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CORRELATION BETWEEN ELASTIC PARAMETERS AND THE CBR INDEX: APPLICATION IN FOKAMEZO LATERITIC SOILS – EVALUATION METRICS

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ABSTRACT

This study consisted of the characterisation of the lateritic gravels of Fokamezo in the southern slope of Bambouto's Mountains with the aim to propose correlation models between the CBR and the moduli of elasticity in the optimization of pavement design. Geotechnical laboratory identification tests were carried out on four samples taken from the study area. The results obtained show that the material studied has a specific density of 2.6 t/m^3. The average dry density at the Proctor optimum obtained is 1.706 t/m^3 for an optimum water content of 15.9%. With an average CBR of 59.9, this material belongs to the bearing capacity class S5. The average Young's modulus of 221.562 MPA obtained by punching, an average Young's modulus of 29.7019 MPa obtained by compression and an average Poisson's ratio of 0.381 were recorded for this material. A polynomial correlation of CBR values and moduli of elasticity is proposed: $E = 0.8676(CBR)^2 – 85.529(CBR) + 2231$, with R^2 =0.99; E in MPa), and $\nu = 0,0152(CBR)^2 - 1,7659(CBR) + 51,22$; with R^2 = 0,99). The E=f(CBR) models are efficient with the NS criteria of 0.9 while the =f(CBR) models are exact and fair with the MAE, MSE, RMSE and RMSLE values close to 0. This soil can be used as a sub-base and base layers material for all types of traffic.

KEYWORDS: *CBR, Young's modulus, Poisson's ratio, Lateritic gravel, Pavement.*

1. INTRODUCTION

In African countries and even throughout the world, pavement sizing is a major concern, both for the scientific and technical world and for land development policies. The characterization of the behaviour of infrastructure soils is very important for sizing and longevity of a pavement structure. The function of a road pavement structure is to withstand various stresses, in particular those due to heavy traffic, and to ensure the distribution of forces induced by this same traffic in the infrastructure soil. The sizing parameters are the value of the index bearing CBR and the Traffic. Construction materials are characterized by their elastic parameters, including Young's modulus and Poisson's ratio, which are very important in terms of structural verification.

In fact, from the perspective of the evolution towards economic development of nations, the road is directly involved in all stages of economic development. However, despite the huge road investments made, there is a quick deterioration of the barely completed road infrastructure in the sub-region and even in several other countries around the world. The design phase of a road project (Missions G1, G2 and G3 of standard XP P94-010, 1996) consumes a great deal of geotechnical testing, specifically compaction and deformation tests. It should be the same for stress-strain tests, but they are quite expensive and take more time to perform, sometimes requiring empirical formulas for determining some technical parameters. This can be noted in the work of many authors such as Cao and Law, 1992; White et al., 2007, Cerni et al., 2012 in the study of reversible modules.

Permanent deformation accumulates with each loading cycle for all layers of the pavement system, which can eventually lead to structural rutting of the pavement (Mbayang, 2020). In conventional pavement analysis and design approaches, it is generally considered that most of the rutting is attributable to the subgrade, especially when it is made of thin material of low stiffness (Sun et al., 2015). This is the case of lateritic soils used in tropical countries in the construction of pavement layers. The dimensioning of pavement structures being conditioned by the control of some parameters such as the deformations and the stresses of the materials of the different layers of pavements in tension and in compression, there are not yet certified average values of the elastic parameters of the different materials. Premises used in pavement layers, even less a standard correlation established between these constants and the heights of the different layers to be implemented in the pavement structures. This results in the use of values from materials studied elsewhere. This sometimes results in a poor design materialized either by under-sizing or over- sizing. In addition, faced with geotechnical characteristics variability of lateritic materials, the concern also lies in establishing correlations between the mechanical properties mainly conditioning their use in pavement layers, in order to simplify road design and simultaneously ensure structures sustainability.

The main objective of this work is to offer a correlation between the index carrying CBR and the Young's modulus and the Poisson's ratio from the mechanical characteristics of the lateritic soils of Fokamezo- Doumetsa in order to optimize in quality and in cost the pavement sizing and design. To do this, it will be about making a geotechnical and mechanical identification of the lateritic soils of the study environment, subsequently classifying them and finally making a correlation between the parameters.

2. MATERIALS AND METHODS

2.1. Location of the study area

The study area chosen is Fokamezo. Administratively, it is a village in West Cameroon belonging to the Bafou group, located in the Menoua Department and the Nkong-ni district (Fig.1). Geographically, it lies between latitudes N 05° 24'17" and N 05°32' and longitudes E 10° 07' and E 10°10'30".

2.2. Field study method

After tracking the lateritic loan studied, 4 sampling points were set up (Table 1), two at the bottom of the slope, one halfway down the slope and one at the top of the loan. Wells with an average depth of 1.20 m were then dug at each of these points. These pits allowed a description of the soil profile in place to be made, a description based both on direct observation and by touching the constituent material of each horizon. Reworked samples were taken from each of these pits. The operation consisted of extracting a representative quantity of the material in place from the gravelly horizon of each pit. For this purpose, approximately 70 x 4 kg of material was taken per sample for identification tests. These four samples were coded E1, E2, E3 and E4.

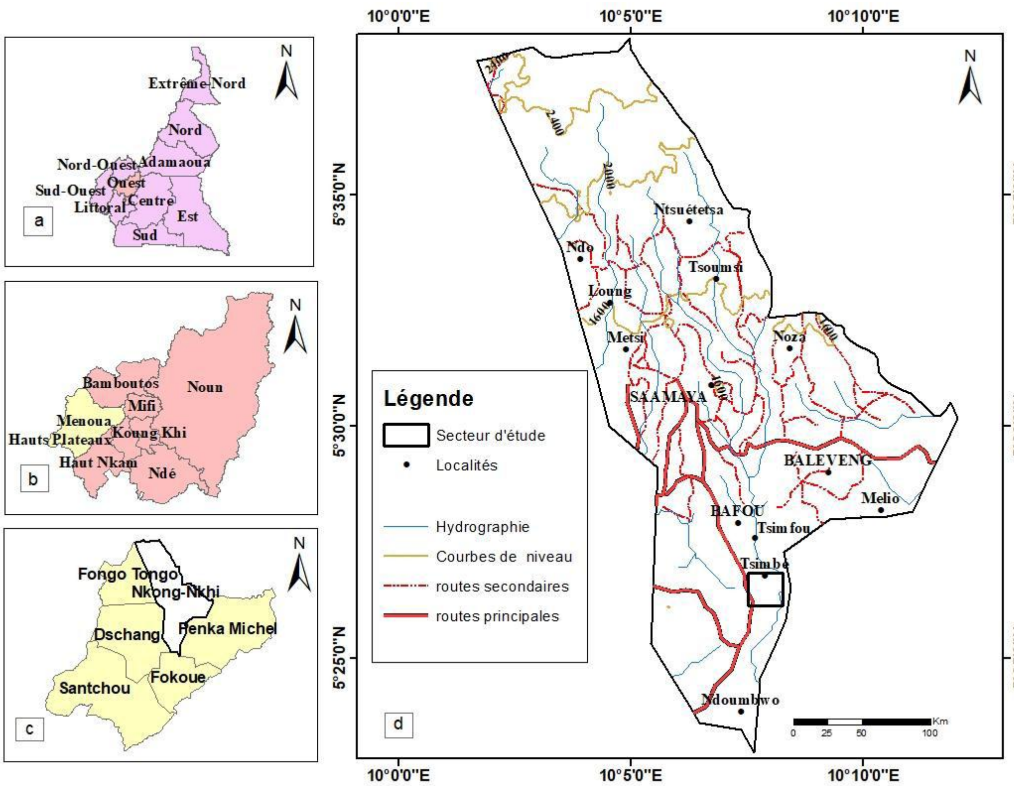

Figure 1: Location map of the study area.

(a) Location of the Western Region in Cameroon;

(b) Location of the Menoua Department in the Western Region;

(c) Location of the Nkong-ni District in the Menoua Department;

(d) Location of the study area in the Nkong-ni District, map extracted from the topographic base NB32_XV1_3b.

Table 1: Coordinates of the sampling points.

Sampling point	Sample code	GPS coordinates (utm) 32		
		X	Y	Z (m) 33
1	E1	0625194	0601763	1530
2	E2	0625380	0501741	1510 34
3	E3	0625218	0601711	1540
4	E4	0625373	0601611	1556 35

2.3. Laboratory work

The work carried out in the laboratory consisted of doing several tests aimed at determining the geotechnical characteristics of the site materials. To this end, several tests will be carried out, particularly those done to determine the physical parameters (natural water content, Atterberg limits, particle size analysis, specific density), tests to determine the compaction parameters (modified Proctor test, CBR test) and tests to determine the elasticity parameters

(CBR punching and uniaxial compression).

II.4 Establishing correlations between CBR index and elasticity parameters

Young's modulus and Poisson's ratio are parameters which are used in pavement design because their values have a direct impact on the pavement layers thickness to be laid. To this end, two correlations have been established, one between the CBR index and the Young's modulus (E), the other between the CBR index and the Poisson's ratio (ν). The purpose of these correlations is to find a relationship that will allow the value of one of these parameters to be determined in relation to the other. For the establishment of the correlations between these different parameters, the mathematical model by linear regression was chosen.

3. RESULTS

3.1. Physical properties

3.1.1. Specific gravity

The specific gravity test was used to determine the actual density of the samples analysed. Overall, the specific gravity values ranged from 2.532 t/m^3 (E1) to 2.745 t/m^3 (E4) with an average of 2.6 t/m^3. Samples E2 and E3 recorded values of 2.541 t/m^3 and 2.604 t/m^3 respectively (Table 3).

3.1.2. Particle size analysis

The particle size analysis test carried out on each of the four samples taken made it possible to establish the particle size curves in figure 2. The distribution of the different granular fractions identified is recorded (Table 2) and it can be seen that the maximum percentage of sieves is recorded for the gravel class. This percentage ranges from 46.3 for sample E2 to 65.4 for sample E4. This maximum percentage is preceded by that of the fine soils, with percentages ranging from 15.5 for sample E3 to 31.1 for sample E2.

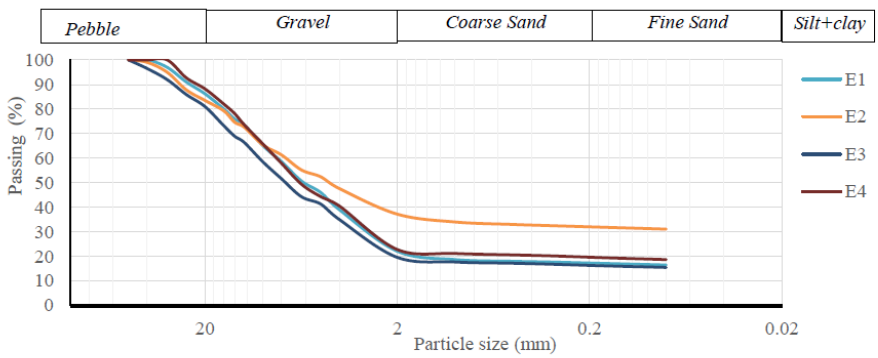

Figure 2: Cumulative sizing curves.

Table 2: Granular proportions of analysed samples.

Samples	E1	E2	E3	E4	Average
Pebble (%)	13.8	16.5	18	11,8	15,02
Gravel (%)	64,1	46,3	62,4	65,4	59,55
Sand (%)	5,6	6,1	4,1	4,1	4,98
Silt+clay (%)	16,5	31,1	15,5	18,7	20,45

3.1.3. Atterberg limits

The liquidity limit values obtained vary from 60.1% (E4) to 65.6% (E2) with an average of 61.6%. Samples E1 and E3 show a value of 60.3% (Tab 3).

The plasticity limit values range from 30.3% (E1) to 33.3% (E2). The average obtained is 31.4%. Samples E3 and E4 have values of 30.7% and 31.2% respectively. The plasticity index values are between 28.9% (E4) and 32.3% (E2) with an average of 30.2%. For samples E3 and E1, 29.6% and 30% respectively are obtained. The samples analysed have consistency index values between 1.25 (E1) and 1.527 (E2). The average consistency index is 1.41. Samples E3 and E4 have a value of 1.41.

Table 3: Summary of results for moisture content, density and Atterberg limits.

Samples / Parameters	E1	E2	E3	E4	Average	Max.	Min.
W (%)	22,75	16,26	18,4	19,3	19,17	22,75	16,26
d (t/m^3)	2,532	2,541	2,604	2,745	2,6	2,745	2,532
WL (%)	60,3	65,6	60,3	60,1	61,6	65,6	60,1
WP (%)	30,3	33,3	30,7	31,2	31,4	33,3	30,3
IP (%)	30	32,3	29,6	28,9	30,2	32,3	28,9
IC	1,25	1,527	1,415	1,41	1,41	1,527	1,25

3.2. Mechanical properties

3.2.1. Modified Proctor and CBR

At the end of the Modified Proctor test, dry density values vary slightly from one sample to another, ranging from 1.69 t/m^3 (E4) with a water content of 15.3% to 1.721 t/m^3 (E2) with a water content of 16.8%. The average dry density was 1.706 t/m^3 with an average moisture content of 15.9%. The CBR test determined CBR values ranging from 52.9% (E3) to 63.7% (E2). Sample E1 had a CBR value of 59.9%, while sample E4 had a value of 63%. The average CBR value for all samples is 59.9% (Tab 4).

Table 4: Summary of mechanical parameters.

Parameters	Modified Proctor		CBR (%)	E (by punching) in MPA	E (by compression) in MPA	Poisson's ratio (Compression)
Samples	γ_{dopm} (t/m^3)	w_{opm} (%)				
E1	1,712	16,6	59,9	221,56	29.16	0,435
E2	1,721	16,8	63,7	305,81	30,83	0,353
E3	1,702	14,8	52,9	134,18	26,93	0,309
E4	1,690	15,3	63	282,41	31,87	0,429
Average	1,706	15,9	59,9	235,99	29,70	0,381
Maximum	1,721	16,8	63,7	305,81	31,87	0,435
Minimum	1,690	14,8	52,9	134,18	26,93	0,309

3.2.2. Young's modulus

The Young's modulus values obtained by punching vary considerably (Fig 3 and Tab 4), ranging from 134.18 MPA (E3) to 305.81 MPA (E2). Samples E1 and E4 recorded values of 221.56 MPA and 282.41 MPA respectively. The overall average is 235.99 MPA. On the other hand, there is less variation between the Young's modulus values obtained by uniaxial compression (Fig 3 and, Tab 4), ranging from 26.93 MPa (E3) to 31.87 MPa (E4). Samples E1 and E2 recorded 29.16 MPa and 30.83 MPa respectively, giving an average of 29.70 MPa.

3.2.3. Poisson's ratio

The values of the Poisson's ratio vary significantly. However, the averages of these results give values ranging from 0.309 (E3) to 0.435 (E1). All the values obtained add up to an average of 0.381 (Fig 5 and Tab 4).

3.3. Correlations: CBR index - Young's modulus, CBR index - Poisson's ratio

3.3.1. CBR index - Young's modulus correlation

The scatter diagram (Fig 4) analysis derived from the projection of CBR indices and Young's modulus corresponding to each sample led to the drawing of the straight line of equation $y = 15.358x - 683.59$ translating the equation $E = 15.358CBR - 683.59$, with the correlation coefficient is 0.9788. It give also $y = 0.8676x^2 - 85.529x + 2231$; which means $E = 0.8676(CBR)^2 - 85.529(CBR) + 2231$, with $R^2 = 0.9988$ and E is expressed in MPA.

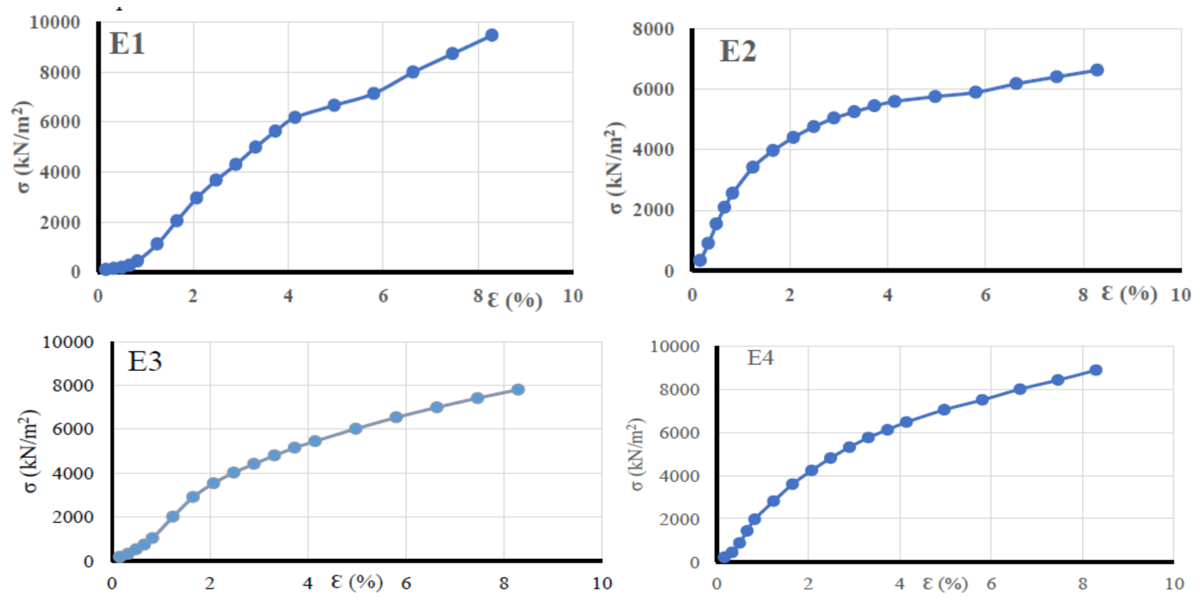

Figure 3: Stress-strain curves obtained by punching.

3.3.2. Correlation of CBR index and Poisson's ratio

The CBR index and Poisson's ratio values obtained from the samples analysed allowed to establish the correlation shown in figure 4, which presents the Poisson's ratio curve as a function of the CBR index. The scatter diagram analysis derived from the projection of the CBR indices and the Poisson coefficient corresponding to each sample led to the drawing of the straight line of equation y = 0,0023x + 0,1371 translating the equation ν = 0,0023(CBR) + 0,1371, with R^2 = 0,0035; it give also y = 0,0152x^2 - 1,7659x + 51,22 which means ν = 0,0152$(CBR)^2$ - 1,7659(CBR) + 51,22 with R^2 = 0,9991.

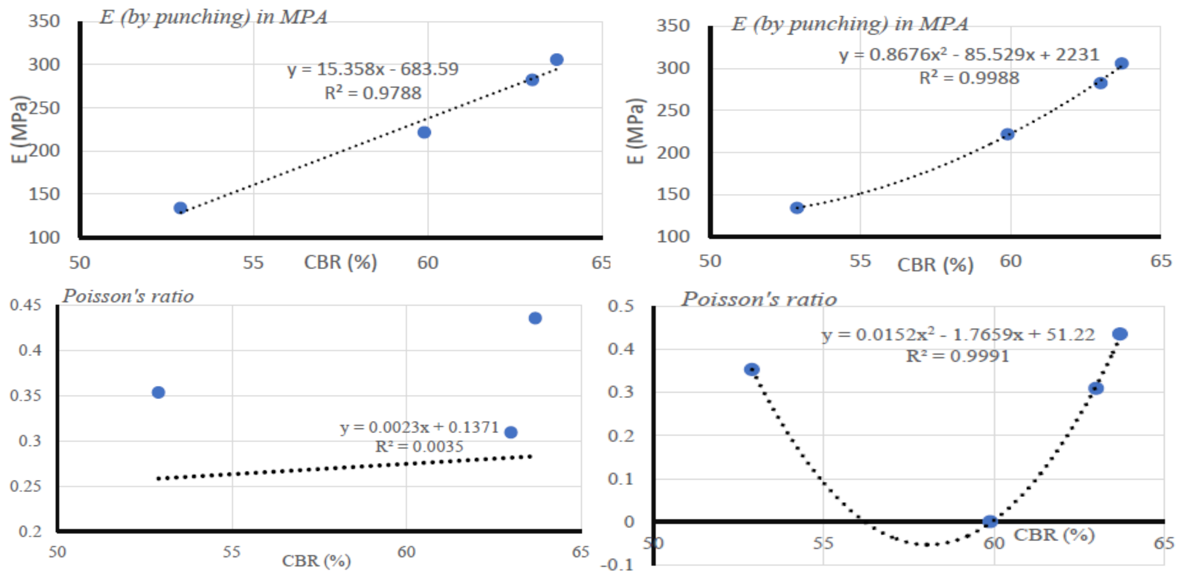

Figure 41: Correlation (linear and polynomial) line between CBR and elastic parameters (by punching and by compression)

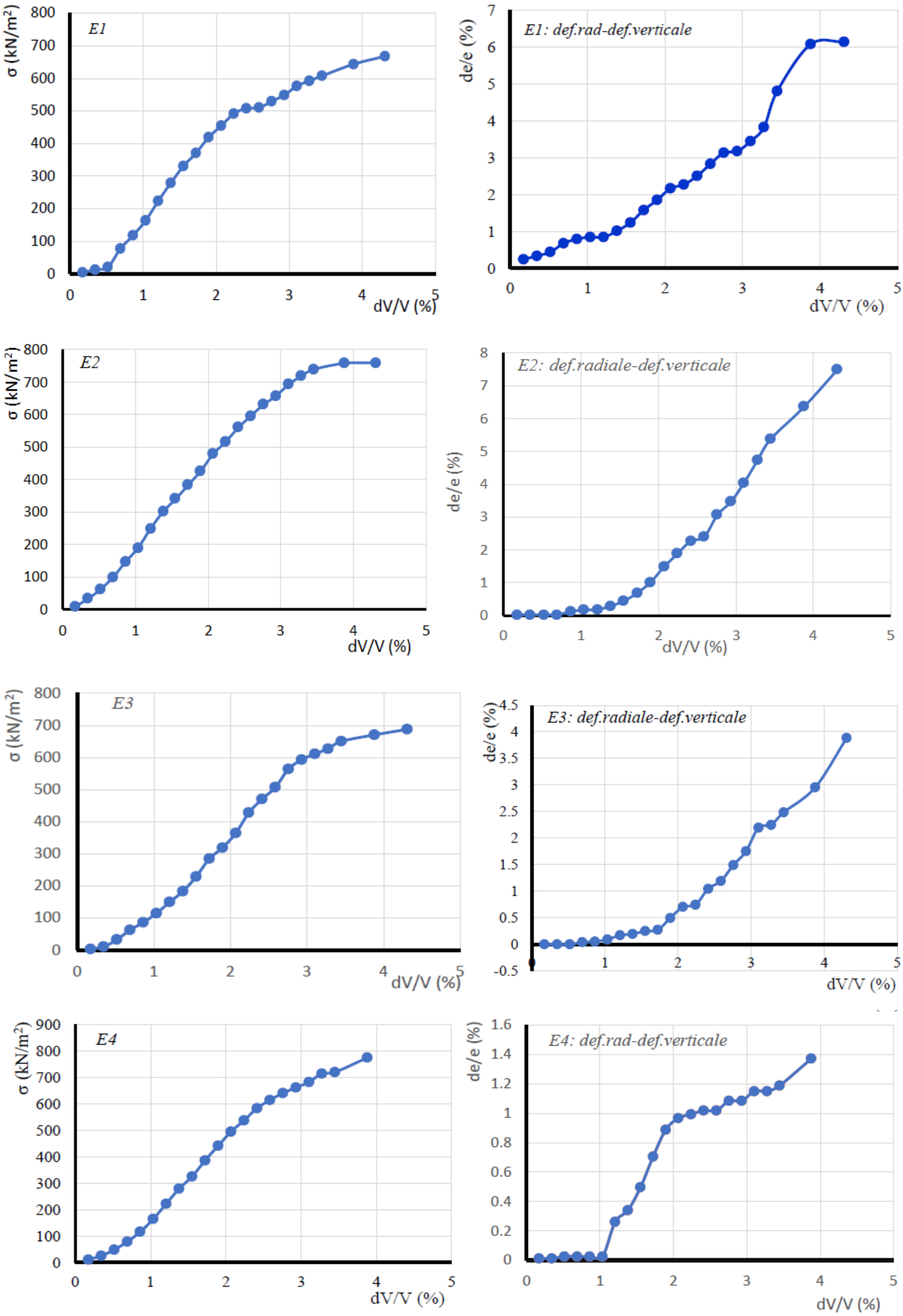

Figure 5: Stress - radial and volumetric strain curves.

4. Discussion and interpretation

4.1. Classification

The data obtained from the particle size analysis and the Atterberg limit tests allowed to classify the samples analysed in subclass A-2-7 of the HRB classification system (Tab 5). This subclass is characteristic of soils with a maximum percentage of passings through the 80µm sieve of 40 and a minimum plasticity index of 10%. It therefore refers to silty or clayey gravels and sands, which are generally considered as medium to poor quality materials for pavement subgrade. On the other hand, the GTR classification places the material studied in class B, characterised a maximum grain diameter ≤ 50 mm and a percentage of 80 µm sieve passings ≤ 35%. Since the four samples analysed are characterized by CBR values all above 30, they all belong to bearing capacity class S5. This confirms the research of Eyo and Abbey, 2021 on soil classification: “The need to appropriately classify soils, especially for geotechnics field practice, cannot be over-emphasised”. It should be noted that these soils could have CBR indices above 80% if they had been treated as in the case of clayey soils stabilized by volcanic ash from Rabaul in East New Britain Province and Finschaffen in Morobe Province of Papua New Guinea by Hossain et al in 2006.

Table 5: Classification of.

Samples	Classification		
	HRB	GTR	LPC
E1	A-2-7(14)	B6	GA
E2	A-2-7(2)	B6	GL
E3	A-2-7(14)	B6	GA
E4	A-2-7(15)	B6	GL

4.2. Elastic properties

4.2.1. Young's modulus

The Fokamezo lateritic gravel analysis led to an average Young's modulus of 235.995 MPa obtained from the punching test and an average Young's modulus of 29.719 MPa obtained from the uniaxial compression test were recorded, it is then outstanding that the difference between these two values is very significant.

However, the Young's modulus obtained from the punching test is the closest to the actual Young's modulus values of lateritic gravels generally used in road construction, values which are in the order of hundreds of megapascals. This is due to the fact that the conditions for determining Young's modulus by punching test are closer to real field conditions, unlike uniaxial compression test where the compressed sample is free of any horizontal stress. The average Young's modulus values obtained from the Fokamezo lateritic gravels are significantly higher than those determined by Donjo (15251.3 KN/m² or 15.251 MPA) in 2019 on the Ndziih lateritic gravels on a basaltic bedrock. They are also significantly higher than those obtained by Donwoung (8848.01 KN/m² or 8.84801 MPA) in 2019 on the lateritic gravels of Tsinfou developed on a basalt base. Indeed, the more rigid a material is, the higher its modulus of elasticity. Marcin and Marek, 2021 found a Young's modulus of 50 MPa for platform soils using the Random Finite Element Method (RFEM) proposed by Fenton and Griffiths (Griffiths and Fenton, 2001; Fenton and Griffiths, 2003).

4.2.2. Poisson's ratio

The approach used to determine the coefficient of Fokamezo lateritic gravels led to an average value of 0.381. Indeed, values of the Poisson's ratio of the materials are between 0 and 0.5. The value 0.5 characterises practically incompressible materials such as iron. Furthermore, the standard Poisson's ratio value used in pavement design for natural lateritic gravel is 0.35. However, although the Poisson's ratio data obtained is highly variable, an average of 0.381 is obtained. Marcin and Marek, 2021 found a Poisson's ratio of 0.25 for platform soils using the RFEM method.

4.3. Correlation between parameters

The correlation between the Young's modulus values of Fokamezo lateritic gravels and their CBR indices led to a correlation coefficient line of 0.9788 for linear curve and 0.9988 for polynear curve. With such a correlation coefficient (almost equal to 1), the relationship between the two parameters is said to be satisfactory. The resulting equation is E= 15.358CBR - 683.59 (E in MPA) or $E = 0.8676(CBR)^2 – 85.529(CBR) + 2231$. With a correlation coefficient of 0.93, Donjo, 2019 got the equation E= 819.19CBR - 12492 (with E in KN/m^2) after characterising the Ndziih lateritic gravels developed on basalt bedrock.

Manefouet et al, 2019 obtained a correlation coefficient of 0.90 for the equation E = 143.46(CBR) - 523.72 (E in KN/m^2) from the lateritic gravels of Tatching1 and Meyomakote. Hossain et al in 2006 find the relation CBR = 41.8460E + 1.3802 (R^2 = 0.9298) for clayey soils stabilized by volcanic ash from Rabaul in East New Britain Province and Finschaffen in Morobe Province of Papua New Guinea. Similar work has been done by Varghese et al, 2008 for subgrades of lateritic soils of the Dakshina Kannada district of India; evaluating techniques such as the California bearing ratio (CBR) test and the dynamic cone penetrometer (DCP) test, the use of non-destructive testing devices such as the portable falling weight deflectometers (PFWDs) were made. They have shown that Log (CBR) = 1.675 – 0,7852Log(DCPI), with R^2 = 0.82 and E_{pfwd} = 162.48DCPI$^{-0.6397}$ with R^2 = 0.73. The correlation between the Poisson's ratio values of the Fokamezo lateritic gravels and their CBR indices resulted in the equation ν = 0,0152(CBR)^2 - 1,7659(CBR) + 51,22 with a correlation coefficient of 0,9991.

4.4. Evaluation metrics for regression models

Table 6: Performance parameters: MAE, MSE, RMSE, RMSLE.

	E(MPa) = 15.358CBR - 683.59	**E(MPa) = 0.8676CBR^2 - 85.529CBR + 2231**	**= 0.0023CBR + 0.1371**	**= 0.0152CBR^2 - 1.7659CBR + 51.22**
MAE	8.194	2.690	0.107	0.168
MSE	93.205	9.390	0.014	0.057
RSME	9.654	3.064	0.117	0.239
RMSLE	0.018	0.005	0.038	0.086
NS	0.979	0.998	-3.880	-19.398

The evaluation metrics of the models was done and the results are shown in Table 6. the calculated parameters are: MAE (Mean Absolute Error), MSE (Mean Square Error Error), RMSE (Root Mean Square Error), RMSLE (Root Mean Square Log Error) and NS (Nash-Sutcliffe criterion). MSE is always positive and closer to 0, lower value is better. It is generally accepted that the NS criterion must be greater than 0.7 to be able to say that a model is satisfactory, i.e. that the model and the observed values are consistent.

Thus, the Young's modulus models are efficient (NS), i.e., are well consistent with reality, while the Poisson's ratio models are faithful (MAE) and exact (RMSE, MSE).

4.5. Value of studied lateritic soils in road construction

Soil classification is considered as one of the most fundamental steps in planning, design, development, and implementation of various infrastructural projects and related undertakings that have to do with static and dynamic interactions with the ground (Kaliakin, 2017). This is mainly because the results obtained from classifying soils could be used as valuable indices in determining mechanical properties, such as compressibility, permeability, shear strength, and swelling. (Eyo and Abbey, 2021). The quality of material used in pavement layers is a very important factor in their design, as it is closely linked to pavement sustainability. This section aims to situate Fokamezo lateritic soils according to required conditions for material use in road construction.

The lateritic gravels from the site studied have an average CBR value of 59.9%, a value well above 10, the required value for its use in subgrade by CEBTP (Tab 7). With a plasticity index relatively equal to 30 and a percentage of sieve passings of 0.08 mm lower than 35, the materials studied meet all the specific criteria for use in subgrade. They can therefore be used in subgrades for all types of traffic (T1, T2, T3, T4 and T5).

Table 7: CEBTP (1984) requirements for subgrades.

CBR (%)	YdOPM	IP (%)	Passing at 0.08 mm (%)
Average material characteristics			
59,9	1,706	30,2	20,45
a) Requirements for subgrades - CEBTP specifications (1984)			
≥ 10	-	≤ 30	≤ 35
b) Requirements for sub-bases - CEBTP specifications (1984)			
≥30	≥1,80	≤30	≤35
c) Requirements for base layers - CEBTP specifications (1984)			
≥ 80	≥ 2	≤ 15	≤ 20
d) Requirements for unpaved pavement layers - CEBTP specifications (1984)			
≥ 30	-	15≤ IP ≤30	≤ 32

Although the dry density at the Proctor optimum obtained on the material studied is slightly lower than that required, with regard to the CBR value obtained from the material studied (a value significantly higher than required), the lateritic gravels of the site can nevertheless be used in sub-base layers because their plasticity index and percentage of passes through the sieve of 0.08 mm verify the CEBTP specifications (Tab 7). This material can therefore be used in sub-bases for all types of traffic.

For base layer, according to the CEBTP 1984 specifications (Tab 7), only the percentage of sieve passings of 0.08 mm meets the requirements. The values of plasticity index, dry density at the Proctor optimum and CBR index differ substantially from those required for use in a base layer. However, according to the classification table of CBR indices according to traffic classes, Fokamezo lateritic gravels can only be used as a base layer for T1 traffic because their average CBR index is almost equal to the minimum value required, i.e. 60%.

Lateritic gravel studied can be used as a material for making unpaved pavements because the parameters CBR index, plasticity index and percentage passing the 0.08 mm sieve meet the CEBTP specifications.

5. CONCLUSION

The main objective of this work was to find a relation between the moduli of elasticity and the CBR in the laterites, particular case of the lateritic soils of Fokamezo. The identification studies allowed to classify these soils as being a mixture of silty gravels or clayey and silty sands or clay (class HRB A-2-7). The results obtained show a positive and strong linear and polynomial correlations with Young's modulus (–, with a correlation coefficient of 0.97; $E = 0.8676(CBR)^2 - 85.529(CBR) + 2231$, with a correlation coefficient of 0.99; E in MPa), but very weak linear correlation with Poisson's ratio (ν = 0,0023(CBR) + 0,1371 with a correlation coefficient of 0,0035), however a strong polynomial correlations with Poisson's ratio ($\nu = 0{,}0152(CBR)^2 - 1{,}7659(CBR) + 51{,}22$; with a correlation coefficient of 0,9991). Based on the results obtained, it definitively can noticed that Fokamezo lateritic gravel can be used as a pavement layer for unpaved roads. As far as paved roads are concerned, they can also be used as a sub-base and base layer for all types of traffic. However, it can only be used as a base layer for T1 traffic.

Nevertheless, this material can be used as a base layer for higher traffic levels if it is treated (improved) with lime or cement.

Furthermore, outlooks for this work will be to extend sampling to the entire locality in order to sharpen the results.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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