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Study of the Physical and Mechanical Characteristics of Limbita Land 2 in the Guinean Coastal Zone

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Abstract

The article characterises the soil of the Limbita 2 plain (Dubréka, Guinea) to assess its suitability for producing adobe bricks. Standard geotechnical tests (particle size distribution, Atterberg limits, modified Proctor, CBR, direct shear, oedometer) were conducted. The results indicate a clay-silt-sand mixture with moderate plasticity (LL ≈ 35.8%, PI ≈ 19.8%), a maximum dry density of 1.80 g/cm^3, an optimum moisture content of 17.9%, a CBR value of 11, moderate shear strength ($\varphi \approx 29.7^{\circ}$, C ≈ 0.191 bar), and low compressibility. The authors conclude that the soil is suitable for earthen construction, provided that moisture is carefully controlled.

Keywords

Characteristics, Physical, Mechanical, Coastal Zone, Swelling

1. Introduction

Population growth and rapid urbanization in the Conakry and Dubréka regions are leading to an increased demand for accessible building materials adapted to local conditions. In this context, the clay soils of the Limbita area, located in the rural commune of Khorira, are actively sought after by mud brick manufacturers. However, despite their frequent exploitation, few scientific studies have been carried out to characterize these materials and assess their suitability for construction in a coastal environment subject to specific climatic constraints.

Indeed, concrete constructions in these areas are often exposed to salt-laden sea winds, which accelerate the phenomena of corrosion and structural degradation [1] [2]. This issue underlines the need to develop alternative materials that are more sustainable and better adapted to local conditions. Natural soils, combined with plant fibers, represent a promising avenue for the implementation of low-cost, ecological and climate-resistant composite materials [3] [4].

Research carried out on the lands of Kenendé, also located in the Guinean coastal zone, has shown that these soils have physical and mechanical characteristics favourable to the manufacture of bricks, with a low swelling potential and good cohesion [5]. Other studies have highlighted the interest of plant fibers as reinforcements in composite materials, in particular to improve mechanical strength and durability in humid climates [6].

The present study is part of a thesis entitled "*Study of the physical and mechanical characteristics of composite materials based on soil from the Guinean coastal zone and plant fibers*". It aims to fill the data gap on the soil properties of Limbita 2, by carrying out a series of geotechnical tests (particle size, Atterberg limits, modified Proctor, CBR, shear, oedometer). These analyses will provide a better understanding of the behaviour of these materials and their potential for use in sustainable construction.

The central issue can thus be formulated as follows: *To what extent can the land in the Guinean coastal zone, particularly that of Limbita, be used as composite materials for construction, taking into account climatic constraints and mechanical requirements?*

2. Materials and Methods

2.1. Sampling Sites

Sampling was conducted as part of the thesis to identify a site with clay-rich soil located in a lowland area. On each site, a homogeneous plot of 10 m × 10 m was delineated, and samples were collected from five points (four corners and the centre) at a depth of 0 to 30 cm. The sub-samples were homogenised to form a composite sample of approximately 6 kg, ensuring good spatial representativeness. The samples were collected on July 22, 2022. To directly determine the natural moisture content of the soil on site, we first carried out its complete drying. Then, we gradually added water to identify the water content corresponding to the soil's maximum strength, that is, the optimal moisture level.

The selected site, Limbita 2, is in the rural commune of Khorira, within the prefecture of Dubréka, on the Atlantic coast. It was chosen for its proximity to Conakry and the high likelihood of encountering diverse soil types. The geographical coordinates of the site are latitude 9.871402 and longitude 13.5414. However, the findings presented in this study are based on a single sampling site. For a more robust evaluation of soil variability across the region, future studies should include multiple sampling locations. Find **Figure 1** showing the location of the study area.

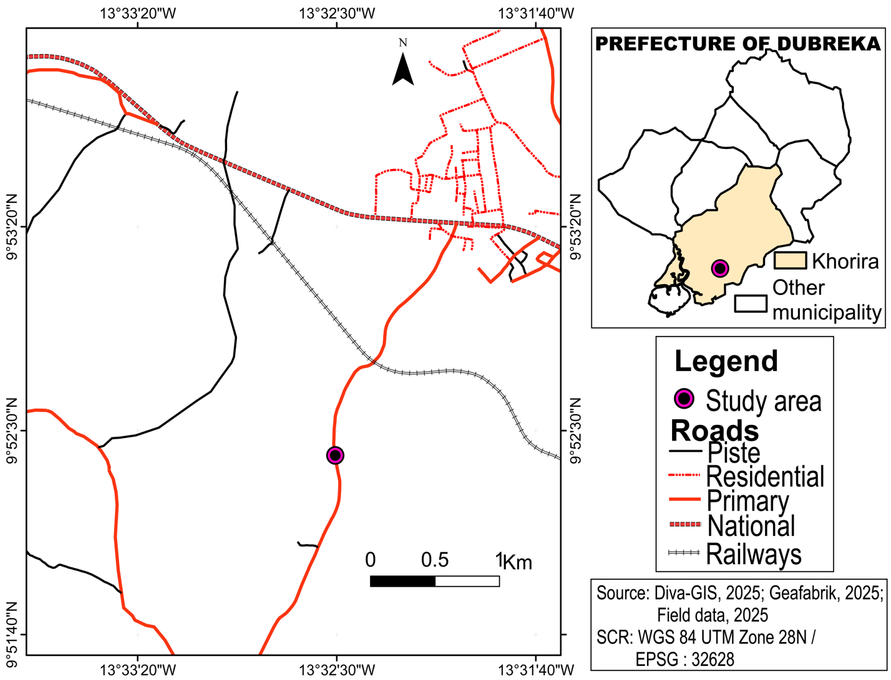

Figure 1. Location map of the area.

2.2. Sample Collection

During sampling, three 50 kg bags were taken from the site, including 2 bags for the Laboratory. To extract the samples, a hoe, a shovel and a pickaxe were used to scrape earth from top to bottom on three fronts of the Limbita 2 open quarry. The samples taken from the three fronts were collected, mixed and after three rounds of quartering, a quantity of 200 kilograms of representative sample was put into bags.

2.3. Laboratory Testing

2.3.1. Particle Size Analysis

The particle size analysis by sieving is carried out in accordance with the NF P94-056 standard. It uses square mesh screens that range in size from 100 mm to 0.080 mm. For particles smaller than 0.080 mm, the analysis is carried out by sedimentation according to the NF P94-057 standard.

Soil samples were collected using a composite sampling approach, homogenized, and reduced by the quartering method to obtain a representative sample of the site. The net wet mass and water content were then measured, after which the sample was immersed in water to promote particle separation. A wash is carried out using a 0.080 mm sieve placed on a 2.5 mm support screen. Once the wash is complete, the sample is placed in an adjustable temperature oven for drying. After drying, sieving is carried out using a column of interlocking sieves. The rejects obtained on each sieve are then weighed using a precision electronic scale (0.01 g).

The equipment used includes a washing device with sprinkler, a sieve column with lid and bottom, an electronic scale, bowls, a drying oven, a mortar with rubber pestle, as well as brushes and brushes for cleaning the sieves.

2.3.2. Atterberg Limit Tests

The Atterberg limit test is performed on particles with a diameter of 0.40 mm. Sampling is carried out on material that has not been dried in the oven, taking enough to obtain 150 g of mortar at each test set. Before sieving, the sample is immersed in an airtight container for 24 hours.

Sieving is done manually by stirring the sample over a sieve with a soft brush. During sieving, a small amount of wash water is added. After the washing water has been decanted, it is carefully siphoned off, so as not to carry away elements smaller than 0.40 mm. Then, the sample is brought back to room temperature. The fraction of elements with dimensions of less than 0.40 mm (in the paste-like state) is subjected to the Atterberg limit test after drying and sieving.

1) Liquidity limit WL (Casagrande's method)

The determination of the liquidity limit is done using the Casagrande apparatus. To do this, a portion of the sample is placed in a cup where a groove has been previously traced using a V-shaped instrument. Then, the cup is subjected to a certain number of blows in order to close the groove by about 1 cm. The moisture content of the soil sample is then measured. This process is repeated 4 times with decreasing water contents, so that the number of strokes on each try is between 15 and 35. The liquidity limit is then determined from a graph representing the water content (W), measured on each try, as a function of the logarithm of the number (N) of corresponding strokes. By definition, the liquidity limit (WL) is the water content (W) which corresponds to the closure of the groove over 1 cm in length in 25 strokes. Since it is often difficult to get the exact close in 25 moves, the liquidity limit is read directly on the chart for N = 25 moves.

2) Plasticity limit

The objective of the Proctor test is to determine the optimal moisture content to achieve the maximum dry density of compacted soil. For this analysis, a 15 kg sample, previously sieved using a size 5 sieve, was taken. It was then divided into five portions of 3 kg each, intended for different water contents.

The equipment used for the test includes a Proctor mould, consisting of a metal cylinder with an inner diameter of 10.15 cm and a height of 11.7 cm. Compaction is carried out using a standard drum, consisting of a cylindrical shell 5.1 cm in diameter, guided by a rod inside a scabbard. For the modified Proctor, the sheep has a mass of 2.49 kg and a fall height of 30.5 cm.

Additional equipment includes trowels and spatulas for mixing, as well as tools such as mallets, chisels, mortars and knives for demoulding. Two types of scales are used: a gram-accurate scale, with a minimum capacity of 20 kg, and a precision scale of 0.01 g. Tares and an oven that can be adjusted up to 105˚C are also required for drying the samples.

The implementation of the Proctor test began with the preparation of the sample on the mixing table. First, the sample was sprayed with an approximate amount of water needed for the first compaction. It was then kneaded to achieve uniform wetting of the mass. The compaction process took place in five successive layers about 2.5 cm thick, and each layer was compacted with 55 strokes of the queen. After compaction, the surplus was removed and the specimen was taken from the upper mould to be weighed to the nearest gram. This same process was repeated on five identical samples, but with different amounts of water.

2.3.3. Modified Proctor

The purpose of the Proctor test is to determine the moisture content at which the soil must be compacted to achieve the maximum dry density.

A 15 kg sample sieved using 5 mm opening sieves was taken and divided into 5 piles of 3 kg.

The materials used during the Proctor test are: the Proctor mould, consisting of a cylindrical metal tube with an internal diameter of 10.15 cm and a height of 11.7 cm; The standard lady consists of a cylindrical sheep 5.1 cm in diameter guided by a rod inside a sheath about a certain centimetre in length. The sheep weight for the modified Proctor is 2.49 kg and its drop height is 30.5 cm; trowels and spatulas for mixing; a scale that is sensitive to the nearest gram, with a maximum capacity of at least 20 kg and a balance with an accuracy of 0.01g; tars and an oven with a range of 105˚C.

The implementation of the Proctor test began with sample preparation on the mixing table. The sample is first sprayed with the approximate amount of water required for the first compaction, then it has undergone a kneading to obtain a uniform humidification of the mass.

The compaction process takes place in five stages, where each layer about 2.5 cm thick receives 55 strokes of the queen. Once compaction is complete, the top part of the mold is removed to weigh the specimen and obtain the precise weight of the sample, with an accuracy of one gram. This process is repeated on five identical samples, each of which has received a different amount of water.

2.3.4. California Bearing Ratio (CBR) Test

The CBR test operation began with the sieving of the samples using size 5 sieves. After sieving, a weight of 16 kg was measured and used for this test. The sample is then weighed with the mold, and the amount of soil put into the mold is determined by subtracting the weight of the mold. The amount of water used is that of the optimum Proctor.

This volume is added to the sample, which is then kneaded. Then, a quantity of soil sample corresponding to one hand (500 ml) is placed in the mold, and receives 55 queen strokes. Then, five layers, each corresponding to one hand, are compacted with the same number of strokes. After compaction, the sample is weighed with the mold. The same procedures were repeated for 25 and 10 shots.

The next step was to submerge the filled and compact mussels for four (04) days. To measure the deformation of the sample, a comparator and a load were placed on the specimen, and then the whole thing was immersed in water. After the four (04) days of immersion, the variations were read, and then the mussels with their contents were removed from the water. Samples taken from the mussels were weighed, put in the oven, and then reweighed to determine water content.

2.3.5. Shear Test

The shear test was carried out on three specimens made from the same soil, in order to evaluate its strength parameters. Each specimen was placed in a shear box consisting of two independent half-boxes. These devices were subjected to normal stresses of 1 bar, 2 bar and 3 bar respectively. The separation plane between the two half-boxes corresponds to the shear plane of the sample.

The test was carried out in the following steps:

- A constant vertical stress was applied to the top surface of each specimen throughout the duration of the test.
- A 24-hour consolidation phase was observed, allowing the ground to reach a state of stability under load.
- A horizontal displacement at a constant speed was then imposed between the two half-boxes, generating the shear according to the sliding plane.
- The induced shear force was measured as a function of displacement.
- The normal stress and shear stress values were used to plot the intrinsic line of the material.
- From this line, the shear strength parameters were determined: the angle of internal friction (φ, in degrees) and the cohesion (C, in bars).

2.3.6. Oedometric Compressibility Test

The test is carried out on a specimen placed inside a rigid cylindrical enclosure. A device is applied to this specimen to exert a vertical axial force. The specimen is drained at the top and bottom and kept saturated with water for the duration of the test. The load is applied gradually and constantly, following a defined program, loading and then unloading successively. Specimen height changes are measured during the test, after a period of 24 hours of load application, using two comparators. The average of the measurements of the variation in the height of the specimen is then calculated.

3. Results

3.1 Particle Size Analysis

Determining the particle size composition is essential for making practical decisions, including accurately classifying soil according to its classification. This makes it possible to evaluate the mechanical properties of the soil. In addition, it makes it possible to approximate the permeability of the soil, to evaluate its use as an embankment, dike or dam body, to choose the optimal size of the filters, to evaluate the use of soft soil as a building material and as an aggregate for concrete. **Figure 2** shows the diameter of grains de-crossing the soil.

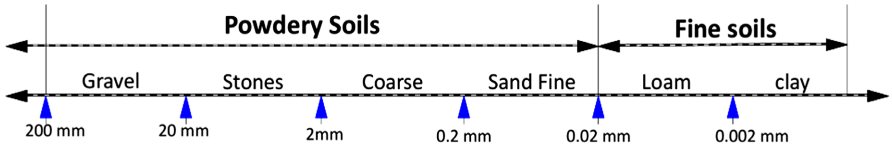

Figure 2. Decreasing grain diameter.

According to the particle size analysis of the sample from the Limbita 2 site, the proportions of the different types of particles are as follows:

- 2% gravel,
- 47% sand,
- 51% silt (silt) and clay.

The particle size analysis carried out on the sample taken at Limbita 2, according to the NF P 94-056 and NF P 94-057 standards, reveals a fine texture dominated by particles of dimensions less than 0.25 mm. Sieving shows that 51% of the grains pass through the 0.08 mm sieve and 30% through the 0.045 mm sieve screen, which confirms the sandy loam clay nature of the soil. This composition indicates good cohesion and shapeability, while suggesting reduced permeability. Classified according to the NF P EN ISO 14688-2 standard, this floor has characteristics favourable to the manufacture of mud bricks, although special attention is required in case of prolonged exposure to humidity, due to its potential for retention and moderate swelling. Figure 3 shows the particle size curve.

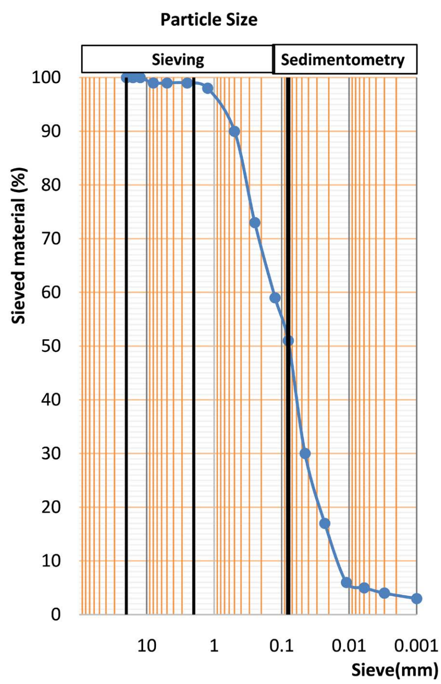

Figure 3. Particle size curve.

On analysis of Table 1, the earth of Limbita 2 is essentially composed of fines, with a high proportion of silt and clay (51%) and sand (47%), which indicates a cohesive texture suitable for use in construction.

Table 1. Limbita 2 earth component rate.

Pebbles (%)	Gravel (%)	Sand (%)	Silt & Clay (%)
0	2	47	51

3.2. Atterberg Limits

The Atterberg limits are a fundamental tool in geotechnics for characterizing the behavior of fine soils. They are used to assess the consistency, plasticity and water sensitivity of clay materials such as silts, clays and clay sands. These parameters are essential to anticipate the workability, stability and cohesion of soils in a construction context. According to the NF P 94-051 standard, the liquid limit (wL) corresponds to the water content at which the soil changes from the plastic to the liquid state, while the plasticity limit (w_P) marks the transition between the plastic and the solid state. The plasticity index (PI), defined as the difference between wL and wP, indicates the range of water content in which the soil can be worked without changing consistency.

These limits are particularly useful for assessing the suitability of soils for mud brick making or stabilization. For example, Ngoro-Elenga *et al.*, [7] recommend a liquidity limit of between 25% and 35% and a plasticity index of less than 20% for mud bricks improved with cement or lime. Similarly, Phung [6] points out that soils with moderate plasticity offer better workability and more stable mechanical strength in soil-plant fiber composite materials. Derfouf *et al.* [8] have shown that the liquidity limit strongly influences the compressibility of unsaturated clay soils, particularly in the shrinkage and swelling phases. Kacprzak [9], in his thesis on sand–clay mixtures, confirms that the mechanical properties of soils vary significantly according to their position between the Atterberg boundaries, which impacts their consolidation and shear behavior. Figure 4 shows the Atterberg limit test.

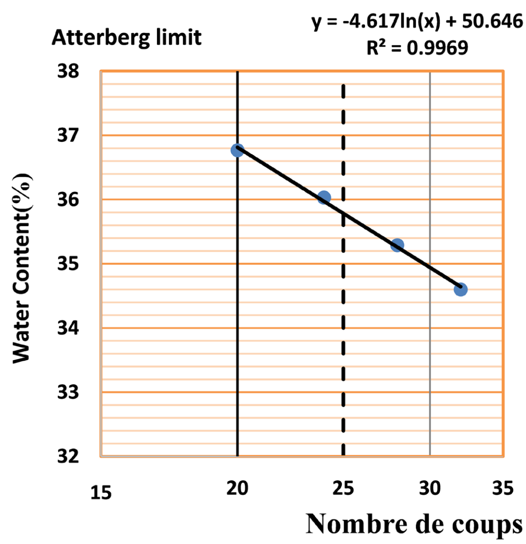

Figure 4. Atterberg limit test curve.

The graph of the Atterberg limit tests of the Limbita 2 sample, carried out with 25 strokes, reveals the following water contents: The liquidity limit is 35.8%. The plasticity limit is 16%. The plasticity index is 19.8%.

Table 2 presents the synthesis of the particle size analyses and the Atterberg limits, which allowed us to determine the soil type.

Table 2. Summary of particle size analysis and Atterberg limits.

Particle size analysis				Atterberg Limit			GTR Class
Thames (%)				WL	WP	IP	
50	20	2	0.08				
100	100	98	51	35.8	16.0	19.8	A2

The type of soil is fine clay sand, silt, clay and marl with very little plastic, arenas.

3.3. Modified Proctor

The Proctor changes the soil structure and seed distribution of the soil. This is done by using controlled dosing in order to decrease porosity. The objective of the Proctor test is to determine the moisture content at which a soil must be compacted to achieve the maximum dry density. Show below the modified Proctor Curve (Figure 5).

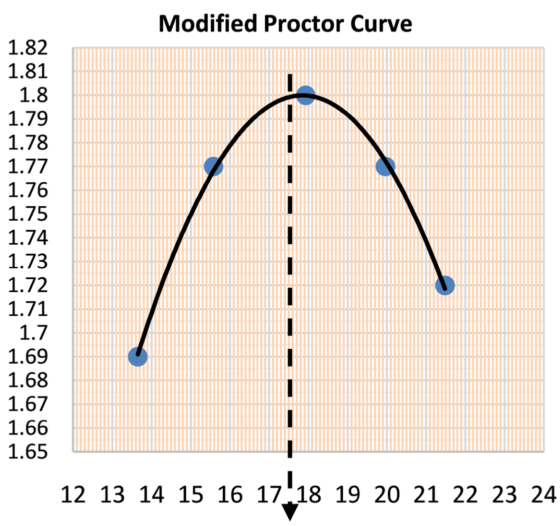

Figure 5. Modified proctor curve.

The Proctor assay revealed a maximum dry density of 1.80 g/cm3 with an optimal moisture content of 17.9%. This means that to achieve maximum compaction of the seeds in a test tube, it must be made with a moisture content of 17.9% and the energy of the Proctor must be used to achieve this density. Figure 5 shows the curve of the Proctor Modified test.

3.4. California Bearing Ratio (CBR) Test

The CBR test measures the shear strength of a soil as well as its swelling when it is immersed in water for 4 days. It also allows us to calculate the bearing capacity of the ground using its resistance to puncturing. Figure 6 shows the curve of the California Bearing Ratio (CBR) test.

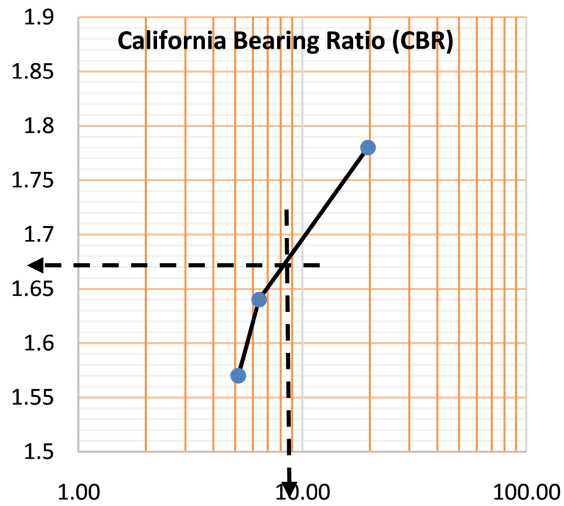

Figure 6. California bearing ratio (CBR) test curve.

The CBR assay of the Limbita 2 sample yielded a CBR index of 95% of the Proctor optimum, *i.e.* 11. This value corresponds to a dry density of 1.71 g/cm3. Using a compaction energy of 55 strokes per layer and after a four-day immersion, a relative swelling of 0.015% is observed. On the other hand, using only 10 strokes per coat and after an immersion of four (04) days, the relative swelling is 0.28%.

3.5. Shear Test

Figure 7 shows the curve of the shear test.

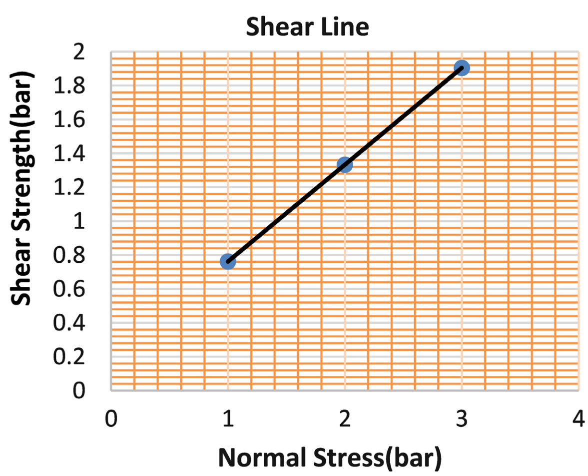

Figure 7. Shear curve.

The rectilinear shear test carried out on the silty-sandy clay soil of Limbita 2 determined an internal friction angle of 29.73˚ and a cohesion of 0.191 bar, indicating a good mechanical strength of the material, with a consistent evolution of the shear strength as a function of the normal stress applied.

3.6. Oedometric Compressibility Test

The oedometric compressibility test was performed on the same sample. The results obtained are as follows: initial vacuum index e_c, = 0.591, preconsolidation pressure σ'_p = 1.241 bar, compression index *cc* = 0.0577 and swelling index *cg* = 0.0033. Figure 8 shows the oedometric curve.

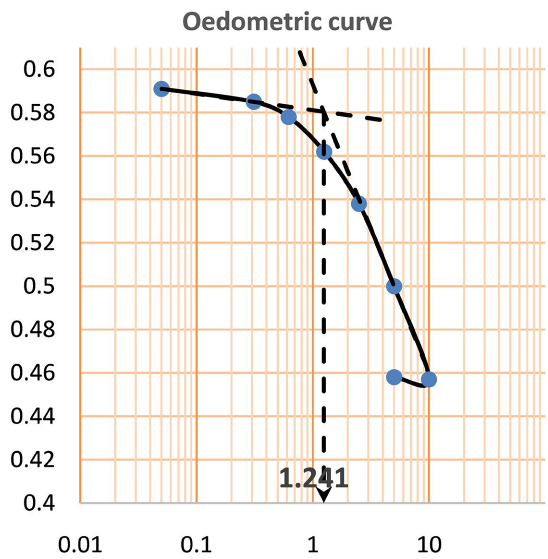

Figure 8. Oedometric curve.

The oedometric compressibility test carried out on the sandy loam clay soil of Limbita 2 reveals a low compressibility, with a compression index of 0.0577 and a very low swelling index of 0.0033, indicating a stable behaviour under load and a favourable suitability for construction in coastal areas.

4. Discussion

4.1. Analysis of the Particle Size Characteristics of the Limbita 2 Sample

Particle size plays a fundamental role in the manufacture of raw earth bricks, as it directly influences the plasticity, mechanical strength, permeability and dimensional stability of the material. An optimal balance between sandy, silty and clay fractions is essential to ensure the quality and durability of the bricks. According to Jamal. [10], soil suitable for this use should contain between 15 and 25% clay, 20 to 30% silt, and 45 to 65% sand, which ensures good cohesion while limiting the risk of shrinkage or cracking. Maachi *et al.* [11] showed that the petrographic nature of soil strongly influences essential properties such as porosity, thermal conductivity and fire behaviour, highlighting the importance of mineralogical composition in the choice of materials. In addition, Carrasco *et al.*, [12] emphasize that a well-distributed grain size improves soil cohesion and compressibility, which are two key parameters for producing high-performance and durable bricks, particularly in ecological construction contexts or in areas with high humidity.

The comparison of the soils of Limbita with those of other coastal areas highlights significant variations in their particle size composition, influenced by geomorphology and topographic position. The soil of Limbita 2, characterized by a sandy loam clay texture with 51% fines, has good cohesion but remains sensitive to moisture, which can affect its stability in saturated conditions. On the other hand, the soil of Limbita 1, located on a hillside, is more gravelly, which gives it better permeability but less cohesion. These differences are typical of the contrasts between lowland areas and sloping terrain. The study by [5] on the Kenendé site, also located in the prefecture of Dubréka, confirms the presence of a soil with a comparable grain size, with a maximum dry density of 1.80 g/cm^3 and a cohesion of 0.287 bar, values that reflect a favourable suitability for the manufacture of mud bricks. For his part, Diatta [13], in his work on Boké clays, highlights geotechnical properties compatible with eco-construction, in particular low plasticity and satisfactory shear strength, reinforcing the idea that soils in the Guinean coastal region can be recovered in sustainable building materials.

These comparisons underline the importance of particle size analysis to adapt implementation techniques to local specificities. They also make it possible to identify the most suitable soils for brick making, taking into account their mechanical behaviour and water sensitivity, two essential criteria in areas subject to maritime climatic constraints.

Coastal environments present specific constraints that directly affect the durability of building materials, especially reinforced concrete. The sea winds, laden with saline particles, promote the penetration of chlorides into the structures, which accelerates the corrosion of the metal reinforcement and compromises the long-term stability of the structures. Ngala & Page [14] demonstrated that the carbonation of concrete, combined with the infiltration of chloride ions, alters the porous structure of the material and reduces its resistance in the marine environment. In addition, Guiraud [15] identifies several areas of aggression typical of coastal sites, such as sea spray, direct sprinkling and tidal range, which expose materials to repeated cycles of humidity and desalination, aggravating the phenomena of cracking and degradation. These observations underline the importance of choosing materials adapted to saline conditions, or of considering alternatives such as stabilized earth bricks, which are less sensitive to corrosion and more compatible with local climatic constraints.

The valorization of plant fibers in composite materials represents a significant advance in the field of sustainable construction. The integration of fibers such as flax, hemp or miscanthus into earthen bricks improves several essential properties of the material, including flexural strength, durability and thermal behavior. Fall *et al*. [16] reported that the use of flax straw leads to improved mechanical performance compared to wheat straw, while also contributing to a reduction in density, resulting in a lighter and more workable material. Dujardin [17], on the other hand, highlighted the specific chemical properties of plant fibers, highlighting their ability to strengthen the earthy matrix and improve the internal cohesion of the composite. In the framework of the FIBRABETON project, Karimah *et al*., [18] have shown that these natural fibres can effectively replace synthetic fibres in fluid screeds, while maintaining comparable mechanical performance. These results confirm the potential of plant fibers as ecological and functional alternatives in building materials, especially in areas where local resources and climatic conditions require adapted and resilient solutions.

4.2. Analysis of the Plasticity and Water Retention Properties of the Limbita 2 Sample

The results of the Atterberg limit tests performed on the Limbita 2 sample reveal a liquidity limit of 35.8%, a plasticity limit of 16%, and a plasticity index of 19.8%, indicating moderate to high plasticity. These values reflect the soil's ability to deform without breaking under stress, which is favourable for its use in earthen construction applications. Compared to the Burkina Faso sample studied by Millogo [19], which has a liquidity limit of 22.5%, a plasticity limit of 12% and a plasticity index of 10.5%, the soil of Limbita 2 appears more plastic and wetter, which may influence its suitability for the manufacture of improved mud bricks. According to Millogo's recommendations, a liquidity limit of between 25% and 35% and a plasticity index of less than 20% are ideal for cement or lime stabilized bricks. Thus, although the floor of Limbita 2 slightly exceeds these thresholds, its high plasticity could offer better workability, provided that other parameters such as chemical composition and mechanical strength are controlled.

In addition, the comparison with the Limbita 1 sample [20], which has a liquidity limit of 55%, a plasticity limit of 27% and a plasticity index of 28%, shows that the latter has a greater capacity to retain water and a wider plasticity range. These differences, linked to the geographical position of the sites, Limbita 1 on the hillside and Limbita 2 on the lowlands, have implications for the reactivity to humidity, the workability and the performance of the bricks produced. Additional studies, such as those by Dabin and R. Maignien [21], Gomis [2], Maachi *et al.* [11], L. Laou *et al*., [22], and Phung [6], confirm that soil plasticity strongly influences soil compactness, durability and sensitivity to water variations. This work also highlights the importance of rigorous control of the conditions of implementation, particularly with regard to water content, compaction method and chemical stabilization, to guarantee the performance of raw earth bricks in restrictive environments.

In short, although the Limbita 2 floor has a plasticity slightly higher than the thresholds recommended for improved mud bricks, its properties remain compatible with use in sustainable construction, provided that the manufacturing techniques are adapted to the specificities of the material.

5. Conclusion

The land of Limbita 2 is highly prized by brick manufacturers in the prefecture of Dubréka and the Conakry area, but its physical characteristics are now known. It is important to note that despite the performance of this earth in the manufacture of bricks, it has a low swelling potential. This unappreciable feature should be addressed.

Conflicts of Interest

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

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