# Characterisation of laterite for road construction

Ndiaye Massamba[a,b], Magnan Jean-Pierre[a], Cissé Ibrahima Khalil[b], Cissé Lamine[c*]

*[a]UPE, IFSTTAR, Marne-la-Vallée, France*
*[b] École Polytechnique de Thiès, Thiès, Sénégal*
*[c]Agence des travaux et de Gestion des Routes (AGEROUTE), Dakar, Sénégal*

**Abstract**

Lateritic soils exist in many places in tropical regions of Africa and America. They are frequently used for road construction. It is important to use them in an optimised way and attempts are made to improve their description and characterisation for road applications.
Laboratory work done in Brazil, Senegal and France was aimed at including specific properties of laterites in their classification, especially the degradability of their gravelly and sandy fractions due to weathering and compaction during construction works. The paper presents results of laboratory tests, which highlight the importance of particle size reduction due to compaction and its variability. The link between the grain sizes of raw laterites and those of the same laterite after compaction should be further studied, in order to help the road designer in tropical and equatorial countries.

*Keywords:* laterite, particle size, degradability.

**Résumé**

Les sols latéritiques existent dans beaucoup de régions tropicales d'Afrique et d'Amérique. Ils sont fréquemment utilisés pour la construction des routes. Il est donc important de les utiliser de façon optimale et des essais sont faits pour améliorer leur description et leur caractérisation pour les applications routières.
Le travail de laboratoire exécuté au Brésil, au Sénégal et en France avait pour but d'inclure les propriétés spécifiques des latérites dans leur classification, particulièrement la dégradabilité de leurs fractions graveleuses et sableuses du fait de l'altération et du compactage pendant les travaux de construction. L'article présente les résultats d'essais de laboratoire qui mettent en évidence l'importance de la réduction de la taille des particules du fait de leur compactage et de leur variabilité. L'étude de la relation entre les tailles des particules des latérites brutes et des mêmes latérites après compactage devrait être poursuivie, afin d'aider les concepteurs de routes dans les pays tropicaux et équatoriaux.

*Mots-clé:* latérite, dimension des particles, dégradabilité.

* Corresponding author: Jean-Pierre Magnan, IFSTTAR, Dept. GERS. Tel.: +33 1 81 66 82 60; fax: +0-000-000-0000 .
*E-mail address*: jean-pierre.magnan@ifsttar.fr.

## 1. Introduction

Laterites and lateritic soils are common materials in tropical and equatorial countries and they have been used for a long time in road construction as fill material and as aggregates for road base and foundation layers. In Senegal and other French speaking African countries, road materials are selected according to the CEBTP 1972 rules, which were revised in 1980. Gravelly lateritic soils used in road structures have to compel to granularity conditions: their grain size curve must lie between lower and upper limit curves before or after compaction. Additional conditions are put on CBR index, plasticity index and modified Proctor optimum.

Grain size has a major effect on the behaviour of gravelly base and foundation layers and the fragmentation of particles during compaction is known to produce worse mechanical behaviours. This was recognized and accounted for during the revision of CEBTP 1972 rules. The lower and upper limits used in 1972, defined on raw quarry materials (figure 1), were replaced in 1980 by lower and upper limit curves defined on the compacted material, that is after the fragmentation of some of the lateritic grains during compaction (figure 2).

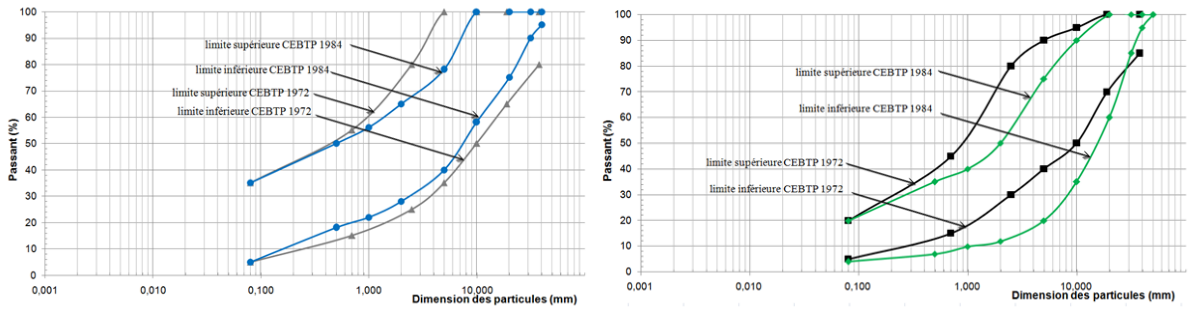


Fig. 1. Upper and lower limit CEBTP curves: (a) Foundation layer; (b) Base layer

The modification of criteria requires coarser gravelly lateritic soils, which is due firstly to the modification of the limit curves in a more restrictive way and secondly to the influence of compaction, which shifts the grain size curve to the left (Figure 2).

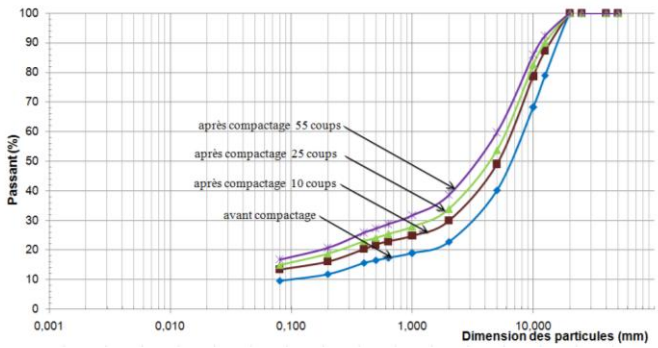


Fig. 2. Influence of compaction in a CBR mould on the grain size curve of a lateritic gravelly soil

The influence of compaction on lateritic gravels is not constant all over the world, but depends on the origin, history, present structure, mineralogy and chemical characteristic of the grains. These characteristics may vary much at the scale of a country, a region and even a deposit.

The effects of compaction of lateritic gravels was analysed on lateritic samples from two quarries located in Senegal (Lam Lam and Sindia quarries) and two other quarries from Brazil (quarries of Natal airport and Picos, respectively in Rio Grande Do Norte and Piaui states). More detailed analyses were made on Lam Lam laterites, which are presented in section 2 of this paper. The three other laterites confirm the tendencies, which were observed on the first site (section 3). Details can be found in the Dr. thesis of the first author (Ndiaye, 2013).

## 2. Study of lateritic gravels from Lam Lam quarry (Senegal)

Ten samples taken from different places in the quarry were used. Their CBR index ranges from 35 to 70, with a mean of 51. Their fines content is low and their average plasticity index is 20.1 (Table 1).

Table 1. Properties of Lam Lam lateritic gravel samples before compaction

| | Grain size analysis (%) | | | Fragmentability index ($I_{FR}$) | Degradability index ($I_{DG}$) | Plasticity index ($I_P$) | Proctor | | $I_{CBR}$ at 95% OPM |
|---|---|---|---|---|---|---|---|---|---|
| | 0.08 mm | 2 mm | 10 mm | | | | $w_{OPM}$ (%) | $\rho_d$ (g/cm$^3$) | |
| Minimum value | 5.30 | 14.42 | 51.04 | 2.00 | 1.10 | 17.10 | 10.00 | 1.91 | 35 |
| Maximum value | 11.44 | 27.08 | 71.26 | 4.70 | 1.10 | 24.65 | 12.50 | 2.09 | 70 |
| Mean value | 8.46 | 19.89 | 59.63 | 3.57 | 1.10 | 20.09 | 11.13 | 2.00 | 51 |
| Standard deviation | 1.64 | 4.05 | 6.05 | 1.01 | 0.00 | 2.89 | 0.93 | 0.06 | 14.5 |
| Interval of variation | 5.3-11.44 | 14.42-27.08 | 51.04-71.26 | 2.00-4.70 | 1.10 | 17.10-24.65 | 10.00-12.50 | 1.91-2.09 | 35-70 |

Grain size analyses were done on all samples, before and after CBR compaction, to follow the granularity changes. The comparison of the granular classes of the initially 0/20mm material before and after CBR compaction shows that the particles larger than 10 mm are strongly transformed after 10 blows and 25 blows compaction, whereas the transformation concerns the smaller particles (larger than 5mm) too, after 55 blows compaction. This evolution produces an important increase in the quantity of smaller particles (Figure 3 and Table 2). Besides, it follows from these data that the reduction in particle sizes increases with the compaction energy (10 blows, 25 blows, 55 blows).

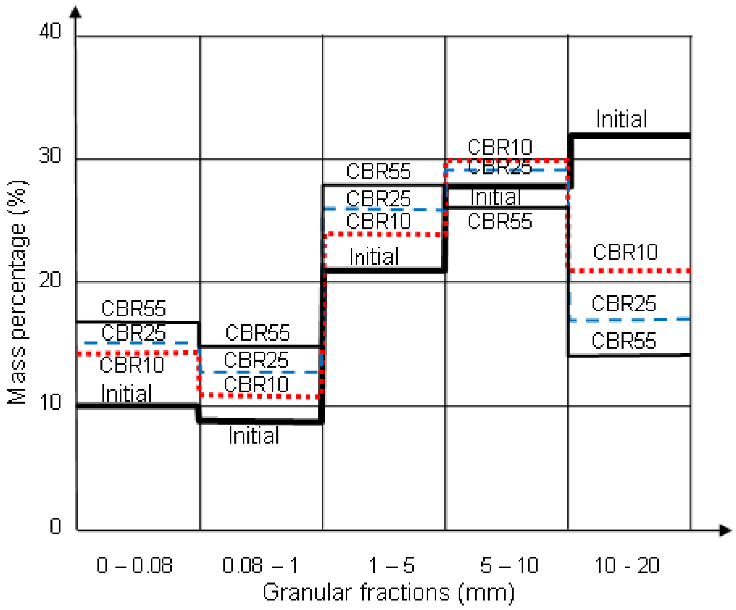


Fig. 3. Average variation of granular fractions of 0/20 mm Lam-Lam laterite during CBR compaction

The concretion hardness index $I_{HC}$ defined by Novais-Ferreira and Correira (1965) confirms this evolution. This index is the ratio of the sum of oversize fractions on 1"- 3/4"-1/2"-3/8"-N°4- N°10- N°40 and N°200 sieves, before and after compaction. These authors compared the situation before and after a modified Los Angeles test, but the same definition was later used for usual compaction CBR tests. On a given sample, this hardness index decreases when the applied compaction energy increases. The mean values for the ten samples are 0.9, 0.86 and 0.83 respectively after 10 blows, 25 blows and 55 blows compaction.

Table 2. Mean changes of Lam Lam laterite granular fractions before and after CBR compaction

| Granular fraction (mm) | 0 to 0.08 | 0.08 to 1 | 1 à 5 | 5 à 10 | 10 à 20 |
|---|---|---|---|---|---|
| Initial sample (0/20 mm) | 10 | 9 | 21 | 28 | 32 |
| After CBR compaction 10 blows | 14 | 11 | 24 | 30 | 21 |
| After CBR compaction 25 blows | 15 | 13 | 26 | 29 | 17 |
| After CBR compaction 55blows | 17 | 15 | 28 | 26 | 14 |

The fragmentability tests, which were performed on the 10/20mm fraction of the samples, show that the concretions of Lam Lam laterite have a low fragmentability ($I_{FR,average}$ = 3.57). The percentage of fines (passing at 80µm sieve) varies from 9.7 before compaction to 13.5 after 10 blows, 15 after 25 blows and 16.9 after 55 blows. These results suggest that the behaviour of the global 0/20mm material differs from that of the coarser fraction (10/20mm).

The degradability index has an average value of 1.10. The fragmentability tests made after the degradability ones show the influence of wetting - drying cycles on the durability of the 10/20mm fraction. In order to show the influence of these wetting-drying cycles on the evolution of the 10/20mm fraction, a rate of evolution τ was introduced, with the following definition:

$$\tau = \frac{I_{FR}(4) - I_{FR}(0)}{I_{FR}(4)} = 1 - \frac{I_{FR}(0)}{I_{FR}(4)},$$

where $I_{FR}(0)$ is the fragmentability index obtained on the 10/20mm fraction of the raw material (not submitted to wetting-drying cycles and $I_{FR}(4)$ the fragmentability index obtained on the 10/20mm fraction after 4 wetting-drying cycles. The results obtained from the tests are given in Table 3.

Table 3. Results of the fragmentability tests

| Identification of samples | $I_{FR}(0)$ | $I_{FR}(4)$ | τ |
|---|---|---|---|
| $L_1$ | 4.3 | 4.7 | 0.09 |
| $L_2$ | 4.7 | 4.7 | 0.00 |
| $L_3$ | 3.3 | 4.3 | 0.23 |
| $L_4$ | 3.6 | 4.7 | 0.23 |
| $L_5$ | 2.3 | 4.2 | 0.45 |
| $L_6$ | 2.4 | 4.2 | 0.43 |
| $L_7$ | 4.3 | 5.1 | 0.16 |
| $L_8$ | 4.5 | 5.1 | 0.12 |
| $L_9$ | 4.3 | 4.7 | 0.09 |
| $L_{10}$ | 2.0 | 4.4 | 0.,55 |

The results obtained on Lam Lam samples show that the evolution rate t is a decreasing function of $I_{FR}(0)$ (Figure 4).

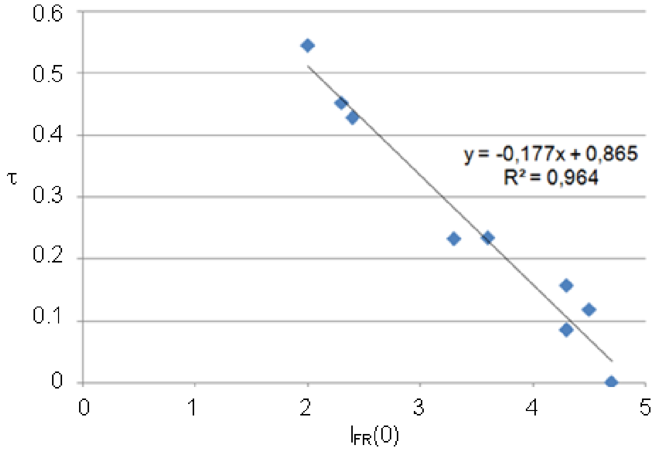


Fig. 4. Variation of the evolution rate τ versus initial fragmentability index

## 3. Behaviour of laterites from Sindia, Natal Airport and Picos quarries

Fourteen samples were taken from different places in Sindia quarry. Their average CBR index equals 61 and their average plasticity index is 17.6 (Table 4).

Table 4. Properties of Sindia lateritic gravel samples before compaction

| | Grain size analysis (%) | | | Fragmentability index ($I_{FR}$) | Degradability index ($I_{DG}$) | Plasticity index ($I_P$) | Proctor | | $I_{CBR}$ at 95% OPM |
|---|---|---|---|---|---|---|---|---|---|
| | 0.08 mm | 2 mm | 10 mm | | | | $w_{OPM}$ (%) | $\rho_d$ (g/cm$^3$) | |
| Average value | 14.3 | 26.0 | 75.6 | 6.71 | 1.09 | 17.10 | 11.3 | 2,1 | 61 |

These samples were submitted to CBR compaction, with increasing number of blows. The granular classes of the compacted samples are presented in Figure 5 and Table 5. As for Lam Lam samples, the larger particles are progressively transformed into smaller ones.

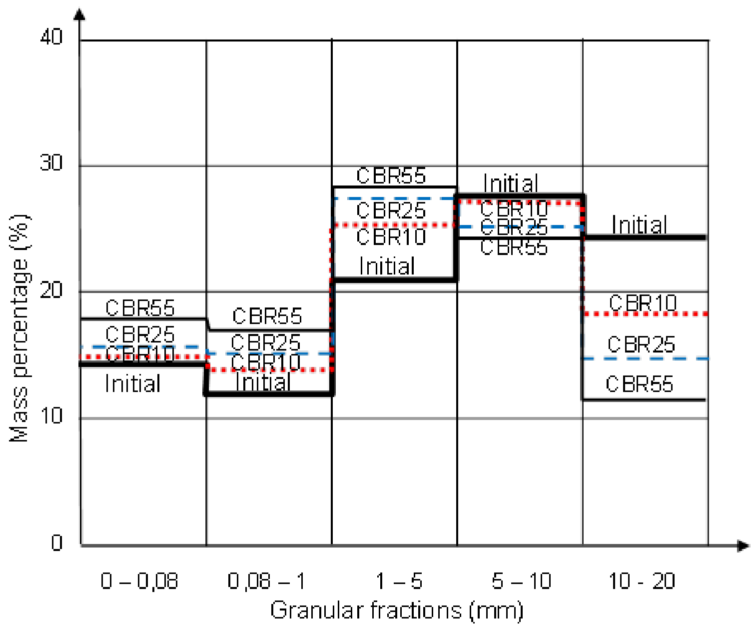


Fig. 5. Average variation of granular fractions of Sindia laterite during CBR compaction

Table 5. Average changes of Sindia laterite granular fractions before and after CBR compaction

| Granular fraction (mm) | 0 to 0.08 | 0.08 to 1 | 1 à 5 | 5 à 10 | 10 à 20 |
|---|---|---|---|---|---|
| Initial sample (0/20 mm) | 14.3 | 12.2 | 21.3 | 27.8 | 24.4 |
| After CBR compaction 10 blows | 15.1 | 14 | 25.5 | 27 | 18.4 |
| After CBR compaction 25 blows | 16.6 | 15.4 | 27.7 | 25.5 | 14.8 |
| After CBR compaction 55blows | 17.9 | 17.3 | 28.6 | 24.5 | 11.7 |

The laterites from Brazil are finer and less plastic than those from Senegal. Their mean properties are given in Table 6

Table 6. Properties of Natal Airport and Picos lateritic samples before compaction

| | Grain size analysis (%) | | Plasticity index ($I_P$) | Proctor (modified) | | $I_{CBR}$ à 95% OPM |
|---|---|---|---|---|---|---|
| | 0.075 mm | 2 mm | | $w_{OPM}$ (%) | $\rho_d$ (g/cm$^3$) | |
| Natal Airport | 19.2 | 98.5 | 1.3 | 6.9 | 2.12 | 45 |
| Picos | 24.8 | 50.3 | 5.7 | 10.9 | 1.92 | 31 |

Figure 6 and 7 and Tables 7 and 8 present the evolution of the granular classes of these laterites due to CBR compaction at increasing number of blows.

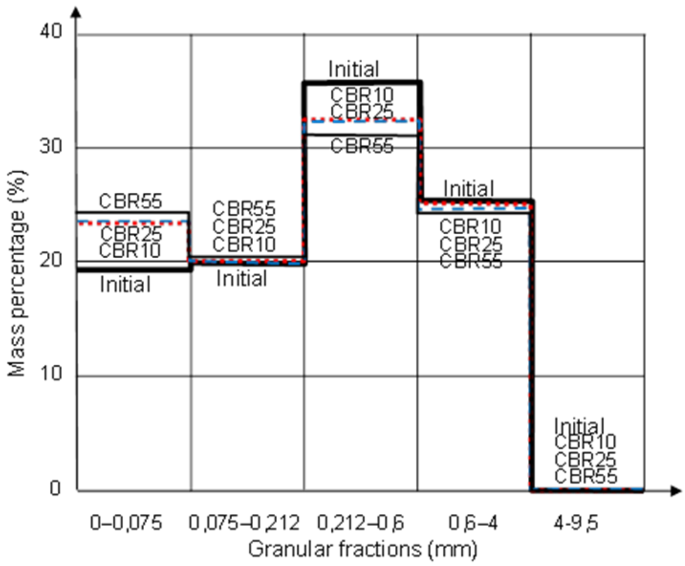


Fig. 6. Average variation of granular fractions of Natal Airport laterite during CBR compaction

Table 7. Average changes of Natal Airport laterite granular fractions before and after CBR compaction

| Granular fraction (mm) | 0 to 0.075 | 0.075 à 0.212 | 0.212 à 0.6 | 0.6 à 4 | 4 à 9.5 |
|---|---|---|---|---|---|
| Initial sample (0/20 mm) | 19.2 | 20 | 35.4 | 25.3 | 0.06 |
| After CBR compaction 10 blows | 22.7 | 20.4 | 32.3 | 24.6 | 0.04 |
| After CBR compaction 25 blows | 22.7 | 20.4 | 32.3 | 24.6 | 0.02 |
| After CBR compaction 55blows | 24.3 | 20.5 | 31 | 24.2 | 0.01 |

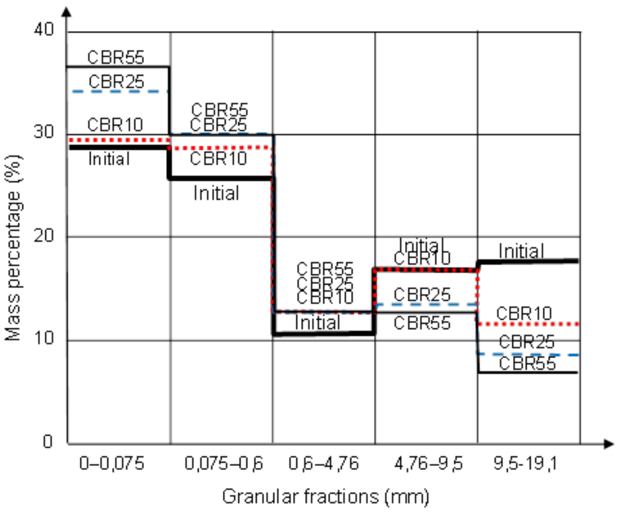


Fig. 7. Average variation of granular fractions of Picos laterite during CBR compaction

Table 8. Average changes of Picos laterite granular fractions before and after CBR compaction

| Granular fraction (mm) | 0 to 0.075 | 0.075 to 0.6 | 0.6 to 4.76 | 4.76 to 9.5 | 9.5 to 19.1 |
|---|---|---|---|---|---|
| Initial sample (0/20 mm) | 28 | 26 | 11 | 17 | 18 |
| After CBR compaction 10 blows | 29 | 29 | 13 | 17 | 12 |
| After CBR compaction 25 blows | 34 | 30 | 13 | 14 | 9 |
| After CBR compaction 55blows | 37 | 30 | 13 | 13 | 7 |

## 4. Conclusion

The results of CBR compaction tests on laterites from Senegal and Brazil highlight the sensitivity of lateritic concretions to compaction efforts. The modification of the CEBTP prescriptions from 1972 to 1980 reflects the importance of the reduction of particle size in lateritic gravels and sands. The mechanical properties of the compacted laterites depend on their final grain size curve and it was wise to ask for the determination of the grain size curve on compacted lateritic materials. Yet, this demand is troublesome for the designers, who still often prefer to determine the grain sizes of the raw material.

Rules for linking the compacted grain sizes to the initial ones would be of interest to simplify the design procedures. Such rules, which cannot be general because of the variability of laterites between continents, countries and even quarries, might be established at regional scale, with due account of the state, chemical properties and history of the laterite deposits. They could be stated in the future revision of the CEBTP rules for the design of roads in tropical and equatorial countries.


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