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RESEARCH ARTICLE

STUDY OF THE GEOTECHNICAL CHARACTERISTICS OF STRUCTURAL FOUNDATION SOILS: THE CASE OF THE AKPAKPA REGION IN THE REPUBLIC OF BENIN

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ABSTRACT

The construction of infrastructure capable of withstanding future hazards in the Akpakpa district requires good control of the foundation soils. The test results showed that the Ayélawadjè and Sodjèatimey soils are class D according to the GTR classification and sub-class D1 (VBS<0. 1): insensitive to water, weakly organic and presenting an over-consolidated state, while the Avotrou soils are of class A according to the GTR classification and of sub-class A4 (IP>40%): very plastic with the following main characteristics: very coherent and almost impermeable. In sum, for the Ayélawadjè and Sodjèatimey soils, it is important to ensure that the soils are uniform and adequately compacted before building on them, as the soils are not very sensitive to water and should not liquefy in the event of heavy rain. However, it is important to ensure that the soils are well drained to avoid problems with moisture and long-term stability. Avotrou soils can be subject to shrinkage and subsidence, which can lead to long-term stability problems.

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INTRODUCTION

The increase in population density is accompanied by numerous geotechnical problems [1]. Some authors, including [2]-[9] have examined soil characterisation. Several authors, such as [10]-[50] have dealt with the question of soil characterisation in their articles [2], [3], [8]. The design and dimensioning of a structure requires the development of a geotechnical model, the characteristics of which are derived from the results of tests carried out during geotechnical investigations [51]. However, building infrastructure capable of withstanding this potential natural disaster requires in-depth knowledge of the geotechnical characteristics of the foundation soils. These characteristics have a direct influence on the bearing capacity of the soil and therefore on the stability and durability of the structures built. It is therefore essential to carry out an in-depth geotechnical study to assess the quality of the foundation soils before building any structure. Geotechnical soil characterisation is a crucial stage in civil engineering projects such as the construction of roads, bridges, buildings, dams, etc. The geotechnical properties of soils are essential for assessing the stability of foundations, the risk of landslides, the bearing capacity of soils, etc. The commune of Cotonou in general, and the Akpakpa district in particular, is characterised by strong demographic growth and rapid urbanisation, which has led to an increase in demand for infrastructure such as buildings, roads, bridges and so on. In fact, certain localities such as Ayélawadjè, Avotrou and Sodjatinmè are at altitudes of between 5m and 45m, which constitutes a natural outlet, resulting in the prolonged stagnation of water. These three localities are in the city of Cotonou, a coastal town in Benin, which is one of the worst affected, with the frequency and intensity of rainfall increasing steadily [52]. Soil instability is defined as a lack of constancy, equilibrium and stability according to [53]. As a result, building a structure on such soil without carrying out an appropriate soil survey and without taking the right precautions, causes a great deal of damage to the structure of the structure (punching of foundation footings, dislocation of masonry such as the appearance of cracks); damage due to the phenomena of settlement and shear failure observed most frequently on these soils and which are at the root of a significant proportion of civil engineering problems. The city of Cotonou is known in part for its marshlands or swampy areas, i.e. low-lying regions where stagnant water accumulates in shallow layers, and where soft or compressible soils (soft clays, silts, mud, peat) are generally present. The city of Cotonou contains large depressions that run along the cordons forming either marshes with outcropping or overcropping water or lagoons or lakes, the most important of which are the coastal lagoon, Lake Ahémé and Lake Nokoué. [54]. This geomorphological situation is likely to lead to an intense accumulation of clay particles, mud or peat in certain areas of Cotonou as a result of the repeated overflows of the various hydro-geographical basins located there.

It is crucial to understand the geotechnical properties of soils in order to minimise the associated risks in infrastructure construction. With this in mind, this study aims to characterise the physical and mechanical properties of the Akpakpa soils in order to gain a better understanding of their nature and assess their impact on the stability of the foundations laid there.

MATERIALS AND METHODS

Study environment

Study area: Akpakpa (COTONOU II): These images show the three (03) zones covered by our study.

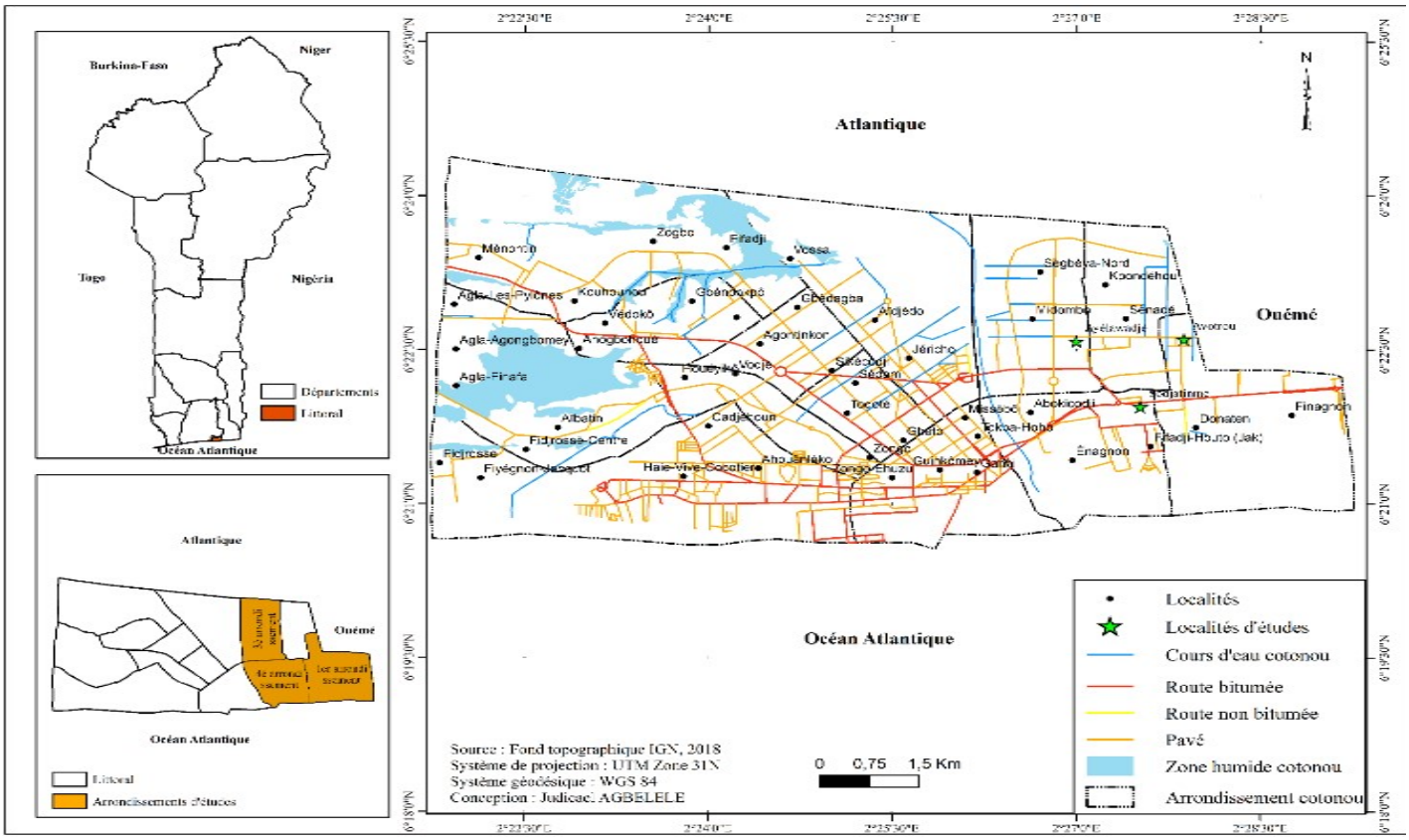


Figure 1. Map of the municipality of Cotonou

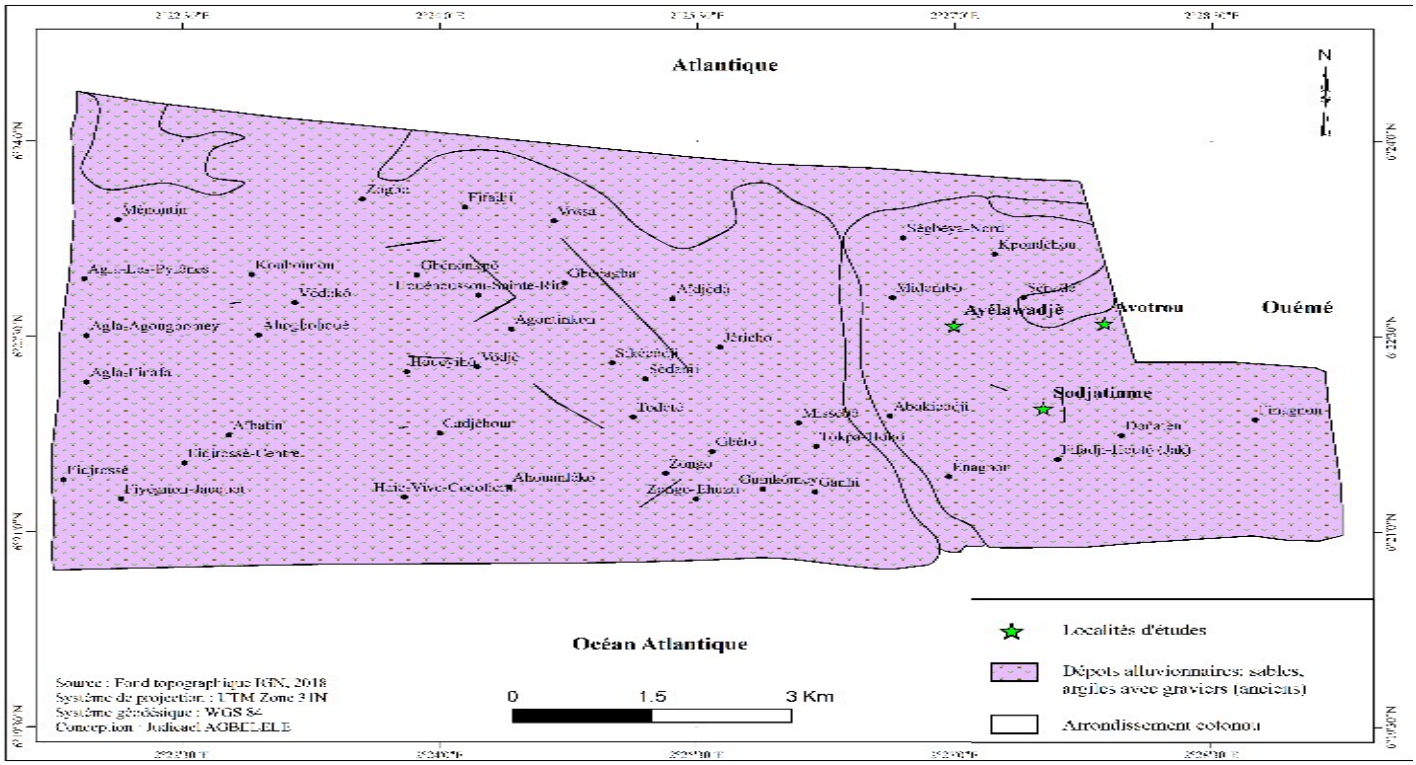


Figure 2. Geological map of Cotonou

Presentation of sampling sites: To ensure adequate representation of the study area, three sampling sites were carefully and strategically selected. Details of the sampling sites, including their sampling depths and Cartesian coordinates, are presented in the table below.

Test methodology: The following table sets out the technical details of the tests.

Atterberg limits: Based on the results obtained, it was observed that the liquidity limit of the Avotrou soil is greater than 80%, with a value of 87.5. Moreover, the plasticity index is also higher than 40%, reaching a value of 40.4%. These results suggest that the Avotrou soil is highly plastic, given that its plasticity index is greater than 40. Consequently, it can be concluded that the Avotrou soil can be considered a silty soil, given that its plasticity index is greater than

Table 1. Table of geographical coordinates of sampling sites

Order number	Sites	Depth	Cartesian coordinates	
			X	Y
1	Avotrou	1.5 m	442001.47	706008.08
2	Ayelawadje	1.5 m	439788.08	704567.11
3	Sodjeatimey	1.5 m	440094.87	704167.58

Table 2. Technical details of tests

Methods	Type of sample	Type of test	Objectives
Indirect	Revamped	Simple geotechnics	Granulometry, Atterberg limits, specific weights and organic matter content
Direct	Intact	Mechanicals	Compressibility and cohesion

Table 3. Summary of soil qualifications studied.

Properties	Peat	Organic soils	Soft clays
Water content W (%)	200-1000	100-200	30-100
Void index e	3-10	2-3	1.2-2
Compressibility index C_c	1.6-8.8	0.6-1.4	0.33-0.9
Density of solid particles	1.4-2	2-2.6	2.6-2.7

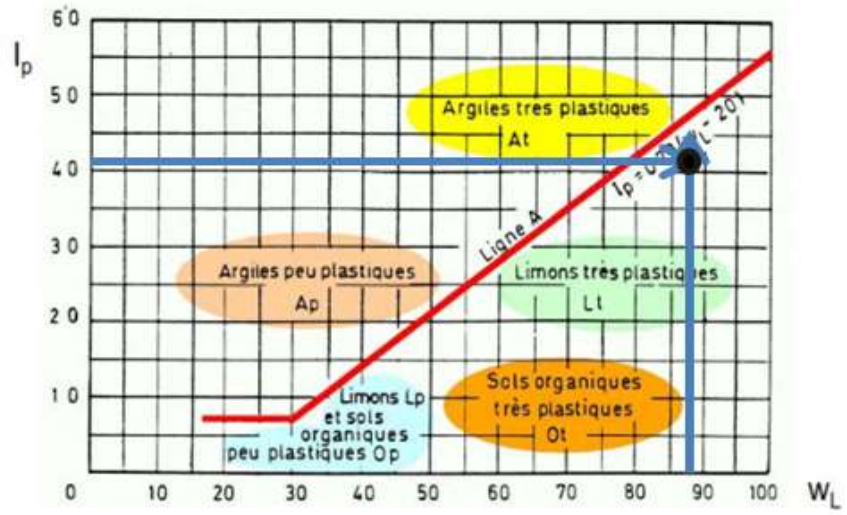


Figure 3. Classification of fine soils: Plasticity diagram (according to L.C.P.C)

Sampling techniques: Intact and reworked samples were collected as follows [55].

Tests: A series of physical and mechanical geotechnical tests were carried out to assess soil properties.

RESULTS AND DISCUSSION

Physical characteristics

Particle size analysis by sieving: The results of the particle size analysis carried out on the various samples taken from the Ayelawadje and Sodjeatimey sites show that the sand is fine, well graded and has a uniform particle size.

Particle size analysis by sieving and sedimentation: After particle size analysis by sieving, we found that the soil at Avotrou is fine.

40, thus confirming our initial hypothesis and the results of other authors such as [56]-[60]. According to the LCPC plasticity diagram, this is a very plastic silt.

Organic matter content

According to standard NF P 94 - 055, the Ayélawadjè and Sodjeatimey sites have an organic matter content of 10 and the Avotrou site has an organic matter content of 90. The following table summarises the results of the various qualifications that can be given to our samples. Based on the results obtained, it can be concluded that two of the soil samples studied, Ayélawadjè and Sodjeatimey, have a low organic matter content and can be classified as muddy soils.

Their organic matter content is estimated at between 3 and 10%. The Avotrou sample, on the other hand, stands out for its high organic matter content of around 90%, and can be considered a highly organic soil belonging to the peat category.

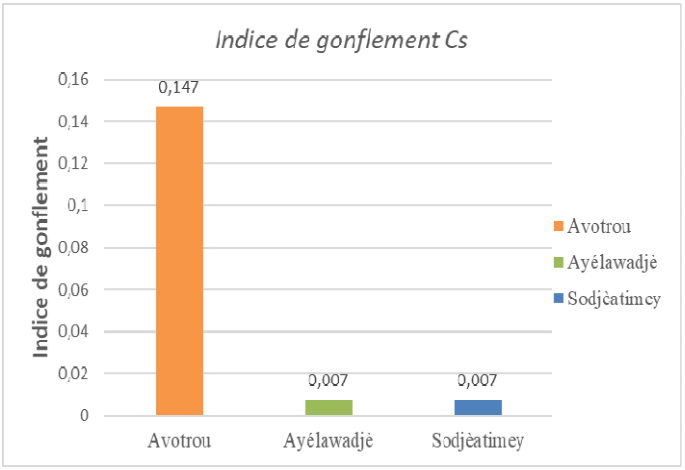
Mechanical testing

Table 4. State of consolidation of the soils studied

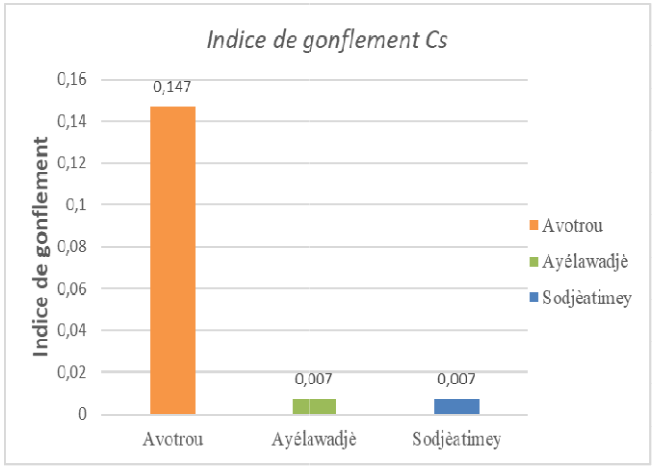
Sites	AVOTROU	AYELAWADJE	SODJETIMEY
Vertical stresses in place	1.8	0.8	0.8
Pre-consolidation constraints	44	43	52
Consolidation status	Over-consolidated	Over-consolidated	Over-consolidated

Table 5. Compression index [61]

Sites	Qualification
AYELAWADJE	Low organic matter content
SODJEATIMEY	Low organic matter content
AVOTROU	Very organic soil



Graph 1. Compression index of the soils studied



Graph 2. Swelling index of the soils studied

Table 6. Proposed soil classification according to swelling index[62]

Classification according to swelling index I_G	Susceptibility of soil to changes in volume
< 2	Low
$2 < I_G < 2.5$	Average
$2.5 < I_G < 3$	Strong
> 3	Very high

Table 7. Shear stress in the soils studied

Sites	AVOTROU	AYELAWADJE	SODJEATIMEY
Stress 1 (kPa)	19.44	29.72	31.11
Stress 2 (kPa)	25	63.33	56.39
Stress 3 (kPa)	44.17	111.94	118.06
Stress 4 (kPa)	85.56	235.83	224.17

Table 8. Cohesion and angle of friction for each site studied

	Avotrou	Ayelawadje	Sodjeatimey
Cohesion C_u (kPa)	7.4	0.9	3.3
Friction angle φ(degree)	10.9	30.2	29

The Avotrou soil is characterised by a compression index of between 0.33 and 0.90, which classifies it as soft clay according to Table 15. For the Ayélawadjè and Sodjèatimey soils, the compression indices measured are between 0.05 and 0.10, indicating that they are sandy soils with low compressibility, according to Table 15. The different values found are represented by the following trends. According to this table, the soils in the three study areas are not very susceptible to variations in volume.

Shear strength (Unconsolidated undrained UU test): This test is interpreted in terms of total stresses and makes it possible to estimate C_u undrained cohesion. The angle of internal friction φ_u is generally assumed to be zero. This test is best suited to fine soils.

From the results obtained for the mechanical properties of the soils studied in this locality of Akpakpa, the soil in the Avotrou area has typical clay properties, while those in Ayelawadje and Sodjeatimey tend to be a mixture of sand and clay compared with the results of [63], [64],[65],[66]. In short, the results of these studies indicate that the mechanical properties of soils in the region vary considerably according to geographical location.

General Conclusion

From a geotechnical point of view, these differences in the mechanical properties of soils can have important implications for construction and engineering. For example, clay soils tend to be more compressible and undergo greater deformation when subjected to

stress. On the other hand, sandy soils tend to be more cohesive and have greater load-bearing capacity. These results give an important indication of soil composition in different regions, which can be useful for planning and designing construction and engineering projects in these areas.

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