Number of lanes Both direction	Lane No. 1	Lane No. 2	Lane No. 3	Lane No. 4
2	100	-	-	-
4	100	100	-	-
6	20	80	80	-
8	20	20	80	80
Lane No. 1 is next to the centerline or median on the driver's left				

Table 3a: Pavement Section 1 - Thickness Design Result Using N-Flex-Pave

Material	Design CBR (%)	Thickness above layer(mm)	Thickness of layer(mm)	Adjusted/Actual thickness (mm)
Subgrade	2.0	761	-	-
Sub-base	20	205	556	546
Base	80	93	112	115
Surface			93	100
Total Thickness			761	761

Table 3b: Pavement Section 2 - Thickness Design Result Using N-Flex-Pave

Material	Design CBR (%)	Thickness above layer(mm)	Thickness of layer(mm)	Adjusted/Actual thickness (mm)
Subgrade	3.0	625	-	-
Sub-base	23	197	428	405
Base	83	82	115	120
Surface			82	100
Total Thickness			625	625

Table 3c: Pavement Section 3 - Thickness Design Result Using N-Flex-Pave

Material	Design CBR (%)	Thickness above layer(mm)	Thickness of layer(mm)	Adjusted/Actual thickness (mm)
Subgrade	4.0	516	-	-
Sub-base	25	182	334	311
Base	85	80	102	105
Surface			80	100
Total Thickness			516	516

Table 3d: Pavement Section 4 - Thickness Design Result Using N-Flex-Pave

Material	Design CBR (%)	Thickness above layer(mm)	Thickness of layer(mm)	Adjusted/Actual thickness (mm)
Subgrade	5.0	478	-	-
Sub-base	28	170	308	278
Base	88	74	96	100
Surface			74	100
Total Thickness			478	478

Table 3e: Pavement Section 5 - Thickness Design Result Using N-Flex-Pave

Material	Design CBR (%)	Thickness above layer(mm)	Thickness of layer(mm)	Adjusted/Actual thickness (mm)
Subgrade	6.0	427	-	-
Sub-base	30	171	256	217
Base	90	66	105	110
Surface			66	100
Total Thickness			427	427

Table 4a: Pavement Section 1 – Thickness Design Using Design Curves

Material	Design CBR (%)	Thickness above layer(mm)	Thickness of layer (mm)	Adjusted/Actual thickness (mm)
Subgrade	2.0	763	-	-
Sub-base	20	210	553	550
Base	80	88	122	113
Surface			88	100
Total Thickness			763	763

Table 4b: Pavement Section 2 - Thickness Design Using Design Curves

Material	Design CBR (%)	Thickness above layer(mm)	Thickness of layer (mm)	Adjusted/Actual thickness (mm)
Subgrade	3.0	620	-	-
Sub-base	23	200	420	400
Base	83	85	115	120
Surface			85	100
Total Thickness			620	620

Table 4c: Pavement Section 3 - Thickness Design Using Design Curves

Material	Design CBR (%)	Thickness above layer(mm)	Thickness of layer (mm)	Adjusted/Actual thickness (mm)
Subgrade	4.0	520	-	-
Sub-base	25	180	340	320
Base	85	80	100	100
Surface			80	100
Total Thickness			520	520

Table 4d: Pavement Section 4 - Thickness Design Using Design Curves

Material	Design CBR (%)	Thickness above layer(mm)	Thickness of layer (mm)	Adjusted/Actual thickness (mm)
Subgrade	5.0	475	-	-
Sub-base	28	175	300	265
Base	88	70	105	110
Surface			70	100
Total Thickness			475	475

Table 4e: Pavement Section 5 - Thickness Design Using Design Curves

Material	Design CBR (%)	Thickness above layer(mm)	Thickness of layer (mm)	Adjusted/Actual thickness (mm)
Subgrade	6.0	430	-	-
Sub-base	30	165	265	220
Base	90	60	105	110
Surface			60	100
Total Thickness			430	430

Table 5a: Comparison of Result – Pavement Section 1

Material	**CBR**	**Thickness Above Layer(mm)**		**Thickness Of Layer(mm)**		**Adjusted/Actual Thickness(mm)**	
		N-Flex-Pave	**Design Curves**	**N-Flex-Pave**	**Design Curves**	**N-Flex-Pave**	**Design Curves**
Subgrade	2.0	761	763	-	-	-	-
Subase	20	205	210	556	553	546	550
Base	80	93	88	112	122	115	113
Surface				93	88	100	100
Total Thickness				761	763	761	763

Table 5b: Comparison of Result – Pavement Section 2

Material	CBR	Thickness Above Layer(mm)		Thickness Of Layer(mm)		Adjusted/Actual Thickness(mm)	
		N-Flex-Pave	Design Curves	N-Flex-Pave	Design Curves	N-Flex-Pave	Design Curves
Subgrade	3.0	625	620	-	-	-	-
Subase	23	197	200	428	420	405	400
Base	83	82	85	115	115	120	120
Surface				82	85	100	100
Total Thickness				625	620	625	620

Table 5c: Comparison of Result – Pavement Section 3

Material	CBR	Thickness Above Layer(mm)		Thickness Of Layer(mm)		Adjusted/Actual Thickness(mm)	
		N-Flex-Pave	Design Curves	N-Flex-Pave	Design Curves	N-Flex-Pave	Design Curves
Subgrade	4.0	516	520	-	-	-	-
Subase	25	182	180	334	340	311	320
Base	85	80	80	102	100	105	100
Surface				80	80	100	100
Total Thickness				516	520	516	520

Table 5d: Comparison of Result – Pavement Section 4

Material	CBR	Thickness Above Layer(mm)		Thickness Of Layer(mm)		Adjusted/Actual Thickness(mm)	
		N-Flex-Pave	Design Curves	N-Flex-Pave	Design Curves	N-Flex-Pave	Design Curves
Subgrade	5.0	478	475	-	-	-	-
Subase	25	170	175	308	300	278	265
Base	88	74	70	96	105	100	110
Surface				74	70	100	100
Total Thickness				478	475	478	475

Table 5e: Comparison of Result – Pavement Section 5

Material	CBR	Thickness Above Layer(mm)		Thickness Of Layer(mm)		Adjusted/Actual Thickness(mm)	
		N-Flex-Pave	Design Curves	N-Flex-Pave	Design Curves	N-Flex-Pave	Design Curves
Subgrade	6.0	427	430	-	-	-	-
Subase	30	171	165	256	265	217	220
Base	90	66	60	105	105	110	110
Surface				66	60	100	100
Total Thickness				427	430	427	430

Table 6a: Comparison of N-Flex-Pave - Calculated and Design Curve - Measured Thickness Above Layer

Pavement Section	Base			Subbase			Subgrade		
	Calculated	Measured	*Ratio*	Calculated	Measured	*Ratio*	Calculated	Measured	*Ratio*
Section 1	93	88	***1.05***	205	210	***0.98***	761	763	***0.99***
Section 2	83	85	***0.97***	197	200	***0.98***	625	620	***1.01***
Section 3	80	80	***1.00***	182	180	***1.01***	516	520	***0.92***
Section 4	74	70	***1.06***	170	175	***0.97***	478	475	***1.00***
Section 5	66	60	***1.10***	171	165	***1.04***	427	430	***0.99***

Table 6b: Comparison of N-Flex-Pave - Calculated and Design Curve - Measured Pavement Layer Thickness

Pavement Section	Surface			Base			Subbase		
	Calculated	Measured	*Ratio*	Calculated	Measured	*Ratio*	Calculated	Measured	*Ratio*
Section 1	100	100	***1.0***	115	113	***1.02***	546	550	***0.99***
Section 2	100	100	***1.0***	120	120	***1.00***	405	400	***1.01***
Section 3	100	100	***1.0***	105	100	***1.05***	311	320	***0.97***
Section 4	100	100	***1.0***	100	110	***0.91***	278	265	***1.05***
Section 5	100	100	***1.0***	110	110	***1.00***	217	220	***0.99***

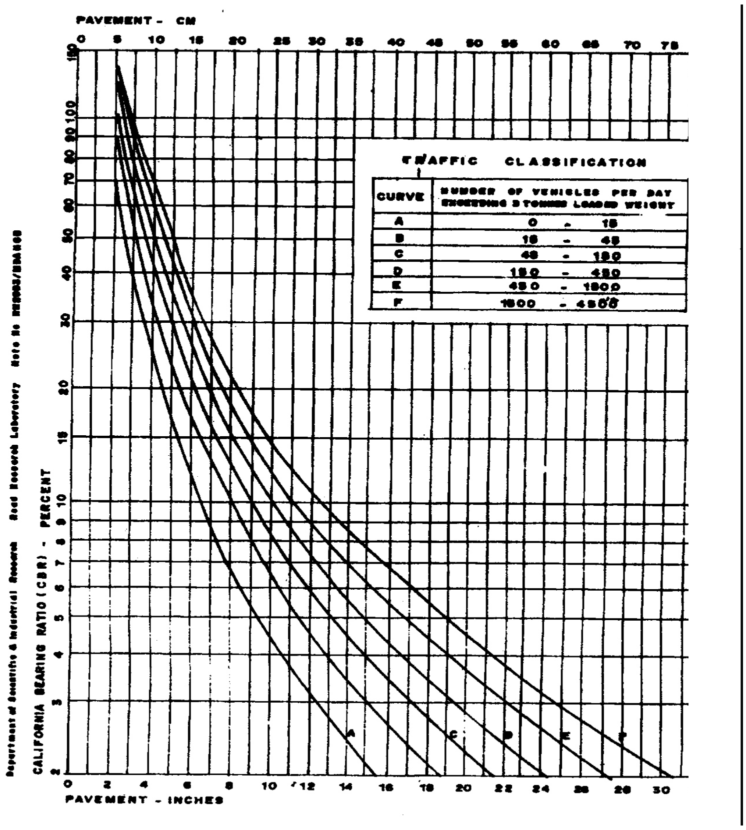

Figure 1: The Nigerian (CBR) Flexible Pavement Design Chart

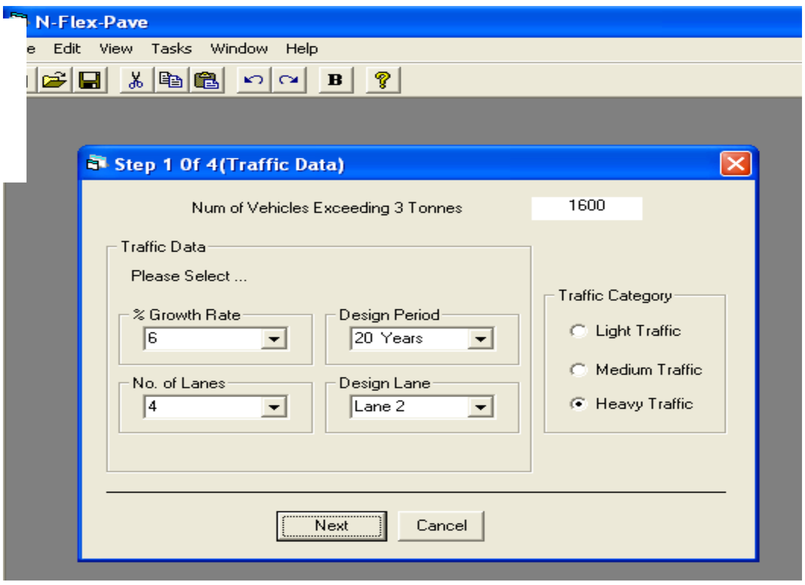

Figure 2: Traffic Data Window– Step 1 of 4

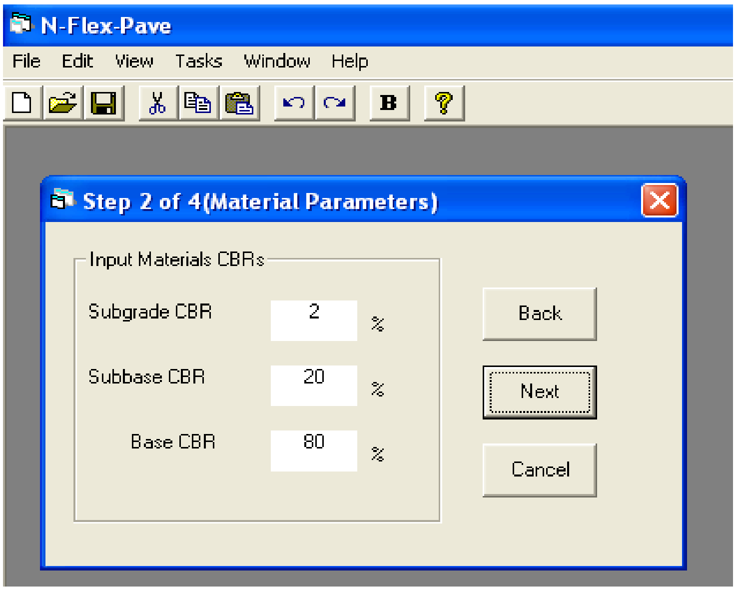

Figure 3: Material Parameter Window – Step 2 of 4

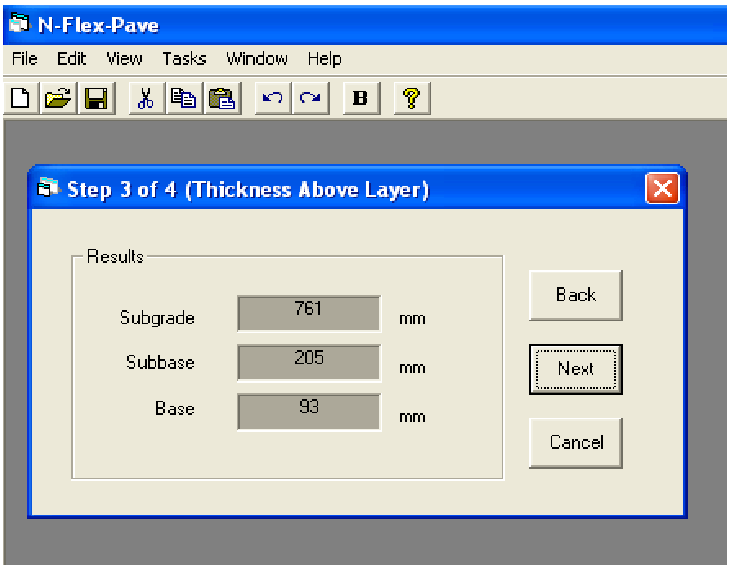

Figure 4: Thickness Above Layer Window

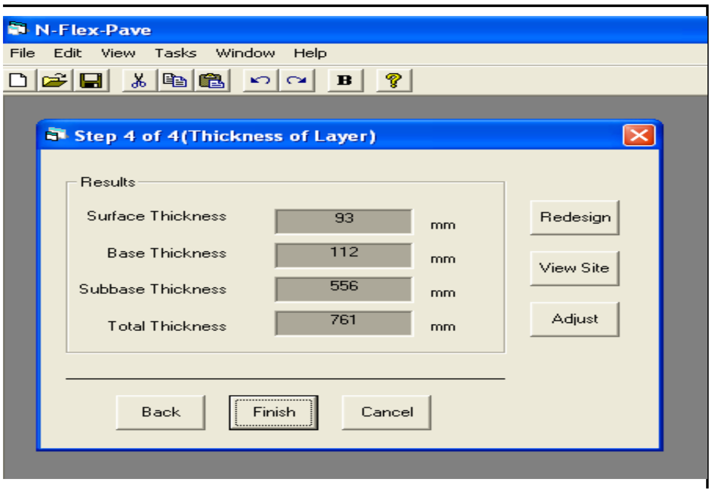

Figure 5: Thickness of Layer Window

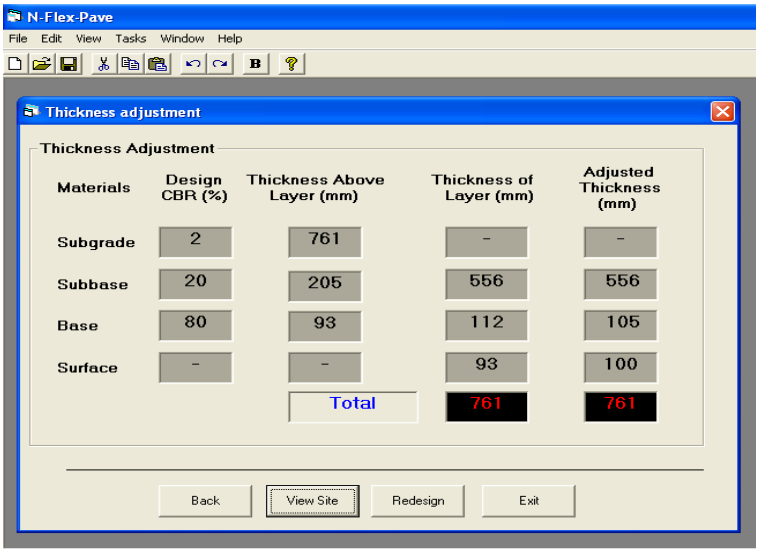

Figure 6: Thickness Adjustment Window

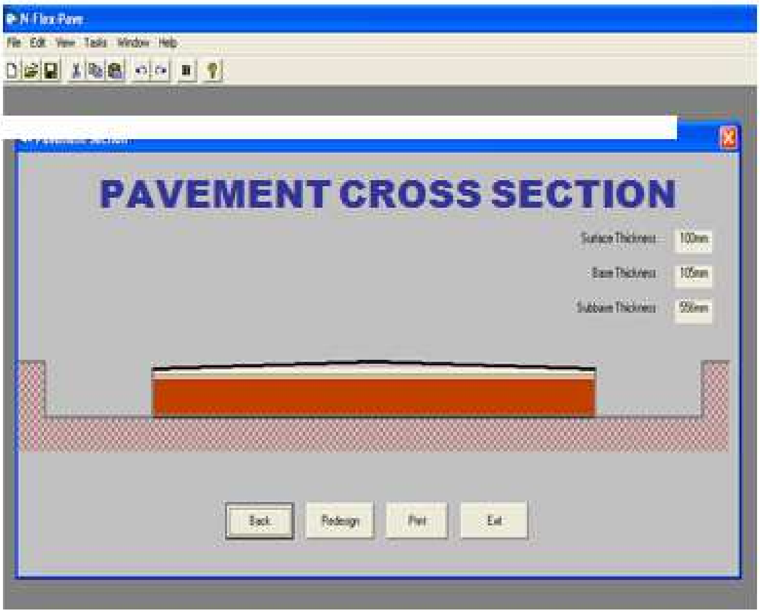

Figure 7: Pavement Cross Section

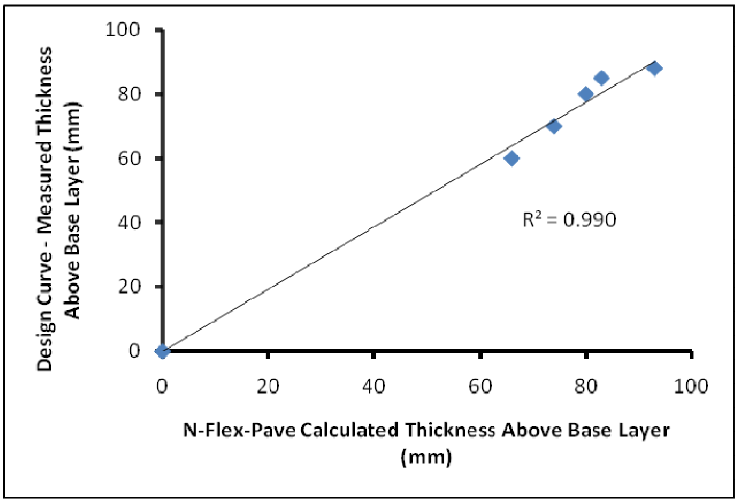

Figure 8a: Calibration of Calculated and Measured Total Pavement Thickness above Base Layer

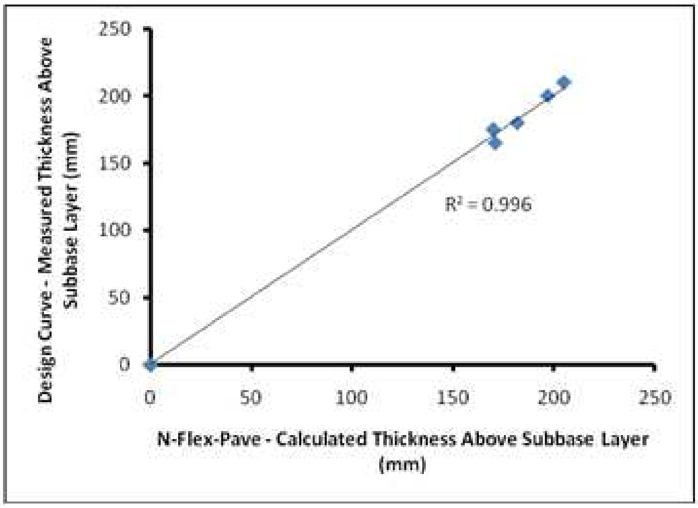

Figure 8b: Calibration of Calculated and Measured Total Pavement Thickness above Subbase Layer

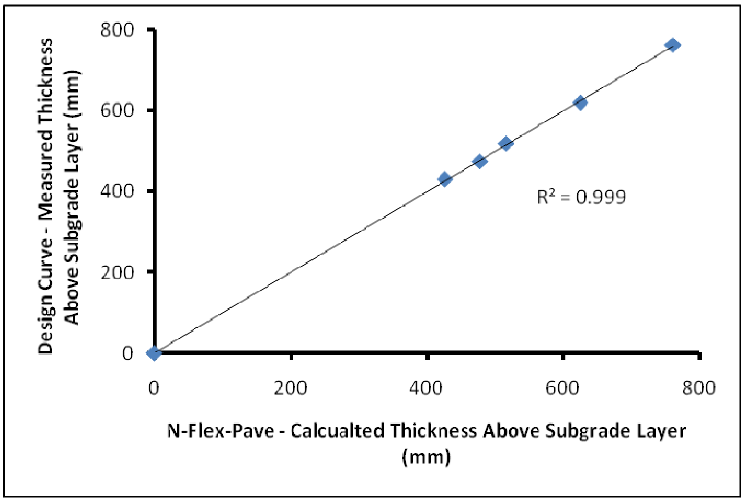

Figure 8c: Calibration of Calculated and Measured Total Pavement Thickness above Subgrade Layer

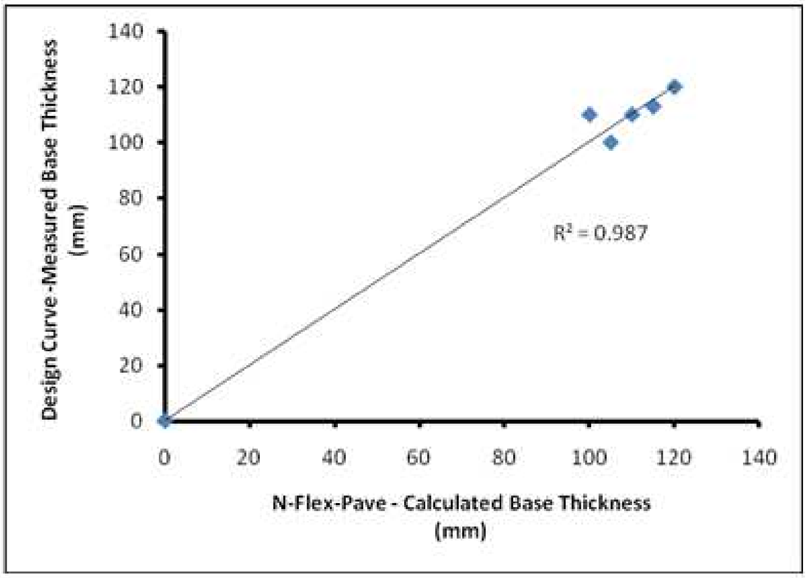

Figure 9a: Calibration of Calculated and Measured Pavement Base Thickness

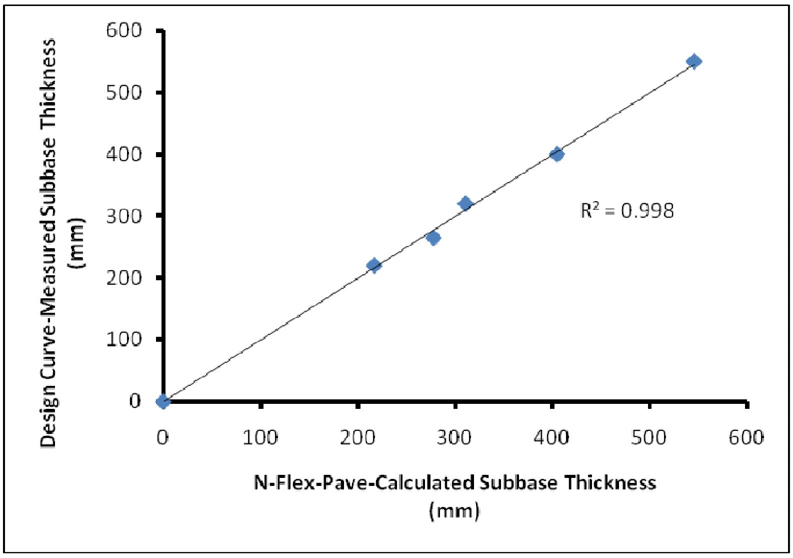

Figure 9b: Calibration of Calculated and Measured Pavement Subbase Thickness

CONCLUSION

From the results of the study, the following conclusions are hereby made:

1. The result of N-Flex-Pave design compare favorably with result of design using conventional design curves and Tables.
2. That N-Flex-Pave is a good estimator of pavement layer thickness for Nigerian (CBR) design procedure for flexible pavement.
3. The design of flexible pavement using Nigeria (CBR) procedure is faster and easier with the N-Flex-Pave program than the conventional procedure.
4. The N-Flex-Pave should be recommended for use by pavement designers in Nigeria for the design of flexible pavement.

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