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Study of Correlation between CBR and Certain Physical Characteristics of Lateritic Gravels

LARE Douti[1], P'KLA Abalo[1], PASSOLI Abelim[2], AYITE Yawovi Mawuénya Xolali Dany[1]

[1]Laboratoire de Recherche en Sciences de l'Ingénieur (LARSI), Ecole Polytechnique de Lomé, University of Lome, 01BP1515 Lomé 01 Togo
[2]Institut National de la Recherche Scientifique, Lomé Togo

Corresponding Author: LARE Douti

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ABSTRACT

The aim of this work is to study the possibility of establishing a correlation between the CBR value and the percentage of fines, the plasticity index, the Proctor density and the water content at the Proctor optimum of laterites that can be used in pavement layers. To this end, data was collected on the physical (percentage of fines, Atterberg limits) and mechanical (Proctor and CBR) characteristics of lateritic gravels available in Togo. In accordance with current standards, the data collected was analysed using Excel software and correlated using Matlab, with CBR as the explained variable and percentage of fines, plasticity index, Proctor density and water content at the Proctor optimum as the explanatory variables.
A total of 479 test results on lateritic gravels were identified and used to carry out this study. The results of this study show that it is possible to correlate the CBR as a function of the percentage of fines and density using Matlab software. This correlation is obtained in the form of a bi-harmonic surface linking the CBR to the density and the percentage of fines, which is the solution of a partial differential equation solved by the weak form (numerical approximation using finite elements or finite differences) and not by the strong form (writing a formal solution).

Keywords: laterite, road pavement, CBR, correlation

INTRODUCTION

Road geotechnics enables the engineer to determine, through tests (in situ and in the laboratory), the different characteristics of the materials he intends to use in road construction, and also the characteristics of the materials on which the road will be built. These tests, which are numerous, are costly in terms of time and money. There is also the question of verifying the results obtained during the tests.
In the West African sub-region, laterite is a material that is found almost everywhere. To use this laterite effectively in road construction, the geotechnician carries out identification tests to determine certain physical (percentage of fines, Atterberg limits) and mechanical (Proctor and CBR) characteristics. Of these tests, the CBR test is the most difficult (in terms of equipment and time) and the most important when it comes to designing a pavement structure using raw materials. For treated materials (with hydraulic or hydrocarbon binders), other tests are more appropriate.
To save time, the experience of geotechnicians (collectively or individually) is fundamental, enabling correlations to be determined between certain geotechnical characteristics of soils and materials. Correlations "make it possible to estimate an unknown characteristic on the basis of other characteristics determined during geotechnical reconnaissance". [11]

Furthermore, it is often illusory to base decisions on test results. In fact, several standards, including Eurocode 7, require that a conservative estimate of the average value of the geotechnical parameter be used for the characteristic value of the ground and soil properties, with a confidence level of 95%. This means carrying out at least 15 tests on the same layer of soil in order to be sure of the result used. This number of tests is very high and practically impossible to carry out for a lateritic borrow deposit, for example, so the control of results obtained in the laboratory by correlations is therefore reinforced. [11]

Our work therefore focuses on determining a correlation between CBR and the other physical parameters of laterite. Determining such a correlation will save time and will also provide road authorities with a valuable tool for verifying and validating the results presented by geotechnical design laboratories.

MATERIALS & METHODS

In order to achieve the objectives, set, existing data on lateritic gravel was first collected from the study reports available from the Directorate General of Public Works (DGTP), CITAFRIC (Urban and Municipal Development Agency) and the various geotechnical study laboratories currently approved in Togo, namely the Public Works Laboratory (LAB-TP), the National Building and Public Works Laboratory (LNBTP) and the Geotechnical Laboratory GEOTECH-SA. The studies used were carried out from 2010 to 2019 and cover a total length of 4,235 km of road for a total number of 479 loans studied.

This approach is based on the standard (EN 1997-1) which explicitly requires the use of experience and correlations in the engineer's approach and which also specifies that correlations must be made between at least the results of two (02) different types of test. [11] The results used here come from four (04) different laboratories, so the condition is satisfied.

The total number of test results used is representative in order to be able to determine a correlation. These data were then processed using Microsoft Excel to assess the values obtained for each test, based on existing standards [1; 2; 3; 5]. The test results used were: dry density, CBR, Plasticity Index (PI) and percentage of fines. Thus, we determined the best possible correlation between CBR and the percentage of fines (%<80µ), the plasticity index (PI) and the density at the Proctor optimum (ɣd OPM).

The various possibilities considered are as follows:

- ✓ Correlation between CBR and plasticity index and percentage of fines;
- ✓ Correlation between CBR and plasticity index and density; and
- ✓ Correlation between CBR and percentage of fines and density.

Weighting is a technique used to introduce a fifth variable into a statistical analysis. So for each of these hypotheses we tried to weight either with the variables themselves or with other variables not initially taken into account. Given that the analysis envisaged uses 5 to 6 variables in total, it was not possible to carry it out using a standard analysis tool such as Excel. We used MATLAB to carry out the analysis.

The software allows us to search for correlations using the following different types of approximation:

- ✓ by interpolation (nearest neighbour, linear, cubic, bi-harmonic or spline (function defined piecewise by polynomials) with a thin plate;
- ✓ minorant (linear or quadratic); and
- ✓ polynomial.

To assess each type of approximation, the following elements are compared:

- ✓ the R2 value: this is the coefficient of determination calculated by comparing the actual variables and the approximated variables. Its calculation depends largely on the model used for the approximation. **The closer the value obtained is to 1, the better the approximation used**;

- ✓ the SSE value: this statistical value measures the total deviation of the actual values from the estimated values. **A value close to 0 means that the model has a small error compared to the actual values and that the model is more useful for correlation**.

Although each of these values can be used separately, it is usual to carry out an analysis by crossing these two values for greater reliability.

In this way, for each case, all possibilities have been considered, and only the best result has been retained. The results obtained are presented in the following sections.

RESULT & DISCUSSION

Raw data collected.

Table 1 gives the statistical parameters of the data collected. These data are analysed in detail for each characteristic.

Table 1: Summary of the main characteristics of the data collected.

	Percentage of fines (size <80µ)	Plasticity Index	Optimum density (γd OPM)	Water content at Proctor optimum (Wopt)	CBR at 95%
Number of studies consulted	480	480	480	480	480
Number of data available	479	468	480	480	479
Data not available rate	0,21%	2,50%	0,00%	0,00%	0,21%
1st_Quartile	11,00	9,50	2,05	8,00	32,00
Median	15,00	12,00	2,12	9,00	43,00
3rd_Quartile	19,05	15,00	2,18	10,30	58,00
Mean	15,53	12,82	2,11	9,26	45,54
Standard deviation	6,48	4,62	0,10	2,03	18,97

✓ Percentage of fines:

A material with a percentage of fine greater than 20% is bad, while a percentage of fine less than 15% is a good material. Thus, a material is deemed acceptable if its percentage of fines is between 15% and 20% [1,2,4,10].

Table 3 presents the distribution of the laterites studied according to the percentage of fines.

Table 2: Data on the percentage of fines

Interval of percentage of fines (%)	*Number of data recorded*	*Observation rate*
0 – 15	*237*	*49,48%*
15 – 20	*132*	*27,56%*
20 – 45	*110*	*22,96%*

It can be seen from the analysis of Table 3 that the lateritic materials encountered in Togo are 49.48% good. 22.96% is bad and 27.56% is acceptable from the point of view of the percentage of fines.

✓ Plasticity Index (PI):

Table 4 illustrates the distribution of data according to the PI as well as the assessment of a soil according to the PI. In construction, it is preferable to use little plastic soils to avoid swelling phenomena [1,2,4,10]

Table 3: Distribution and assessment of data according to plasticity index

Plasticity Index (PI)	Soil condition	*Number of data recorded*	*Observation rate*
0 – 12	Not plastic	214	45,73%
12 – 20	Little plastic	224	47,86%
> 20	Plastic	30	6,41%

Of all the lateritic loans analyzed, it appears that 45.73% are weakly clayey and 47.86% are moderately clayey and 6.41% are clayey. It is noted that only 6.41% of the laterites studied are to be rejected for use in pavement layers according to the PI values.

✓ Proctor:

In the context of this study, it is the water content of the Proctor optimum and the Proctor dry density that interested us. In particular, the dry density tells us about the use of the material in road technology. In general, it is assumed that a material with a

Proctor dry density of less than 1.8 cannot be used [1,2,4,10].

Thus, the analysis of the data collected shows that only 1.25% of the lateritic borrows encountered in Togo are not usable with regard to their density (Table 5).

Table 4: Distribution and assessment of data according to density

Density	Number of data recorded	Observation rate
0 – 1,8	6	1,25%
1,8 – 2,3	474	98,75%

- ✓ **CBR:**

The CBR (Californian Bearing Ratio) test, proposed in 1938, is universally used to assess the resistance of road surfaces. The Proctor study and the CBR test are almost systematically associated. This test is described in standard NF P 94-078, but also for road materials in standard EN 13286-47:2012. Table 6 shows the distribution of loans according to the CBR.

Table 5: Distribution and assessment of data according to the CBR

CBR	Appreciation	Number of data recorded	Observation rate
0-30	Cannot be used as a road surface as is	91	19,00%
30-60	Can be used as foundation layer	274	57,20%
60-80	Can be used as a base layer for low traffic	94	19,62%
> 80	Can be used as a base layer for high traffic	20	4,18%

Knowing that the materials whose CBR is less than 30 are not used for the construction of roadbeds, we note that 19% of borrows cannot be used as is for the construction of roadbeds, while 57 20% of the materials have a CBR between 30 and 60 and could be used as a base course and 23.80% of the materials have a CBR greater than 60% and could be used as a base course.

Correlations used to determine CBR.

- ✓ Correlation of CBR with plasticity index and percentage of fines

Figure 1 shows the correlation between CBR and plasticity index and the percentage of fines.

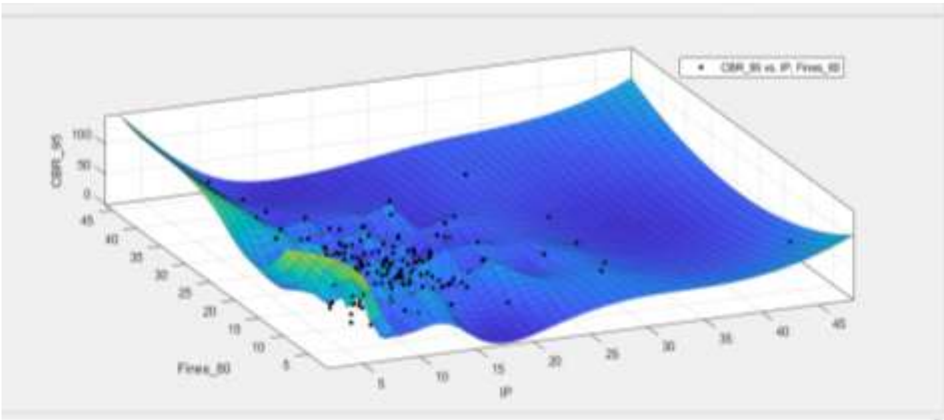

Figure 1: CBR correlation surface as a function of plasticity index and percentage of fines

After multiple simulations we obtain:

- Best correlation method: CBR (PI, %<80µ) = Biharmonic surface
- Confidence level of the approximation: SSE = 3.273e+04 and R2 = 0.7686

Note that this correlation gives a biharmonic surface that results from solving a partial differential equation. It does not therefore give an explicit formula.

In addition, although the R2 coefficient is satisfactory, the SSE coefficient is a long way from the ideal value, which is 0.

- ✓ **Correlation of CBR with plasticity index and density**

The correlation of CBR as a function of plasticity index and density is shown in Figure 2.

After multiple simulations we obtain:

- Best correlation method: CBR (PI, ɣd OPM) = Biharmonic surface
- Confidence level of the approximation: SSE = 2.379e+04 et R2 = 0.8319

On analysing this result, we note that this correlation gives a biharmonic surface which results from solving a partial differential equation. This correlation does not therefore give an explicit formula.

Furthermore, although the R2 coefficient is satisfactory, the SSE coefficient is very far from the ideal value, which is 0.

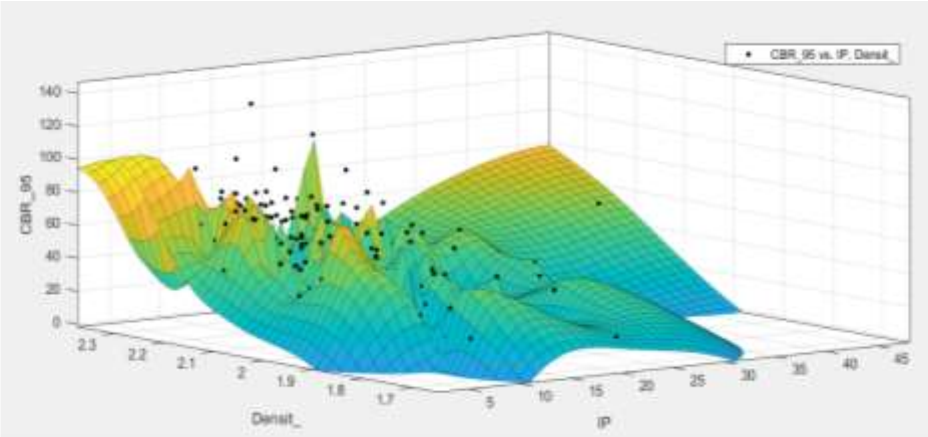

Figure 2: CBR correlation surface as a function of plasticity index and density

✓ Correlation of CBR with percentage of fines and density

The correlation of CBR with the percentage of fines and density is shown in Figure 3.

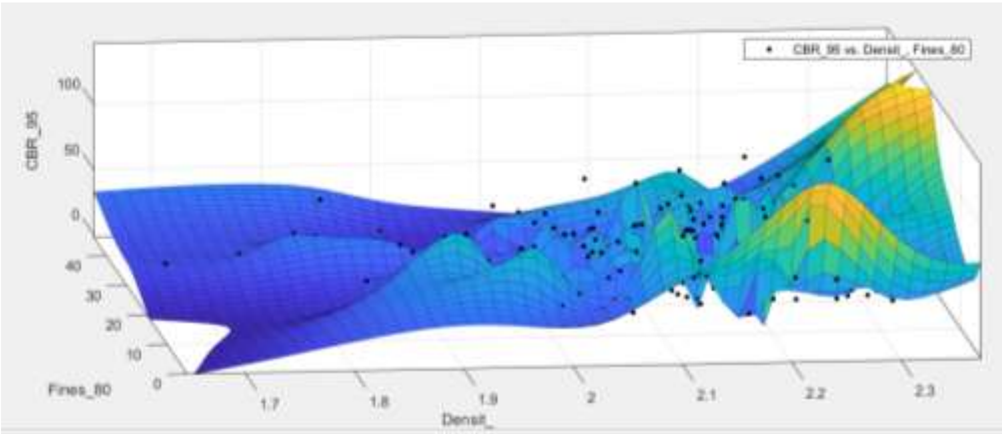

Figure 3: CBR correlation surface as a function of percentage of fines and density

After multiple simulations we obtain:

- Best correlation method: CBR (%<80µ, ɣd OPM) = Biharmonic surface
- Confidence level of the approximation: SSE = 1.947e+04 et R2 = 0.8674

On analysing this result, we note that this correlation also gives a biharmonic surface which results from solving a partial differential equation. This correlation does not therefore give an explicit formula.

Furthermore, although the R2 coefficient is satisfactory, the SSE coefficient is very far from the ideal value, which is 0.

Table 6 summarises the results obtained. Analysis of this table shows that the best correlation is obtained with a bi-harmonic surface, which relates the CBR to the density and percentage of fines.

Table 6: Summary of correlation.

Type of correlation	SSE Value	R2 Value	Comments
CBR with plasticity index and percentage of fines	3.273e+04	0.7686	
CBR with plasticity index and density	2.379e+04	0.8319	
CBR with percentage of fines and density	1.947e+04	0.8674	Largest R2 value and smallest SSE value

It is important to note that for a bi-harmonic surface, the software does not give a specific formula for the solution. This is because it is the solution to a partial differential equation, and in the current state of knowledge, these equations are solved using the weak form (numerical approximation using finite elements or finite differences) and not the strong form (writing a formal solution).

If a reasonable R2 value is obtained, the value of the SSE coefficient seems to indicate that another type of solution could be considered and give a better approximation.

CONCLUSION

This study focused on determining a correlation between CBR and some of the physical characteristics of laterites in the context of their use in road engineering. After identifying the data available on laterite quarry pavements in the context of road studies, these data were processed in order to determine the best possible correlation. The possibilities considered are (i) determination of CBR as a function of plasticity index and percentage of fines; (ii) determination of CBR as a function of plasticity index and density; and (iii) determination of CBR as a function of percentage of fines and density.

In conclusion, we can state that it is possible to determine a correlation between the CBR and the physical characteristics of the laterites. By processing with Matlab software, this correlation is obtained in the form of a bi-harmonic surface linking the CBR to the density and percentage of fines, which is the solution of a partial differential equation solved by the weak form (numerical approximation using finite elements or finite differences) and not by the strong form (writing a formal solution). Nevertheless, it should be noted that there is still progress to be made in order to arrive at a simplified formula that can be used by everyone.

Declaration by Authors

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