Scientific Research Publishing

Open Journal of Soil Science, 2023, 13, 340-354
https://www.scirp.org/journal/ojss
ISSN Online: 2162-5379
ISSN Print: 2162-5360

Study of the Physical and Mechanical Characteristics of the Soil of Limbita 1 in the Guinean Coastal Area

Labilé Kolie[1], Simon Pierre Lamah[2], Alama Camara[3]

[1]Department of Civil Ingeenring, University Gamal Abdel Nasser of Conakry, Conakry, Republic of Guinea
[2]Department of Hydrology, University of N'Zerekore, N'Zerekore, Republic of Guinea
[3]Scientific Research Centre of Conakry-Rogbané (CERESCOR), Conakry, Republic of Guinea
Email: klabile2017@gamil.com

How to cite this paper: Kolie, L., Lamah, S.P. and Camara, A. (2023) Study of the Physical and Mechanical Characteristics of the Soil of Limbita 1 in the Guinean Coastal Area. *Open Journal of Soil Science*, **13**, 340-354.
https://doi.org/10.4236/ojss.2023.137015

Received: May 2, 2023
Accepted: July 25, 2023
Published: July 28, 2023

Abstract

Limbita 1 is a hilltop settlement in the rural town of khorira, the district of Dubreka. It is a land of the locality commonly called "limbita quarry", and widely converted by bricks manufacturers of Dubreka district and those of conakry area. However, no information about the characteristics of this land's soil is yet available. The soil's characteristics are then determined through the series of tests (granulometry, Atterberg limits, modified proctor, CBR, shear, odometric compressibility). These tests are carried out with samples derived from the site of Limbita within the area of Limbita 1. This work shows very consistent results that made it possible to deduce the very swelling nature of the soil.

Keywords

Characteristics, Physical, Mechanical, Coastal Area, Zone

1. Introduction

The choice of Limbita area as part of the soil study within the Guinean coastal side is motivated by the conakry and dubreka inhabitants' orientation towards there, in search of the adequate soil to building construction. The observation shows that most of buildings in these locations are not adapted to the climate conditions, in particular, the winds coming from sea loaded with salt particles, which gradually degrade concrete to be used for constructions.

The study in fact focused on the physical and mechanical characteristics identification of the soil within the Guinean coastal side, as part of thesis, that could serve as a source of information about the characteristics of the environment being visited by the earthen bricks' manufacturers.

Several studies have been carried out about the characteristics of soils and lands. In terms of environment, the raw earthen materials allow to minimise the environmental footprint of buildings, and are easily adaptable to climate conditions, particularly, in the coastal maritime areas, where the wind is loaded with salt vapours, known as a degrading factor in concrete constructions. In addition, the mechanical properties of the raw building materials undergo a degradation that is difficult to predict under the environment constraints. Also, the energy consumption during the life of buildings depends on different factor: the raw building materials, construction, the usage, the maintenance and demolition at the end of its life. Currently, for most buildings, almost all energy consumption is related to its exploitation (the usage) [1]. However, the evolution of the building towards high energy performance leads to an increase in the share of building materials to the detriment of the usage. The orientation towards utilisation of the composite materials is a factor to reducing the energy consumption and the émission of CO_2 [2].

There are dozen ways to using earthen materials for construction of buildings. The most common of which are: adobe, mud, earthenware with straw, cob, and compressed blocks and wallow [3]. Beyond this, several reasons justify the attention that the world of buildings' construction focuses on the utilisation of the composite materials based on soil and vegetable fibers. The composites are light, resistant and stainless, and are heterogeneous materials consisting of matrix and a reinforcement. The combination of two materials with different properties facilitates the obtention of a new material with extraordinary properties.

The project designers are costantly searching for new matirials that are lighter, more efficient, resistant, and less expencive. The reason for reinforcing a matirial is to be able to produce a structural material which is lightweight, resistant and rigid, in other words, having specific properties (ratio of strength, or the rigitity to very high density). It is important to imphasize that the rigidity of a material is not related to the density, since the separation of atoms resisistance is controled by the valence's electrons by the peripheral side not by the nucleus [4].

Different construction processes ixist in France: in Britain and in Normandy, the wallow supplants the other earthen construction methods. In the southeast, it is adobe; the molded earthen brick that allows to make masonry walls. In the North and East of France, the dominant technique is the mud-gathering, A mixture of soil and vegetable fibers maintained in a laod bearing framework, which is generally made of wood. In the region of Rhone-Alpes, the prefered technique is ramming, from the soil compacted between banches, using a scraper to produce the monolithic walls. The production and the implementations are extremly variable in terms of extraction and preparationof the materials used from the site [5].

In the developping countries, the earthen habitat may correspond to 50% of the rural population and around 20% of the urban and peri-urban population [5]. Moreover, the population of these countries tends to move away from the such modes of construction. In Burkina Faso, according to a study, mud construction is no longer accepted by the Ugandans, because of it is part of "the poor people's materials"; poorly designed buildings' construction that are not good examples; the high cost of labouring; the stabilization and the unsuitable design as well as a poor quality of the soil which leads to unsustainable construction. To make this happen, they believe that the promotion of BTC should be done through properly designed pilot buildings, that is to say, with walls of 44 cm uncoated thickness and a roof of 29 cm in stroller protected by an over-roof: and via bricklaying formations as well as the cours within the univesity.

For this author, the main cause of the earthen material's rejection and the different proposed approaches to popularize BTC are not exclusive but, invite to global reflection about the changes that should be made in the housing policy in Burkina Faso, in order to promote the local materials to the population [6]. In Sénégal, a study on the physical and mechanical propeties of soils within the coastal zone of Dakar, made recommandations for the construction of the sustainable buidings in the region [7]. In Cote d'Ivoir, another study also examined the physical and mechanical properties of coastal areas, particularly in the region of Abidjan. the study analyzed the soil properties to be used in road and building construction, and proposed solution to improve the sustainability of construction within the region [8].

Despite different results of reseachers on the earthen material utilizable for construction, earth as a material for building construction is part of solution. It is by improvingthese performances, through the utilization of secondary resources from industrial or agricultural sub-products, that the architect and the engineer can convince the population for which the soil has been, and remains a material of future building ithem [9].

The novelty of this study is the fact that it is concentrated specifically on the zone of Limbita in Guinea, where the inhabitants of Conakry and Dubreka look for the adequate soils for construction. This study thus provides important information about the physical and mechanical characteristics of the soil of this zone, together with the challenges of durable construction within this region.

Furthermore, the study is particularly relevant in the actual context of Guinea, where the durable urban planning has become a priority for the local authorities. This study in fact could contribute to the enhancement of urban planning within the region of Conakry, in providing the accurate information about the characteristics of soils from the Guinean coastal areas, together with recommendations for the durable constructions within this region.

2. Materials and Methods

2.1. Identification of Sampling Sites

The whole process began by the identification, the geo-localization of sampling sites as well as the description and collection of soil samples.

The site of Limbita 1 is located in the rural town of Khorira, at the mangrove side of Dubreka district. Dubreka is situated at the coast Atlantic Ocean about 10˚15'0"N of latitude and 13˚25'0"W of Longitude (voir **Figure 1**). This district is bounded among the southwest by the Atlantic Ocean, the south Conakry city, the east of Kindia and Coyah towns, the northwest of Boffa and north of Fria districts.

It comprises six (06) sub-districts: Bady, Falésadé, Khorira,Wassou, Tanènè and Dondon. Dubreka is characterized by flat land to the southwest, northwest and west by a sea tide. The relief is dominated by Mount Kakoulima with 1007 m height, Mount Dixinn or Elephant's head (530 m).

The District consist of plains, low hills on the coast with plateau and alluvial plains.

Dubreka district was chosen as the area for sampling because of its proximity to Conakry, and its high probability of lateritic soil, clay soil, and mangrove soil locality. The sampling side is chosen in Limbita after the rail-ways, on a top hill located at 9.878857 of latitude and 13.540083 of longitude. You will find below, **Figure 1** which presents the location map of this locality.

2.2. Collection of Samples

200 kg of soil is taken from the site as a sample.

To excavate the sample, the hoe, shovel and pickax were used to weed the soil

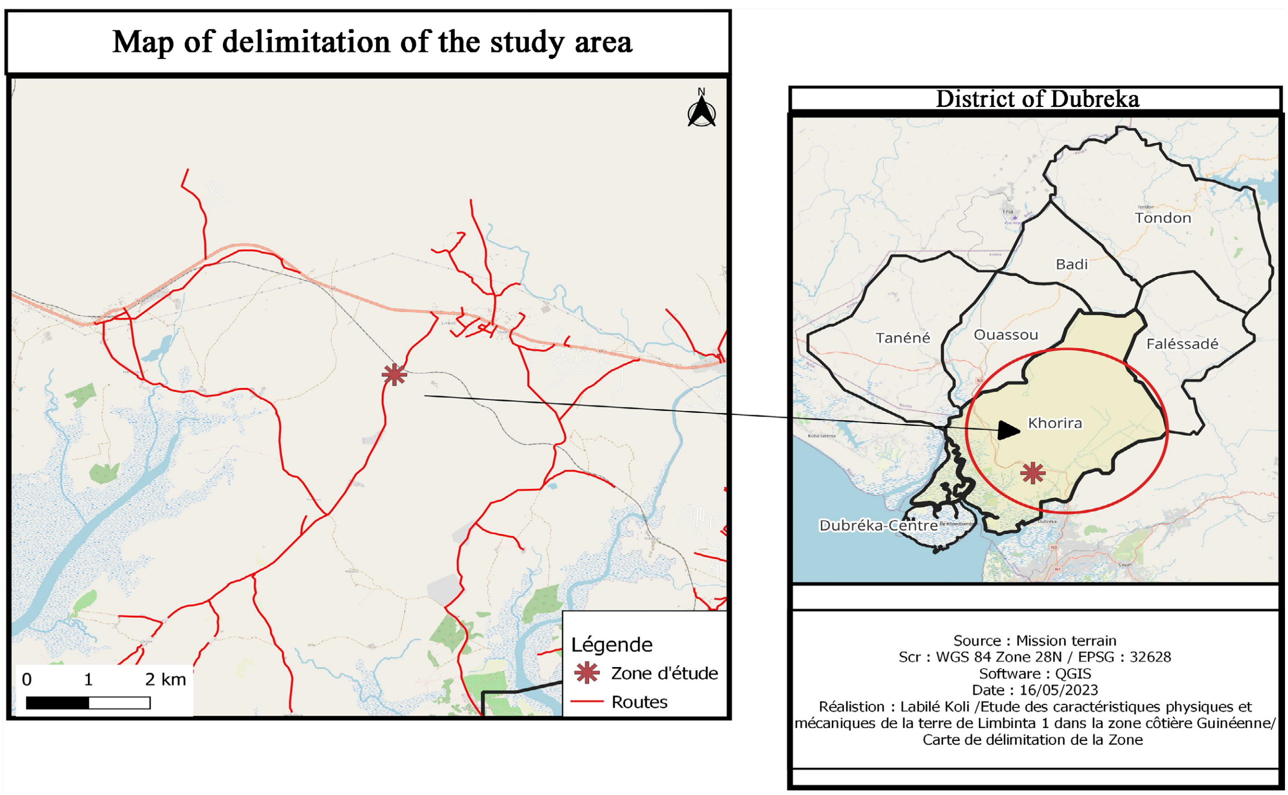

Figure 1. Map of localization of the study area.

from top to bottom on three fronts of Limbita 1 site. The sample collected from the three fronts are gathered, mixed and after three quartering series and a quantity of two hundred (200) kilograms of representative sample is placed in bags.

2.3. Laboratory Analysis

2.3.1. Particle Size Analysis

The particle size analysis by sieving is carried out according to the NFP standard of 94-056, using square mesh sieves with dimensions between 100 mm and 0.080 mm. For particles with dimensions less than 0.080 mm, is done by sedimentation according to standard of NFP 94-057.

Equipement:

- A washing device with sprinkler;
- A stackable sieve column with lid and bottom;
- A 0.01 g precision electronic scale;
- The bowls;
- The drying oven with adjustable temperature;
- Mortara with rubber pestle;
- Brushes.

Procedure:

- Sampling after quartering, to determine the net humid mass and the water content;
- Soaking of the sample to properly separate the particles;
- Washing with 0.080 mm sieve by 2.5 mm support sieve;
- stove drying;
- Screening;
- Weighing of refusals.

2.3.2. Atterberg Limite Tests

The Atterberg limit test is made of 0.40 mm loops. Sampling is done with undried material in the oven, a sufficient quantity of material has been sieved to obtain 150 g of mortar for each sample. Before sieving, the sample was soaked in water for 25 hours in a sealed container.

The sieving is carried out manually, by stirring the sample using a soft brush on the sieving cloth. The sieving process was accompanied by the addition of some washing water.

After decantation of the washing water, the water was carefully sponged off with precaution so as not to cause elements lesser than 0.40 mm, and then the sample was brought to the temperature room. The fraction of elements with the dimensions less than 0.40 mm (in the pasty situation) is subjected to the Atterberg limit test after drying and sieving.

1) liquidity limit WL (Casagrande method)

Liquidity limit WL is determined by using Casagrande instrument. A portion of sample is placed in cup, in which a groove is previously traced using V-shaped instrument. The cup is then subjected to a number of blows to close the groove by approximately 1 cm. The water content from the soil sample is then determined. The same test is repeated 4 times by decreasing water contents and such that the number of strokes through each test stay between 15 and 35.

The liquid limit is then determined from the graph of water content (W); as a function of the logarithm of the number (N) of corresponding strokes. By definition, the liquid limit (WL) is the water content (W) which corresponds to the closing of the groove over 1 cm in length within 5 strokes. As it is difficult to obtain the close at 25 moves, the liquidity limit is directly read on the graph for N = 25 moves.

2) Limit of plasticity

The WP plasticity limit (Rolling-test) is determined by the procedure defined in the standard of (AFNOR, 2002).

2.3.3. Modified Proctor

The purpose of the proctor test is to determine the water content to which the soil should be compacted to achieve the maximum dry density.

A 15 kg sample sieved using a 5 mm opening sieve was taken and divided into 5 heaps of 3 kg.

The materials that were used during the proctor test are:

- The proctor mold consisting of a cylindrical metal tube with an inside diameter of 10.15 cm and a height of 11.7 cm;
- The standard dame consists of cylindrical hammer 5.1 cm in diameter guided by a rod inside a sheath over certain centimeter in length. The weight of the harmer for the modified proctor is 2.49 kg and its drop height is 30.5 cm;
- Trowels and spatulas for mixing;
- A sensitive scale to the nearest gram, with a maximum capacity of, at least, 20 kg and a precision scale equal to 0.01 g;
- Tars and an oven with a temperature of 105˚C.

The implementation of proctor test began with the preparation of sample on the mixing table. The sample is first prickled with the quantity of water approximately necessary for the first compaction, then it is mixed to obtain a humidification uniform of the mass.

The compaction process is done in five successive layers about 2.5 cm thick, and each layer received 55 strokes from the dame. After compaction, the super and the specimen at the upper level of the mold are removed to weigh it for obtaining the weight of the sample to the nearest gram. Five identical samples underwent the same process with different quantity of water.

2.3.4. Testing: "California Bearing Ratio" (CBR)

The CBR testing operation began with the sieving of the samples using 5 mm aperture sieves. After sieving, 16 kg were measured and used during the test. The sample is weighed with the mold, then the quantity of soil that is put in the mold is determined after subtracting the weight of the mold. The volume of water used is that of the optimum proctor. This volume of water is added to the sample, then mixed, a (500 ml) hand of soil sample is placed in the mold to receive 55 strokes. Successively, five layers are compacted with the same number of strokes. After compaction, the sample is weighed together with the mold. The same procedures are repeated for 25 shots and 10 shots.

The next step was the immersion of the molds filled with compacted earth, for four (4) days. To measure the deformation of the sample, a comparator and a load are placed on the specimen, and then immersed together in water. After the four (4) days of immersion, the variation becomes readable, the mussel with their contents are removed from water. The samples taken from the tare, weighed are placed in an oven and then, reweighed to determine the water content.

2.3.5. Shear Testing

This test is carried out on three specimens made from the same soil. These specimens are each placed in a shearing box made up of two independent half-boxes, respectively under the loads: 1 stroke, 2 strokes and 3 strokes. The separation plan of the two half-boxes constitutes a sliding plan corresponding to the shear plan of specimen, that consist of:

- to apply on the upper face of the sample, a consistent vertical force kept throughout the duration of the test;
- after consolidation of the specimen for 24 hours under the vertical force, to produce shear of the specimen along the horizontal sliding plan of the two half-boxes one in function of the other, by imposing on both, a relative movement at a constant speed;
- To measure the corresponding horizontal shear force;
- To draw the intrinsic line (normal stress - shear stress);
- To determine the angle of the internal fraction φ(o) and the cohesion C (stoke).

2.3.6. Oedometric Compressibility Testing

This test is carried out on a specimen placed in a rigid cylindrical enclosure. A device is applied to this specimen exerts a vertical axial force, the specimen being drained at the top and at the bottom is kept saturated with water during the test.

The load is applied by the constant kept increments successively increasing and decreasing according a defined program. The variation height of the specimen is measured during the test after a load application time for 24 hours using two comparators. The average of the measurements of the variation in the height of the specimen is calculated.

3. Presentation and Analysis of the Results

3.1. Particle Size Analysis

The particle size analysis of the soil sample of Limbita1 gives:

- 31.2% of stone;
- 19.8% of sand;
- 49% of silt (Limon) and clay.

Table 1 and **Figure 2** present information on the different components of

Table 1. Particle analysis NF P EN ISO 94-056 & NF P 94-057.

Provenance: Limbita 1

Date of sample collection: 7 juin - 22

Date of test: 14 juin - 22

Operators; Labilé KOLIE & Souleymane CONTE

Classification
Norme NF P EN ISO 14688 - 2

Silty gravelly clayey soil

Tamis (mm)	20	16	12.5	8	5	2.5	1.25	0.5	0.25	0.125	0.08	0.044	0.023	0.011	0.006	0.003	0.001
Tamisât (%)	100	97	86	86	75	71	63	56	52	52	49	16	10	7	5	4	3

Cailloux (%)	Gravier (%)	Sable (%)	Silt & Argile (%)
0	31.2	19.8	46

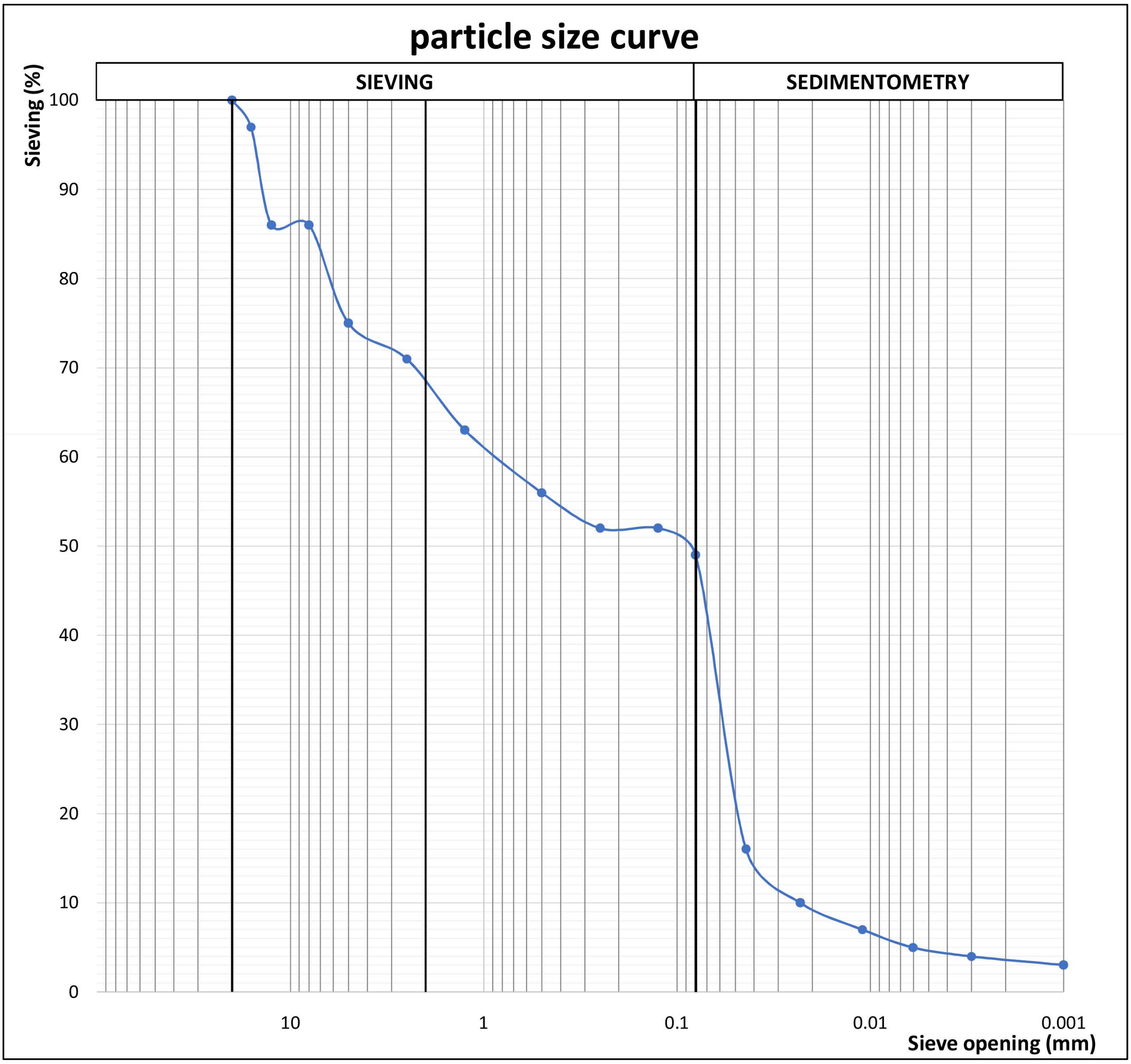

Figure 2. Particle size analysis sheet.

limbita earth 1.

The determination of the particle size composition is necessary to decide many practical questions and in particular, the precise naming of the soil according to the classification, which gives the possibility of judging the mechanical properties of the soil; it also makes it possible to calculate approximately the permutability, the assessment of the soil as embankment, dike, dam body, the choice of the optimum orifice for filters, the appreciation of lost soil as a building material and as an aggregate for concrete. **Figure 3** below shows the diameter of decreasing grains of a soil.

This graph shows the high content of the soil of Limbita1, in terms of clay with the presence of some silt and stone fractions, leading to classify the land in category of adequate soils.

3.2. Atterberg Limits

The Atterberg limits provide essential data on soil mechanisms. They consist of estimating the extent of the field of plasticity and possibly, the cohesion of more or less clayey soils, such as silt, clay and clayey sand. (Yaon, 2017). **Table 2** presents the bulk of the data on the Atterberg boundaries of Limbita 1 Land. **Figure 4** shows the curve of the Atterberg boundary test of this earth.

The analysis of the graph of the Atterberg limit tests of Limbita1 sample at 25 strokes gives the following water contents:

- The liquidity limit is 55;
- The plasticity limit is 27;
- And the plasticity indext is 28.

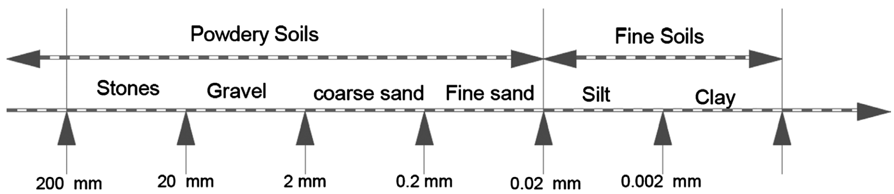

Figure 3. Particle size analysis sheet

Table 2. Water content (%).

Origin: Limbita 1 *Date of sample collection: 7 juin - 22* *Date of test: 14 juin - 22* *Operators; Labilé KOLIE & Souleymane CONTE*	*Classification* *Norme NF P EN ISO 14688 - 2* *silty gravelly clayey soil*			
Nomber of strokes	18	22	26	30
Water content (%)	56.38	55,63	54,9	54,16
Liquidity Limit WL (%)			55.0	
Plasticity Limite WP (%)			27.0	
Index of PlasticityIP (%)			28.0	

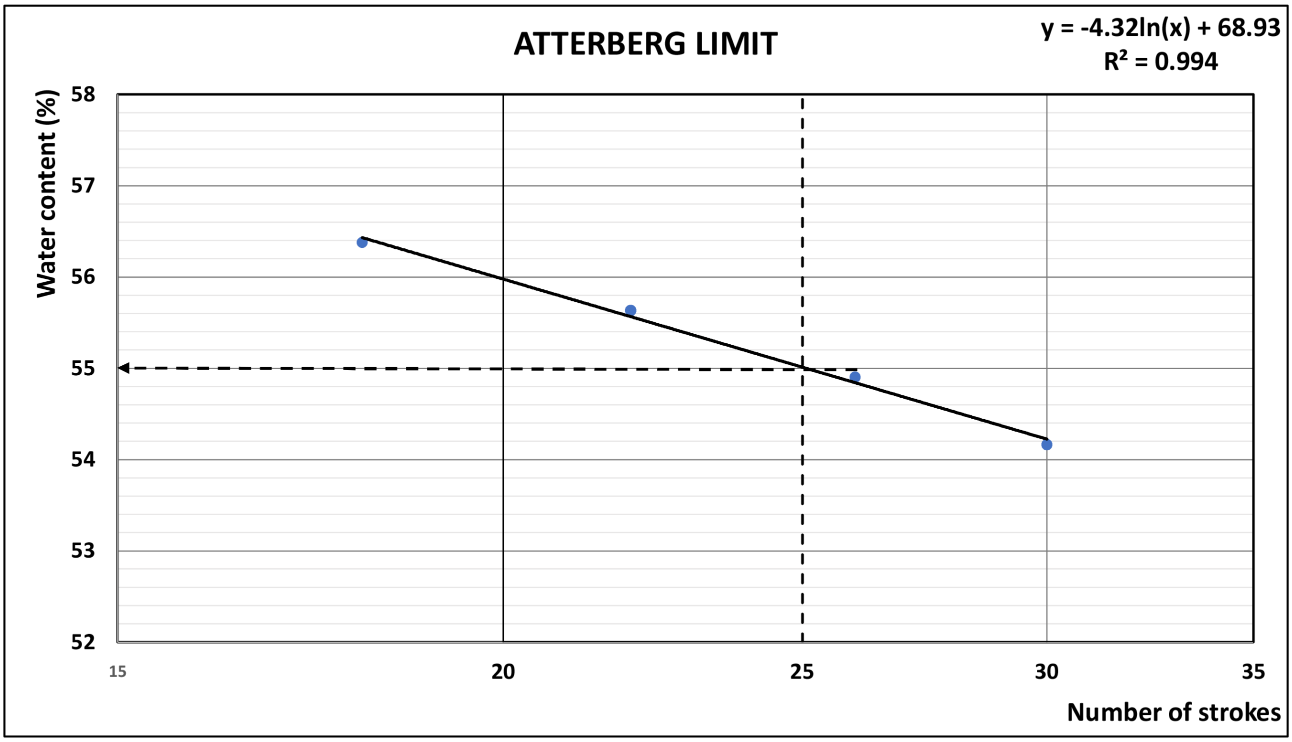

Figure 4. Atterberg limit testing sheet.

Table 3. Synthesis of particle size and Atterberg limit analysis.

Particle size analysis				Atterberg Limits		
sieve (%)				WL	WP	IP
50	20	2	0.08			
100	100	68,8	49	55	27.0	28.0

Table 3 above indicates the particle size and modified proctor analysis and Atterberg Limits which allowed us to determine the type of soil.

According to the NFP EN ISO 14688-21, the soil is the "silty gravelly clay soil" type.

3.3. Modified Proctor

Compaction changes the structure of the soil and the distribution of the soil seeds. This is done by using water with a controlled dosage as to reduce porosity. The purpose of the proctor test is to determine the water content with which a soil must be compacted to obtain the maximum dry density.

The proctor analysis gave us a maximum dry density of 1.594 g/cm^3 with optimum water content of 18.30/cm^3, which means, to have a maximum tightness of the seeds for a testing specimen. It must be made with the 18.30 content to the Proctor energy of this density. **Table 4** presents the data of the modified proctor test (Standard NF P EN ISO 14688-2) on Limbita land 1 and **Figure 5**: curve of the modified proctor test.

Table 4. Values of dry density and water content (modified proctor test).

Origin: Limbita 1		*Classification*			
Date of sample collection: 7 juin - 22		*Norme NF P EN ISO 14688 - 2*			
Date of test: 14 juin - 22					
Opérators; Labilé KOLIE & Souleymane CONTE		*Silty gravelly clayey soil*			
Nomber of strokes	14.42	15.9	17.71	19.52	21.06
Water content (%)	1.46	1.54	1.59	1.58	1.52
Optimum content				18.30	
Maximum density (g/cm^3)				1.594	

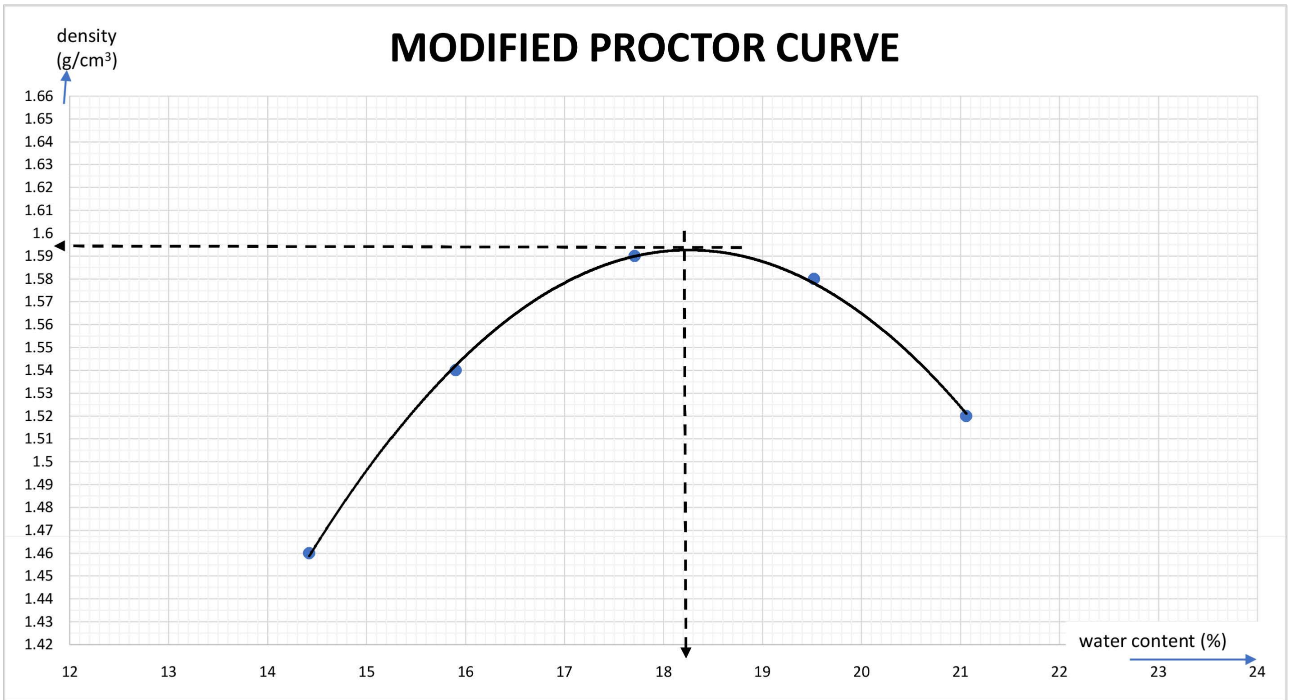

Figure 5. Modified proctor curve.

3.4. Testing: "California Bearing Ratio" (CBR)

The CBR testing measures the shear strength of a soil and the swelling of the soil when it is immersed in water for 4 days. It allows us to calculate the bearing capacity of the soil, knowing its punching resistance.

You will find below, **Table 5** of the CBR test to 95% OPM and the curve of CBR test about NF P 94-078 and **Figure 6** showing the curve of the CBR test NF P 94-078.

The CBR test of the sample of Limbita1 gives an index, bringing CBR to 95% of the optimum Proctor equal to 12. To this value corresponds a dry density of 1.514 g/cm^3.

For an energy of 55 blows per layer, and after four (04) days of immersion, a relative swelling of 0.19% is obtained. As for 10 strokes per layer, and after four

Table 5. CBR à 95% OPM-modified proctor test NF P 94-093 & CBR test NFP 94-078.

origin: Limbita 1	*Classification*				
Date of sample collection: 7 juin - 22	*Norme NF P EN ISO 14688 - 2*				
Date of test: 14 juin - 22					
Operators; Labilé KOLIE & Souleymane CONTE	*Silty gravelly clayey soil*				
a. PROCTOR					
Water content	14.42	15.9	17.71	19.52	21.06
Dry density (g/cm^3)	1.46	1.54	1.59	1.58	1.52
Optimum content			*18.30*		
Maximum content (g/cm^3)			*1.594*		
b. CBR			**Immersion 4 days**		
Nomber of strokes	CBR	Y_d (g/cm^3)	W (%) before	W (%) after	swel (%)
55	28.80	1.69	17.74	18.24	0.190
25	23.80	1.62	17.74	18.77	0.270
10	9.60	1.48	17.74	19.95	0.280
CBR à 95% OPM			*12*		

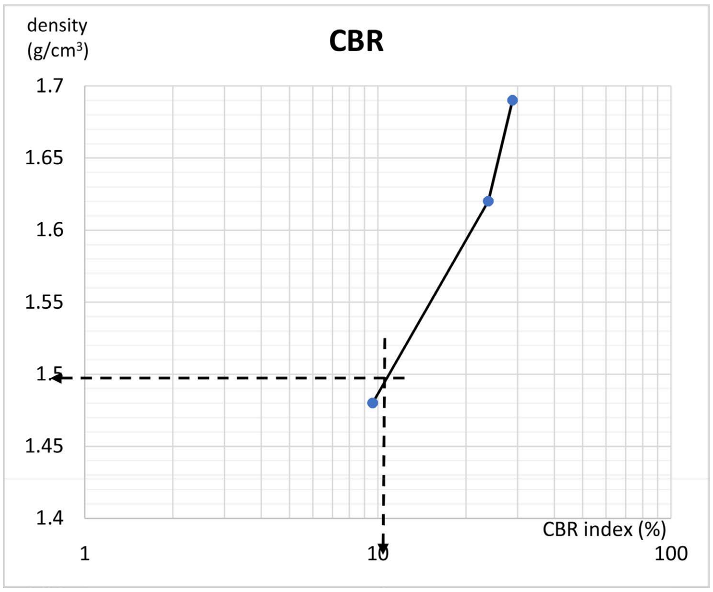

Figure 6. CBR test sheet.

(04) days of immersion, a relative swelling of 0.28% is obtained.

3.5. Shear Testing

The results of the shear test are given on the sheet (Table 6).

Figure 7 below shows the curve of the shear test.

The shear strength τ is parallel to the rupture plane (face of a material), in the other hand, the stress applied is constant and normal to it. The shear test of the sample taken from Limbita 1 gave a friction angle $\varphi = 26.70˚$ and a cohesion c = 0.209 bar. This ground is then essentially frictional.

3.6. Oedometric Compressibility Testing

The ability of a soil to shrink in volume under the action of external forces depends on the type, structure and condition of the soil. The oedometric compressibility test on the sample taken from Limbita 1 gave an initial void index

Table 6. Result of the straight shear test.

origin: Limbita 1 *Date of sample collection: 7 juin - 22* *Date of test: 14 juin - 22* *Operators; Labilé KOLIE & Souleymane CONTE*		*Classification* *Norme NF P EN ISO 14688-2* *Silty gravelly clayey soil*	
Test tube N˚	I	II	III
Normal constraint	1	2	3
settlement	0.081	0.198	0.138
Water content	21.05	22.84	20.86
Dry density	1.54	1.61	1.57
Shear strength	0.72	1.200	1.726
Friction angle φ (˚) = 26.70		26.70	
Cohesion C (bar) = 0.209		0.209	

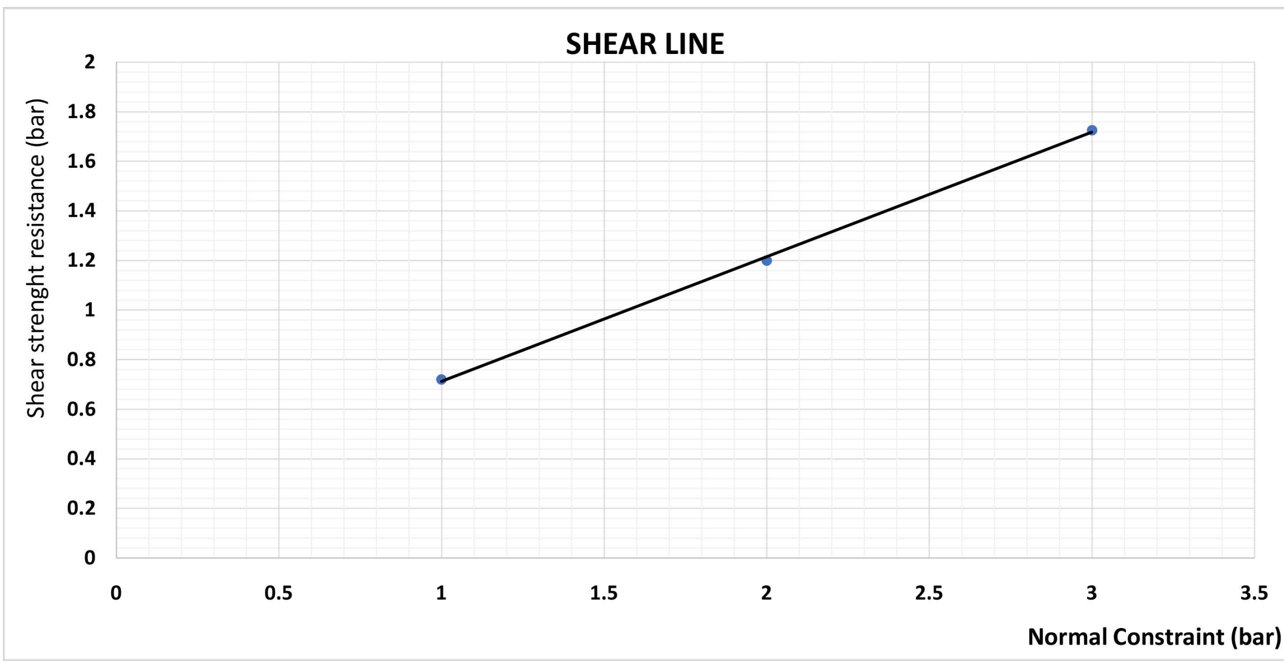

Figure 7. Shear testing sheet.

e_c = 0.970, a pre-consolidation pressure σ'_p = 1.794 storke, a compression index c_c = 0.0880 and a swelling index c_g = 0.0027 (Table 7).

Table 7. Result of oedometric compressibility test.

origin: Limbita 1 *Date of sample collection: 7 juin - 22* *Date of test: 14 juin - 22* *Operators; Labilé KOLIE & Souleymane CONTE*					*Classification* *Norme NF P EN ISO 14688 - 2* *Silty gravelly clayey soil*			
Constraint (bar)	0.05	0.31	0.62	0.62	1.25	2.5	5	10
Index of air space	0.970	0.965	0.958	0.958	0.944	0.917	0.870	0.803

Test tube characteristics	Results
Specific weight γ_s = 2.86 g/cm^3	Index fo the initial air space e_o = 0.970
Humid density γ_h = 1.76 g/cm^3	Consolidation pressure σ'_p = 1.794
Dry density γ_d = 1.47 g/cm^3	Index of compression Cc = 0.0880
Water content W(%) = 19.99	Index of swell Cs = 0.0027

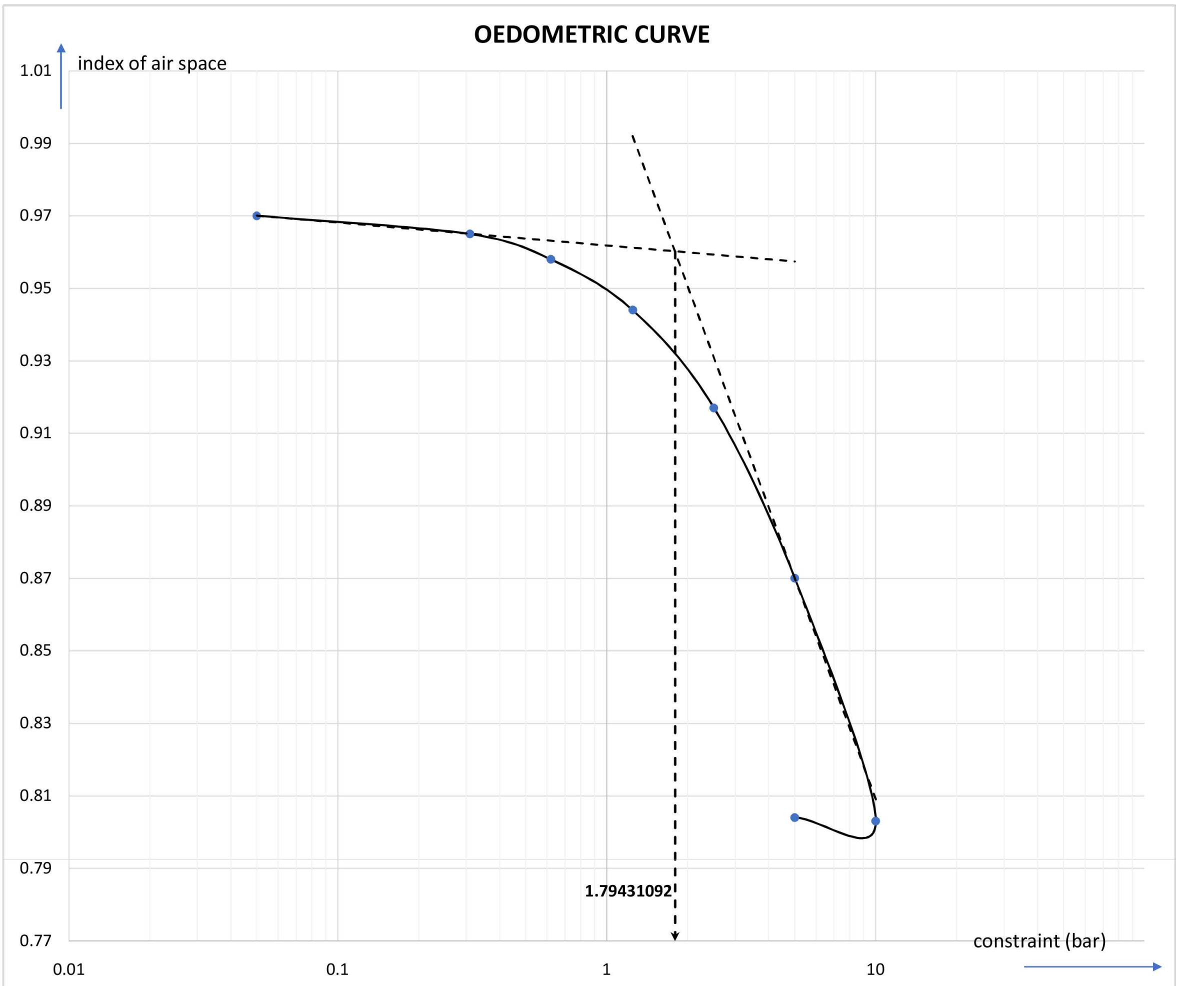

Figure 8. Oedometric compressibility testing sheet.

Thus from **Figure 8**, we determined the pre-consolidation constraint, vertical effective constraint and the index of initial voids.

4. Conclusion

Limbita 1 soil, highly coveted by bricks manufacturers in the district of Dubréka and Conakry area, now has its known physical characteristics. It should be noted that despite the performance in the practice of the manufacture of bricks, this soil is a very swelling material. This is not appreciable characteristic of the soil in fact. It deserves to be corrected for a good use in the building process.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Hallonet, A. (2016) Development and Caracterization of Composite Material Based on the Flax Fibers: Application to the Renforcement of Concrete Structures by the Externa Bonding. Ph.D. Thesis, University of Lyon, Lyon, p. 259.

[2] Phung, T.A. (2018) Formulation and Caracterization of Composite Vegetable Earthen-Fibres: Wallow. Ph.D. Thesis, University of Normandy, Rouen, p. 180.

[3] Houben, H., Guillaud, H., Dayre, M., *et al.* (2006) Reseach and Application Center for the Earthen Construction (Grenoble: Villefontaine). Work on the Earthen Building Construction. Éd. Parenthèses, Marseille.

[4] Gagné, V. (2011) Streamlined Use of Composite Materials in Overhead Power Transmission Lines. Faculty of Engineering, Department of Civl Engineering, p. 192.

[5] Villain, V. (2020) Sociology of the Raw Earthen Construction Site in France (1970-2020). Ph.D. Thesis, University of Lyon, Lyon.

[6] Paulus, J. (2015) Raw Earthen Construction: Qualitative, Constructive and Architectural Dispositions—Application to One practical Case: Ouagadougou. MSc. Thesis, University of Liège, Liège, p. 223.

[7] Sadio, M., Camara, I. and Aichet Seck et Madina Noblet (2019) Evaluation de la vulnérabilité du secteur de la zone côtière à la variabilité et aux changements climatiques dans la région de Fatick. Projet d'appui scientifique aux processus de plans nationaux et d'adaptation. 114pages.

[8] Bernadin, B.Z.P. (2008) Caractéristiques des sols latéritiques utilisées utilisés dans la construction des routes: Cas de la région de AGNEBY (Cote d'ivoire). Thèse pour obtention de Doctorant en Ponts et chausées143 pages.

[9] Luc COURARD (2021) Construction in Soil, Secondary Resources and Bio-Sourced: An Avenir for l'Afrique. Ph.D. Thesis, University of Liège, Liège.