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New Approach for Determining Young Modulus and Poisson Coefficient in the Structural Design of the Pavement

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***Abstract*— The French design method integrate two entry parameters that use the Young modulus and Poisson coefficient often useful for pavement structure. The measurements of these parameters are costly in many tropical countries and the change in materials design can change considerably the prescription obtained from the French method. To design the pavement we present an approach that consists of determining an interval of Young modulus and Poisson coefficient in order to deal with the prescribed value and the change in pavement materials in Cameroon. The usefulness of such interval is demonstrated with local data that make use of the French method.**

Keywords*— Pavement structures; French method; Young modulus; Poisson coefficient

I. INTRODUCTION

Many workers had treated the problematic of roadway and highway design and this can be referred in the literature [5], [8], [18], [19], [24]. The mechanical parameters of both ways play an important role and the estimation of the Young modulus and the Poisson coefficient used in various guidelines ([1], [2], [9], [8], [17], [20], [21], [23]) remains a problem in tropical countries.

Under the traffic, certain methods used to design the pavement are applied to model the behavior of the pavement structures. Such modeling permits to build relationship that make use of Young modulus E and Poisson coefficient υ in the design of the pavement structures. In tropical regions, theses parameters often recommended by the literature can change. For example, in Cameroon where the infrastructures are not adapted to determine the desired value.

To overcome this limitation, we propose an interval of mechanical values E and υ that take in account the recommended values and give the possibility to design the pavement structures accurativelly. To validate this approach, we have used the data found in [3], [11], [12], [13] [14], [15] to characterize the parameters E and υ useful to obtain the interval of parameter values.

The section I is the introduction and section II show the procedure accorded to the determination of intervals of parameter values including the materials of the study. In section III, we present these intervals as the main results and conclude this work in section IV with some important perspectives.

II. PROPOSED APPROACH

A. *Input parameters*

For this study, we used materials to achieve our goal; namely 18 pavement structures for 3 different types:

- Type 1 : flexible pavement (bituminous pavement) (Number 1 to 6) ;
- Type 2 : flexible pavement (bituminous concrete denoted by BC) (Number 7 to 12) ;
- Type 3: flexible pavement (seal coat denoted by SC) (Number 13 to 18).

The design of these pavements is done with the help of the software ALIZE 3 taking into account the recommended values E and υ of [22] as it is showed in table I.

TABLE I. YOUNG MODULUS AND POISSON COEFFICIENT

Materials	*BC*[a]	*BG*[b]	*CG/Ci/Po*[c]	*NLG*[d]
E_{cal} (MPa)	2 450	3 500	400	150
υ_{cal}	0, 35	0,35	0,35	0,35

[a] BC. : Bituminous concrete.
[b] BG: Bitumen gravel.
[c] CG: Crushed grave – Ci : Cinder – Po: Pouzzolan.
[d] NLG: Natural laterite gravel.

Other parameters used in the French method are important in the pavement design namely the traffic and the subgrade parameter. Having the materials defined in the table I above, the additional parameters are showed in the tables II and III below.

TABLE II. MECHANICAL CHARACTERISTIC OF THE SUBGRADE [3]

Layer	*Category*	*E (MPa)*	υ
Subgrade	S1	25	0,35
	S2	50	0,35
	S3	75	0,35
	S4	150	0,35
	S5	300	0,35

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In this Table, we denote by S1,…, S5 the subgrade material with given E and υ.

TABLE III. TRAFIC CLASSES DEFINED IN TROPICAL COUNTRIES [3]

EN [a]	***Traffic class***	***Equivalent number of vehicle per day***
< $5x10^5$	T1	< 300
From $5x10^5$ to $1.5x10^6$	T2	300 to 1 000
From $1.5x10^6$ to $4x10^6$	T3	1 000 to 3 000
From $4x10^6$ to 10^7	T4	3 000 to 6 000
From 10^7 to $2x10^7$	T5	6 000 to 12 000

a. EN: Equivalent number of axles.

B. States of stress and strain

In continuum mechanics, the states of stress and strain at a point in cylindric coordinates are determined by:

- σ_r, σ_t, σ_z : normal stresses;
- τ_{tz}, τ_{rz}, τ_{rt} : shear stresses ;
- ε_r, ε_t, ε_z : linear strains;
- δ_{tz}, δ_{rz}, δ_{rt} : angular strains.

With known Young modulus and Poisson coefficient given by the formulas:

$$E_i = \mu_i.(3.\lambda_i + \mu_i)/(\lambda_i + \mu_i) \qquad (1)$$

And

$$\upsilon_i = \lambda_i/(2.(\lambda_i + \mu_i)) \qquad (2)$$

We determine the Lame coefficients μ and λ. According to the model prescribed by Burmister [16], we have the following graphic:

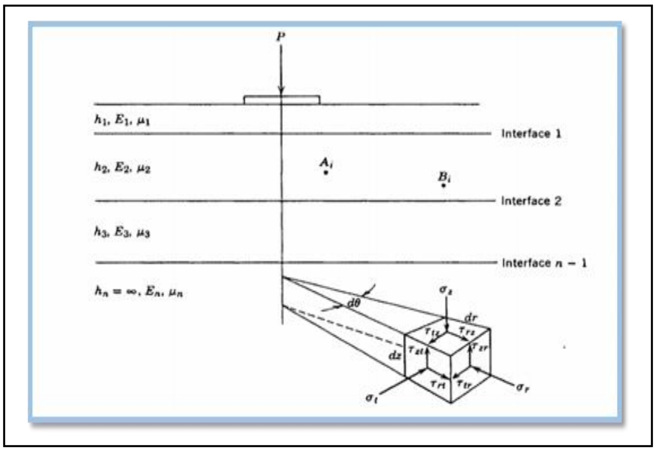

Fig. 1. State of stress at a point in cylindric coordinates

The calculus made with the software ALIZE 3 provides all the information related to the stress and strain tensors for each pavement structure. From these informations, the following values are chosen and compared to admissible values in order to design the pavement structure.

TABLE IV. NATURE OF MAXIMUM STRESS OR STRAIN TO CONSIDERATE [16]

Material	***Stress or strain (max)***
Hydrocarbon materials	ε_t
Concrete and hydraulic binder treated materials	σ_t
Untreated soil and materials	ε_z

We note that the admissible values are found in [3].

TABLE V. ADMISSIBLE DEFLECTIONS IN FUNCTION OF TRAFIC CLASSES [3]

Traffic class	***Admissible deflections (in 1/100 mm)***
T1	125
T2	90
T3	65
T4	40
T5	35

C. Description of the procedure

To determine the interval of value of the parameter E and υ, we followed the steps below:

- The pavement is designed firstly with the recommended values E_{cal} and υ_{cal};
- The perturbation of both values does not change the structure of the pavement and the mechanism used to find the interval of admissible parameter values is done with the help of ALIZE 3.

A way is given to study the sensitivity of the parameter and some operations are done as it is followed:

$$\Delta X = |X_{max} - X_{min}| \qquad (3)$$

$$SX = \Delta X/(2.X_{cal}) \qquad (4)$$

Where X_{max} and X_{min} are respectively the upper bound and the lower bound value of the proposed interval and X_{cal} is the recommended value.

III. PRESENTATION AND ANALYSIS OF RESULTS

A. Case of the design of pavement n°1

In this case, we have the input data:

- Traffic: Class II
- Pavement materials and recommended parameters (E_{cal} and υ_{cal}) (Table VI)
- Subgrade (soil) mechanical characteristics (E and υ) (Table VI)

TABLE VI. MECHANICAL CHARACTERISTICS OF THE PAVEMENT N°1

Layer	*Material nature/ Category*	*Ecal (MPa)*	*υ cal*
Surface course	BC	2 450	0,35
Base course	GB	3 500	0,35
Subgrade	S3	75	0,35

With these entries, the software ALIZE 3 gives us the following thicknesses:

- Thickness of the surface course: 5 cm;
- Thickness of the base course: 32 cm.

By perturbing the mechanical parameters E_{cal} and υ_{cal}, we obtain an interval of admissible values that does not modify the structure of the pavement as we see in the following figures:

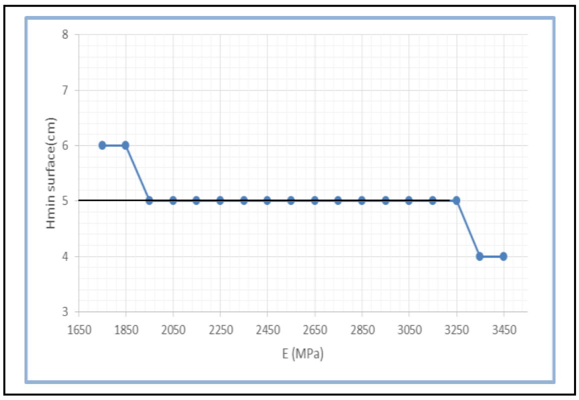

Fig. 2. Thickness of the surface course in function of the Young modulus of the bituminous concrete of the pavement n°1

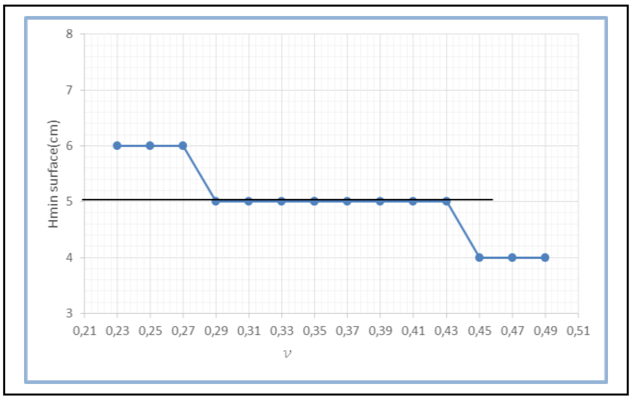

Fig. 3. Thickness of the surface course in function of the Poisson coefficient of the bituminous concrete of the pavement n°1

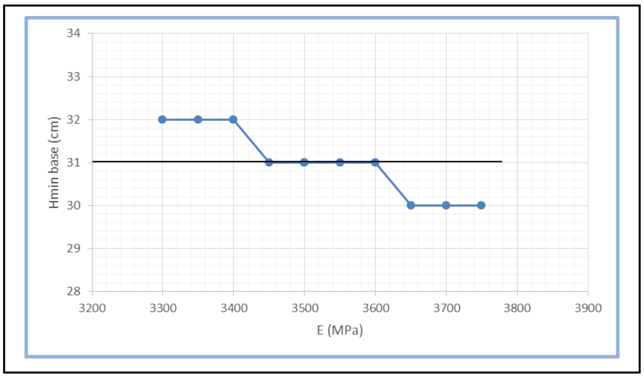

Fig. 4. Thickness of the base course in function of the Young modulus of the bitumen gravel of the pavement n°1

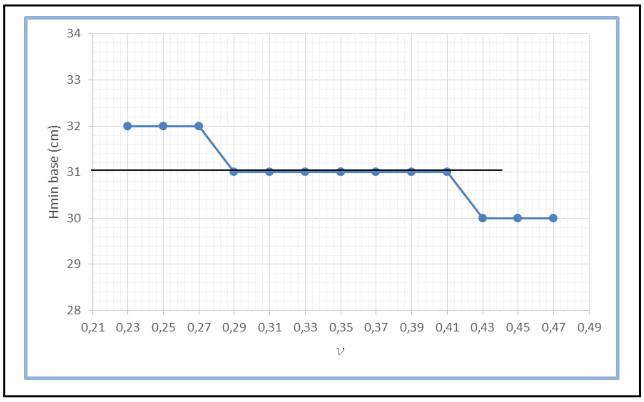

Fig. 5. Thickness of the base course in function of the Poisson coefficient of the bitumen gravel of the pavement n°1

a) Intervals of mechanical parameters *E* and *υ*

According to the figures 2 to 5, we obtain specific intervals of values that correspond to a specific pavement structure

TABLE VII. INTERVAL OF VALUES FOR MATERIAL USED IN THE PAVEMENT N°1

Layer	*Material nature*	*Thickness (cm)*	*Ecal (MPa)*	*L.E.V[a] (MPa)*
Surface course	BC	5	2 450	[1 950, 3 250]
Base course	BG	31	3 500	[3 450, 3 600]

Layer	*SE (%)*	*υcal*	*L.υ.V[b]*	*Sυ (%)*
Surface course	26.5	0.35	[0.29, 0.43]	20
Base course	2.1	0.35	[0.29, 0.41]	17.1

a. **I.E.V** : Interval of *E* values.

b. **I.υ.V** : Interval of *υ* values.

B. Application on a finite number of pavement structures

We applied the procedure described in the previous section to design 18 pavement structures as it is show in the next table.

TABLE VIII. DESIGN OF THE 18 STRUCTURES PAVEMENT

Type of Pavement	Numbered pavement	Surface course		Base course	
		Material	***Thickness (cm)***	***Material***	***Thickness (cm)***
1	1	BC	5	BG	31
	2	BC	5	BG	27
	3	BC	6	BG	36
	4	BC	5	BG	32
	5	BC	7	BG	40
	6	BC	6	BG	36
2	7	BC	4	CG/ Ci/ Po	21
	8	BC	4	CG/ Ci/ Po	11
	9	BC	4	CG/ Ci/ Po	39
	10	BC	4	CG/ Ci/ Po	23
	11	BC	4	CG/ Ci/ Po	47
	12	BC	4	CG/ Ci/ Po	33
3[a]	13	SC	2	CG/ Ci/ Po	26
	14	SC	2	CG/ Ci/ Po	12
	15	SC	3	CG/ Ci/ Po	33
	16	SC	3	CG/ Ci/ Po	18
	17	SC	3	CG/ Ci/ Po	47
	18	SC	3	CG/ Ci/ Po	34

a. The seal coat does not take part in the structural design of the pavement.

Type of pavement	Numbered pavement	*Subbase*		*Subgrade*		*Trafic class*
		Matériau	Thickness (cm)	Category	Thickness (cm)	
1	1	/	/	S3	∞	T2
	2	/	/	S4	∞	T2
	3	/	/	S3	∞	T3
	4	/	/	S4	∞	T3
	5	/	/	S3	∞	T4
	6	/	/	S4	∞	T4
2	7	NLG	25	S3	∞	T2
	8	NLG	20	S4	∞	T2
	9	NLG	24	S3	∞	T3
	10	NLG	24	S4	∞	T3
	11	NLG	25	S3	∞	T4
	12	NLG	21	S4	∞	T4
3	13	NLG	19	S3	∞	T1
	14	NLG	19	S4	∞	T1
	15	NLG	20	S3	∞	T2
	16	NLG	20	S4	∞	T2
	17	NLG	25	S3	∞	T3
	18	NLG	22	S4	∞	T3

The next tables show the interval of mechanical parameters values for the 18 pavement structures including recommended values.

TABLE IX. INTERVAL OF VALUES FOR BITUMINOUS CONCRETE USED IN THE SURFACE COURSE

Numbered pavement	***E_{cal} (MPa)***	***I.E.V (MPa)***	***ΔE (MPa)***	***SE (%)***
1	2450	[1950, 3250]	1300	26.5
2	2450	[1950, 3050]	1100	22.4
3	2450	[1850, 2850]	1000	20.4
4	2450	[2350, 4250]	1900	38.7
5	2450	[1850, 2550]	700	14.2
6	2450	[2050, 3150]	1100	22.4
7	2450	[1850, 2850]	1000	20.4
8	2450	[1650, 3650]	2000	40.8
9	2450	[1750, 2550]	800	16.3
10	2450	[1850, 3250]	1400	28.5
11	2450	[1750, 2550]	800	16.3
12	2450	[1550, 2550]	1000	20.4
Average				24

Numbered pavement	**υ_{cal}**	**I. υ.V**	**Δυ**	**Sυ (%)**
1	0.35	[0.31, 0.43]	0.14	20
2	0.35	[0.27, 0.41]	0.14	20
3	0.35	[0.27, 0.39]	0.12	17
4	0.35	[0.33, 0.47]	0.14	20
5	0.35	[0.25, 0.37]	0.12	17
6	0.35	[0.31, 0.41]	0.1	14.3
7	0.35	[0.05, 0.43]	0.38	54.3
8	0.35	[0.05, 0.49]	0.44	63
9	0.35	]0.00, 0.37]	0.37	53
10	0.35	[0.19, 0.45]	0.26	37.9
11	0.35	]0.00, 0.37]	0.37	53
12	0.35	]0.00, 0.37]	0.37	53
Average				35

TABLE X. INTERVAL OF VALUES FOR BITUMEN GRAVEL USED IN THE BASE COURSE

Numbered pavement	***E_{cal} (MPa)***	***I.E.V (MPa)***	***ΔE (MPa)***	***SE (%)***
1	3500	[3450, 3600]	150	2
2	3500	[3400, 3600]	200	2.8
3	3500	[3400, 3550]	150	2
4	3500	[3450, 3700]	250	3.6
5	3500	[3400, 3550]	150	2
6	3500	[3450, 3600]	150	2
Average				2.4

Numbered pavement	***υ_{cal}***	***I. υ.V***	***Δυ***	***Sυ (%)***
1	0.35	[0.29, 0.41]	0.12	17
2	0.35	[0.00, 0.43]	0.43	61.4
3	0.35	[0.27, 0.41]	0.14	20
4	0.35	[0.33, 0.47]	0.14	20
5	0.35	[0.25, 0.37]	0.12	17
6	0.35	[0.27, 0.43]	0.16	22.8
Average				26.4

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TABLE XI. INTERVAL OF VALUES FOR CRUSHED GRAVEL/ CINDER/ POUZZOLAN USED IN THE BASE COURSE

Numbered pavement	E_{cal} (MPa)	I.E.V (MPa)	ΔE (MPa)	SE (%)
7	400	[370, 420]	50	6.2
8	400	[330, 460]	130	16.2
9	400	[350, 410]	60	7.5
10	400	[370, 430]	60	7.5
11	400	[340, 410]	70	8.7
12	400	[330, 410]	80	10
13	400	[390, 500]	110	13.7
14	400	[360, 470]	110	13.7
15	400	[350, 410]	60	7.5
16	400	[330, 450]	120	15
17	400	[350, 460]	110	13.7
18	400	[320, 410]	90	11.2
Average				11

Numbered pavement	υ_{cal}	I. υ.V	$\Delta\upsilon$	$S\upsilon$ (%)
7	0.35	[0.29, 0.45]	0.16	22.8
8	0.35	[0.25, 0.45]	0.2	28.6
9	0.35	[0.33, 0.5[	0.17	24.3
10	0.35	[0.29, 0.39]	0.1	14.3
11	0.35	[0.31, 0.5[	0.19	27.1
12	0.35	[0.33, 0.5[	0.17	24.3
13	0.35	[0.33, 0.43]	0.1	14.3
14	0.35	[0.29, 0.43]	0.14	20
15	0.35	[0.29, 0.37]	0.08	11.5
16	0.35	[0.31, 0.37]	0.06	8.6
17	0.35	[0.33, 0.37]	0.04	5.7
18	0.35	[0.29, 0.37]	0.08	11.5
Average				17.8

TABLE XII. INTERVAL OF VALUES FOR NATURAL LATERITE USED IN THE SUBBASE

Numbered pavement	E_{cal} (MPa)	I.E.V (MPa)	ΔE (MPa)	SE (%)
7	150	[145, 180]	35	11.6
8	150	[130, 195]	65	21.6
9	150	[145, 205]	60	20
10	150	[105, 155]	40	13.3
11	150	[120, 170]	50	16.6
12	150	[130, 185]	55	18.3
13	150	[145, 180]	35	11.6
14	150	[110, 220]	110	36.6
15	150	[120, 170]	50	16.6
16	150	[120, 190]	70	23.3
17	150	[120, 175]	55	18.3
18	150	[110, 165]	55	18.3
Average				18.8

Numbered pavement	υ_{cal}	I. υ.V	$\Delta\upsilon$	$S\upsilon$ (%)
7	0.35	[0.23, 0.37]	0.14	20
8	0.35	[0.31, 0.37]	0.06	8.5
9	0.35	[0.00, 0.37]	0.37	52.8
10	0.35	[0.29, 0.37]	0.08	11.4
11	0.35	[0.15, 0.50]	0.35	50
12	0.35	[0.33, 0.39]	0.06	8.5
13	0.35	[0.17, 0.37]	0.2	28.5
14	0.35	[0.17, 0.37]	0.2	28.5
15	0.35	[0.19, 0.41]	0.22	31.4
16	0.35	[0.33, 0.27]	0.06	8.5
17	0.35	[0.19, 0.41]	0.22	31.4
18	0.35	[0.31, 0.37]	0.06	8.5
Average				24

C. Summary of the desired sensitivity

The small change of the parameters *E* and υ provide with the help of ALIZE 3 a good level of sensitivity of the Young modulus taken between 14% and 41% in the case of a bituminous concrete in surface course while the sensitivity of the Poisson coefficient can be taken between 17% and 54%.

We observe also that the sensitivity of υ change from 17% to 61% in the case of the bituminous gravel in base course while it decrease from 9% to 53% in the case of laterite gravel in subbase. Another observation is made for the sensitivity of *E* between 12% and 37% for the natural laterite gravel in subbase.

TABLE XIII. SYNTHESIS OF THE SENSITIVITY OF MECHANICAL PARAMETERS *E* AND *υ*

Layer	Material	SE (min, %)	SE (max, %)	$S\upsilon$ (min, %)	$S\upsilon$ (max, %)
Surface course	BC	14	41	17	54
Base course	CG/ Ci/ Po	8	16	6	29
	BG	2	4	17	61
Subbase	NLG	12	37	9	53

These levels of sensitivity are useful in particular for the countries where the infrastructure to design the pavement fails and give an alternative to recommended design parameters.

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IV. CONCLUSION

This work has been based on the fact that determining an interval of mechanical values E and υ permits to decide on the desired design of the pavement in tropical regions, for example in Cameroon. Instead of using the recommended values, these intervals open a large zone of application that can involve different kind of materials. This approach opens a new perspective in the design of the pavement structures in tropical countries.

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