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Geotechnical characterization of Ivorian sedimentary basin soils used in road construction

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ABSTRACT: Quality materials have always interested road technicians. Quality in terms of compact soils capable of withstanding the loads due to road traffic. Previous studies have shown that laterite from decomposition of the source rock, for social-economic and environmental reasons, is often used in road construction. In Côte d'Ivoire, particularly in the south, few paved and unpaved roads are made from clay sands, present in the Ivorian sedimentary basin. Analysis of the clay sands of Samo and Grand-Lahou, revealed that in terms of particle size, despite the high proportion of coarse elements in the clay sands of Samo (66%) and those of Grand-Lahou (50%); these soils contain fine silty-clay matrices capable of creating solid bonds between the grains. Chemically, there are mainly three oxides: SiO_2, Al_2O_3 and Fe_2O_3. The ratio of oxides (S/R) is greater than 2. According to the classification, these are sands corresponding to non-lateritic soils. Mechanical analyzes have shown that these soils must be treated with hydraulic binders before they can be used in pavement layers.

KEYWORDS: Aboisso, Grand-Lahou, Samo, clay sand; Limits of Atterberg, CBR; mechanical properties, physical properties.

1 INTRODUCTION

The road is a means of communication whose proper functioning promotes strong urbanization and accelerated economic development. Its installation results from the superposition of several layers going from the bottom to the top. The seat layer is the part most exposed to mechanical stress. Its role is to transmit attenuated stresses to the other lower layers, namely the form layer and the platform layer **Invalid source specified.**[1]. It is therefore a fundamental element on which the age of a road depends. In Côte d'Ivoire, it is generally made from lateritic soils which meet a well-defined specification (CBR ≥ 80%, dry density ≥ 2, percentage of fine ≤ 35% and the plasticity index ≤ 15%) in order to guarantee the quality of the road (**Invalid source specified.**[2] and [3]**Invalid source specified.**). Unfortunately, most of the roads made from lateritic soils deteriorate at an early stage with emphasis in the coastal region, in the Ivorian sedimentary basin. Indeed, the great climatic diversity which reigns in this region (tropical and highly humid) significantly affects the quality and sustainability of the local raw materials used for road construction. The main effect of this climatic diversity is the excessive production of very humid fine soils characterized by a relatively low CBR index.

Several studies ([1], [4], [5] and [6]**Invalid source specified.**) have shown that the physical and mechanical properties of certain fine soils can be improved by hydraulic binders (cement or lime) under certain conditions. These include sensitivity to swelling, clay content, water stability.

This work aims to determine the physical, chemical and mechanical properties of the clay sands of the Ivorian sedimentary basin, mainly the soils of Samo and Grand-Lahou in order to assess the possibility of using them in road construction.

2 MATERIALS AND METHODS

2.1 RAW MATERIAL COLLECTION SITES

The raw material used was taken from the Samo and Grand-Lahou regions (Fig. 1). The Samo region is in the southeast of Côte d'Ivoire between latitudes 6 ° 00 ’and 5 ° 00’N and longitudes 4 ° 00’ and 3 ° 00’W. It is limited to the northeast by the region of Aboisso; to the west by the Abidjan district and to the east by the Adiake region.

Grand-Lahou is a city in the Ivory Coast in the department of Grand-Lahou. It is in the south of the country, on the edge of the Gulf of Guinea, at the mouth of the Bandama River. Grand-Lahou is located between latitude 5°08'07.9 "N and longitude 5 ° 01'26.3" W.

The raw material samples were taken at a depth of 10 meters for all the sites.

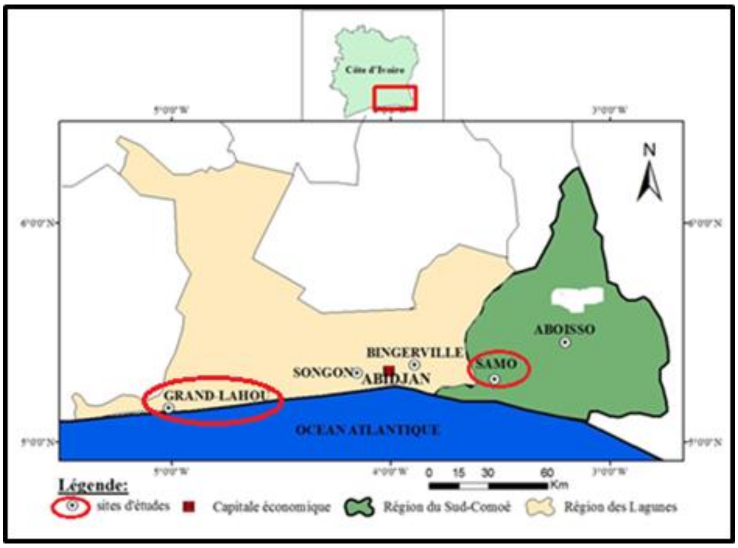

Fig. 1. Main raw material sampling site

2.2 SAMPLING

Sampling is the operation which aims to take a fraction of a material so that the sample taken is representative of the whole mass. All the tests to be performed depend on the care taken in carrying out the sampling. The sampling of the various raw materials was carried out using a sampler according to standard NF EN 932-2 **Invalid source specified.** [7].

2.3 PHYSICAL TESTS

2.3.1 GRANULOMETRIC ANALYSIS

Enough quantity of raw material (2 000 g) was used to determine the granular distribution of the different soils studied. The particle size analysis was carried out by sieving on the grainy fraction (grain size > 80 mm) and by sedimentation for the fine fraction (grain size < 80 mm) in accordance with standard NF EN ISO 17892-4 **Invalid source specified.** [8].

2.3.2 LIMITS OF ATTERBERG

The purpose of the test is to determine the water contents located at the border between the 3 states of matter: solid, plastic and liquid. The liquidity limit (W_L) was measured according to the Casagrande disc method and the plasticity limit (W_P) was determined by the roll method in accordance with standard NF EN ISO 17892-12 **Invalid source specified.** [9].

2.3.3 METHYLENE BLUE TEST

This test is to determine the clay content of soils. The test was carried out in accordance with standard NF EN 933-9 **Invalid source specified.** [10].

2.3.4 Modified Proctor test

The optimal water content (W_{OPM}) and the maximum dry density (γ_{dOPM}) were determined according to the standard NF P 94-093 **Invalid source specified.** [11].

2.3.5 Chemical characteristics

Chemical analysis consisted in determining the minerals contained in the soil samples after they had been placed in acid solution. The samples were then assayed using atomic absorption spectrometry.

2.3.6 Mechanical tests

The CBR bearing test was carried out in accordance with the standard NF P 94-078 **Invalid source specified.**[12]. Test samples were immersed in water for four days before being stamped on a universal press SEDITECH.

3 Results And Discussions

3.1 Physical properties of studied soils

3.1.1 Granulometric analysis

The results of the particle size analysis of the Grand-Lahou and Samo soils are presented below (Fig. 2). This figure shows that the soils of Grand-Lahou consist of about 50% of sand packed in a matrix of fines composed of 20% silt and 30% clay. While Samo's soils consist of 4% gravel, 62% sand, 14% silt and 20% clay. The proportion of fines from Samo soils is 34% compared to 50% from fines for Grand-Lahou soils. This suggests that the soils of Grand-Lahou will have a higher water retention capacity than the soils of Samo given their proportion of fines **Invalid source specified.**.

Fig. 2. Particle size analysis curves of studied soils

The projection of these different soils in Casagrande's textural triangle makes it possible to classify the soils of Samo in the category of clay sands and those of Grand-Lahou in the category of sandy clays (Fig. 3). These soils belong to classes A and B according to the classification of soils adopted in the Road Earthwork Guide [14].

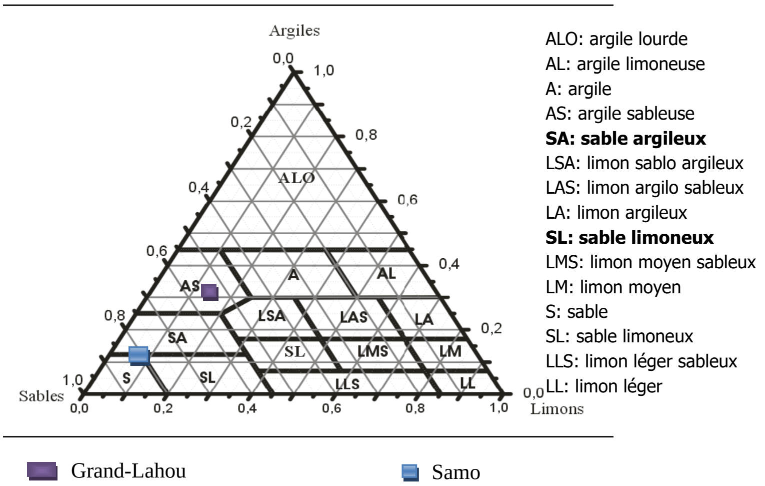

Fig. 3. Classification of studied soils in the Textural Triangle of Casagrande

According to this classification, taking passers-by into the 80 µm sieve, Grand-Lahou soils could belong to subclasses A1, A2, A3 and A4 because their proportion of fines is between 35% and 100%. Whereas, Samo soils could belong to subclasses B5 and B6 because their proportion of fines is between 12% and 35%. The two soils contain more than 50% of coarse elements, i.e. sand and gravel. They therefore belong to the family of grainy soils **Invalid source specified.**. In the creation of a road structure, the desired floors must have a high resistance to traffic and a low sensitivity to water [13]**Invalid source specified.**.

3.1.2 LIMITS OF ATTERBERG

Limits of Atterberg determination test are shown in Table 1. The values are higher for the Grand-Lahou soils than for the Samo soils. This is explained by the higher clay content of the soils of Grand-Lahou.

The projection of the Atterberg limits of these soils in the Casagrande plasticity diagram **Invalid source specified.** [14] indicates that the soils studied are of a plastic clay nature and belong to subclass A3.

Table 1. Values of Atterberg limits of studied soils

	Soils of Samo	**Soils of Grand-Lahou**
Liquidity limit (%)	$46{,}2 \pm 0{,}7$	$47{,}4 \pm 0{,}5$
Plasticity Limit (%)	$23{,}2 \pm 0{,}3$	$23{,}9 \pm 0{,}4$
Plasticity index (%)	$23 \pm 0{,}2$	$23{,}5 \pm 0{,}2$

3.1.3 METHYLENE BLUE TEST

The results are presented in Table 2. The soils studied correspond, according to the classification **Invalid source specified.**[14], to poorly plastic sandy-silty soils because the values obtained are between 0.2 and 1.5. Similar results have been obtained by Rahman [15]**Invalid source specified.** on lateritic soils in Nigeria.

Table 2. Methylene blue values of studied soils

Soils of	**Values obtained**
Samo	0,2
Grand-Lahou	0,6

3.1.4 MODIFIED PROCTOR TEST

The results of the modified Proctor test on the different soils are presented in Table 3. The dry density of the Samo and Grand-Lahou soils is of the same order of magnitude (difference of less than 1%). On the other hand, the difference is greater in terms of the optimal water content. The soils of Grand-Lahou have 10% higher water contents than those of Samo. The high content of fines in Grand-Lahou soils compared to Samo soils can justify this difference [13].

Table 3. Values of dry density and optimum water content of studied soils

Soils of	Dry density (g_{dOPM})	Optimal water content (W_{OPM})
Samo	$1{,}89 \pm 0{,}02$	$14{,}32 \pm 0{,}1$
Grand-Lahou	$1{,}88 \pm 0{,}03$	$16{,}02 \pm 0{,}2$

3.2 CHEMICAL PROPERTIES OF STUDIED SOILS

Chemical tests were used to determine the different proportions of oxides in the soils studied. The results of the chemical analysis of different are shown in the table below.

Table 4. Oxides content of different soils

Soils of	Mass percentage of the elements dosed				
	% SiO_2	% Al_2O_3	% Fe_2O_3	% TiO_2	MgO
Samo	56,91	16,04	12,09	1,01	0,03
Grand-Lahou	45,60	18,96	15,35	1,43	0,04

Table 4 shows that the soils of Samo are richer in SiO_2 than those of Grand-Lahou and relatively poor in Fe_2O_3. These results confirm those obtained on the physical characteristics of these soils. Indeed, the sand content of the soils of Samo was higher than that of the soils of Grand-Lahou. The presence of the couple (TiO2 + Fe2O3) in an amount greater than 5% justifies the red to ocher yellow color of these soils. In agreement with the works of Millogo and Ouedraogo [5]**Invalid source specified.**, the difference noted in the chemical composition of soil Samo and those of Grand-Lahou is linked to environmental factors that impact on the laterization process. Grand-Lahou is a coastal city while Samo is located far from the coast.

The degree of the soils studied laterization determined from the equations (1) and (2) below can be concluded that the soils studied are non-lateritic soils [5] (Table 5). The value of the S/R ratio being greater than 2.

$$\mathrm{Ki} = \frac{\frac{SiO_2}{60}}{\frac{Al_2O_3}{102}} \qquad \text{(Eq. 1)}$$

$$\frac{S}{R} = \frac{\frac{SiO_2}{60}}{\frac{Al_2O_3}{102}+\frac{Fe_2O_3}{160}} \qquad \text{(Eq. 2)}$$

Table 5. Values of the S / R and Ki coefficients of studied soils

Soils of	S/R	Ki
Samo	4,04	6,04
Grand-Lahou	2,25	4,09

3.3 MECHANICAL PROPERTIES OF STUDIED SOILS

The results obtained on the bearing tests are shown in Table 6. These results indicate that the soils of Samo have a better bearing capacity than those of Grand-Lahou. Samo soils have CBRs over 30% higher than Grand-Lahou soils. These differences come from the granulometry of these soils. Those of Samo with more gravel than the soils of Grand-Lahou. According to the criteria of acceptability of materials for road construction, Samo soils can be used as a form layer for traffic of less than 300 vehicles per day **Invalid source specified.** [16].

Table 6. CBR values of studied soils

Soils from	CBR		Equivalent layer	Types de route
	95%	98%		
Samo	20±0,1	27±0,3	Shape layer	T1
Grand-Lahou	14±0,3	17±0,4	Platform	-

4 CONCLUSION

According to the results obtained from the various tests, following conclusions can be made:

- Physical characterization tests of the soils of Samo and Grand-Lahou, show that these soils cannot be used without improvement or treatment in road construction. The values obtained are below the regulatory values.
- Physical tests however make it possible to classify these soils in the family of low-plastic clay sands, which augurs their ability to be improved by hydraulic binders.
- Bearing ratio test carried out on these soils allows us to conclude that Samo soils can be used as a form layer for low traffic pavements (<300 vehicles / day), unlike Grand-Lahou soils which cannot be used in its natural state in road construction.

The results obtained however make it possible to envisage the possibility of improving the physical and mechanical properties of these soils by hydraulic binders for their use in road construction.

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