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Rationalization of the Use of lateritic soils in Low Cost Durable Pavement Base

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ABSTRACT. *Previous studies of the influence of texture, grain size distribution and mineralogy on the stability of materials used in pavement bases have shown that the mechanical behavior of lateritic soils is strongly influenced by their physical and mineralogical properties, as demonstrated by literature review researches and by the analysis of observations and knowledge gathered in Africa, as well as regional experience from Brazil, India and Australia. Development of new procedures for the classification of these soils as new building materials, that consider designs appropriate for humid tropical environments, the nature and state parameters associated with mechanical behaviour, can broaden the use of a higher percentage of local soils in pavement layers for low cost roads compared to traditional techniques.*

RÉSUMÉ. *Les études sur l'influence de la texture, de la granulométrie et de la minéralogie sur la stabilité des matériaux utilisés en plateforme de chaussées ont montré que le comportement mécanique des Sols Latéritiques est fortement influencé par leurs propriétés physiques et minéralogiques, comme le démontrent les recherches bibliographiques et les analyses empiriques portant sur l'expérience française dans le continent africain, ainsi que sur les expériences brésiliennes, indiennes et australiennes. Le développement de nouvelles procédures de classification et de nouveaux matériaux de construction, qui considèrent des conceptions appropriées au milieu tropical humide et aux paramètres de nature et d'état associés au comportement mécanique, permettent de prévoir l'utilisation de couches de chaussées de faible coût avec l'utilisation d'un pourcentage plus élevé de Sols locaux.*

KEYWORDS: tropical soils; lateritic soils; laterites; classification ; road.

MOTS -CLÉS : sols tropicaux ; sols latéritiques ; latérites; classification ; routes.

1. Introduction

The difficulty of classifying tropical soils located in areas where "the laterization process" has a fundamental importance on their physical, chemical and mechanical properties lies in the inadequacy of traditional systems to correctly predict the mechanical behaviour of these materials under the action of traffic and the environment. Classification systems such as those developed by the American Association of State Highway and Transportation Officials (AASHTO) and the Unified Soil Classification System (USCS) are not relevant when applied to some of these soils. Studies and practices have shown that recommendations based on these systems, particularly the activity of the clay fraction in the presence of water and the long term performance of gravel and sand fractions are not compatible with results observed in the field and laboratory.

In this paper we analyze, based on Brazilian, Indian and Australian national experiences and transnational experience from the African continent the influence of texture, grain size and mineralogy on the stability and classification of materials used in low cost pavement bases. A new procedure for the classification of lateritic soils is proposed.

2. Laterization process

The laterization process includes a set of phenomena that lead to a considerable degree of weathering of the initial rock, and an identification of elements such as silica and metal oxide hydrates or hydroxides, especially iron, aluminium, manganese and titanium [MAI 66].

This process may be followed by other soil processes such as dragging of hydroxides from the surface to a half-depth horizon; hardening of previously individualized and sometimes accumulated metal hydroxides in concretions or shells or armors ; segregation of elements of a horizon by hydromorphy [TUE 83] [SCH 09].

2.1. Influence factors

Factors that influence the laterization process are climate, topography, vegetation, bedrock, formation period with optimization by drainage conditions [AUT 83].

2.2. Geographic location of laterization process

A global census conducted by FAO shows that the lateritization process is localized in tropical regions (South America, Africa, India, Australia and South East Asia) (Figure 1) [FAO 06]. It is therefore mainly in developing countries where transport infrastructure development issues are vital.

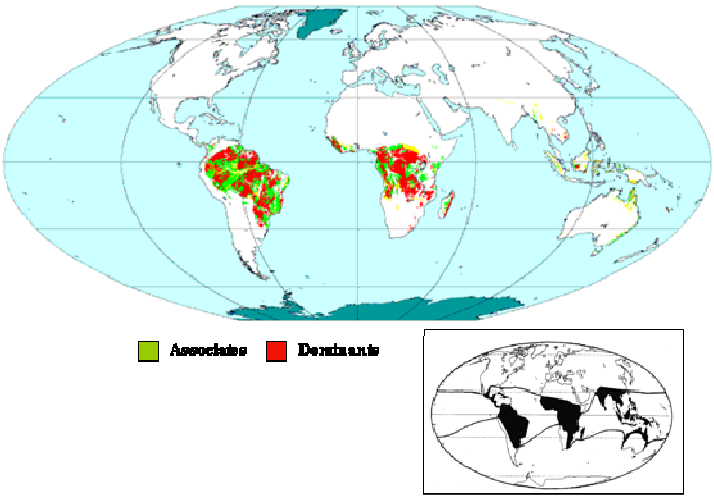


Figure 1. *Worldwide distribution of Lateritic soils (Ferralsols) [FAO, 06)].*

2.3. Product Release "Lateritic Systems "

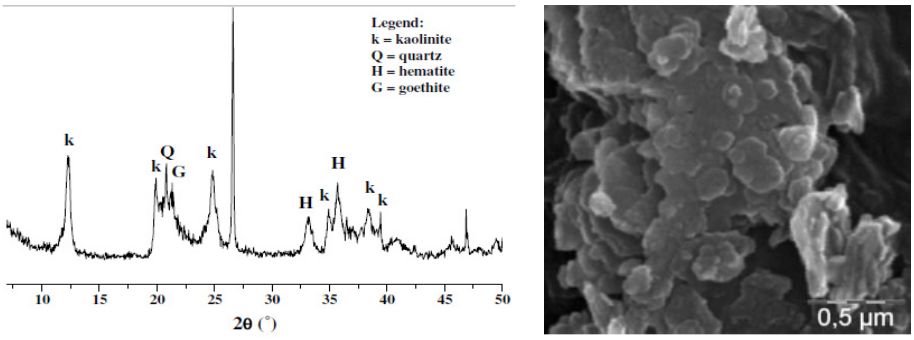
Lateritic soils used in civil engineering are characterized by a high degree of weathering of minerals from the original rock with elimination of almost all alkaline and alkaline-earth elements, and partial elimination of silica; advanced decomposition of organic matter and a varying accumulation of Fe, Al, Ti, Mn hydroxides and oxides. To this may be added, in varying degrees, the accompanying processes of leaching, accumulation of organic matter and induration [SCH 09].

2.4. Chemical composition of lateritic soil

A high percentage of the chemical components contained in Lateritic soils are Fe and Al oxides and hydroxides (iron and / or alumina oxides and hydroxides - sesquioxides) which can represent for some Gravelly lateritic soils nearly 80% of the laterization process products.

Generally in lateritic soils, these components do not exhibit the specific behaviours typically observed for clay minerals under tempered climates. Thus, although having a high surface area and small size, they do not present a swelling behaviour, have a negligible cation exchange capacity in the pH conditions prevailing in these soils and have an excess of positive charges (not negative as in the case of clay minerals) [GON 95], [VIL 09].

The microstructure of fine grained lateritic soils can be observed by scanning electron microscopy (SEM). The presence of relatively large "cloud" or "popcorn" shaped flakes, agglomerating clay particles and measuring from 1 to 2 and up to 50 to 100 mm in their largest dimension are observed (Figure 2).



(a) (b)

Figure 2. *Test results for lateritic soils from Cameroon (a) X-ray diffraction (b) SEM [LEC 09].*

3. Morphology of lateritic soils

The induration of samples depends on factors such as the components' degree of crystallization, the various constituent assemblages and the degree of aging.

The extremely varied structure can be reduced to three main types: hardened elements form a consistent and continuous skeleton. These indurated elements are concretions or nodules which are free in the middle of an earth mass and cement the pre-existing materials.

Their pigmentation is due to more or less hydrated iron oxides and sometimes manganese. The colour of the soil is mixed but generally of strong intensities. The most common colours are: pink, red, yellow, brown and ochre.

The density varies in relatively large proportions (2.5 to 3.6) and depends on the chemical composition of the lateritic soil. It increases with iron content and decreases with alumina concentration. Oxidized forms are denser than hydrated forms.

The evolution of rock towards the surface is characterised by different sets overlapping each other allowing to generally distinguish a set of weathering, a intermediate set of overall accumulation of metal oxyhydroxides and clay phases and a set of washed up upper crust of residual resistant primary minerals.

4. Pedogenic classifications

Lateritic soils can be classified in a synthetical or analytical manner. The first classification is based on genetic factors and on properties of factors or pedogenic processes. The second considers mainly morphological characters, including pedogenic concerns [MAI 66]. The main denominations are: Laterite, tropical soils, lateritic soils, ferruginous soils, lateritic soils, Soil Ferseallitiques, ferrisols, Ferrasol, Andosols, Oxisols, Podzols, Latossols and Plinthosols.

5. Geotechnical classification

5.1. Particle size ditribution

The particle size distribution of lateritic soils generally has:

- a high proportion of fines (below 80 μm sieve) from 10 to 40%;

- a refusal on the 2 mm sieve from 20 to 60%;

- a variable hardness of gravels in the same deposit which depends on the concretionned lateritic particles' maturity and on the amount of sesquioxide which predominates in the aggregate;

- frequently, grading curves present a step or a curvature indicating the absence of certain granular fractions. This step is between 8 and 0.2 mm;

- materials with hard iron-rich aggregates tend to have stable mechanical behaviours;

- In the granular fraction, the mineralogical composition of the silt fraction is generally simple, the predominance of quartz with the presence of lumps of clay appears clearly;

- The main constituents of the clay fraction (diameter less than 0.002 mm) can be classified as: clay minerals, iron and / or aluminum oxides and hydroxides and organic constituents.

5.2. Influence of test methodology on particle size distribution

The metastable structure of lateritic soils is sensitive to changes in levels of thermal energy and therefore so are their physical properties. In terms of size, drying causes an increase in particle size, leading the clayey and silty fractions to agglomerate up to the grain size of a sand due to the coagulation of iron oxide during heating [TER 58], [MOH 69], [LYO 71].

Because of the vulnerability of lateritic soils, an increase in mechanical energy results in an increase of the apparent maximum dry density and fine sand content, especially with the fraction in excess on the 80 μm sieve and for fine soils which have a low clay content and a high Fe_2O_3 content [NOV 72].

5.3. Plasticity limit

The influence of sesquioxides (Al_2O_3 and Fe_2O_3) in lateritic soils is responsible for a plastic behaviour which differs from the behaviour of soils under temperate climates. During testing, disintegration of particles and/or breakage of granular soil structure increases the surface area with consequently an increase in water absorption by the sample [MOH 69], [VIL 09].

5.4. Shrinkage limit

Knowledge of the shrinkage limit is important to predict whether lateritic soils, and especially their fine fractions, are likely to be subject, mainly in countries with well marked dry seasons, to shrinkage which could lead to cracking. It would then become preferable to keep them safe from moisture changes or even not use them without improvement or stabilization (Figure 3) [AUT 83].

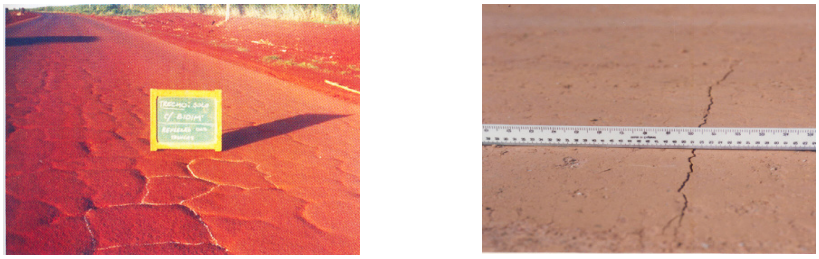


Figure 3. *Cracking on pavement made of fine and coarse lateritic soils [VIL 09].*

5.5. Durability

The strength and durability of hardened laterites depend on their chemical composition, age and homogeneity. The iron-rich hardened laterites are harder than those that are rich in alumina [LYO 71], [ENU 92].

The results of specific gravity and absorption measurements show a relationship with the durability of the coarse particles. The durability of coarse elements increases with weight. The behaviour of fine elements can be linked with the absorption and not with density. The durability of coarse and fine elements increases when the water absorption decreases.

5.6. Compaction characteristics

Factors influencing compacted lateritic soil properties can be separated into two groups [LYO 71]. The first group of these factors is related to soil genesis, the second relates to pretreatment methods applied prior to testing. The factors are:

- texture: the most important genetic factor;

-influence of the transformation of hydrated halloysite into méthalloysite due to oven drying;

- sample position in the soil profile (depth of the sample);

- erosion of concretionned lateritic gravel during compaction and the degree of laterization process maturity;

- for a given energy and for fine grained lateritic soils rather than gravelly soils, drying in the oven always gives higher maximum dry densities and lower optimum moisture contents, while soils at natural water content give the lowest maximum dry densities and the highest optimum water contents.

5.7. Bearing characteristics

For [IST 90] the stability and bearing capacity of lateritic soils depend on:

- the maximum grain size D;
- the sieving of 80 μm;
- the residue on the sieve of 20 mm;
- the step of the grading curve between 80 μm and 2 mm;
- plasticity;
- the nodule fragility (changes during compaction) and;
- The mineral nature of fine particles.

5.8. Resilient behaviour

In studies on fine and gravelly lateritic soils from south-eastern and northern Brazil, [MED 06] apply models described by the following formulas 1 to 3. The authors conclude, for this specific case, that formula 3 is most appropriate to explain the relationship of the resilient modulus as a function of the stresses acting on the specimen.

$$M_R = k_1 \sigma_3^{K_2} : \qquad \text{Formula [1]}$$

$$M_R = k_1 \sigma_d^{K_2} \qquad \text{Formula [2]}$$

$$M_R = k_1 \sigma_3^{K_2} \sigma_d^{K_1} \qquad \text{Formula [3]}$$

where k_1 and k_2 are the constants of the soil;

σ_3 : confining pressure;

σ_d : deviatoric stress.

6. Classification system for lateritic soils used in low cost paving platforms

Various studies show that it is possible to establish classification systems tailored to lateritic soils [FAL 93], [SHA 01] for use in low cost pavements based on nature and state parameters and mechanical properties. To do this, it is important that the testing procedures are compatible with the specificities of soils in tropical regions, the measured reference values to be adopted, and are consistent with the type of traffic on the constructed pavements [NOG 95], [VII 09].

Figure 4 illustrates the logical sequence of a proposed classification for lateritic soils based on numerous literature reviews and using as inputs nature and state parameters and the mechanical behaviour measured by laboratory testing.

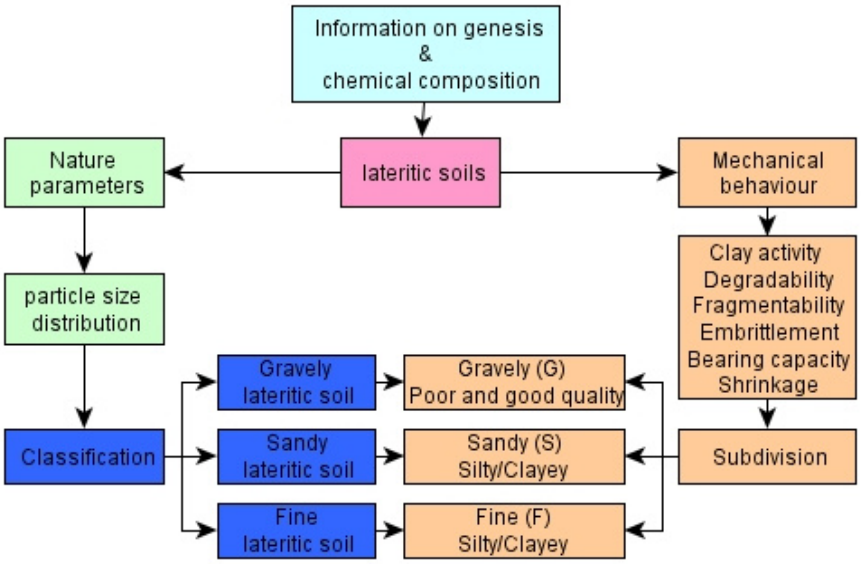


Figure 4. *Chart with the criteria for a proposed classification of lateritic soils*

In this method two aspects are considered: first, lateritic soils' metastable structure, sensitive to changes in levels of thermal and mechanical energy and secondly, physical and mineralogical properties (the influence of sesquioxides) compared to resistance, durability and plasticity.

Soils are classified according to their plasticity and particle size (gravelly, sandy or fine soil). Finally, classes are established based on the mechanical behaviour obtained from degradability, fragmentability, embrittlement, bearing capacity and shrinkage limit test results (Figure 5).

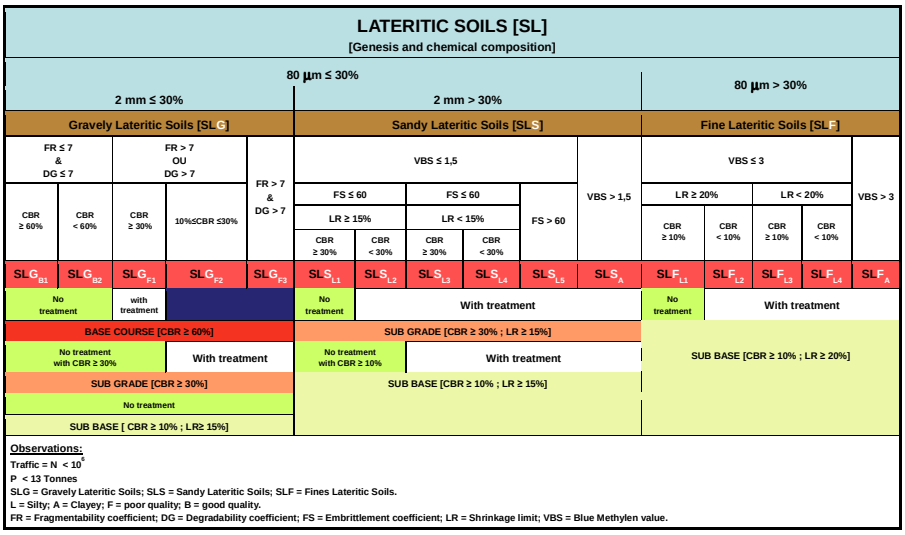


Figure 5. *Proposition of a classification system for lateritic soils used in low cost paving platform.*

At this stage of our study, creation of a database of cases will allow the validation of this new classification. This will be done in the framework of an international cooperation.

7. Conclusion

The new classification procedure proposed, which takes into account design criteria appropriate to tropical humid climates, specific nature and state parameters associated with the mechanical behaviour of lateritic soils, is expected to provide for much higher use of local soils in pavement layers.

This study is part of a growth policy leading to saving resources and optimizing the lifecycle of infrastructure adapted for emerging countries.

8. Aknowledgement

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