Model of the Evolution of the Modulus of Elasticity E, As A Function of the Bearing Capacity Index I_{CBR} of Gravelly Laterites. Case of the Banka Locality (Westcameroon)

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Abstract-- The objective of this study is to model the evolution of the values of the modulus of elasticity E as a function of the bearing capacity index I_{CBR} of Banka lateritic gravel, with the aim of reducing the cost and time of laboratory tests for the determination of the modulus of elasticity and the CBR index. Geotechnical identification tests were carried out on 18 laterite samples taken from the Banfeko, Bakoye and Ketcho sites in the Banka locality. I_{CBR} values ranged from 31 to 51.92 and E-modulus values ranged from 80 MPa to 165 MPa. The resulting model is polynomial for all sites of the form:

$E = a * I_{CBR}^5 + b * I_{CBR}^4 + c * I_{CBR}^3 + d * I_{CBR}^2 + e * I_{CBR} + f$
This model has the highest degree of interdependence of value 1.

Keywords-- lateritic gravel, model, modulus of elasticity E, bearing capacity index I_{CBR} , Banfeko, Bakoye, Ketcho.

I. INTRODUCTION

Lateritic soils are very popular materials in the road construction industry in tropical areas. In Cameroon, this abundant resource covers about 70% of the national territory [1]. The various identification and characterization tests commonly carried out in the laboratory on these materials include granulometric analysis, density, modified Proctor test, CBR test, Atterberg limits, compression test, etc. [2].

These tests are carried out in the context of major road projects, they are long and costly. In spite of the huge investments made, pavements deteriorate rapidly due either to poorly laid pavements, poor quality materials, or special local conditions, which in either case lead to over-consumption of laterites, which are a non-renewable resource. To characterize these materials, in most cases, the Proctor and CBR tests, which allow the determination of the bearing capacity index I_{CBR} , are easily accessible to the contractors, unlike the compression test used to determine the modulus of elasticity. This causes shortcomings in the knowledge of the properties of these materials. The objective of the present study is to establish a correlation model between the values of the modulus of elasticity E and the CBR bearing capacity indices of Banka lateritic gravel pits in order to facilitate the determination of the modulus of elasticity E knowing the CBR index (I_{CBR})

II. LOCATION AND SAMPLING

LOCATION

Administratively, the Banka district is located in the Department of Haut-Nkam, West Cameroon region. It covers an area of 203 km². Figure 1 shows the location of Banka and various sampling sites.

Figure 1: Location map of sites in the study area

Sampling Source : [3]

Sampling was carried out in several successive stages, in the different areas selected for the study:

- In situ, the extent of each loan was determined, using the double-step technique. Thus, the Banfeko loan covers nearly 30,000 m², the Bakoye loan covers about 28,700 m² and the Ketcho loan covers about 29,140 m². The different loans had identical mesh sizes of 100 m x 90 m.

- Then, 18 sampling points were determined at a rate of 06 points per loan. Using a conventional pickaxe, a shovel and polystyrene bags, representative samples were collected and labelled; overall, sampling was done in such a way that the soil obtained was a mixture in which blocks with a maximum diameter greater than 50 mm were discarded with reference to Ghogue's standard criteria [2]. Figure 1 shows precisely the sampling borrow sites.

**Table 1:
GPS coordinates of the central points of the sampling sites**

Sampling sites	N	E	Average altitude (m)	Number of samples
Banfeko	05.15955	10.22198	1315	6
Bakoye	05.16220	10.23300	1258	6
Ketcho	05.18620	10.20115	1282	6
Total				18

Source : [3]

III. EXPERIMENTAL METHODS

After the field sampling campaign, the analyses of the samples were carried out in the laboratory of “*Sol Solution Central Africa*” in Cameroon. Following the laboratory analyses, the results obtained were processed using Microsoft Word and Excel 2016 software. The various tests carried out in the laboratory are among others the modified Proctor test, the CBR test, the compression test.

The determination of the optimal moisture content and the maximum dry density of the soil was done by the Modified Proctor test. This test was carried out in accordance with NF P 94-093 [4]. The CBR bearing capacity and linear swelling were determined according to the requirements of NF P 94-078 [5].

The compression test was carried out on compacted samples in CBR moulds and under the same conditions as the CBR test. After four days of soaking, the mould was covered with a solid disc 15 cm in diameter and 3 mm thick when punched.

The graphical option of the spreadsheet on Microsoft Office Excel 2016, made it possible to obtain the point clouds corresponding to the couples modulus of elasticity E and CBR index (ICBR). Using the trend curves, adjustments were established for the various loans. The various fitting functions were obtained as well as the values of the correlation coefficients R. These are linear, polynomial, power, exponential and logarithmic fitting functions. The analysis of the correlation coefficients R of the different graphs made it possible to adopt the fitting function model that has the highest degree of interdependence R. The polynomial model was the best with $R = 1$.

IV. RESULTS AND DISCUSSION

Modified Proctor Test

Table 2 shows the different values of the modified Optimum Proctor (optimum water content and maximum dry density), the CBR index (ICBR) and the free swelling.

Table 2:
Modified Optimum Proctor, CBR Index (ICBR) and Free Swelling values.

Sites and averages	N° of the wells	Dephs (cm)	w_{OPM} (%)	$\rho_{d\max}$ (g / cm^3)	ICBR at 95%	Free swelling (%)
Banfeko	P1	133	13.4	1.957	60.04	0.323
	P2	128	11.3	2.001	36.38	0.611
	P3	131	12.2	1.955	48.73	0.218
	P4	129	13.3	2.014	25.07	0.454
	P5	130	14.0	2.038	49.90	0.197
	P6	129	14.2	1.902	35.70	0.213
average		130	13.6	1.978	42.64	0.337
Bakoye	P7	122	10.7	1.962	60.04	0.514
	P8	120	12.8	1.900	36.38	0.043
	P9	118	13.3	2.025	48.73	0.615
	P10	123	9.6	1.920	25.07	0.623
	P11	121	13.3	2.045	49.90	0.536
	P12	118	11.9	1.988	35.70	0.454
average		120	11.9	1.973	31.51	0.464
Ketcho	P13	131	9.7	2.071	55.18	0.346
	P14	130	14.8	1.845	62.07	0.142
	P15	127	14.3	2.100	49.65	0.187
	P16	133	10.8	1.889	47.81	0.340
	P17	130	13.2	2.204	50.01	0.298
	P18	129	13.8	2.134	46.77	0.119
average		130	12.7	2.041	51.92	0.239

Source : [3]

Table 2 shows that the optimal water contents vary from 11.3% to 14% with the exception of the P6 well, which has a value of 14.2 % for the Banfeko site. These optimal water contents range from 9.6 % to 13.3 %, with an arithmetic mean of 11.9 % for the Bakoye site, and from 9.7 % to 14.8 %, with an arithmetic mean of 12.7 % for the Ketcho site. These values are in the same proportions as those found by Takala [6] for the soils of Batoufam (13 %), by Ngo'o Zé [7] in the Akonolinga zone (11.5 % and 16 %), and by Nanga [8] in Ebolowa (9.8 % and 14.3 %). Maximum dry densities ranged from 1.902 g/cm³ to 2.038 g/cm³, with an arithmetic mean of 1.978 g/cm³ for the Banféko site. From 1.90 g/cm³ to 2.045 g/cm³ with an arithmetic mean of 1.973 g/cm³ for the Bakoye site and from 1.845 g/cm³ to 2.204 g/cm³ with an arithmetic mean of 2.041 g/cm³ for the Ketcho site. These values are higher than those found by Eyenga [9], (1.67 g/cm³) and lower than those found by Takala [6], (2.23 g/cm³) respectively at Sa'a and Batoufam. These values are in line with those recommended for the foundation layer, i.e. > 1.90 g/cm³ and do not seem to hold in the base layer because the required value is > 2 g/cm³.

CBR test and measurement of linear swelling

Table 2, presents the different values of the 95% CBR lift index (ICBR), as well as the results of the linear swelling.

The values in Table 2 show that the 95% CBR values range from 25.07 to 60.04, with an arithmetic mean of 42.64 for the Banfeko site. They are slightly scattered for the Bakoye site, and oscillate around the arithmetic mean value of 31.51.

For the Ketcho site, they vary between 46.77 and 62.07, with an arithmetic mean value of 51.92. The swelling results give mean values of 0.337%, 0.464% and 0.239% respectively for the Banfeko, Bakoye and Ketcho sites. The values of the bearing indices found are in agreement with those found by Nana and Takala [6] in the nodular level of the Melen alteration profile, i.e. between 47 and 49.4; but much lower than those found by Djuickouo [10] at Dschang, i.e. 98. . According to the CEBTP specifications [11], the lateritic soils of Banfeko, Bakoye and Ketcho belong to the S5 bearing capacity class (CBR >30). These values, coupled with linear swelling values of less than 1 %, indicate that these materials can be used as pavement subgrade soils without prior treatment. From this point of view, they can also be used to improve subgrade soils, and as a subgrade for all types of traffic from T1 to T5. Sikali et al. [1], working particularly on the soils of West Cameroon, point out that with a CBR of between 30 and 60, a lateritic material can be used as a sub-base layer for T1 to T3 traffic. Bagarre [12] also points out that gravel with a CBR of at least 30, after immersion for 4 days, can be used as a sub-base for traffic of less than 300 vehicles per day. For these authors, as for the CEBTP guide [11], these materials can be used directly in the foundation layer. However, their use in base courses requires an improvement of the bearing capacity, because the CEBTP [11], specifies that in this case 95% of the modified Optimum Proctor is required, a CBR of at least 80. Table 3 groups the values of the moduli of elasticity of the different samples as well as their arithmetic mean per site.

Table 3:
A summary of the elastic modulus results and their average per site.

Borrow sites	N° of the wells	Dephs (cm)	Modulus of elasticity E (MPa)	Averages (MPa)
Banfeko	P1	133	119	123.5
	P2	128	153	
	P3	131	80	
	P4	129	165	
	P5	130	140	
	P6	129	84	
Bakoye	P7	122	158	125
	P8	120	123	
	P9	118	153	
	P10	123	83	
	P11	121	135	
	P12	118	98	
Ketcho	P13	131	105	123
	P14	130	141	
	P15	127	165	
	P16	133	92	
	P17	130	118	
	P18	129	117	

The values in Table 3 show that for the Bakoye site, the moduli of elasticity vary from 80 MPa to 165 MPa. These values range from 83 MPa to 158 MPa, with an arithmetic mean of 125 MPa for the Bakoye site. They range from 92 MPa to 165 MPa, with an arithmetic mean of 123 MPa for the Kétcho site. These values show notable dispersions between them.

However, they are in agreement with those obtained by Ahlounessou [13] for lateritic soils at 0% cement dosage of PO, ZINARE, SAARA and DORI according to which the moduli of elasticity are respectively 205 MPa, 119 MPa, 15 MPa and 63 MPa. The same remark is made on the elasticity modulus values of GOUDIANE lateritic soils which vary between 67.7 MPa and 115.3 MPa at 0% cement.

On the other hand, they are much lower than 300 MPa and 500 MPa, reference values required by the Milfeuil programme described in the practical guide for pavement design [10] for tropical countries for the sub-base and base layers respectively.

Model of the evolution of the modulus of elasticity E as a function of the bearing capacity index ICBR

- Figure 2 shows the model obtained for Banfeko's lateritic loan. With equation:

$$E = -0.0034 \cdot I_{CBR}^5 + 0.7326 \cdot I_{CBR}^4 - 61.986 \cdot I_{CBR}^3 + 2569.1 \cdot I_{CBR}^2 - 52058 \cdot I_{CBR} + 411595$$

The correlation coefficient is $R = 1$.

Figure 3: Polynomial model of the Bakoye site

- Figure 4 shows the model obtained for the lateritic loan of Ketcho.

$$E = 0.010114 * I_{CBR}^5 - 6.3070277 * I_{CBR}^4 + 1556.708568 * I_{CBR}^3 - 190062.6316 * I_{CBR}^2 + 11481057.76307 * I_{CBR} - 274514731.5346717$$

The correlation coefficient is $R = 1$

Figure 4: Polynomial model of the Ketcho site

Table 4:

Summary of the results of the evolution of E according to the ICBR of the sites of Banfeko, Bakoye and Ketcho.

Banfeko site			
Type of equation	Equation	Value of R ²	Value of R
Polynomial	$E = -0.0034 \cdot I_{CBR}^5 + 0.7326 \cdot I_{CBR}^4 - 61.986 \cdot I_{CBR}^3 + 2569.1 \cdot I_{CBR}^2 - 52058 \cdot I_{CBR} + 411595$	1	1
Bakoye site			
Polynomial	$E = 0.8844 \cdot I_{CBR}^5 - 140.53 \cdot I_{CBR}^4 + 8917.3 \cdot I_{CBR}^3 - 282467 \cdot I_{CBR}^2 + 1613.715 \cdot I_{CBR} - 3289.9$	1	1
Ketcho site			
Polynomial	$E = 0.010114 \cdot I_{CBR}^5 - 6.3070277 \cdot I_{CBR}^4 + 1556.708568 \cdot I_{CBR}^3 - 190062.6316 \cdot I_{CBR}^2 + 11481057.76307 \cdot I_{CBR} - 274514731.5346717$	1	1

The values of the correlation coefficients are equal to 1 for the Banfeko, Bakoye, and Ketcho sites. These are strong correlations.

V. CONCLUSION

The polynomial model, is the best for all sites. This model is of the form:

$$E = a \cdot I_{CBR}^5 + b \cdot I_{CBR}^4 + c \cdot I_{CBR}^3 + d \cdot I_{CBR}^2 + e \cdot I_{CBR} + f$$

Where: a, b, c, d, e and f are constants, depending on the career concerned, ICBR and E are variables.

This equation is used to determine the value of the modulus of elasticity E knowing the value of the ICBR.

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