

Stabilization of Clay Soil for the Durability of Structures: Case Study of the Soils of the Locality of Zalimé, Commune of Zogbodomey in the Republic of Benin

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Abstract

Structures erected on swelling clay soils are subjected to several stresses which are at the origin of the premature deterioration of the infrastructures. The soils being supports for the works, the improvement of their weak characteristics with cotton fibers will not only increase the bearing capacities of these soils and the resolution of the environmental problem, by eliminating the CO₂ produced by the burning of the stems after harvest. The objective of this study is to contribute to the improvement of the characteristics by cotton stalk powder of the swelling clay soils used as the foundation of the infrastructures in order to guarantee their durability. Identification and mechanical parameterization tests were carried out on raw soil samples taken at 1.5 meters deep and on samples improved with cotton stalk powder at different levels (3%, 6% and 10%). The results from the physical tests reveal that the soil studied is very plastic silt. As for the mechanical tests, it appears that by adding 3% cotton stalk powder to dry density which goes from 1.435 t/m³ compared to the control sample with a dry density of 1.50 t/m³; which reflects an improvement in the compaction characteristics of the soil studied. The dry densities are 1.445 t/m³ and 1.29 t/m³ for the samples improved with 6% and 10% cotton stalk powder.

Keywords

Improvement, Swelling Clay, Cotton Stalk Powder, Silt, Dry Density

1. Introduction

The phenomena of shrinkage-swelling of certain clayey soils and clayey geological formations induce differential settlements which are manifested by disorders mainly affecting structures built on the surface (buildings, shallow foundations, retaining structures, embankments,) and buried structures (tunnels, piles, pipeline, deep foundation). Examples of disorders in infrastructures linked to the presence of swelling clays are numerous and varied [1]-[6].

These soils considered as unstable soils therefore creating an economic and technical handicap for the various parties involved in this field. They swell and become plastic in the presence of water and shrink with drought. This state of affairs mobilizes the know-how of engineers in general and geotechnicians in particular to analyze, study, reinforce and consolidate these soils in order to increase their stability and improve their performance.

In geotechnics, several techniques are used to improve soils. Stabilization is the method of mixing different soils or adding additives to soil to enhance soil characteristics such as strength, durability, gradation, and plasticity, which makes soils more stable [7]. The main purpose of soil mass reinforcement is to improve its stability to increase its bearing capacity, and to reduce settlements and lateral deformations [8]. The choice of stabilization techniques depends on several parameters such as; economic considerations [9], the nature of the soil to be treated, the duration of the operation, and the availability of the materials to be used as well as the environmental conditions.

There are different methods of soil reinforcement, such as: stone columns [10], root piles, soil nailing and reinforced earth. Reinforced earth is a composite material consisting of compacted backfill and artificial reinforcing materials such as fibrous materials (geosynthetic and randomly distributed fibers) [7].

The concept of reinforced soil has been used for the first time by Henri Vidal, as part of the Reinforced Earth technique that he invented and developed in the early 1960s [11]. The main advantages of these materials are that they are available locally. They are biodegradable and therefore do not create any environmental problem [12] [13]. Thus, research carried out with plant fibers shows that some can be used to improve certain mechanical characteristics of clay soils [9] [12] [13] [14] [15] [16]. The use of certain vegetable fibers contributes to the prediction of cracks. Thus, the inclusion of treated sisal fibers suppresses the development of long cracks as they act as tension reinforcements [13].

Many researchers such as SI Al-Azzo, SM and TA Salim in [17] conducted the experimental work mainly on the compressive strength and swelling properties

of reinforced clay reinforced with metal fibers.

Different percentages of fibers mixed with soil were used to prepare the specimens to be tested. It was found that the maximum strength and breaking strain increased with increasing fiber content, while the swelling pressure and swelling potential decreased with increasing fiber content.

The appropriate percentage of fiber content has been found to be 8% [7].

D. Baglari, and SK Dash, on the other hand in [18] improved the property of expansive soil by the combined application of lime and geosynthetic reinforcement using an experimental approach [7].

2. Materials and Methods

2.1. Study Zone

In the context of this study, materials first clay soils have you prepares in the locality of Zalimé, commune of Zogbodomey.

The locality of Zalimé is located in the district of Massi which covers an area of 238 km² and is between 6°54'0" and 7°60'30" of latitude North and 2°4'0" and 2°21'0" East longitude.

The district of Massi is bounded to the north by the districts of Tanwéhèssou, Zoukou, Avlamè and Koussoukpa, to the south by the municipality of Toffo, to the east by the district of Kpokissa and to the west by Akiza Ward Geologically, the arrondissement of Massi is located on the north-central border of the coastal sedimentary basin, where outcrop formations of maestrichtian, lower-middle paleocene (50 m) and upper paleocene age, locally covered with lateritic cuirasses of the clay and limestone. locally covered with lateritic cuirasses of clay and limestone. **Figure 1** and **Figure 2** show the location and geological constitution of the soil in the study area.

2.2. Materials and Materials

The equipment used for the physical and mechanical parameters of the soils in our study area are: a Casagrande device for determining the Atterberg limits, a set of sieves for determining passages through the various sieves including the 2 µm sieve, an oven for drying the materials, scales for weighing the materials, a thermometer for measuring the temperature, a normal Proctor and CBR mold for determining the dry density (γ_s), the optimal water content (ω_{opt}) and the bearing index of the soil (I, CBR).

2.3. Methods

According to Briançon *et al.*, 2018, mass soil improvement techniques are used to increase the mechanical characteristics of granular materials over large areas and depths [19].

The methodology used for the case of our study is centered on three points: field work, laboratory tests and analysis and data processing. The fieldwork

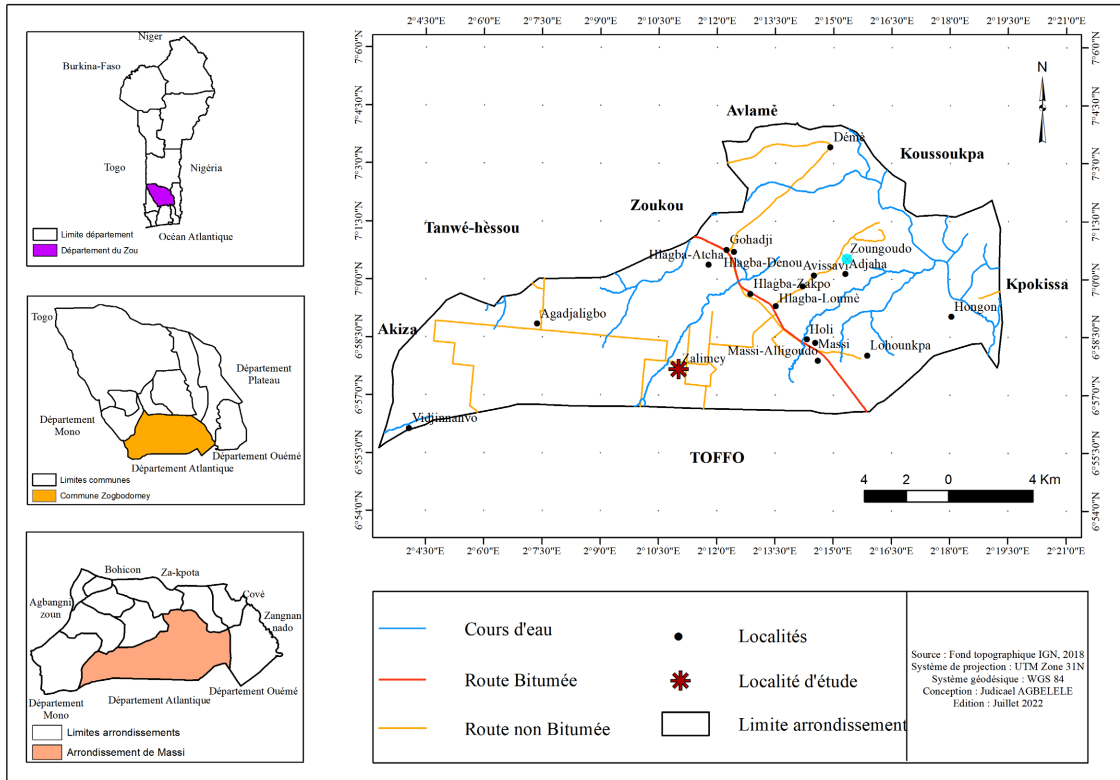


Figure 1. Map illustrating the locality of the sample.

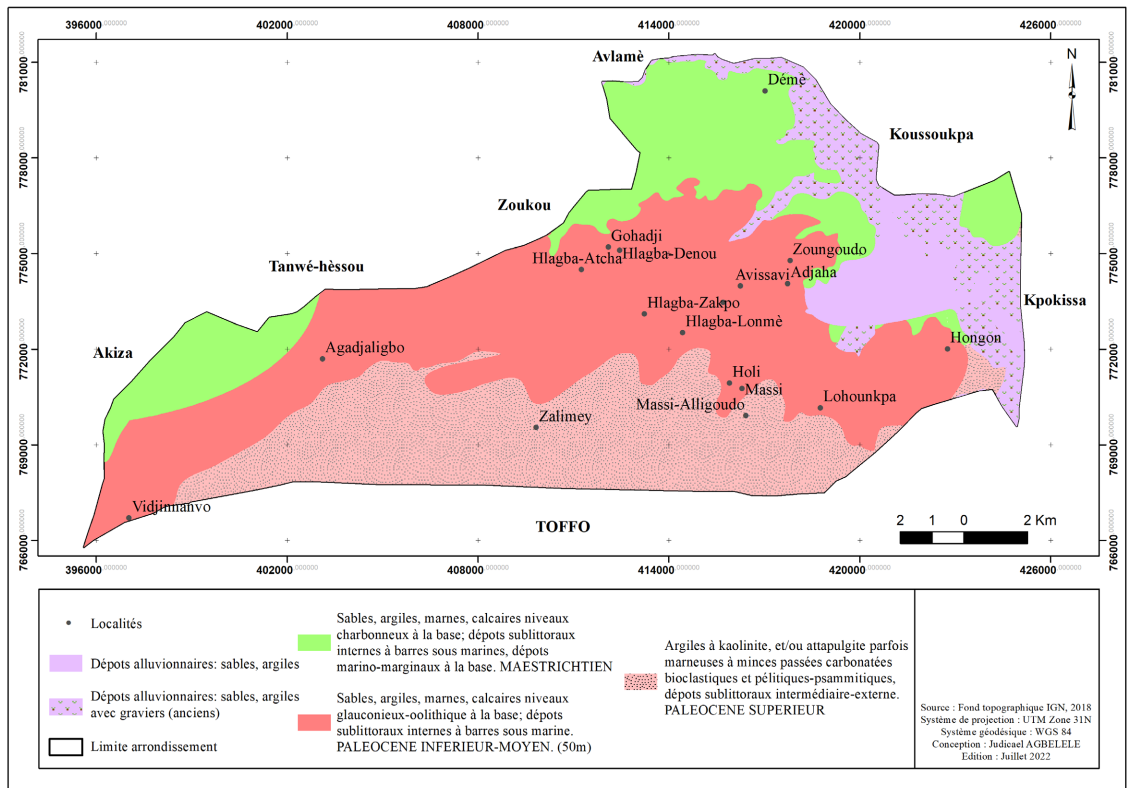


Figure 2. Geological background map of the study area.

initially consisted of sampling intact and reworked samples from a manual well drilled at depths of 0 - 0.5 m and 0.5 - 1 m.

Then, plant stalks (cotton stalks) were taken. As part of this study, cotton stalks were collected from a cotton field in Dassa-Zoumè (Republic of Benin). After sampling, the stems are transformed into a powder mixed in proportions of 3%, 6% and 10% [16] [20] with clay samples for carrying out the various tests.

The tests carried out are: Particle size analysis by sieving and by sedimentometry, methylene blue absorption, Atterberg limits, Proctor Normal test and CBR test.

The particle size analysis by sieving and by sedimentometry was carried out according to the standards EN 933-1 (2012) and NF P94-057 (1992). Once finished, we are determining the clay content of the sample by the methylene blue method, referring to standard NF P 94-068 (1993).

The liquid limit (WL) was carried out with the Casagrande disk method and the plastic limit (WP) with the roller method. These two tests were carefully carried out according to standard NF P94-051 (1993). As for the optimum water content (W_{opt}) and the maximum dry density (δ_{opt}), they were determined by the normal Proctor test according to standard NF P94-093 (1999). Finally, the CBR test was carried out in accordance with standard NF P94-078 (1997).

Once the tests have been carried out, the data analysis and processing phase will lead to the determination of the physical and mechanical characteristics of the raw sample (without mixing) and of the clay samples improved at 3%, 6% and 10 % clay samples enhanced with 3%, 6% and 10% cotton stalk powder. The punching tests will be carried out according to standard NF P94-078.

3. Results

Geotechnical Characterization

Physical characteristics

The results of the physical characteristics of the soil studied are recorded in **Table 1** below.

According to the results of the physical characterization of the soil recorded in **Table 1** the classification of REIFFSTECK inspired of Casagrande shows that we are in the presence of a sample made up of kaolinite minerals.

Table 1. Results of the physical characteristics of the soil studied.

No.	Soil properties	Values
1	% passing through a 2 μm sieve	1.58
2	% passing through a 63 μm sieve	88.95
3	liquidity limit	95.5
4	plasticity index	42.3
5	Classification of soils according to AASTHO	A-7-5

Methylene blue test

The test carried out on our sample gives us a VBS value of 12.57. We can therefore conclude from the classification table of the Guide Français de Terrassement [21], that the soil studied is very clayey because the VBS is well above 8.

Normal Proctor test

From the analysis of these curves (Figure 3), it can be noted that the results of the normal Proctor test carried out on the soil with the addition of 3% cotton stalk powder show an improvement in the dry density which goes from 1.435 (t/m^3) relative to the control sample at a dry density of 1.50 (t/m^3); it will mean that the soil has become denser.

When the analysis of the curves is continued, a drop in these characteristics is observed when the cotton stalk powder content is increased to 6% and 10%; the characteristics change to 1.445 (t/m^3) and 1.29 (t/m^3) respectively for the dry density.

We also found that the Proctor curve of the sample improved to 10% is further from that of the other mixtures as well as that of the raw material.

The results of these tests therefore reveal that the more cotton stalk powder is added in high proportions, the compaction characteristics, that is to say the maximum dry density of the mixture, becomes weak compared to the raw material.

Furthermore, the maximum dry density of the mixture increased compared to that of the clay under study when the cotton stalk powder content was 3%.

The same results are obtained by ZAMOUM Loubna in [20] in the works of reinforcement of the capping layer of the pavements by biomaterials-fiber of Date palm where one noticed the improvement of the characteristics of compaction by using a ground with addition of date palm fiber compared to the control soil.

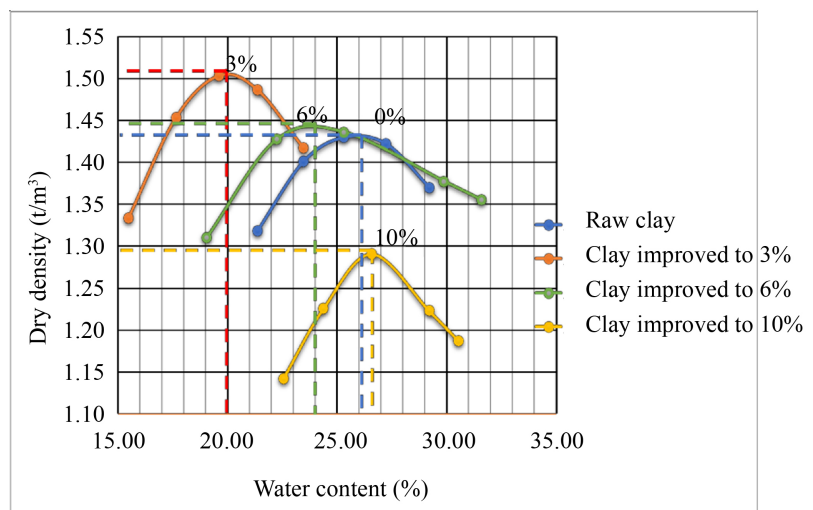


Figure 3. Proctor curve of the different mixtures.

CBR test

Punching tests at different degrees of compaction energy 56, 25 and 10 blows were carried out on the raw sample and on the mixed samples.

4. Discussion

The analysis of **Figure 4** reveals to us that for a depression of 10 mm, an effort of 15 kN and 12.5 kN was required at the level of the samples improved at abres-pective content of 3% and 6% in cotton stalk powder while at the level of the raw sample, it is found that an effort of 11 kN is required. We can therefore say that compared to the raw sample; we note a densification of the soil. Continuing the analysis, we find for the sample improved to 10%, the depression of 10 mm is obtained with a force of 10 kN.

Figure 5 is about the punching test carried out on the samples at 25 blows shows that for a depression of 10 mm, 11 kN are required for the 3% improved sample, while for the green sample, 10 kN are required. It is observed that the punching force decreases when the fiber content increases.

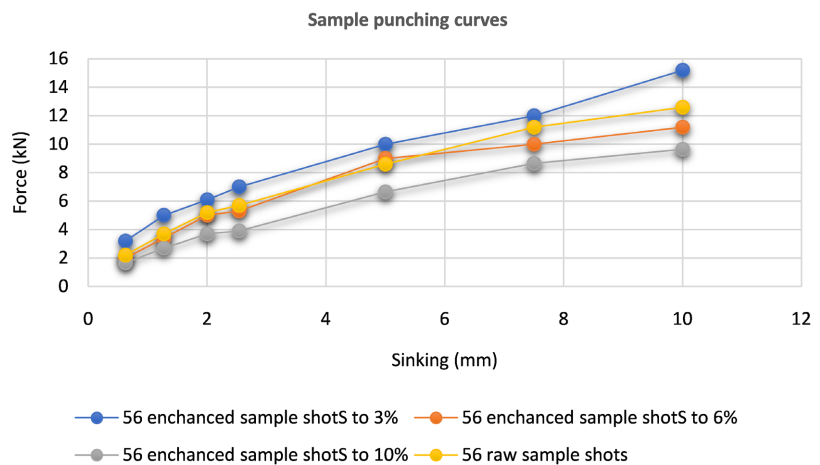


Figure 4. Punching curves of samples at 56 strokes.

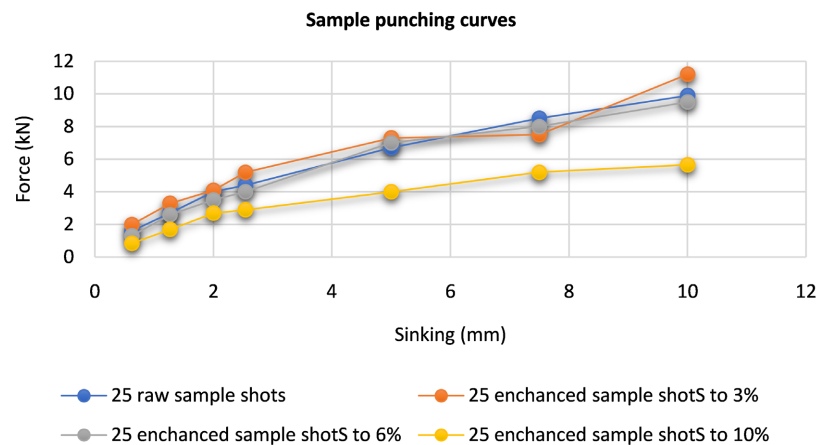


Figure 5. Punching curves of samples at 25 strokes.

The test carried out on the sample at 10 blows as the **Figure 6** shows also reveals an increase in the puncture force of the sample improved with 3% in cotton stem powder compared to the raw sample, likewise the force decreases when the fiber content increases to 10%.

We found from the results recorded in **Table 2** that the CBR index (52%) of the 3% improved mixture is higher than that of the raw sample (43%). The indices are higher than that of the raw sample (43%). The indices of the improved mixtures at 6% and 10% respectively are 45% and 33%. It is observed that the CBR index decreases considerably when the fiber content increases (10%).

According to the work of ZAMOUM Loubna on the study of the reinforcement of the capping layer of pavements by biomaterials-fiber of Date palm [20], the quantity of fiber added is in the proportions of 3%, 5% and 7%. They found that the 7% fiber content is the specific value where the CBR obtained the 20% improvement over the regular sample.

Within the framework of our study, we noticed that the specific value of the CBR which enabled us to have a rate of improvement of 9% compared to the ground of study is that of the mixture carried out with 3%.

5. Conclusion

The present study is focused on the stabilization of clay soil by cotton stalk

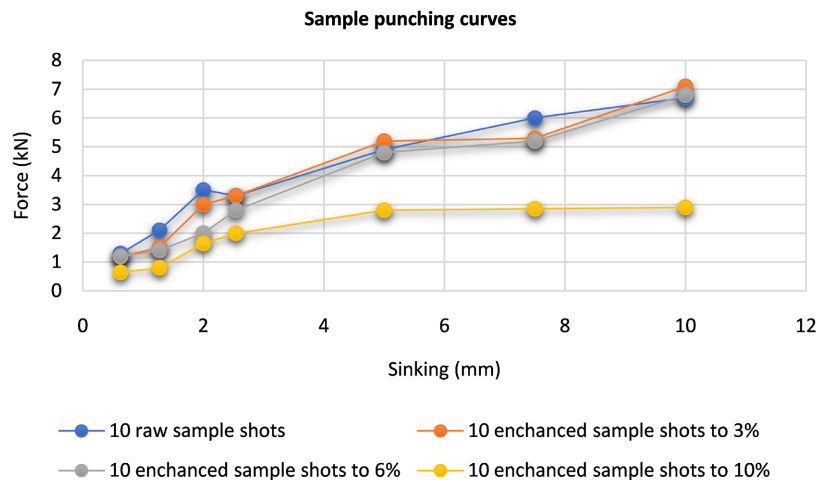


Figure 6. Punching curves of samples at 10 strokes.

Table 2. Summary table of the characteristic values of the indentation test.

Features	raw sample	Cotton stalk powder enhanced sample (%)		
		3	6	10
Dry density (t/m ³)	1435	1.51	1,445	1.29
ICBR. 56 (%)	43	52	45	33
ICBR. 25 (%)	34	39	35	22
ICBR. 10 (%)	25	26	24	15

powder to improve the characteristics of the soil supports of the works for their durability. At the end of the studies carried out on the soil of the locality of Zalimé, it appears that the soil in place is of a kaolinite mineral. The mixtures in the proportions of 3%, 6% and 10% of cotton stalk powder with clay allowed us to have a density which went from 1.435 t/m³ for the raw sample to 1.51 t/m³ for a 3% mix and decreasing to 1.29 t/m³ for a 10% mix. It can then be concluded that increasing the cotton stalk powder content further decreases the dry density of the mixture as well as the CBR index. It therefore happens that the improvement of the soil compaction characteristics will be of better quality if the mixture is made at a low content (3%). Thus, stabilization consists of improving the mechanical characteristics of the soil in place and it appears that a low percentage of cotton stalk powder would be more effective than a high percentage. We would like to work on the chemical properties of the cotton stem in order to determine chemical state of the material, such as the oxide content, carbonate content, acidity and alkalinity. These results will allow us to identify possible reactions between the cotton stem powder and the soil sample.

Conflicts of Interest

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

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