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Soil Characterization for the Manufacture of Compressed Earth Blocks in Bujumbura, Burundi

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Abstract: Social housing and urbanization policies in Burundi are ongoing, long-term projects, hence the need for large quantities of construction materials. The use of environmentally friendly construction materials such as earth bricks has a promising future. To prevent premature deterioration of civil engineering structures, in-depth studies of materials prior to their use are essential. It is within this framework that this study was initiated. It aims to determine the physical and mechanical properties of soils at potential sites for the manufacture of compressed earth blocks in Bujumbura, a region located in western Burundi. The samples taken underwent a complete geotechnical characterization, including grain size analysis by sieving and sedimentometry, consistency limits, and modified Proctor tests. The GTR classification (Technical Guide for the Construction of Embankments and Subgrades) identifies them as clayey sands (A1), materials that are acceptable for the manufacture of BTCs, either in their natural state or with the addition of clean sand to remove clay if necessary. The plasticity indices (PI) of 10.1% and 8.5%, liquidity limits WL of 34% and 33%, and Proctor optimums observed for maximum dry densities of 1.99 t/m³ and 1.994 t/m³ for 11.1% and 12% water, are characteristics that qualify them for the manufacture of BTC.

Keywords: *Clayey Sand; Geotechnical Characterization; BTC; Burundi.*

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I. INTRODUCTION

Burundi's social housing policy is an ongoing, long-term project, hence the need for large quantities of building materials.

Building materials such as cement account for 5% of global industrial energy consumption and a significant proportion of CO2 emissions. In addition, concrete buildings consume a great deal of energy. In France, 44% of energy is consumed by the building sector alone. (1)

In masonry, compressed earth blocks (CEBs) are raw and do not require high-temperature firing like fired bricks or polluting manufacturing processes like concrete blocks. (2)

The use of earth as a building material offers the possibility of using a resource that is abundant and locally available in our everyday environment. However, to be used effectively in construction, earth must have specific characteristics, in particular good cohesion. It is mainly thanks to the presence of clay, a natural binder, that earth acquires this necessary cohesion. (3)

Due to costs and environmental concerns, the use of environmentally friendly building materials such as rammed earth bricks has a promising future.

It is in this context that we ask the general question: Can modern earth construction techniques meet the huge social housing construction program in the city of BUJUMBURA in particular and urbanization programs in general in the country?

This study focuses on characterizing the soils of potential sites for manufacturing BTCs in Bujumbura.

Three sites in the city of Bujumbura or its suburbs have been selected, and samples have been characterized in the soil mechanics laboratory to determine whether the soils of

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Bujumbura have characteristics that are better suited to the manufacture of BTCs that meet the mechanical requirements of construction.

II. MATERIALS AND METHODS

A. Raw Material

Three potential sites for extracting soil suitable for manufacturing compressed earth blocks have been identified and studied. Site number 1 is located on MUNANIRA hill, in the RUGAZI area, MPANDA commune. Sites 2 and 3 are located on SAMARIRO Hill in the MUTIMBUZI area of NTAHANGWA commune. All three sites are in Bujumbura province.

Illustrative photos of the quarry and locations can be found in Figures *"Fig.1"* and *"Fig. 2"*.

Fig 1 Quarries at Potential Sites 1, 2, and 3

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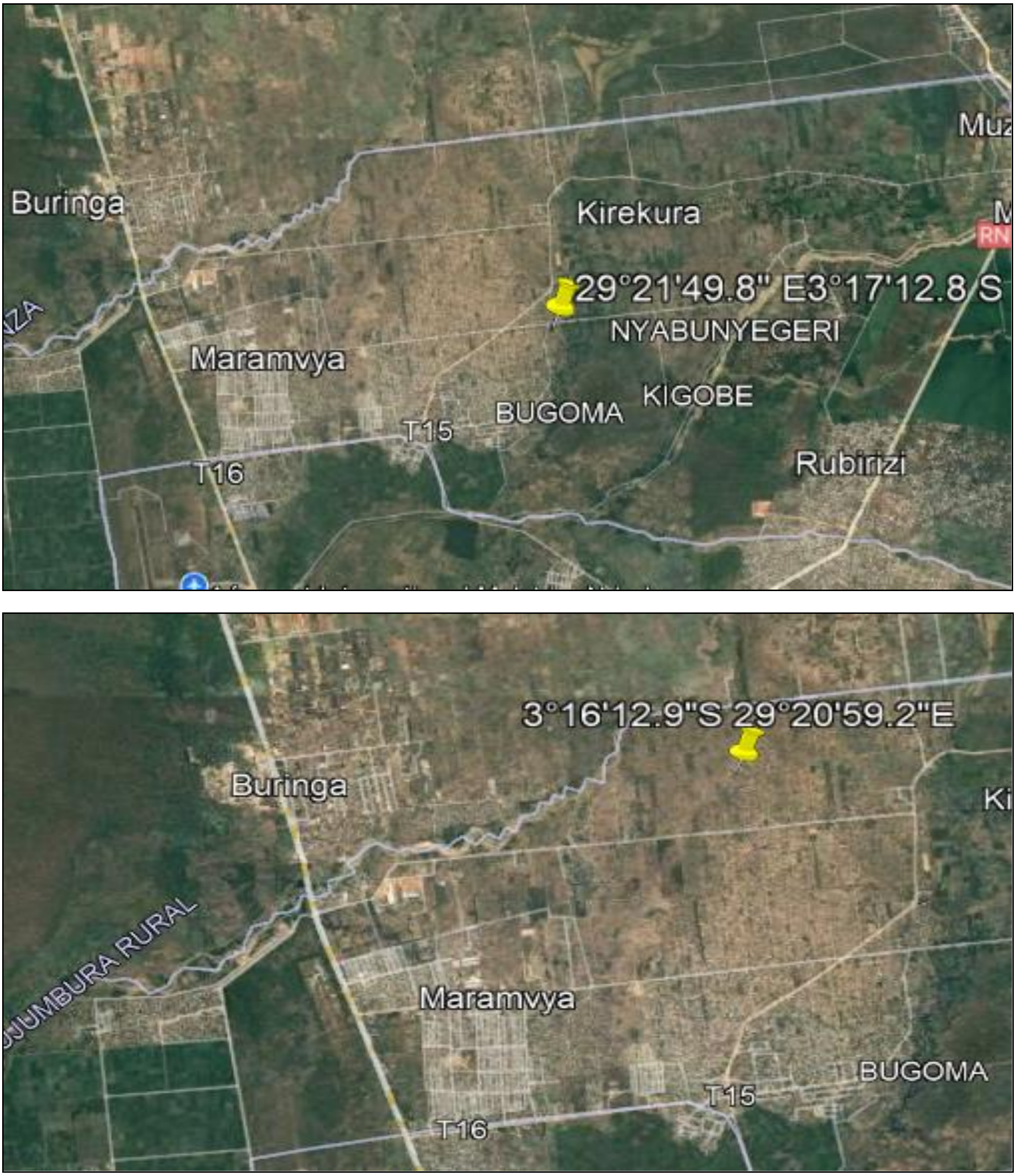

Fig 2 Location of the Sites of Origin of Samples 1, 2, and 3

B. Methodology

In collaboration with the Burundian Office of Mines and Quarries (OBM), which provided authorization to take samples and technical support through its geological research and mining cadaster department, the Burundian Office of Urban Planning, Housing, and Construction (OBUHA), whose research department and laboratory granted us access to the laboratory, we conducted geotechnical analyses to characterize the soils.

➢ *Particle Size Analysis Test*

Soil particle size analysis is based on two standards: standard NF P 94-056 concerns particle size analysis by sieving, and standard NF P 94-057 deals with particle size analysis by sedimentation. (4)

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- *By Sieving:*

The test consists of dividing and separating a material into several grain size classes of decreasing size using a series of sieves *"Fig. 3"*. The mesh sizes and number of sieves are chosen according to the nature of the samples and the required accuracy. (5) The process used is wet sieving followed by dry sieving. The masses of grains retained on the different sieves are related to the initial mass of material. The cumulative percentages passing through each sieve are presented in numerical form and, if necessary, in graphical form. (5) The equipment consists of a series of sieves, bottoms and lids, an oven, washing equipment, scales accurate to ±0.1%, trays, brushes, and a sieving machine (optional).European standard NF EN 933-1 outlines the principle of sample preparation, the operating procedure, the calculations and expression of results, and the test report format.

Fig 3 Series of Sieves and Scales Accurate to ±0.1%.

- *By Sedimentometry:*

Sieving, for the weight distribution of particles greater than or equal to 80 microns.

Sedimentometry, for the weight distribution of particles smaller than 80 microns. Sedimentometry is based on Stokes' law, which gives the limiting velocity of a particle falling under the action of gravity in a viscous liquid. (6)

Grains of different diameters sediment in a liquid medium at rest at different speeds. The relationship between grain diameter and sedimentation velocity is given by Stokes' law. (7) As this relationship was established for spherical grains, applying it to soil elements will only give "equivalent diameters." (8)

The specific equipment consists of a torpedo-shaped densimeter graduated from 0.995 to 1.030 g/cm3 with graduations every 0.0005 g/cm3, test tubes, and a mechanical stirrer whose rotation speed can be adjusted from 0 to 10,000 rpm. (8)This stirrer must be of the "immersion" type, i.e., the shaft supporting the rotating paddle is inserted into the container holding the solution; this container must not have smooth cylindrical walls. A deflocculant: sodium hex metaphosphate; a manual stirrer for homogenizing the suspension before testing.

Readings are taken at: 30 seconds, 1, 2, 5, 10, 20, 40, 80, 240 minutes (and possibly at 1,440 minutes, i.e. after 24 hours); these times are counted from the start of the test. The three readings at 30 seconds, 1 minute, and 2 minutes are taken without removing the hydrometer from the suspension. Only after the readings at 2 minutes is the temperature of the suspension recorded to the nearest 1/10 of a degree. For the other readings, immerse the hydrometer 15 to 20 seconds before taking the reading. Record the temperature after each reading. (8)

The LPC test method describes in detail the equipment, sample preparation, test procedure, corrections, calculations, and presentation of results.

Here are photos of some details in Figure *"Fig. 4"*.

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Fig 4 1. Hydrometer 2. Test Tubes 3. Mechanical Stirrer 4. Container 5. Deflocculant 6. Demineralized Water (Distilled Water)

- *Atterberg Limits: Penetration Cone Method*

Depending on its water content, the same fine soil can behave like a viscous liquid (liquid state), a plastic solid (plastic state), or a non-plastic solid.

Swedish agronomist ATTERBERG proposed a method for precisely defining the limit water contents for each state, which are called Atterberg limits. (9) The most commonly used in soil mechanics are the liquidity limit WL and the plasticity limit WP. They are measured on mortar, i.e., the fraction of soil that passes through a 0.40 mm sieve. (9)

An important parameter derived from these limits is the plasticity index IP, which is proportional to the clay content of the mortar. IP=WL-WP

This coefficient is characteristic of the nature of clays. (9)

The liquidity limit can be determined using the cup method according to standard NF P94-051 or the penetration cone method according to standard NF P94-052, which is the method used in our study, and the plasticity limit using the roller method.

The cone penetration test consists of measuring, after a set time, the penetration of a cone, under its own weight, into a sample of reworked soil *"Fig. 5"*. (10)

The standard cited above details the equipment generally used for soil preparation, including an oven, scales, stopwatch, spatula, knife, and equipment for conducting the test "*Fig. 5"*, the operating procedure, and the expression of results.

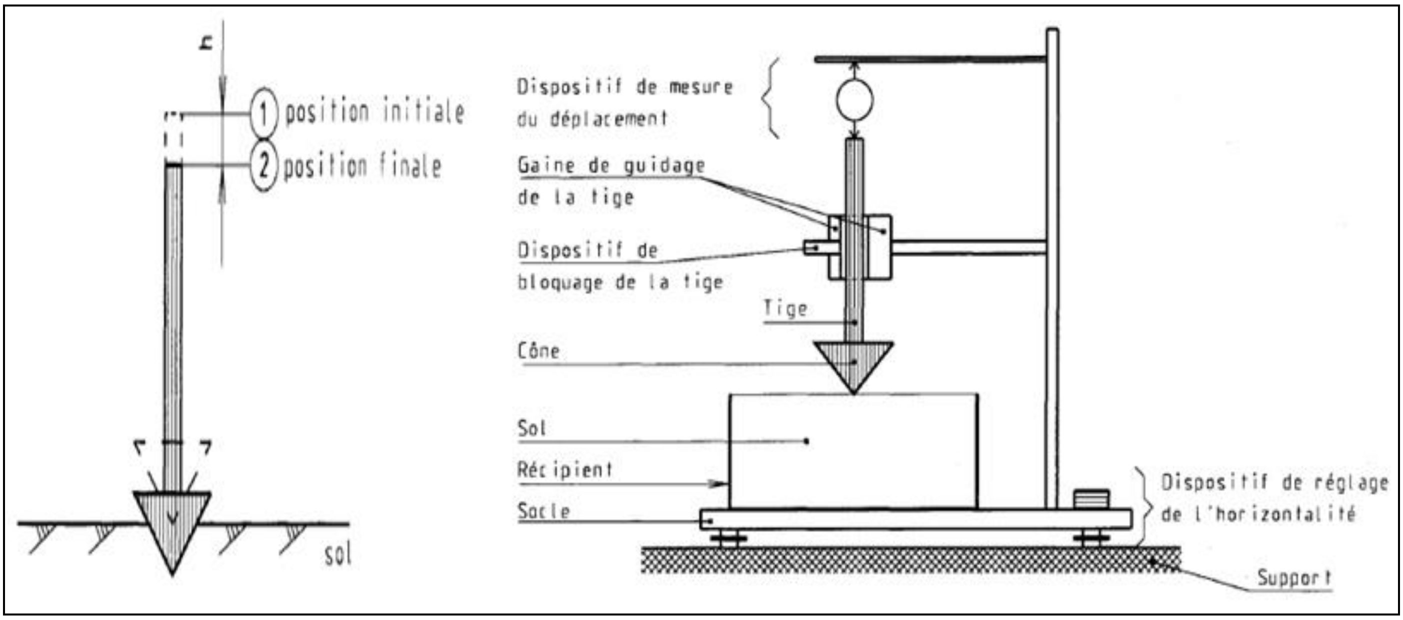

Fig 5 Principle of the Cone Penetration Test and Diagram of the Equipment (10)

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When conducting the test, adjust the base so that it is level; ensure that the tip of the cone is clean and smooth; mix the entire amount of previously prepared sieved material on the smooth plate to obtain a homogeneous, almost fluid paste; fill the container with part of this paste using a spatula, taking care not to trap any air bubbles. Level with a knife to obtain a smooth, flat surface; Place the container in position and adjust the position of the cone tip approximately to the center of the container surface by sliding the cone stem in the guide sleeve so that the tip is just flush with the surface of the soil. Mark the position of the cone. Release the cone and allow it to sink into the soil for 5 s ± 1 s, then lock it in place. Note its new position; remove the cone; take a soil sample from the container in the area where the cone penetrated. This test sample is placed in a cup of known mass, weighed immediately, then placed in an oven for drying and measurement of its water content in accordance with standard NF P 94-050. (10)

The complete operation is performed at least four times on the same paste with a different water content for each test. Depending on the case, the paste is slightly dried with demineralized water and then homogenized. The cone indentations must be within 20 mm, located between 12 mm and 25 mm, and the difference between two consecutive values must be between 2 mm and 5 mm inclusive. (10)

Here are photos of some details in Figure *"Fig. 6".*

Fig 6 Principle of the Cone

➢ *Proctor Test*

The Proctor compaction characteristics of a material are determined using tests known as the standard Proctor test or modified Proctor test.

The two tests are identical in principle, differing only in the values of the parameters that define the compaction energy applied.

The principle of these tests consists of moistening a material with several water contents and compacting it, for each water content, according to a conventional process and energy. For each of the water content values considered, the dry density of the material is determined and the curve of the variations in this density as a function of water content is plotted. (11)

In general, this curve, called the Proctor curve, shows a maximum value for the density of the dry material, which is obtained for a particular water content value. These two values are referred to as the optimal compaction characteristics of normal or modified Proctor, depending on the test performed. (11)

The test used in our study is the modified Proctor test performed in accordance with standard NF P 94-093.

➢ *Characteristics of Soil or Soil/Aggregate Mixtures for BTC*

Soil intended for use in BTC construction refers to the base material composed mainly of the following components in specific proportions, before mixing with a binder or water: gravel, sand, silt, and clay. These components can be defined according to a metric classification or, in the case of fines, by their mineralogical nature. The main characteristics of soil are defined by: its particle size distribution, plasticity, "clay content" (quantification of the clay fraction), and nature.

The granularity of the material used should preferably fall within the range of the texture diagram below *"Fig. 7"*and follow its general pattern. The limits of the recommended range are approximate. Materials whose texture falls within the range give satisfactory results in most cases.

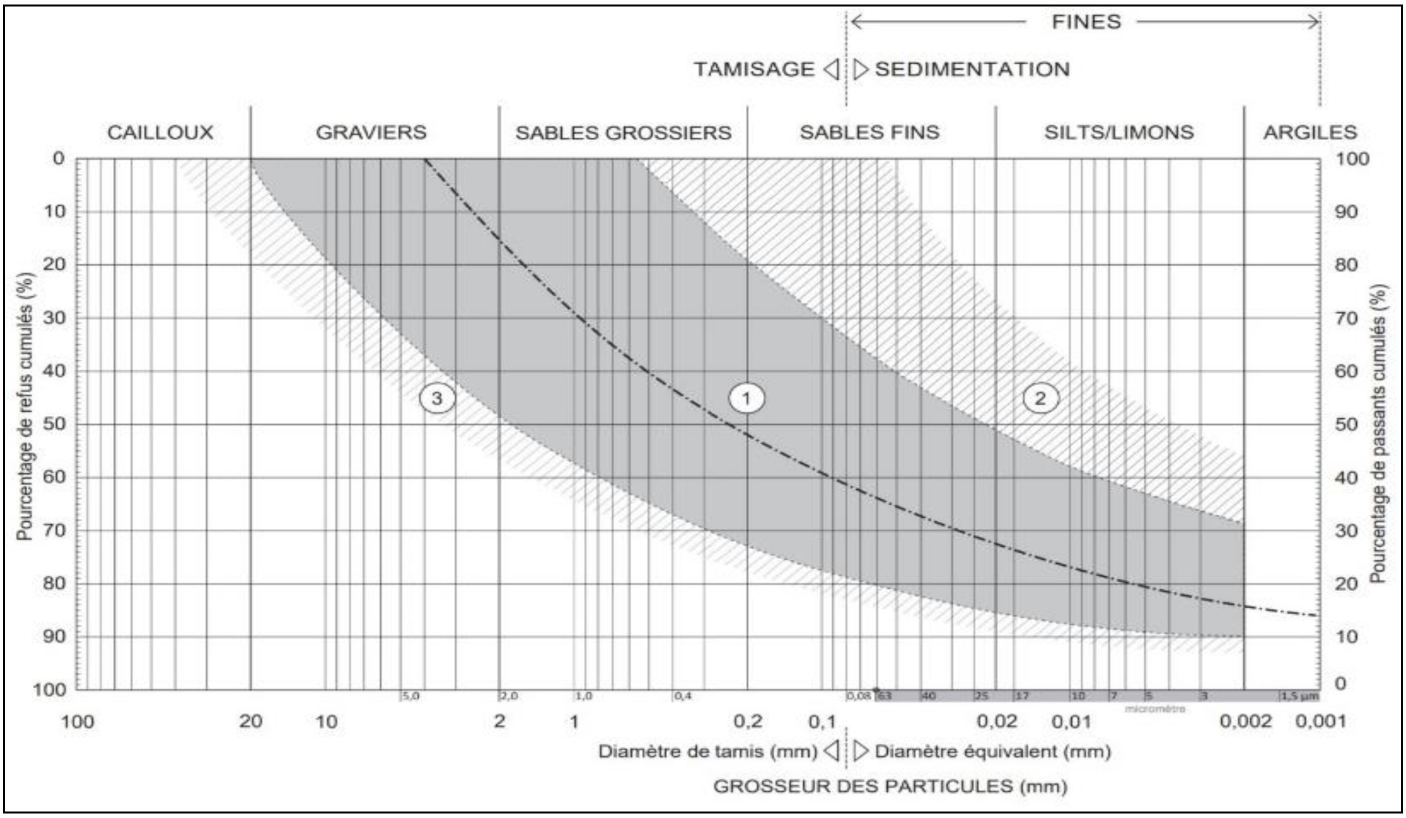

Fig 7 Soil Texture Diagram Range (12)

The plasticity of the material should preferably be within the range of the plasticity diagram below *"Fig. 8"*. The limits of the range are approximate. Materials whose plasticity is within the recommended range give satisfactory results in most cases. Materials whose plasticity is not included in the range may still give acceptable results, but they must then be subjected to a series of tests to verify their suitability.

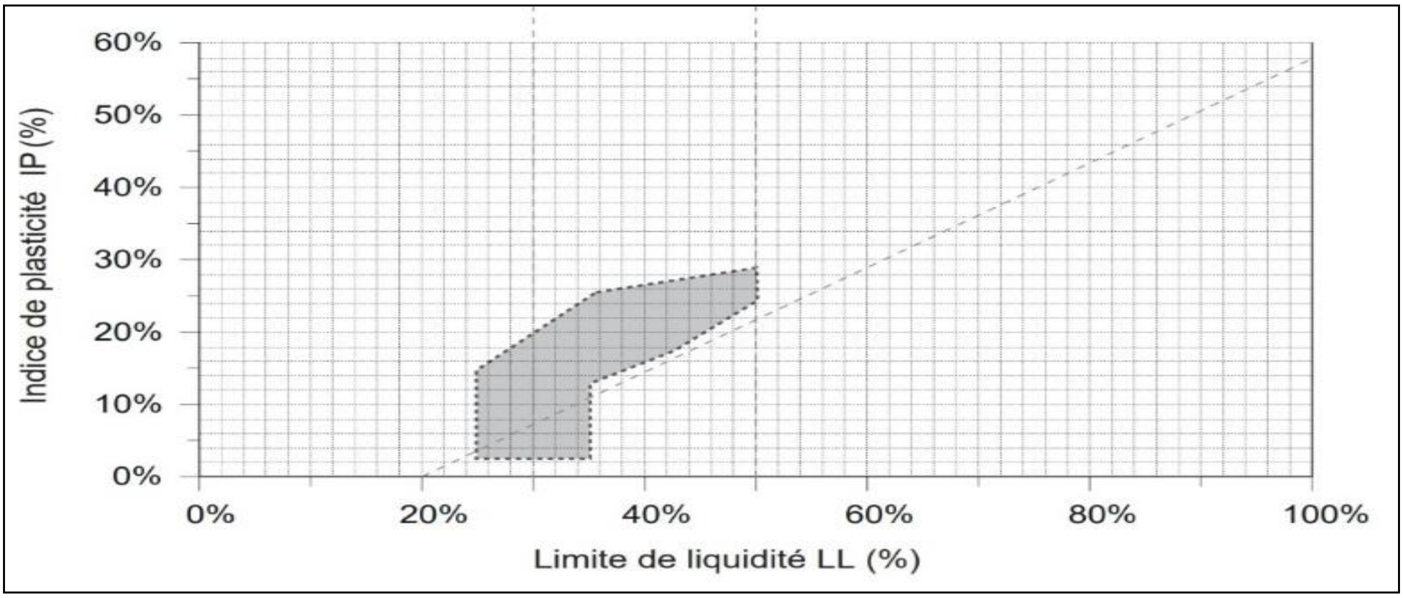

Fig 8 Soil Plasticity Diagram Spindle (12)

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III. RESULTS AND DISCUSSIONS

➢ *Grain Size Analysis and Atterberg Limits*

The results of the grain size analysis and Atterberg limits are generated by automatic laboratory models and are summarized in the following table number 1:

Table 1 Results

	E.1	**E.2**	**E.3**
Sand content %	50.39	56,46	57.02
Liquidity limit W_L	43	36	30
Plasticity limit W_P	32.4	28.5	28.5
Plasticity index IP	10.1	7.5	1.5
LCPC classification	SL	SL	SL
HRB classification	A5	A4	A4
GTR classification	A1	A1	A1
Suitability for use with BTC	Materials acceptable but with a little too much fine material	Materials acceptable but with a little too much fine material	Materials acceptable but with a little too much fine material

According to the granulometric analysis, the three soils fall well within the categories of soils suitable for the manufacture of BTC. The same applies to the GTR classification, as these soils are class A1, which is an acceptable material but with a slightly excessive amount of fine particles.

For the Atterberg limits, observing the range of the soil plasticity diagram for BTC (Figure 8):

Soil E.1, with an IP of 10.1, indicates that the soil is moderately plastic, which is acceptable for BTC. However, a WL of 43 is a little high, which means that the soil is quite clayey and may retract (crack) when drying. The soil needs to be slightly de-clayed with clean sand.

Soil E.2 falls well within the range and can be used naturally in the manufacture of BTC. However, adding a light stabilizer, a small amount of sand or fibers increases cohesion.

Soil E.3, with a plasticity index (PI) of 1.5, is not suitable for manufacturing BTCs. It lacks plastic clay and therefore has very little natural binder, meaning that the blocks break easily after drying. They can be improved by mixing them with more clayey soil (PI>10%) or stabilized by adding plant fibers for dry strength.

After analyzing these results, the experiment shows the amount of sand needed to remove clay from soil E.1 by adding 10%, 12%, and 15% clean sand and repeating the tests. The conclusion is to add 20% for soil E.1 and 10% for soil E.2, hence the origin of the samples named E.5.1 and E.5.2, which are well suited for the manufacture of BTCs. The results are shown in the following table number 2.

Table 2 Results

	E.5.1	**E.5.2**
Sand content %	60.52	58,24
Liquidity limit W_L	34	33
Plasticity limit W_P	25	24.7
Plasticity index IP	8.5	8.3
LCPC classification	SL	SL
HRB classification	A4	A4
GTR classification	A1	A1

➢ *Proctor Test*

The results of the Proctor test, modified successively for the two samples, are shown graphically in the following figure number 9:

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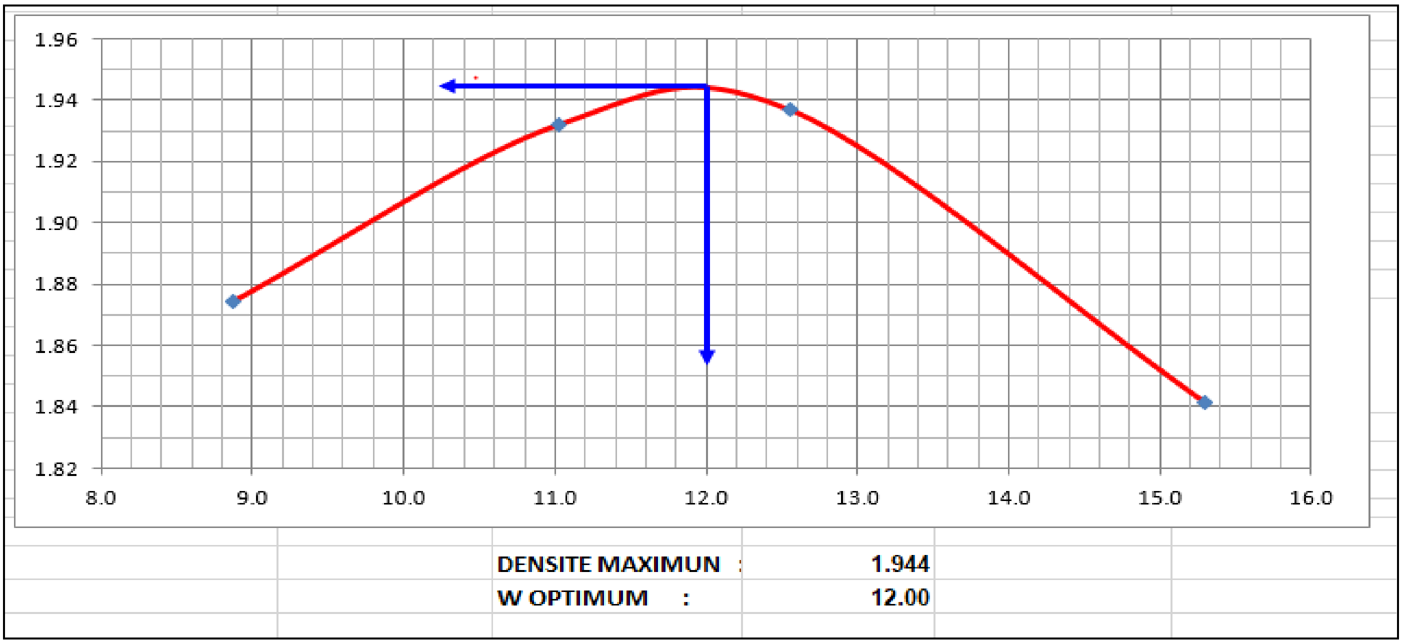

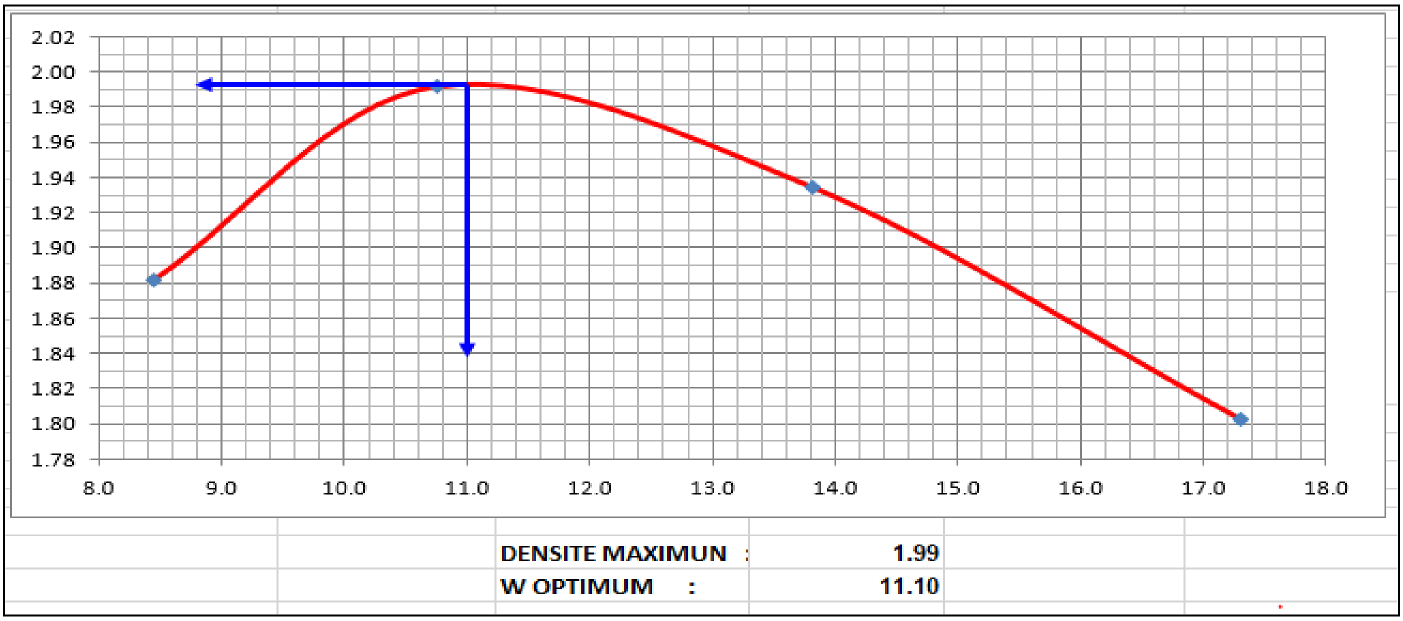

Fig 9 Proctor Curves for Two Samples E.5.1 and E.5.2

IV. CONCLUSION

This study aims to determine the geotechnical characteristics of sandy clay deposits in the city of Bujumbura and its suburbs with a view to using them in the manufacture of compressed earth blocks.

To this end, a complete characterization is based on identification tests: granulometric analysis by sieving and sedimentometry, Atterberg limits, and mechanical performance evaluation using the modified Proctor test.

The results show that these soils are good materials for the manufacture of BTCs, either in their natural state or when mixed in well-tested proportions. Their sandy clay nature, plasticity indices (PI) of 10.1% and 8.5%, liquidity limits of 34% and 33% combined with excellent mechanical characteristics, notably maximum dry densities of 1.99 t/m³ and 1.994 t/m³ with optimal contents of 11.1% and 12%, are performances that unambiguously qualify them for the manufacture of BTC.

For the manufacture of eco-friendly BTCs, future research should focus on the influence of local plant fibers, agricultural waste, such as rice straw and palm oil production waste fibers, on the mechanical performance of BTCs in Bujumbura, Burundi, but also in the region

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