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Contribution to the optimal determination of pavements layers

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Abstract: The dimensioning of flexible pavements finds its essence in the pavement sizing guide for tropical countries set up by the CEBTP. For the calculation of deformations in structures, the Alizé software of LCPC-SETRA using the French method of dimensioning is the repository. In the CEBTP typology, five classes of traffic are defined as intervals. [...] In our country, the practice consists in simplifying the dimensioning procedure by considering the traffic of the upper bound of each class for the calculation of the permissible deformations. It leads to the over-dimensioning of pavement structures due to the overestimation of the value resulting in a drastic increase in construction costs. A critical study of all classes of traffic was conducted through simulations with Alizé and Microsoft Office Excel software; and using local materials. As a result, the simplification made can lead to enormous losses of building materials and thus cause disproportionate expenditure. To mitigate this problem, an aid tool has been proposed for determining the permissible deformations taking into account the actual traffic and proposing some flexible pavement structures.

Keywords - **flexible pavements, pavement sizing, classes of traffic, simulations and permissible deformations.**

I. INTRODUCTION

According to analyzes of the road pavement survey data in sub-Saharan Africa in general and Cameroon in particular, severe, early and costly damage to the condition and the users was found. These observations revealed the limitations of the tools used both in the structural design and in the construction of roads and in the calibration of the materials used. **[KOUBIKANA PAMBOU, 2013]**

In view of the above, it is therefore necessary to make a contribution in the search for solutions to this problem. We believe that critical analysis of pavement sizing practice could be a relief to this problem. The following questions should therefore be asked: For a pavement whose traffic belongs to a class, what is the level of impact on the dimensioning if one considers the upper boundary of the latter in place of actual traffic? Why despite this oversizing, we still see early degradation of our pavements before even the lifetime? What measures have the competent authorities taken to remedy these problems?

II. METHODOLOGY

A. Presentation of the French method of dimensioning

1) The dimensioning approach

The French method of dimensioning combined pavement structures:

- ✓ A mechanical analysis of the functioning of the structure;
- ✓ Results of laboratory tests on the fatigue damage of pavement materials;
- ✓ Knowledge derived from the observation of the behavior of actual pavements, given from test sections or from experiments carried out on the road structure study of the Central Laboratory of Bridges and Roads.

The dimensioning approach and the articulation of the different steps are as follows:

Step one: **Predimensioning**

Once the necessary data are compiled, we proceed:

- ✓ At a first choice of the wearing course ;
- ✓ At a pre-dimensioning of the structure with reference to comparable situations.

Step two: **Analysis of structures**

The stresses and strains for the mathematical model of the pavement structure pre-dimensioned at the first stage, under the reference axle of 130 kN, are calculated. Each half-axle comprises:

Single wheel twinning, represented by two loads exerting a uniformly distributed pressure of 0.662 MPa on 2 disks of 0.125 m radius, with a center distance of 0.375 m.

Step three: **Fatigue verification of the structure and deformation of the support**

The check is made by comparing the stresses and deformations calculated in step 2 to allowable values. These limit values are determined according to:

- Cumulative traffic over the calculation period considered;
- The risk of ruin admitted over this period;
- Fatigue strength characteristics of materials;
- Thermal effects;
- Data on the behavior of pavements of the same type.

This last point is expressed by the introduction of a coefficient, called calibration, which allows to take into account on the one hand effects that the mathematical model cannot represent by the simplifications made, and on the other hand, biases related to the representativeness of laboratory tests for the description of the properties of materials.

Step four: **Adjustment of calculated thicknesses**

The layer thicknesses determined at the end of step 3 are then adjusted to:

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- ✓ Take into account the technological constraints of minimum and maximum thickness to achieve the objectives of compactness and uniformity ;
- ✓ Reduce the risk of interface link faults by limiting the number of interfaces;
- ✓ Ensure sufficient protection of the foundations treated with respect to phenomena not apprehended by the previous calculation (cracking in particular).

Step five: Definition of the cross section of the roadway

All previous checks being positive, for the so-called nominal structure corresponding to the right edge of the busiest track; it remains to specify the profile across the roadway. For this, the transverse thickness variations of the layers are fixed according to: the traffic per lane, the characteristics of the layout, the catching of the transverse slopes between the road support platform and the surface layer.

2) Input data

a) Traffic

The traffic is expressed in two different ways:

- ➢ By its average daily intensity, all classes of vehicles included, and for a life expectancy of about 15 years, the average percentage of heavy goods vehicles is supposed to be (in developing countries) in the vicinity 30% of the total traffic. The categories of traffic chosen are recorded in Table 1;
- ➢ That is, the cumulative number of HGVs during the lifespan chosen by the designer, the HGV being defined as a vehicle having a gross vehicle weight greater than 3 tonnes or 5 tonnes. This limit does not take into account passenger cars and bush taxis which have a negligible effect on the behavior of the roadway.

Table 1 : Classes of traffic defined by the CEBTP in Francophone Africa [CEBTP, 1982]

Equivalent Number of trucks (EN)	Classes of traffic	Equivalent Number of vehicle per day
$<5.10^5$	T1	<300
From 5.10^5 to $1,5.10^5$	T2	300 to 1000
From $1,5.10^6$ to 4.10^6	T3	1000 to 3000
From 4.10^6 to 10^7	T4	3000 to 6000
From 10^7 to 2.10^7	T5	6000 to 12000

b) Coefficients

(1) Calibration coefficient (Kc)

It is a coefficient that adjusts the results of the model, it is 1.1 for asphalt concrete. (SETRA-LCPC, 1994)

(2) Risk coefficient (Kr)

Still called Coefficient of adjustment of the admissible deformation, it is expressed as follows:

$$k_r = 10^{-ub\delta}$$

u : Reduced centered variable associated with calculation risk r (r=30% for T1 traffic, 18% for T2 traffic and 10% for T3 traffic)

b : Slope of the right of fatigue of the material (in general, $b = -0,2$ for bituminous materials)

δ : Standard deviation of the distribution of $\log N$ at the breakup

$$\delta = \left[SN^2 + \left(\frac{c^2}{b^2}\right)Sh^2\right]^{0.5}$$

c : Coefficient linking the variation of the deformation to the random variation of the thickness of the roadway. For common roadways, it is of the order of 0.02 cm^{-1}.

Sh: Standard deviation on the thickness of the layers used.

(3) Coefficient related to the lift of the soil (Ks)

It is a minority coefficient taking into account the effect of local heterogeneities of lift of a layer of low rigidity supporting the bound layers. Its values are shown in the following table:

Module in MPa	E<50	50≤E<120	E ≥120
k_s	1/1,2	1/1,1	1

The module to consider is that of the layer underlying the bound layer.

c) Equivalent temperatures

We will take for the continuation an equivalent temperature of 26 ° C.

d) Materials

(1) Mechanical parameters of unprocessed bass

(a) Young's modulus

The CEBTP proposes the values in ***[Table 2]*** for the verification of material damage criteria. They will be used for the simulation because approaching substantially the values found in [1] in 2011 during the study conducted on three sections of road in Cameroon.

Table 2 : Modules of materials (CEBTP, 1984)

Layers	Materials	E (MPa)
Platform	S3	75
	S4	150
Subgrade	Unthreated Gravel (UG)	300
	Clay Sand (CS)	300
	Soil-Cement (SC)	450
	Bitumen Soil (BS)	350
Base course	Broken Aggregate (BA)	500
	Lateritic Aggregate (LA)	300
	Lean Concrete (LC)	8000
	Bituminous Concrete (BC)	4000

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(b) Poisson's ratio

The choice of the Poisson's ratio differs from one author to another, but remains between 0.25 and 0.5. For lateritic aggregate, in [2], a value of 0.35 is proposed as a subbase and 0.4 as a base course. These values will be used for any other material used for these layers.

(2) Mechanical parameters of bituminous materials

Intrinsic characteristics

The mechanical characteristics of bituminous materials depend on the temperature and the frequency of the stresses (f=10Hz, values considered by the LCPC). The calculation must be done for values representative of the project conditions. The calculation method requires:

- ✓ For the representation of the reversible behavior under a load, the data of Young's modulus E, the document [1] proposes for this purpose a value of 2000 MPa for surfacing courses in bituminous materials and the fish coefficient, the document [3] proposes a value of 0.4 for asphalt concrete, this value will also be used for surface coatings and dense asphalt.
- ✓ To represent fatigue damage:
  - The data of the deformation ε ;
  - The slope of the law of fatigue $\frac{\varepsilon}{\varepsilon_6} = \left(\frac{N}{10^6}\right)^b$;
  - The standard deviation SN of the distribution of $\log N$ at breakup for 10^6 cycles and is 0.25 for bituminous concrete.

The values of E, and b being chosen for the value of the equivalent temperature (26 ° C for our case).

Implementation characteristics

The standard deviation Sh on the thickness of the layers used is given by the following table according to the thickness of the bituminous materials.

Table 3 : Standard deviation on thicknesses (SETRA-LCPC, 1994)

e (cm)	e ≤ 10	10 ≤ e ≤ 15	e ≥ 15
Sh (cm)	1	1+0,3(e-10)	2,5

3) Calculations of admissible values

The sizing of flexible pavements is based on the verification of the following admissible limits:

- ✓ Vertical deformation ε_z on the surface of the unbound layers and the supporting soil.
- ✓ Lengthening or streching ε_t at the base of bituminous layers remains below a permissible value.

a) Determination of the admissible vertical deformation

For the different road structures, it is necessary to check that the rutting of the granular layers remains lower than the value held for admissible. The admissible values of the deformation can be calculated with the formula below:

$\varepsilon_{z,ad} = A.(NE)^{-0.222}$

- ✓ For medium and high traffic roads (T > T3) : $A = 0{,}012$;
- ✓ For low traffic roads ($T \leq T3$): $A = 0{,}016$.

b) Determination of admissible tangential deformation

It is calculated with the relation:

$$\varepsilon_{t,ad} = \varepsilon(NE, \theta_{eq}, f) k_r k_c k_s \quad (1)$$

The fatigue law is expressed experimentally with the temperature of 10 ° C and the frequency of 10 Hz, so:

$$\varepsilon(NE, \theta_{eq}, f) = \varepsilon_6(10°C, 10Hz)\left[\frac{E(10°C)}{E(\theta_{eq})}\right]^{0.5} \left(\frac{NE}{10^6}\right)^b \quad (2)$$

With $\theta_{eq} \approx 26°C$ in our case.

For asphaltic concrete,

$$E(10°C, 10Hz) = 7200 MPa$$

$$\varepsilon_6(10°C, 10Hz) = 100 \mu def$$

c) Admissible deflections

The weight of the vehicle is transmitted to the ground in the form of pressures, via the tires. In general, the floors cannot withstand such pressures without damage. If the soil is not strong enough, the tire compresses it and a rut forms.

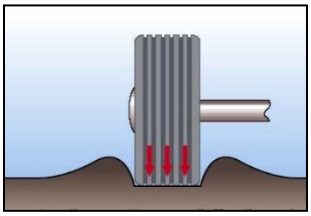

Fig 1 : A rut under the effect of a load

If the soil is bearing, two imperceptible things happen, but it is important to understand:

- ➢ The ground sags under the tire. It is the total deformation: W_t
- ➢ When the wheel moves away, the soil rises but not completely: there remains a residual deformation: W_r

The difference $d = W_t - W_r$ is called « **deflection** ».

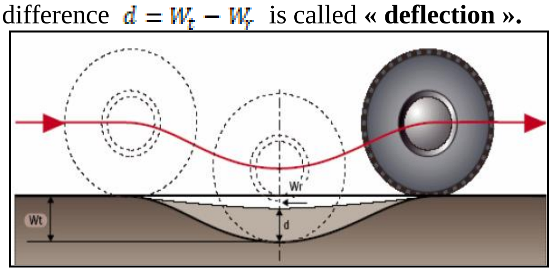

Fig 2 : Deflection on a roadway

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It is usually measured with a Benkelman beam or by a plate test under a reference load (13 tons for the French sizing method). The pavement design guide for tropical countries defines the maximum permissible values of deflections on the wearing courses of road structures according to the traffic classes. These values are defined at the end of the first rainy season following the commissioning of the roadway. Other limits are fixed at the execution for the different layers to ensure compliance with the deflection on the wearing course.

For sizing, we will take as admissible values those proposed by the CEBTP.

Table 4 : Admissible deflections (CEBTP, 1984)

Classes of traffic	Maximum admissible deflections (in 1/100 mm)
T1	125
T2	90
T3	65
T4	40
T5	35

4) Verifications

Verifications are made after the determination of the deformations from the Alizé software in our case Alizé 1.3. The criteria listed here are common to the different structures.

a) Ground support

For the different road structures, it will be verified that the rutting of the supporting soil remains below the value held for permissible. In the absence of other data, we will carry out this verification by retaining a criterion on the vertical deformation ε_z of shape $\varepsilon_{z,ad} = f(NE)$. The equivalent number of axles (EN) is calculated by applying the values of the average aggressiveness coefficient of the CAM traffic.

b) Layers of granular seat

In the case of low traffic pavements (cumulative traffic of less than 250 000 standard axles), composed of a thin surface course on an untreated granular bed, no calculation criterion is applied to the road material seated.

It is by the choice of the characteristics of the material that one empirically ensures of an acceptable behavior of the untreated gravel with respect to the rutting. In other cases: asphalt pavement on untreated gravel foundation, reverse structure ..., the check against rutting is also done at the top of the untreated granular layer according to criteria of the same type as those used for the support floor.

B. Presentation of Alizé-LCPC software

The software Alizé 1.3 implements the French method of pavement design. The Alizé calculation module makes it possible to determine the stresses created by the traffic in the different layers of materials constituting the body of the road structure. It implements the BURMISTER model which relies on the mechanical modeling of the structure by a semi-infinite mass, consisting of a superposition of layers of materials of constant thickness, with isotropic linear elastic behavior. The descriptive parameters of the mechanical behavior of each material are thus two in number: the Young's modulus E and the Poisson's ratio v.

Each interface between adjacent layers can be glued, slippery or semi-glued. In common sizing operations, a single load, referred to as a reference load, is typically applied to the surface of the model.

The computational model gives access, potentially, to the complete tensors of stresses and deformations, as well as to the three components of displacement, at any point of the structure. In practical terms, only the maximum loads calculated at the base of each layer are retained. The maximum stresses to retain depend on the material constituting the layer.

Table 5 : Nature of maximum solicitation to remember

Materials	Solicitations
Hydrocarbon materials	$\varepsilon_{t,max}$
Concrete and materials treated with hydraulic binders	$\sigma_{t,max}$
Soils and untreated materials	$\varepsilon_{z,max}$

III. PERFORMED SIMULATIONS

A. Structure considered for simulation and simulation principle

1) Structure considered for simulation

The most used materials in road construction in Cameroon are:

- ✓ The Lateritic Gravel in subgrade ;
- ✓ The Crushed Gravel in base course ;
- ✓ Two-layer coating, three-layer coating or dense asphalt coating for traffic T1 and T2 and bituminous concrete for traffic T2, T3 and possibly the traffics T4 and T5.

This justifies the use of these materials for simulation. In addition, the specification of the markets very often requires the creation of a platform of class S3 or higher so that heavy equipment can circulate, however the class S5 corresponds to materials insensitive to water, sand and gravel own, materials rocky saints, etc .; old pavements. It is therefore very little encountered. We will use for this purpose the S3 and S4 class platforms for our simulations.

2) Simulation principle

a) Choice of traffic class

We will take into account the different classes of traffic proposed by the CEBTP in the Practical Guide for the Sizing of Pavements for the Tropics. [Table 1]

b) Choice of Basic Thickness Set

The choice of thicknesses will also be based on the Practical Guide for Pavement Sizing for the Tropics, but for the lower limit. [Table 8] shows, for example, the thickness set for the T1 traffic class and the S3 platform where the materials are already fixed with their different characteristics.

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c) Determination of parameters

The parameters to be determined corresponding to each class of traffic are the data concerning the materials (their characteristics, their implementation ....). Their determination is made thanks to the information generated from the French method of pavement design. They are presented as follows:

Table 6: Parameters obtained thanks to the characteristics of the materials

Parameters	Symbols	Values
Slope	b	-0,2
Standard deviation	SN	0,25
E(26°C,10Hz) (Mpa)	2000	2000
E(10°C,10Hz)	7200	7200
Risk	r(%)	5%
VCR	u	-1,645
Sh(cm)	Sh(cm)	1
Calibration coef	k_c	1,1
Coefficient related to lift	k_s	1
c(cm^{-1})	0,02	0,02
Standard deviation of logN	□	0,25
Risk coefficient	k_r	0,827
Agressivity	A	12000

d) Principle

For each class of traffic, we dimension a roadway for its lower bound. Then the thicknesses of the wearing courses and base will be fixed, we will then vary (increase) the thickness of the foundation layer. The deformations will be recorded and compared to the admissible values calculated in a table according to the traffic; which will enable us to find the traffic corresponding to the dimensioning. However, the deflections must remain within the allowable limits because they remain the only verification parameter on our sites.

It is therefore important to show its variation depending on the thickness of the roadway.

B. Results of the simulation

The objective of the simulations is to plot traffic curves according to the permissible tangential deformation on the one hand and the traffic as a function of the vertical deformation on the other hand. From the Microsoft Office Excel software, we will be able to determine trend curves from previous curves in order to approximate the values of admissible deformations by taking into account the real traffic.

We recall that we have used certain materials of Cameroonian geotechnics whose characteristics are recorded in the following table:

Table 7 : Mechanical characteristics of the materials used

Layers	Type of materials	Module (MPa)	Poisson's ratio
Platform (CEBTP)	S3	75	0,35
	S4	150	0,35
Subgrade (E=10CBR$_{min}$)	Lateritic Gravel	300	0,35
Base course (E=10CBR$_{min}$)	Lateritic Gravel	400	0,4 [2]
	Crushed Gravel	500(CEBTP)	0,4
Surface course	Bituminous Conrete Superficial Coating	2000 [1]	0,4 [3]

1) Simulations for traffic T1

Table 8: Initial characteristics of the road layers - Couple (T1; S3)

Interface	Layers	e (cm)	E(MPa)	u
Bonded	SC	3	2000	0,40
Bonded	CG	13	500	0,40
Bonded	NLG	15	300	0,35
	PF S3	Infinity	75	0,35

Table 9 : Simulation results for the couple (T1; S3)

Parameters	Symb.	Values				
Traffic (in Millions)	**Ti**	**0,10**	**0,15**	**0,20**	**0,25**	**0,30**
Thickness (in cm)	**eB**	13	13	13	13	13
	eF	15	16	17	18	19
□$_t$(□ def)	□$_{tad}$	**311,20**	**286,96**	**270,92**	**259,09**	**249,81**
	□$_{tSC}$	-40,80	-41,50	-42,30	-43,10	-43,80
□$_z$(□ def)	□$_{zad}$	**1242,00**	**1135,08**	**1064,86**	**1013,39**	**973,19**
	e_{zCG}	691,70	687,50	683,90	680,70	677,90
	e_{zNLG}	580,90	557,80	540,80	525,80	511,20
	e_{zPF}	1074,40	1039,10	1007,90	977,80	948,60
Deflections (1/100 mm)		**78,8**	**77,7**	**76,6**	**75,6**	**74,6**

Parameters	Symb.	Values				
Traffic (in Millions)	**Ti**	**0,30**	**0,35**	**0,40**	**0,45**	**0,50**
Tchikness (in cm)	**eB**	13	13	13	13	13
	eF	19	20	21	22	23
□$_t$(□ def)	□$_{tad}$	**249,81**	**242,23**	**235,85**	**230,36**	**225,55**
	□$_{tSC}$	-43,80	-44,60	-45,40	-46,20	-47,00
□$_z$(□ def)	□$_{zad}$	**973,19**	**940,45**	**912,98**	**889,42**	**868,86**
	e_{zCG}	677,90	675,40	673,20	671,30	669,60
	e_{zNLG}	511,20	496,90	483,10	469,60	456,50
	e_{zPF}	948,60	920,40	893,10	866,80	841,40
Deflections (1/100 mm)		**74,6**	**73,6**	**72,7**	**71,9**	**71**

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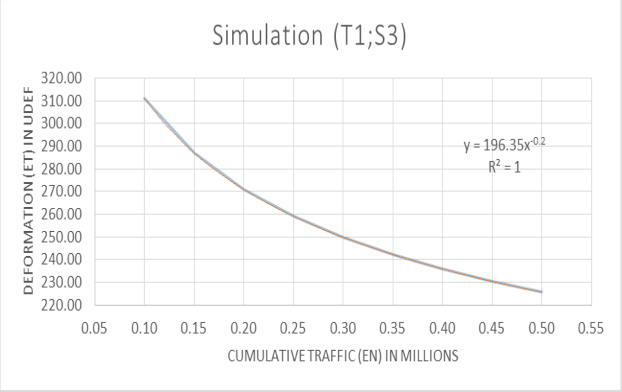

Fig 3 : Traffic curve (NE) as a function of tangential deformation ($\varepsilon_{t,ad}$) for the couple (T1; S3)

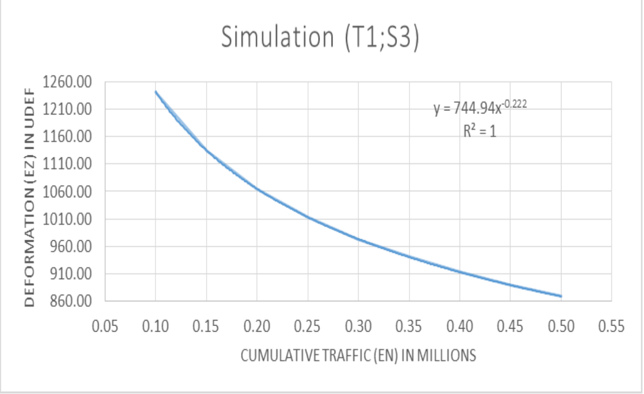

Fig 4 : Traffic curbe (NE) as a function of vertical deformation ($\varepsilon_{z,ad}$) for the couple (T1; S3)

2) Simulations for traffic T2

Interface	Layers	e (cm)	E(MPa)	u
Bonded	SC	4	2000	0,40
Bonded	CG	17	500	0,40
Bonded	NLG	17	300	0,35
	PF S3	Infinity	75	0,35

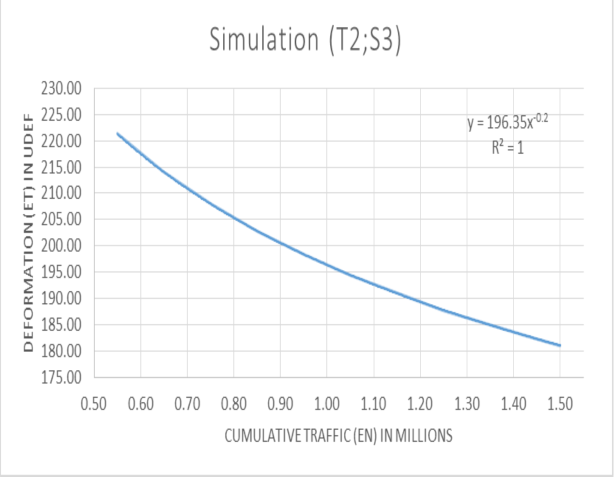

Fig 5 : Traffic curve (EN) as function of tangential deformation ($\varepsilon_{t,ad}$) for the couple (T2; S3)

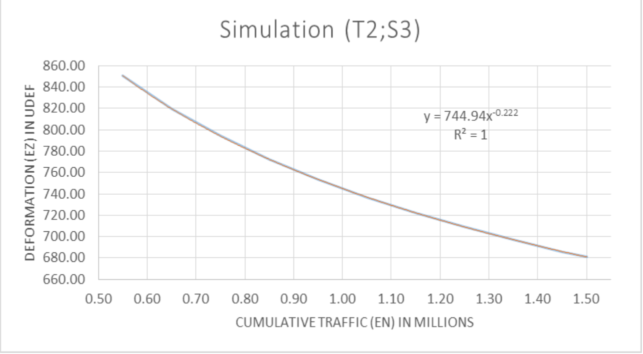

Fig 6 : Traffic curve (EN) as function of vertical deformation ($\varepsilon_{z,ad}$) for the couple (T2; S3)

3) Simulations for traffic T3

Interface	Layers	e (cm)	E(MPa)	u
Bonded	BB	5	2000	0,40
Bonded	CG	20	500	0,40
Bonded	NLG	20	300	0,35
	PF S3	Infinity	75	0,35

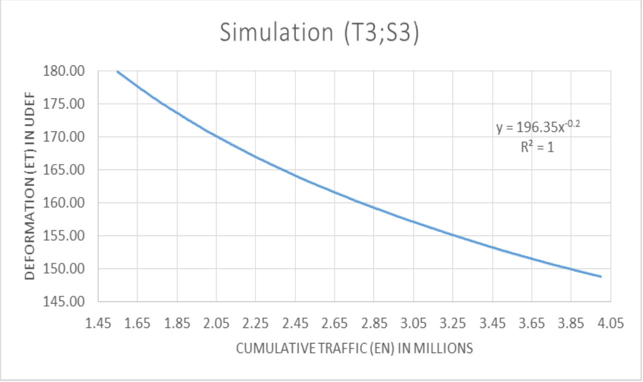

Fig 7 : Traffic curve (EN) as function of tangential deformation ($\varepsilon_{t,ad}$) for the couple (T3; S3)

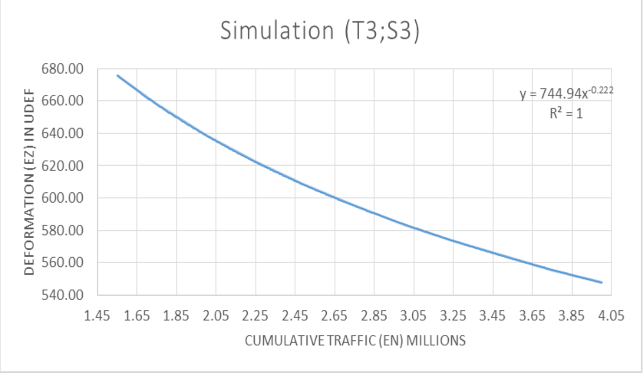

Fig 8 : Traffic curve (EN) as function of vertical deformation ($\varepsilon_{z,ad}$) for the couple (T3; S3)

4) Simulations for traffic T4

Interface	Layers	e (cm)	E(MPa)	u
Bonded	BB	7	2000	0,40
Bonded	CG	27	500	0,40
Bonded	NLG	13	300	0,35
	PF S4	Infinity	150	0,35

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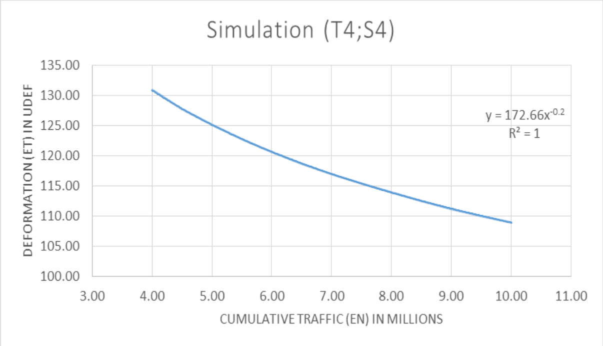

Fig 9 : Traffic curve (EN) as function of tangential deformation ($\varepsilon_{t,ad}$) for the couple (T4; S4)

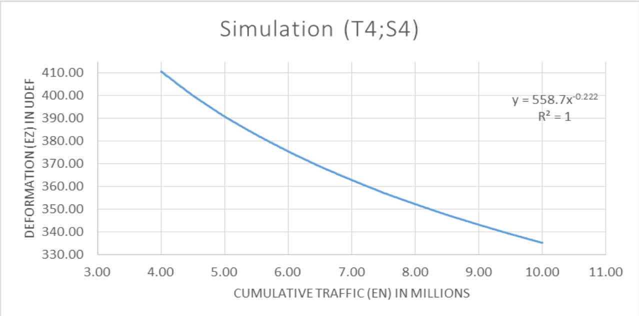

Fig 10 : Traffic curve (EN) as function of vertical deformation ($\varepsilon_{z,ad}$) for the couple (T4; S4)

5) Simulations for traffic T5

Interface	Layers	e (cm)	E(MPa)	□
Bonded	BB	7	2000	0,40
Bonded	CeG	25	800	0,40
Bonded	NLG	18	300	0,35
	PF S4	Infinity	150	0,35

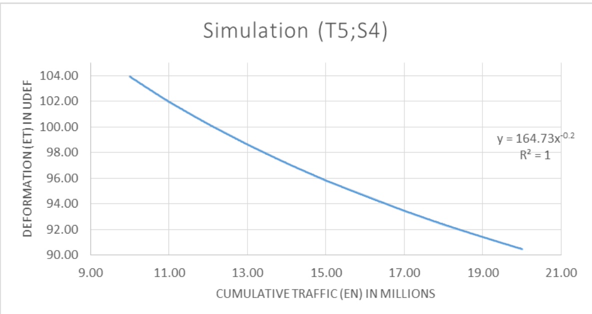

Fig 11 : Traffic curve (EN) as function of tangential deformation ($\varepsilon_{t,ad}$) for the couple (T5 ; S4)

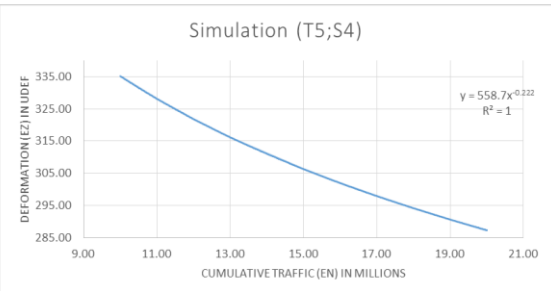

Fig 12 : Traffic curve (EN) as function of vertical deformation ($\varepsilon_{z,ad}$) for the couple (T5; S4)

IV. CONCLUSION AND COMMENTARY

In view of the different simulations made, it appears that the taking into account of the real traffic is very important in the design of the pavements, the deflections remaining admissible, we showed by these simulations the gain of material which one could realize by taking into account counts the actual traffic for the verification of the criteria of damage of the materials. Also, having the deformations admissible for all the classes of traffic and for each traffic, the step 3 of the French method of dimensioning of pavements which is "the verification in fatigue of the structure and the deformation of the support" proves to be this obvious fact.

The platform is the element whose criterion of damage is the most unfavorable, but this is not always the case in general. For example, when the module of the platform is close to that of the foundation layer, the platform, infinite, deforms little, there is no transmission of the deformations of the foundation to the platform where a significant deformation of the foundation layer which crosses even with its thickness, this is the reason why the CEBTP (CEBTP, 1975) proposes bilayer structures from the platform S4 for the classes of traffic T1, T2 and T3 but for the other classes especially T4 and T5, the need to achieve three-layer structures is still needed.

Deflection appears here as a non-determining criterion for the design of the roadway with regard to class T1, T2 and T3 traffic. On the other hand, it remains a very determining parameter for the T4 and T5 class traffics.

These simulations also show the existence of correlations between the actual traffic and the thicknesses of the pavement layers.

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