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(Review Article)

Correlations between CBR index, using the modified optimum proctor characteristics and lateritic soils identification parameters

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Abstract

The selection of soils for construction of engineering structures is done on the basic of set number of criteria. In road construction, the criteria used are the value of the CBR index at 4 days imbibition. For earth dams and road embankments where materials should be compacted at their maximum dry density, we will adopt the criterion: the compaction characteristics at its optimum modified proctor. The determination of these criteria are very time consuming and can generate several delays which is inconsistent with the strategies of productivity of Publics Works companies. To reduce these delays, relations permitting us to predict their values from soil identification parameters should be developed. In this context, 1500 laboratory test results obtained from samples collected throughout the Cameroon territory were studied. Correlations which obtained were tested on around thirty results gave a prediction with error lower than 6.02%.

Keywords: CBR index; Optimum modified proctor; Nonlinear multiple regression; Lateritic soils; Plasticity index

1. Introduction

Road infrastructure is an essential part of a country's economy: transportation of goods, displacement of users and evacuation or delivery of aid to the populations in distress. The mechanical properties of soils that support these infrastructures have a strong influence on their behavior, longevity and this is why they are used in the road design. The most commonly used parameter is the CBR (California Bearing Ratio) index at 4 days of imbibition, which is an indicator of the resistance of the soil used in road construction. A high value of this indicator means the soil used has a very good characteristic which implies the longevity of the road infrastructure. For earth dams or road embankments, the soils in the site should be compacted up to the maximum dry density. The parameters commonly used in measuring the compaction level of soils are: the characteristics at the optimum modified proctor $\left(\gamma_{d_{OPM}}, W_{OPM}\right)$ A high value of $\gamma_{d_{OPM}}$ implies a low level of deformation and a high mechanical resistance of the soils.

Practically, the CBR index (or the characteristics at the optimum Modified Proctor) of the subgrade of any road infrastructure must be determined at regular intervals following the longitudinal or transversal profiles of the road (or embankment). This requires to do several laboratories tests. On the other hand, if the subgrade or the embankment has poor characteristics, it may be necessary to do a mixture of different soils collected from several quarries, in order to obtain the desired soil characteristics. This reconstituted soil will be used as material for embankment. The tests that will be carried out on the soils from different quarries as well as the reconstituted soil is time consuming and this might cause several months of delay in a road construction project. Moreover, to obtain the CBR index of a soil at 4 days

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imbibition (CBR_{4j}), it is necessary to carry out the following test: sedimentation, grain size analysis, plasticity, modified proctor, immediate CBR and the CBR at 4 days of imbibition. This globally requires delay time of about 250 hours. This delay time is very long and inconsistent with the criteria of productivity of Public Work Companies.

Considering the fact that a delay in a construction project of transport infrastructures will inevitably increase its cost, we will propose in this article two prediction models: one to estimate the CBR index at 4 days imbibition and the other to give the value of $\left(\gamma_{d_{OPM}}, W_{OPM}\right)$ at the optimum modified proctor when the soil identification parameters are known.

The evaluation of the CBR is one of the important tasks in the design of the road. In the absence of the appropriate infrastructures, many researchers had worked on the determination of this mechanical parameter in tropical countries. Several correlations had been proposed between the CBR and the local soils properties in Cameroon. The characteristics at the optimum modified proctor, represented by the optimum moisture content and the maximum dry density were determined in order to obtain a representative CBR value. The knowledge of these parameters had permitted to find some correlations between CBR (4 days of imbibition), characteristics at the optimum modified proctor and local soil index properties.

To perform these correlations, we also propose to determine the CBR index at 4 days imbibition and the value of $\left(\gamma_{d_{OPM}}, W_{OPM}\right)$ at the optimum modified proctor when the soil identification parameters are known.

In this work, we describe the parameters of the developed correlations with the statistical analysis. Their significance is tested with local data using SAS software version 9.2 and the results are illustrated by the nonlinear multiple regression models to predict the measured local data when the soil identification parameters are known. We conclude our study with a summary and a short discussion.

2. Previous correlations

The prediction of the properties of a soil from some identification parameters is not something new. From past history, we observe that many empirical correlations have been developed between: the angle of friction by Mamba et al. (2013), the resistance at rupture by Goktepe, et al. (2008), the swelling index and the compressibility on one hand, the granular characteristics and the state parameters of soils on the other hand. We retain the following result:

- The correlation of the characteristics of a soil at its optimum Proctor, have been given by the authors: Ugbe (2011), Maria J. (2010), Gupta (2008), Bohi (2008) and Youssef et al. (2007);
- The correlation of the CBR index, have been also given by the authors: Phyu Phyu Tun et al. (2017), Zohib et al. (2016), Fangleu (2013), Ramasubbarao et al. (2013), Magdi Zumarawi (2012), Nugroho et al. (2012), Datta et al. (2011), Saklecha et al. (2011), Yildirim et al. (2011), Patel et al. (2010), Vinod et al. (2008), Bohi(2008), Satyanarayana et al. (2006), Gregory et al.(2007)and NCHRP (2001).

The common characteristics of these correlations, whether simple or multiple, results from the fact that: they are given in a linear regression form where R^2 is the coefficient of correlation (Table 1).

The advantage with these proposed models is that: they are simple and don't take into consideration all the grain size analysis parameters. Furthermore, they assume that the effect of all the predictors on the predicted values (CBR_{4j} , $\gamma_{d_{OPM}}$ and W_{OPM}) is linear. The reproach we have on these previous models is that: the soils of different classes can have the same CBR index (or same characteristics at the optimum modified proctor) and the nonlinearity between some parameters is not taken into consideration (nonlinearity between the percentage of fine particles, the plasticity index and the liquid limit).

Table 1 Previous Models of Correlations

N°	Authors	Parameter variation range	Models	R^2
1	Saklecha P. P. et al (2011)	$20.30 \leq LL \leq 79.70$ $15.60 \leq PL \leq 44.48$ $1.46 \leq \gamma_{d_{OPM}}$ (g/cc) ≤ 2.31 $8.40 \leq W_{OPM}(\%) \leq 25.5$	$CBR = 0.62W_{OPM} + 58.9\gamma_{d_{OPM}} + 0.11LL + 0.53PL - 126.76$	0.630
2	Satyanarayana R et al. (2006)	$9.0 \leq FF \leq 34.80$ $22.0 \leq LL \leq 48.0$ $1.90 \leq \gamma_{d_{OPM}}$ (g/cc) ≤ 2.32 $12.8 \leq CBRs \leq 56.8$	$CBR_s = -0.388FF - 0.064LL + 20.38\gamma_{d_{OPM}}$	0.960
3	Vinod P., et al. (2008)	$33.0 \leq C \leq 65.80$ $38.1 \leq LL \leq 63.0$ $8.9 \leq CBR \leq 30.4$	$CBR = -0.889W_{LM} + 45.616$ Where $W_{LM} = LL(1 - C/100)$	0.520
4	Ramasubbarao et al. (2013)	$54.0 \leq F \leq 100.0$ $0.0 \leq S \leq 40.14$ $0.0 \leq G \leq 24.0$ $26.0 \leq LL \leq 94.0$ $11.9 \leq PL \leq 56.0$ $1.33 \leq \gamma_{d_{OPM}}$ (g/cc) ≤ 1.84 $12.3 \leq Wopm(\%) \leq 35.4$ $0.8 \leq CBRs \leq 5.86$	$CBRs = -0.061W_{OPM} - 1.810\gamma_{d_{OPM}} + 0.15PL - 0.069LL + 0.033G + 0.082S + 0.064F$	0.463
5	B. Yildirim et al. (2011)	$10.0 \leq F \leq 99.0$ $1.0 \leq S \leq 49.0$ $0.0 \leq G \leq 78.0$ $20.0 \leq LL \leq 99.0$ $11.0 \leq PL \leq 43.0$ $1.21 \leq \gamma_{d_{OPM}}$ (g/cc) ≤ 2.18 $7.2 \leq W_{OPM}(\%) \leq 40.2$	$CBR = 0.22G + 0.045S + 4.739\gamma_{d_{OPM}} + 0.122W_{OPM}$	0.880
			$CBR = 0.180F + 18.508$	0.800
			$CBR = 0.62W_{OPM} + 58.9\gamma_{d_{OPM}} + 0.53PL + 0.11LL - 126.18$	0.630
			$CBR = 0.253G + 3.0798$	0.860
6	Ohandja N. (2011)		$CBR = 53.71\gamma_{d_{OPM}} - 68.73$	0.575
			$CBR = 650.9P_{80} - 85$	0. 560
			$CBR = -1.949PI + 83.77$	0.344
			$\gamma_{d_{OPM}} = -0.008P_{80} + 2.245$	0.303
			$\gamma_{d_{OPM}} = -0.024PL + 2.719$	0.385

LL=liquid limit, PL=plasticity limit, S=sand percentage, G=grave percentage, F=percentage of particles passing though the N° 200 sieve, CBR_s=unsoaked CBR, C=fraction of soil coarser than 425µm

3. Methodology

3.1. Description of soils parameters

Soils can be described by three parameters:

- Granular parameters;
- Plasticity parameters;
- State parameters.

3.1.1. Granular Parameters

The granularity of a soil in our model will be described by: maximum diameter of the particles $D_{\max}$, the percentage of gravel G, the percentage of sand S, the percentage of lemon L, the percentage of fine $P_{80\mu m}$ (corresponding to the percentage of particles passing through the $80\mu m$ sieve), the percentage of clay A and the coefficient of uniformity $C_u = \frac{d_{60}}{d_{10}}$ (where d_n is the diameter corresponding to n% of particles passing through).

3.1.2. Plasticity Parameters

The parameters used to describe the plasticity of soils are [Mamba et al. (2013)]: liquid limit W_L and the plasticity index I_P .

3.1.3. The state parameters

From the state parameters describe by [Mamba M et al. (2013)], we shall retain here the ones which characterize the compaction of a soil at its optimum modified proctor. These parameters are: the maximum dry density $\gamma_{d_{OPM}}$ and the optimum water content W_{OPM} .

In this approach, we take into account a set of variables used for the classification of soils (the granular characteristics and plasticity parameters) and the state variables (for the prediction of the CBR_{4j}).

The granularity of soils is represented by seven variables denoted by:

- $D_{\max}$, the maximum diameter of the particles;
- G , the percentage of gravel;
- S , the percentage of sand;
- L , the percentage of lemon;
- A , the percentage of clay;
- $P_{80\mu m}$, the percentage of particles passing through the 80μm sieve;
- C_u , the coefficient of uniformity;
- The parameters of the plasticity of soils are denoted by;
- LL , the Liquid Limit;
- PI , the Plasticity Index;
- The state parameters that characterize the compaction of soils at its optimum modified proctor are denoted by;
- $\gamma_{d_{opm}}$, the maximum dry density;
- W_{opm} , the optimum moisture contents.

3.2. Proposed model

We are trying to predict the CBR index at 4 days imbibition (CBR_{4j}) and the characteristics at the optimum modified proctor with the help of a nonlinear model and multi linear variables which are given by the relations (1), (2) and (3):

$$\left| \begin{array}{l} CBR_{4j} = F\left(D_{\max}, G, S, C_u, P_{80\mu m}, L, A, I_P, W_L, \gamma_{d_{OPM}}, W_{OPM}\right) \\ CBR_{4j} = D_{\max}^{n_1} \times G^{n_2} \times S^{n_3} \times P_{80\mu m}^{n_4} \times L^{n_5} \times A^{n_6} \times I_P^{n_7} \times W_L^{n_8} \times \gamma_{d_{OPM}}^{n_9} \times W_{OPM}^{n_{10}} \times C_U^{n_{11}} \end{array} \right. \quad \text{....................}(1)$$

Where $n_{j(j=1\ to\ 11)}$ are real.

$$\left| \begin{array}{l} \gamma_{d_{OPM}} = F_1\left(D_{\max}, G, S, C_u, P_{80\mu m}, L, A, I_P, W_L\right) \\ \gamma_{d_{OPM}} = D_{\max}^{l_1} \times G^{l_2} \times S^{l_3} \times P_{80\mu m}^{l_4} \times L^{l_5} \times A^{l_6} \times I_P^{l_7} \times W_L^{l_8} \times C_u^{l_9} \end{array} \right. \quad \text{.............................}(2)$$

Where $l_{j(j=1\ to\ 9)}$ are real.

$$\left| \begin{array}{l} W_{d_{OPM}} = F_2\left(D_{\max}, G, S, C_u, P_{80\mu m}, L, A, I_P, W_L\right) \\ W_{d_{OPM}} = D_{\max}^{m_1} \times G^{m_2} \times S^{m_3} \times P_{80\mu m}^{m_4} \times L^{m_5} \times A^{m_6} \times I_P^{m_7} \times W_L^{m_8} \times C_u^{m_9} \end{array} \right. \quad \text{.......................}(3)$$

Where $m_{j(j=1\ to\ 9)}$ are real.

3.3. Data and criteria of the predictors

Table 2 Maximums, averages, minimums, variance inflation of the parameters of the studied samples

Variables	Number of samples	Minimum	Maximum	Average	Standard deviation
D_{max} (mm)	1500	5.000	20.000	19.720	1.353
I_p (%)	1500	5.200	59.300	21.890	6.645
W_L (%)	1500	17.700	87.600	51.420	10.279
G (%)	1500	8.230	80.730	50.080	11.954
$P_{80\mu m}$ (%)	1500	14.310	91.700	41.210	12.868
A (%)	1500	0.520	13.540	6.620	2.087
C_u (%)	1500	19.090	9399.000	1127.000	1215.000
S (%)	1500	8.770	72.880	29.230	10.589
CBR_{4j} (%)	1500	8.000	150.000	56.860	22.315
$\gamma_{d_{OPM}}$ (T/m^3)	1500	1.640	2.360	2.020	0.125
W_{OPM} (%)	1500	4.400	29.000	13.480	3.018
L (%)	1500	0.420	14.700	5.500	1.824

The used data, which were obtained from tests carried out on the Cameroon's lateritic soils, came from laboratories: of Geotechnics and Materials of the Yaounde National Advanced School of Engineering and from Labogenie. This data were obtained from standard tests realized on soil samples collected from the national territory. The results from each sample were exploited to enable their identification to be done using the twelve following variables:

$$CBR_{4j}, D_{\max}, G, S, C_u, P_{80\mu m}, L, A, I_P, W_L, \gamma_{d_{OPM}}, W_{OPM} \quad \text{.......................}(4)$$

In this work, we obtained a sample of 1500 individuals, identified by the data from the twelve described variables given by relation (4). The maximum, the minimums and averages values of described variables are summarized by Table 2 and three histograms as it is shown in Figures 1, 2 and 3.

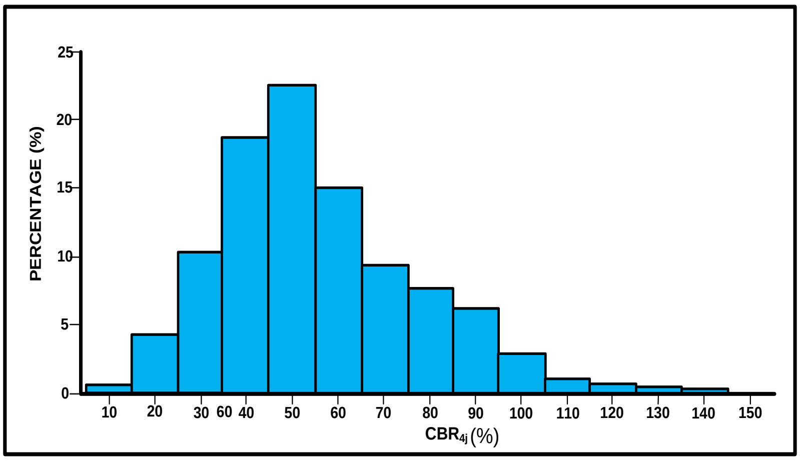

Figure 1 Histogram of measured CBR at 4 days of imbibition

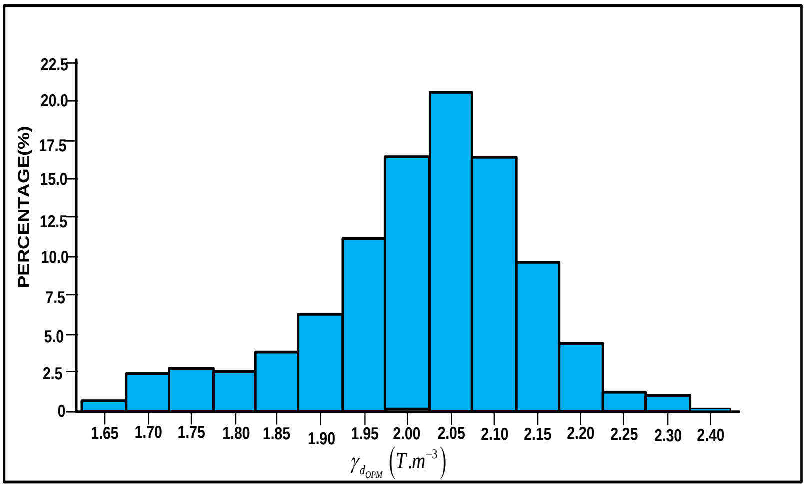

Figure 2 Histogram of measured maximum dry density

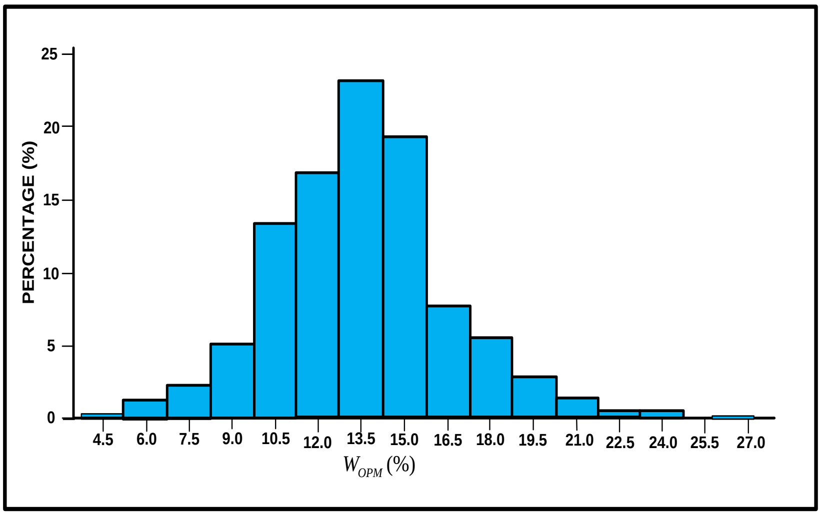

Figure 3 Histogram of measured optimum moisture content

The outcome of this study is the entries data of the present approach using the SAS software version 9.2 (2009) in order to predict the CBR at 4 days of imbibition and the characteristics at the optimum modified proctor.

We used as criteria (SAS,2009), the values of the following parameters for the selection of the correlation:

- The multiple coefficients of correlation R^2. The correlation becomes more significant as the coefficient approaches 1.
- Mallow's coefficient C_p. Good models are ones with small C_p values and/or values of C_p closer to the number of predictor variables.
- For the construction of the correlation matrix, we used Pearson product moment-correlation coefficient, R_{XY} (where X and Y are variables) and the associated probability when we admit that the two variables (X and Y) are independent is such that r_{XY}. This correlation matrix brings out the relations between the different variables of the model. X and Y are variables used for soil identification (4).
- The described variables that have an insignificant effect on the correlation are automatically neglected.

4. Presentation of results

4.1. Proposed linear regression models

To evaluate the relationships between all described parameters, we obtain the following correlation matrix (Table 3):

Table 3 Correlation matrix (the number: in the first line represent Pearson correlation coefficient $r_{XY_{Pearson}}$ and in the second line the associated probability when we admit that the two variables are independents)

	D_{max} (%)	*Ip (%)*	W_L (%)	*G (%)*	$P_{80\mu m}$ (%)	*A (%)*	C_u (%)	*S (%)*	CBR_{4j} (%)	$\gamma_{d_{OPM}}$ (T/m³)	W_{OPM} (%)	*L (%)*
D_{max} (%)	1	0.0255	0.0473	0.10981	-0.1278	-0.1313	0.00391	-0.1762	0.04155	0.0116	0.0495	-0.1653
	0.0000	0.0001	0.1166	0.0003	<0.0001	0.0001	0.8968	<0.0001	0.1683	0.7005	0.1010	<0.0001
Ip (%)		1	0.8108	0.2786	0.1590	0.1661	0.0312	-0.2413	-0.2361	-0.1074	0.1416	0.0476
		0.0000	<0.0001	<0.0001	0.0001	0.0001	0.3017	<0.0001	0.0001	0.0004	0.0001	0.1146
W_L (%)			1	0.2375	0.1524	0.1654	0.0428	-0.2469	-0.2438	-0.2286	0.1981	0.1015
			0.0000	<0.0001	0.0001	0.0001	0.1557	<0.0001	0.0001	<0.0001	0.0001	0.0007
G (%)				1	-0.2998	-0.1489	-0.0333	-0.8145	0.1896	0.3771	-0.1700	-0.5415
				0.0000	<0.0001	<0.0001	0.2694	<0.0001	0.0277	0.0001	0.0001	<0.0001
$P_{80\mu m}$ (%)					1	0.9300	-0.1041	0.2994	0.2656	-0.0591	0.1795	0.6917
					0.0000	<0.0001	0.0005	<0.0001	0.0001	0.0500	0.0001	0.0001
A (%)						1	-0.0814	0.5484	-0.1332	-0.0443	0.1559	0.5978
						0.0000	0.0069	<0.0001	<0.000001	0.1423	<0.0001	0.0001
C_u (%)							1	0.2522	-0.0670	-0.1470	0.0328	0.0832
							0.0000	0.0032	0.0262	0.0001	0.2763	0.0001
S (%)								1	-0.1531	-0.1252	0.0264	0.3786
								0.0000	0.0001	0.0001	0.3811	<0.0001
									1	0.3365	-0.1252	-0.3304

CBR_{4j} (%)									0.000	<0.0001	0.0008	<0.0001
$\gamma_{d_{OPM}}$ (T/m^3)										1	-0.6841	-0.4154
										0.0000	<0.0001	<0.0001
W_{OPM} (%)											1	0.2759
											0.0000	<0.0001
L (%)												1
												0.0000

The correlation we obtained between CBR at 4 days of imbibition (CBR_{4j}) and variables D_{max}, G, S, C_u, $P_{80\mu m}$, L, A, Ip, W_L, $\gamma_{d_{OPM}}$, and W_{OPM} is given by relation (5). In Figure 4, we show the trend between measured and estimated values of CBR_{4j} .

$$CBR_{4j} = D_{\max}^{0.36923}.G^{0.31503}.S^{0.09676}.C_u^{-0.01789}.A^{0.04768}.I_p^{-0.33196}.W_L^{-0.03486}.\gamma_{d_{OPM}}^{2.1942}.W_{OPM}^{-0.45179} \quad ....(5)$$

With $R^2 = 0.9917$ and $C_p = 9$.

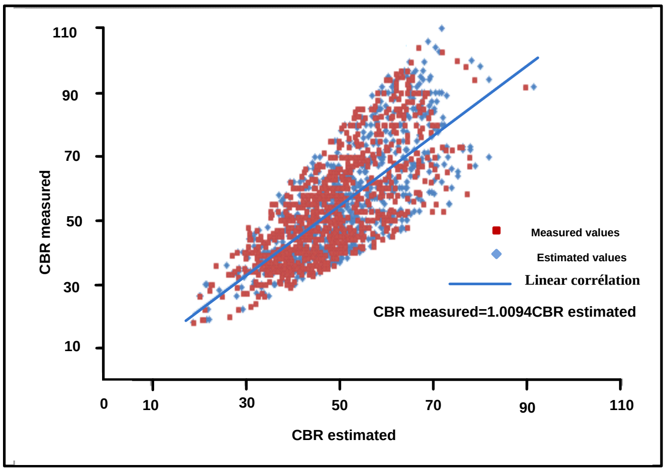

Figure 4 The trend of CBR_{4j} index at 4 days of imbibition

The correlation between maximum dry density ($\gamma_{d_{OPM}}$) and variables D_{max}, G, S, C_u, P_{80}, L, A, Ip and WL is presented by relation (6). In Figure 5 we show the trend between measured and estimated values of γ_{dopm} .

$$\gamma_{d_{OPM}} = D_{\max}^{0.13629} \times G^{0.10104} \times S^{0.0638} \times C_u^{-0.00186} \times L^{-0.00500} \times A^{0.01425} \times I_P^{0.00496} \times W_L^{-0.06699} \quad .... (6)$$

With $R^2 = 0.9917$ and $C_p = 8$.

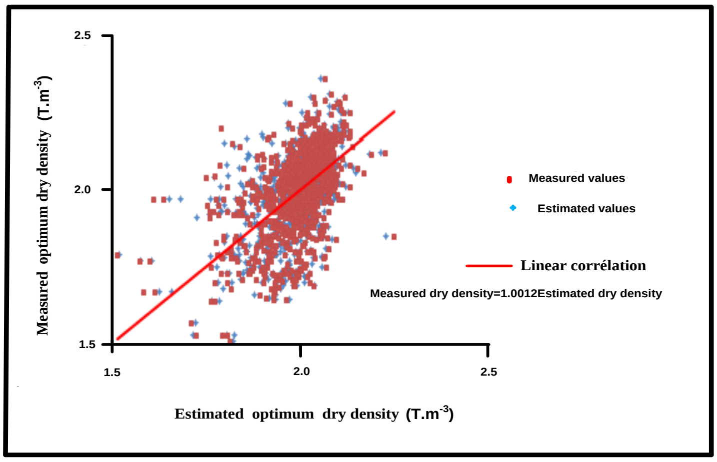

Figure 5 Graph showing the trend of the maximum dry density

The correlation between: optimum moisture content (W_{opm}) and variables D_{max}, G, S, C_u, P_{80}, L, A, Ip and WL as given by relation (7). In Figure 6, we show the trend between measured and estimated values of W_{opm} .

$$W_{OPM} = D_{max}^{0.48006} \times G^{-0.06917} \times S^{-0.01431} \times C_u^{0.01338} \times L^{0.07816} \times A^{0.03294} \times I_P^{-0.00597} \times W_L^{0.030853} \quad \text{.........} (7)$$

With $R^2 = 0.9937$ and $C_p = 8$.

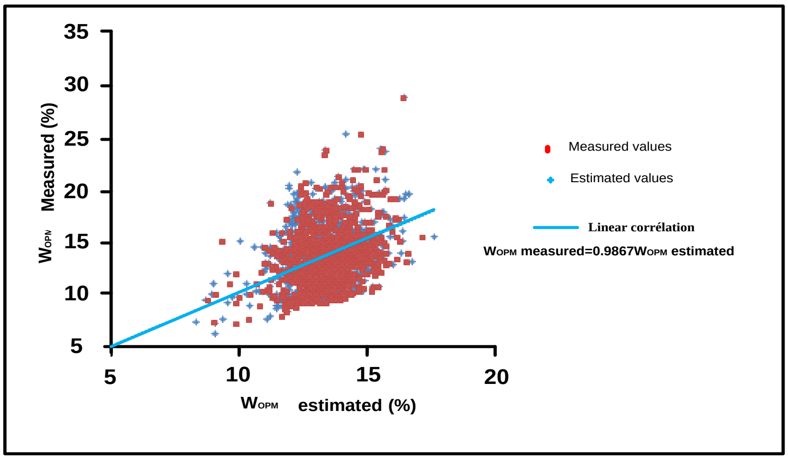

Figure 6 The trend of the optimum moisture content

4.2. Applications of the correlations on local data

In the previous section, the correlations as the function of several described variables have been constructed to predict the CBR at 4 days of imbibition and the characteristics at the optimum modified proctor. These correlations are applied on lateritic soils samples coming from: Dschang, Lom Pangar, Kumba, Yaoundé, Bakebe and Fontem which are the Cameroonians towns. These correlations predict the values of CBR_{4j},(Figure 7) γ_{dopm} ,(Figure 8) and W_{opm} ,(Figure 9) with an error lower than 6.02%, 1.68% et 4.70% respectively.

In order to calculate the error ΔY_{error} of the correlation, we use the relation (8):

$$\Delta Y_{error} = \frac{\sqrt{\sum_{j=1}^{n} \left(Y_{j_{mesured}} - Y_{j_{estimated}} \right)^2}}{n} \quad \text{..................} (8)$$

Where

$Y_{j_{mesured}}$: the measured values of variable Y_j

$Y_{j_{estimated}}$: the value of variable Y_j given by correlation.

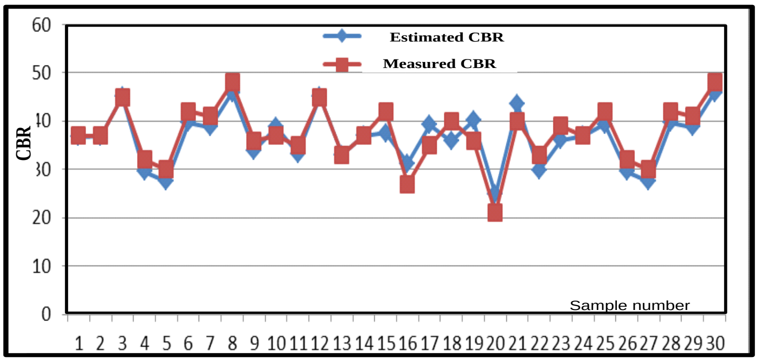

Figure 7 Comparison between laboratory CBR and predicted CBR obtained from equation (5) at 4 days of imbibition

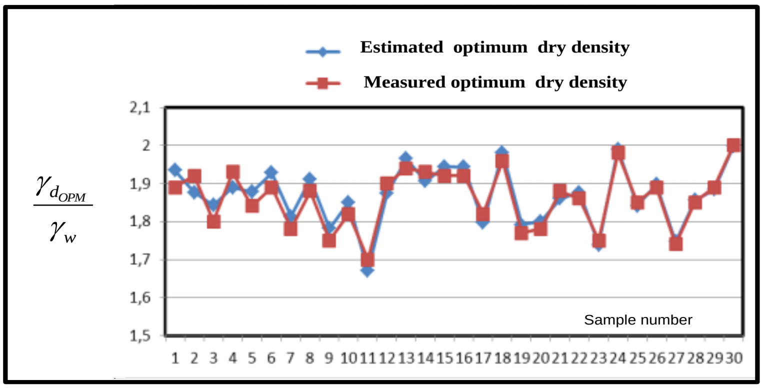

Figure 8 Comparison between laboratory maximum dry density and predicted maximum dry density obtained from equation (6)

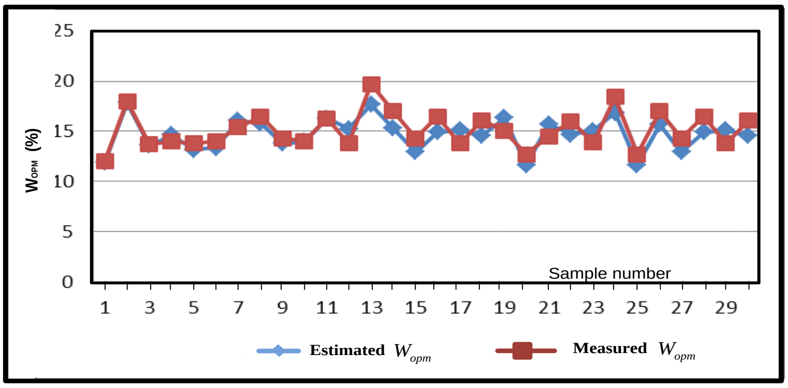

Figure 9 Comparison between laboratory optimum moisture content and predicted optimum moisture content obtained from equation (7)

5. Conclusion

Definitely, these proposed correlations can be used for the rapid selection of pits of laterite soils destined for road construction or as an indicator for the fabrication of reconstituted soils. Once the pits or the reconstituted soil have been selected, laboratories tests for the determination of the characteristics of the optimum modified proctor and CBR index have to be realized to enable the validity of the choices.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors have no conflicts of interest with other authors in connection to the research topic, results and research tools.

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