World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

Check for updates

Variability of cohesion and angle of friction as a function of water content in fine soils in the municipality of Lalo (Benin)

Sènouhoua Victor GBAGUIDI, Nounayon Eric Guillaume ODUNLAMI *, Crépin ZEVOUNOU and Christian Périclès AGBODJAN

Laboratory of Energetics and Applied Mechanics (LEMA), Polytechnic School of Abomey - Calavi, 01BP 2009 Cotonou, Benin.

World Journal of Advanced Engineering Technology and Sciences, 2023, 20(01), 142–152

Publication history: Received on 12 August 2023; revised on 28 September 2023; accepted on 01 October 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.20.1.1993

Abstract

This article deals with the variability of the cohesion and friction angle of clay soils as a function of their water content. It focuses on the fine soils of Lalo in Benin. Clay soils swell or shrink depending on their moisture content, which can cause stability problems and cracks in buildings. Benin's median depression, where the soils studied are located, has clay formations that are prone to shrink-swell, leading to differential settlement and damage to buildings. The aim of the study is therefore to characterise these formations and understand the influence of water content on their shear strength, measured by cohesion and angle of friction. Soil samples have been taken from various sites and subjected to laboratory tests to determine their physical properties. The results show that the soils studied are fine, mainly clay, with a natural water content varying between 27.47 % and 42.92 %. When the water content varies by 10%, cohesion varies from 4 kPa to 25 kPa and the angle of friction varies from 12° to 27°. It can be seen that cohesion and the angle of friction increase with the decreasing of water content. The results of this study will be recorded in a database so that they can be taken into account in the design of structures.

Keywords: Direct shear; Cohesion; Angle of friction; Water content; Clay soil

1. Introduction

Since the end of the 19th century, the Earth's average temperature has risen significantly and scientific data convincingly shows that the planet is warming up [1]. This global warming has a clear impact on clay soils and their physical and mechanical parameters [2-4]. Clay soils are sensitive to changes in their water content. Global warming can lead to higher temperatures and more frequent periods of drought, which can result in land subsidence, cracks and reduced soil bearing capacity, loss of soil cohesion, increased risk of landslides, soil shrinkage, etc....

These clay soils can be found all over the world, but are mainly found in Benin in the southern part of the country known as the Lama depression [5]. The "Lama depression" is a notch in the sedimentary basin of southern Benin, exposing marl and clay from the Eocene, in which Vertisols develop[6]. The clay formations in this depression are subject to the phenomenon of shrinkage and swelling, causing differential settling, which manifests itself in the appearance of disorders, such as cracks, affecting schools, hospitals, administrative buildings and detached houses, most of which were built without taking into account the mechanical parameters of these soils. These instabilities can be explained, on one hand by localised shear failure of the soil affecting slopes or foundations under the effect of an overload and, on the other hand, by variations in their moisture content [7-11]. It is therefore essential to consider these properties during the construction process to avoid undesirable consequences [12-15]. Knowledge of certain mechanical properties of these soils would enable their behaviour to be controlled. One of the aims of studying the mechanical behaviour of a soil is to determine its shear strength using tests to determine the cohesion C, which is the force of attraction between the

* Corresponding author: Nounayon Eric Guillaume ODUNLAMI; Email: oduneric@gmail.com

grains, and the angle of friction φ, which is an intrinsic characteristic of a soil, expressed in degrees, corresponding to the inclination of Coulomb's line.

The aim of the present article is to study the influence of water content on the cohesion C and the angle of friction φ of the direct shear strength of clay soils in Lalo. It is a contribution to the characterisation of clay formations in the Lama depression in Benin.

2. Material and methods

2.1. Presentation of the study area

The study area lies between latitudes 6°48' and 7°01' north and longitudes 1°50' and 2°05' east (Figure 1). The climate is humid tropical, with four alternating seasons, including two rainy seasons and two dry seasons. Average annual rainfall varies between 900 mm and 1100 mm. The area is characterised by low temperature variations around 27 °C, with average annual maxima of 32 °C and average manima of 22 °C. In recent decades, rainfall has become increasingly unpredictable, with droughts occurring at the height of the rainy season.

2.2. Soil sampling

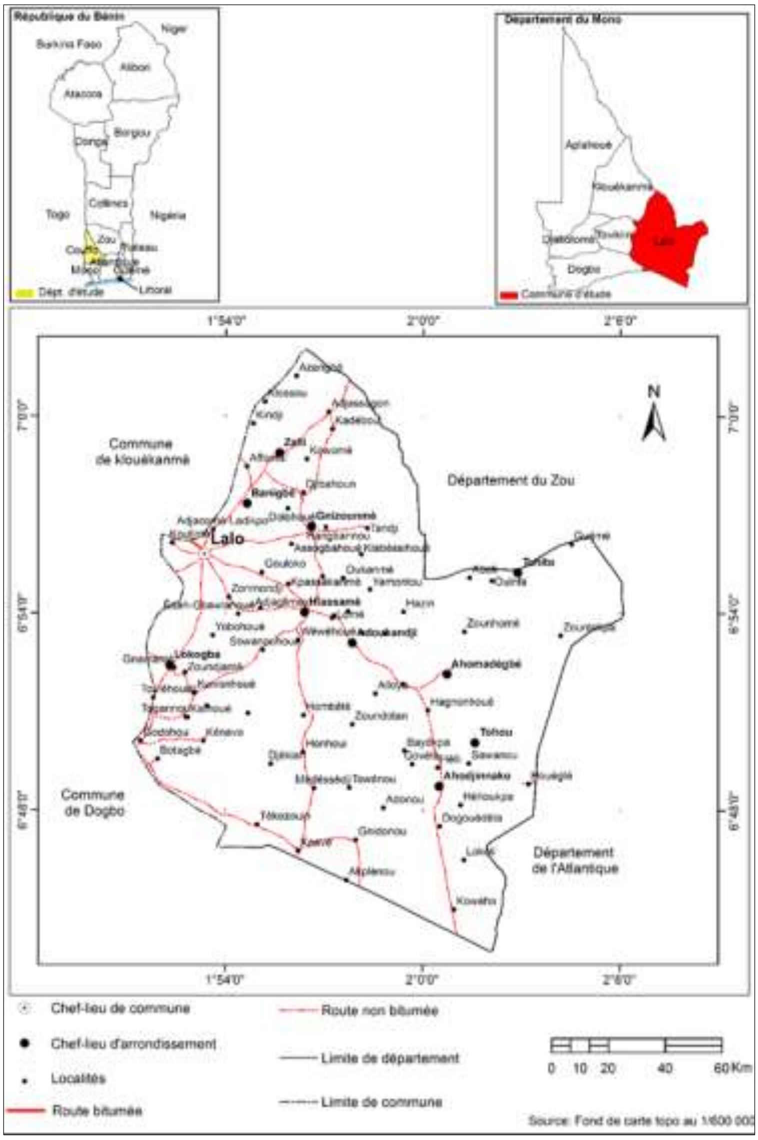


Figure 1 Location of the study area

The sampling sites were selected taking into account the degree of damage observed on the buildings erected on these soils. Soil samples were taken at six locations; the sampling points is located in Ahodjinnako, Ahomadégbé, Ahouada and Tohou; the coordinates of the sampling points are given in Table 1. Samples of reworked and undisturbed soil were taken at each site to a depth of 1.5m. The undisturbed samples were obtained using core drills and sealed at the ends with wax to retain the initial moisture content. These samples were subjected to direct shear testing in the laboratory. The reworked samples were collected in bags for identification tests.

Table 1 Sample collection locations

Sample Nº	Geographical coordinates (GPS)	Sampling locations
LA01	N 6°48'51.8''/ E 2°00'28.5''	Ahodjinnako
LA02	N 6°48'46.2'' / E 2°00'36.7''	Ahodjinnako
LA03	N 6°52'20.7'' / E 2°00'15.4''	Ahomadégbé
LA04	N 6°51'58.3'' / E 2°00'14.9''	Ahomadégbé
LA05	N 6°53'19.2'' / E 1°59'53.9''	Ahouada
LA06	N 6°41'33.0'' / E 1°54'51.9''	Tohou

2.3. Laboratory analysis

In order to associate a name with the different soils studied and to link them to a group of soils with similar characteristics, identification tests were carried out on the reworked soil samples. We then proceeded to prepare the intact soil samples for variation and measurement of their water content, and finally the direct shear test using the Casagrande box was carried out on these samples.

These tests were carried out at the Centre National d'Études et de Recherches des Travaux Publics (CNERTP) and the Laboratoire d'Essai et de Recherches en Génie Civil (LERGC).

2.3.1. Identification tests

These tests include the initial mass water content, the particle size analysis, the Atterberg limits and the methylene blue value. These tests give a description of the properties of the soil particles and the intensity of their bonds with water.

The initial mass water content is measured by oven drying at 105°C for 24 hours in accordance with the standard NF P 94-050 [16].

Particle size analyses were carried out by dry sieving after washing for elements with a size greater than or equal to 80 µm in accordance with standard NF P 94-056 [17] and by sedimentation for particles smaller than 80 µm in accordance with standard NF P 94-057 [18].

The Atterberg limits are reference levels linked to the change in state of the material. They were determined on the 0/400 µm fraction in accordance with the standard NF P 94-051 [19]. The liquidity limit WL, measured using the Casagrande cup, represents the water content in the transition from the liquid state to the plastic state; the plasticity limit WP, measured using the roller method, represents the water content in the transition from the plastic state to the solid state. The difference between these two defined limits is the plasticity index, noted IP, expressed as a percentage.

$$\mathbf{I_P} = \mathbf{w_L} - \mathbf{w_P} \quad (1)$$

The methylene blue test (VBS) is carried out in accordance with standard NF P 94-068 [20]. This test consists of measuring, per 100 g of material, the quantity of methylene blue required to cover the outer and inner surfaces of particles with a charge deficit. The test reveals the presence and concentration of clay particles.

2.3.2. Preparation of samples and measurement of water content

In order to study the influence of the water content on the cohesion C and the angle of friction φ of the direct shear strength, the samples to be sheared were prepared as follows:

- On the undisturbed soil samples from each site, twin samples were cut to the dimensions of the shear box (6cmx6cmx2.5cm) so as to obtain samples of almost identical mass;
- Three of the samples were placed in an oven at a temperature of 105°C for 24 hours in order to determine their dry mass and to deduce the initial average water content of the samples according to the formula:

$$\mathbf{w}(\%) = \mathbf{100x}\frac{\mathbf{m_h - m_s}}{\mathbf{m_s}}\ (2)$$

- The remaining samples are wrapped in plastic film and then in aluminium foil to maintain their initial water content.

The method described by HORTON et al [21] enabled a number of water content points to be scanned. The successive water contents are obtained by progressively dehydrating the sample by drying in a microwave oven. This technique ensures that the water content is evenly distributed throughout the sample [22]. Starting from the initial state, a series of twin samples are introduced into a microwave oven at a power of 70 W; the water content is monitored every ten minutes; its value is determined by reference to the initial dry mass. A reduction in the initial moisture content of 2%, 4%, 6%, 8% and 10% was obtained after several ten-minute cycles on five series of four samples. After each reduction in moisture content, the samples are placed in plastic film and then wrapped in aluminium foil to keep the moisture content fixed until the direct shear test.

2.3.3. Determination of the cohesion C and the angle of friction φ by direct shearing

The test was carried out in accordance with standard NF P 94-071-1 [23] on a soil specimen contained in a shear box itself made up of two independent half-boxes. The plane separating the two half-boxes forms a sliding plane which is the shear plane of the specimen.

A vertical stress σ is applied to the upper face of the specimen before it is sheared at constant speed; the shear stress τ then increases to a maximum value, which is measured. The state of stress at rupture (τ_r; σ_r) of the soil sample is then deduced. The test is carried out three times on the same sample with successive vertical stress values of 100 Kpa, 200 Kpa and 300 Kpa at a speed of 1.27 mm/min.

The three points representing the three states of failure of the soil are plotted on the same graph and to the same scale. The equation of the straight line is determined which is:

$$\boldsymbol{\tau = C + \sigma.\tan\varphi}\ (3)$$

τ = Shear stress
σ = Normal stress
The angle of friction φ is determined from the slope of the straight line
The cohesion C is determined from the y-intercept of the line.

3. Results and discussion

3.1. Soil identification and classification

The results of the identification tests include natural water content, particle size analysis, Atterberg limits and blue value.

The results of the analyses of the six soils are presented in Table 2.

The natural water content of the formations ranged from 27.47 to 42.92%. This variation is due, on the one hand, to variations in the properties of the formations and, on the other hand, to the climatic conditions at the time of the various samples.

All the soils studied have Dmax values of less than 50 mm and a predominantly clay granulometry (% < 2µm varies from 42.96 to 61.36). The percentage of material passing through the 80 µm sieve ranged from 78.89% to 96.40%; all of these values were above 35%. The soils studied are therefore fine soils [24,25].

Soils LA01, LA02 and LA05 have liquidity limits ranging from 91.8 to 97.2; their plasticity indices range from 47.0 to 51.0. These soils are placed below line A in the Casagrande plasticity diagram (Figure 1) and are classified as very plastic silts.

Soils LA03, LA04 and LA06 have liquidity limits ranging from 73.3 to 85.0; their plasticity indices range from 43.2 to 51.5. In the Casagrande plasticity diagram, these soils lie just above line A (Figure 1) and are classified as highly plastic clay soils.

The high values of the methylene blue test (VBS) confirm the high plasticity of the samples.

Table 2 Parameters for identifying the soils studied

Parameters	Samples					
	LA01	**LA02**	**LA03**	**LA04**	**LA05**	**LA06**
Fine content (% < 80µm)	96.40	89.25	76.20	78.89	82.00	89.61
Clay (% < 2µm)	61.36	56.75	50.15	42.96	50.47	60.93
Silt	22.79	21.76	21.02	17.9	16.51	14.39
Sand	15.84	21.49	28.83	39.13	33.02	24.67
Natural water content Wn	42.92	31.92	27.47	41.42	30.01	31.53
Liquidity limit W_L	97.2	91.8	73.3	78.5	94.2	85.0
Plasticity index I_P	50.6	47.0	42.3	45.1	51.0	51.5
VBS(g/100g)	9.71	7.43	8.28	12.00	9.28	9.00

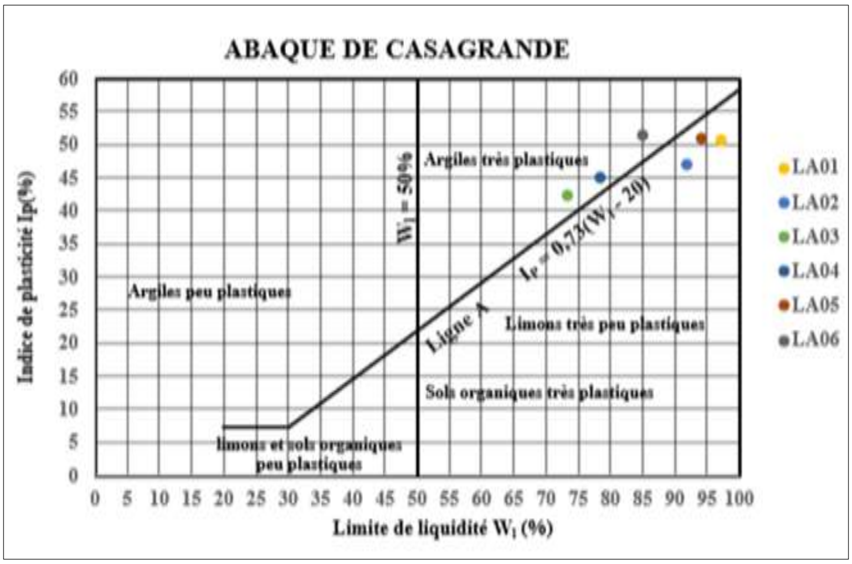


Figure 2 Liquid limit and plasticity index of the soils studied plotted on th Casagrande plasticity diagram

3.2. Variation of moisture content in microwave oven

Table 3 shows the variation in the wet mass of the LA06 sample and the corresponding moisture content and the number of 10-minute cycles at which the 2% variation in moisture content is achieved. It can be seen that the number of 10-minute cycles for which the moisture content decreases by 2% varies with time.

Figure 3 shows the variation in water content as a function of time for the LA06 sample. The dry mass of the sample is 159 g; the range of variation in water content is 10% for each sample. The curves obtained are linear, but the slope varies from one sample to another. This can be explained by the variation in the characteristics of the soils studied and their initial water content. The technique used enabled us to obtain linear variations in the water content of our samples. The number of cycles after which the water content decreases by 2% varies from one sample to another.

Table 3 Evolution of water content of sample LA06

N°	Number of 10 min Passage cycles	Wet masse (g)	Variation in water content (%)	Water content (%)
1	0	230	0	44.65
2	6	226.9	1.95	42.70
3	11	223.6	4.02	40.63
4	21	220.4	6.03	38.62
5	27	217.3	7.98	36.67
6	35	214.1	10	34.65

.

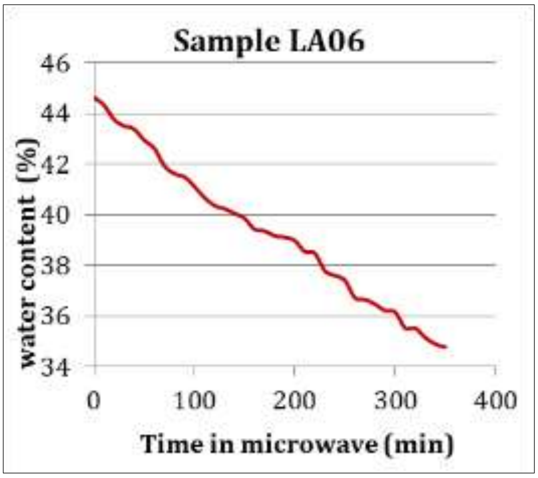


Figure 3 Water content curve for sample LA06

3.3. Shear test

Graph 4 shows the intrinsic curves of sample LA06 for six (6) different water contents. These curves are used to determine the cohesion (C) and the angle of internal friction (φ) of the soil. Table 4 shows the results of the variation in cohesion (C) and the angle of friction (φ) as a function of the water content of the LA06 sample.

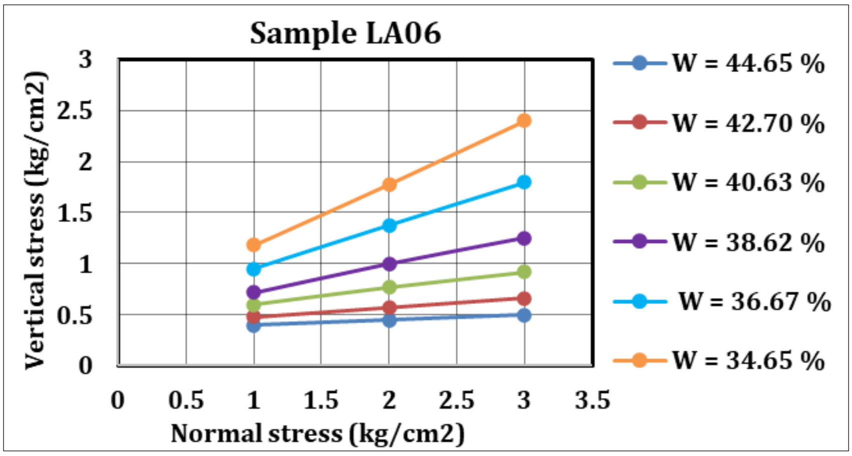
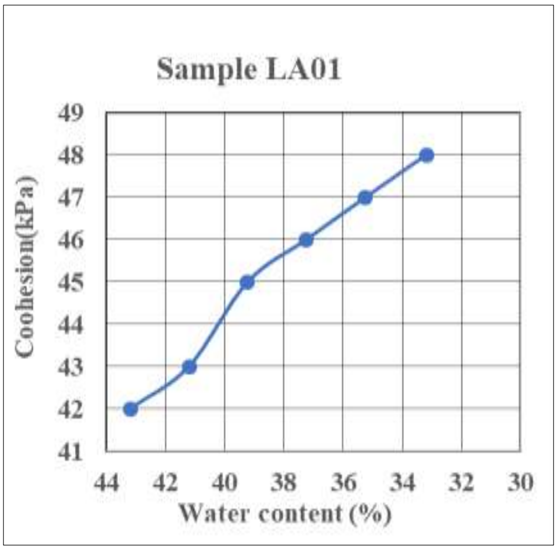


Figure 4 Intrinsic curves of the LA06 samples for different water contents

Table 4 Data on the evolution of the cohesion and the friction angle of sample L06 as a function of the water content

N°	Variation in water content (%)	Water content (%)	Cohesion C (Kpa)	Internal friction angle (°)
1	0.00	44.65	35.00	2.86
2	1.95	42.70	39.28	5.04
3	4.02	40.63	44.67	8.97
4	6.03	38.62	46.51	14.67
5	7.98	36.67	52.74	23.00
6	10.00	34.65	56.24	31.50

Figures 5 to 10 show the variation in cohesion and angle of internal friction of the samples studied as a function of grade.



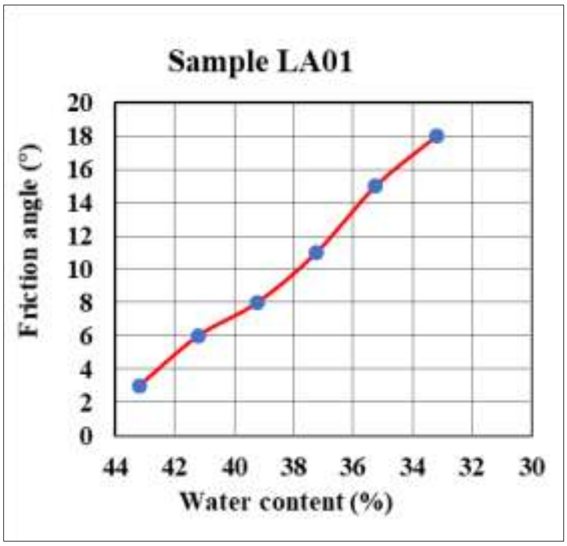


Figure 5 Variation of cohesion and friction angle with water content (LA01)

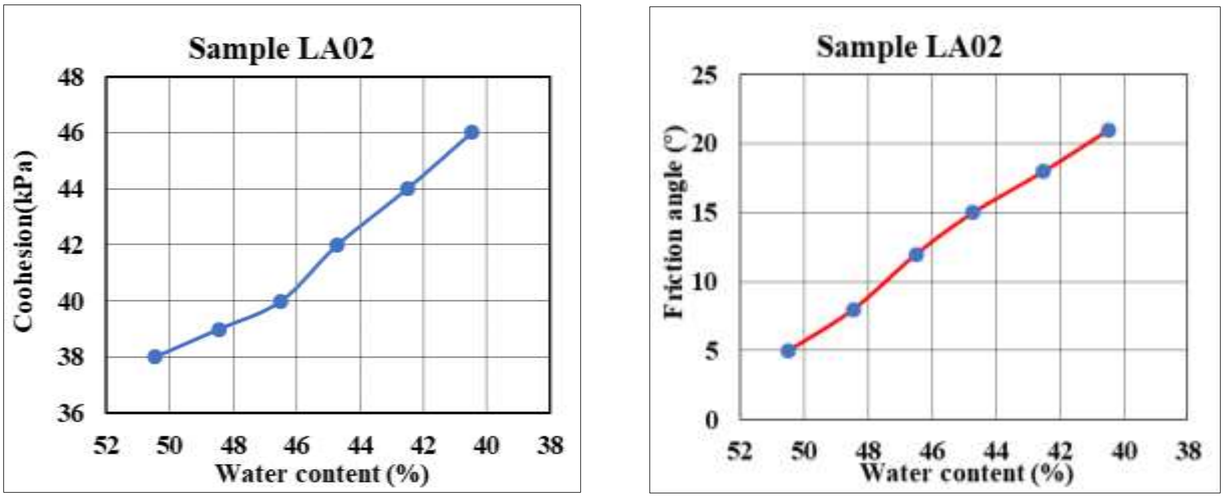


Figure 6 Variation of cohesion and friction angle with water content (LA02)

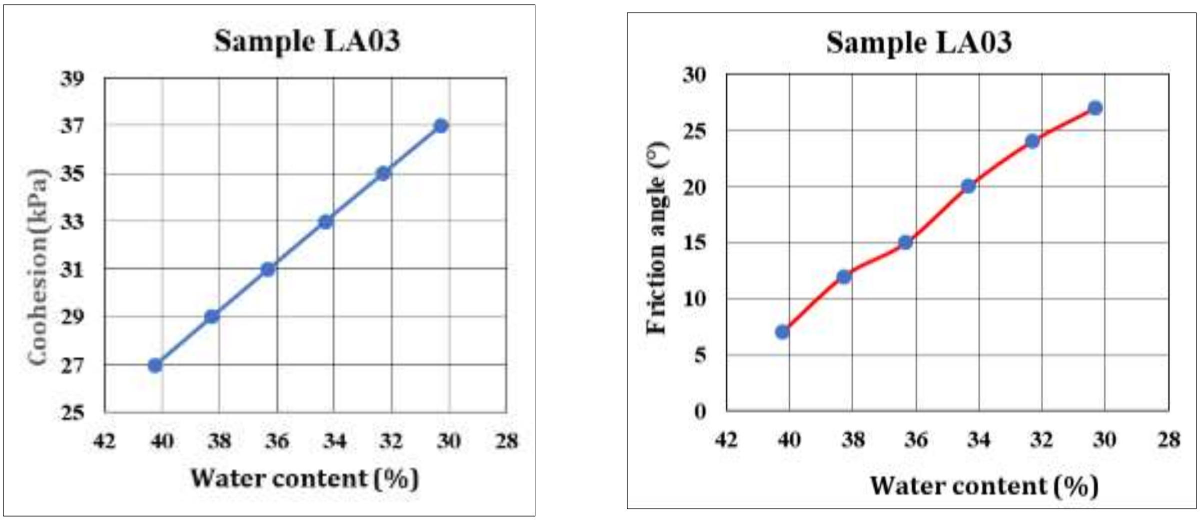


Figure 7 Variation of cohesion and friction angle with water content (LA03)

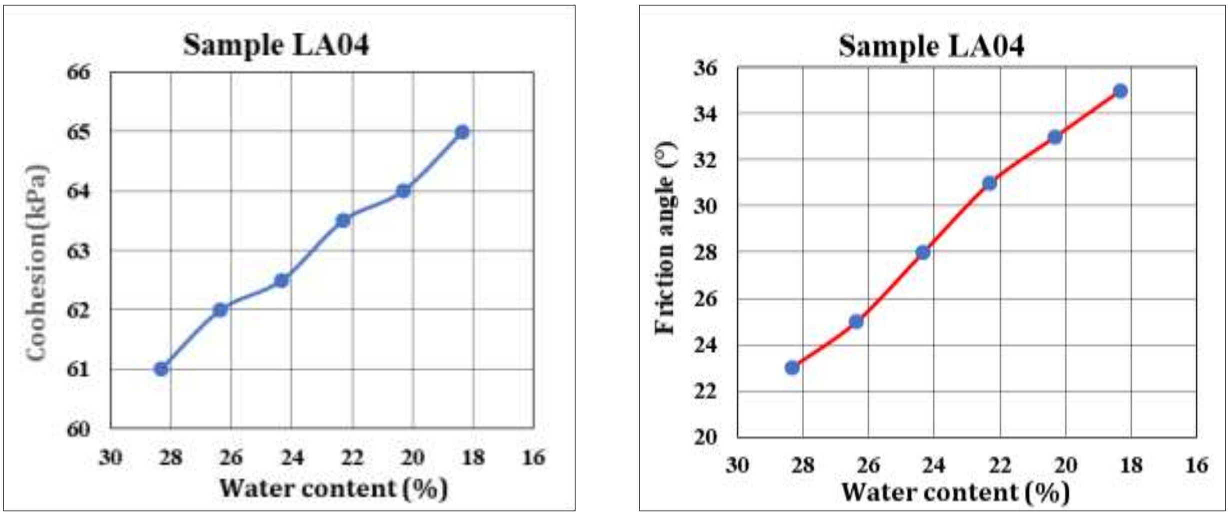


Figure 8 Variation of cohesion and friction angle with water content (LA04)

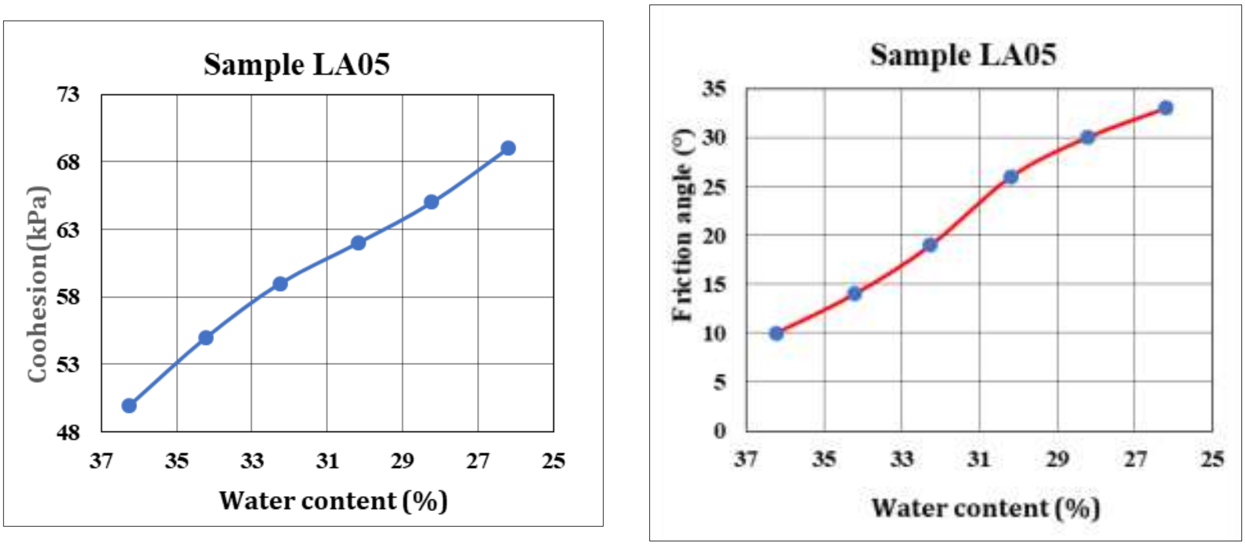


Figure 9 Variation of cohesion and friction angle with water content (LA05)

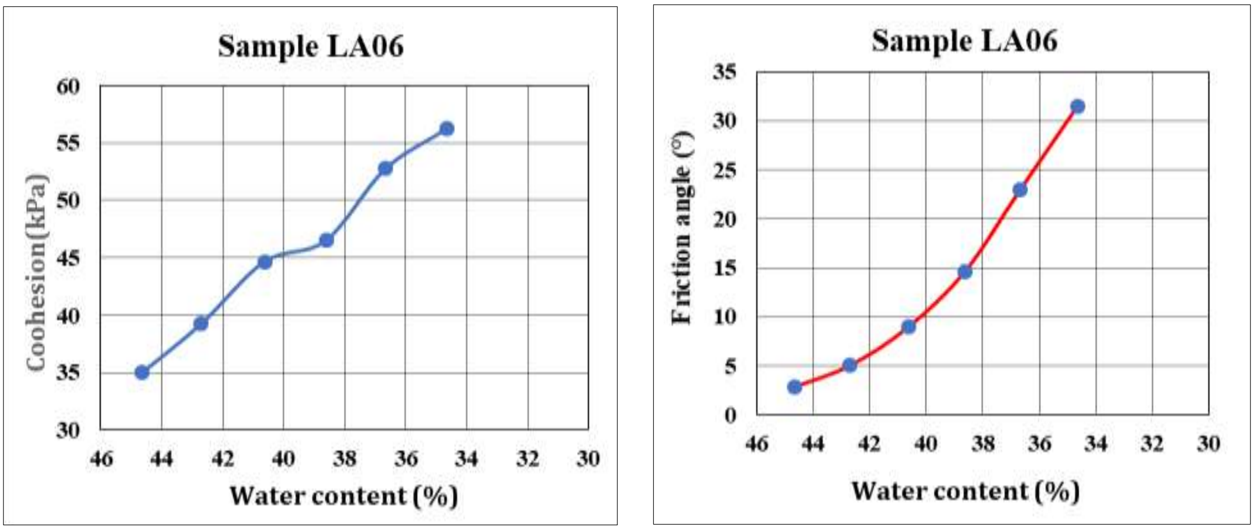


Figure 10 Variation of cohesion and friction angle with water content (LA06)

Analysis of the various curves shows that, generally speaking, cohesion and the angle of friction increase with decreasing water content.

When a clay soil is saturated with water, the clay particles are surrounded and separated from each other by a thin layer of water. This reduces the contact forces between the particles and therefore reduces cohesion. However, when the water content decreases through evaporation or drainage, the clay particles begin to move towards each other; capillary forces begin to develop between the clay particles. These capillary forces result from the attraction between water molecules and clay particles. They tend to bring the particles closer together, increasing the cohesion of the soil.

The angle of friction is a measure of the soil's resistance to flow or sliding under stress. A decrease in the water content of a clay soil reduces the lubrication of the interfaces between the particles, which increases friction and consequently increases the angle of friction.

4. Conclusion

The cohesion and angle of friction of the soils studied are highly dependent on water content and can vary considerably depending on environmental conditions. Taking into account the variation in these characteristics during the design and construction of buildings will help to minimise the potential risks of cracks in walls and planks, subsidence of slabs and floors, instability of foundations and ensure the long-term durability of the building.

Compliance with ethical standards

Acknowledgments

Special thanks are due to the director of ECO - GC for providing us with human and financial resources and rolling stock. We would also like to thank the directors of LERGC and CNERTP for allowing us to carry out the tests in their laboratories.

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

Authors' contributions

Sènouhoua Victor GBAGUIDI (SVG), Crépin ZEVOUNOU (CZ) and Nounayon Eric Guillaume ODUNLAMI (NEGO) are the initiators of this article. They set the context and defined the objective of this article. NEGO is the principal investigator; he collected the samples and carried out the work with Christian Périclès AGBODJAN. NEGO drafted the manuscript; SVG and CZ approved the method adopted and participated in the correction of the manuscript. SVG coordinated and guided the work, and provided scientific content based on knowledge in the field.

References

[1] Valérie Masson-Delmotte. Global warming: state of scientific knowledge, issues, risks and options for action. Geoscience Reports—Planetary Sciences. Volume 352, issue 4-5 (2020), p. 251-277.

[2] KREZIAK C., HEUMEZ S., VILLERS F., LY H. Influence of construction characteristics on the damage caused by the 2003 heatwave. Proceedings of the SEC 2015 International Symposium, Marne-La-Vallée, June 17-19, 2015, p405 -414

[3] SERRATRICE JF Some illustrations of the shrinkage and swelling of clays according to laboratory tests. Proceedings of the 3rd Maghreb Conference in Geotechnical Engineering CMIG'13, Algiers, November 18-19, 2013, 6p.

[4] Lamine IGHIL AMEUR. Houses and roads exposed to RGA put to the test of adaptation to climate change. 11th national days of geotechnics and engineering geology, National Institute of Applied Sciences of Lyon [INSA Lyon], CFMS, CFMR, CFGI, Jun 2022, Lyon, France. hal-03720254

[5] SLANSKY, Maurice. Contribution to the geological study of the coastal sedimentary basin of Dahomey and Togo. 1962 Technip. sl . : Bureau of Geological and Mining Research, 1962. Vol. No. 11.

[6] HA Azontonde, "Physical and hydraulic properties of soils in Benin", Soil Water Balance in the Sudano-Sahelian Zone (Proceedings of the Niamey Workshop, February 1991), IAHS Publ. no. 199, 1991, p. 251,

[7] Delage P., Cui Y., Water in unsaturated soils, Engineering Techniques, Construction Treaty C2 C31, 1-20, 2000

[8] Van Damme H., Water and its representation, in mechanics of unsaturated soils, Fleureau JM, Coussy O., eds Hermès, p. 23-68, 2001

[9] Derriche Z., Iguechtal L., Tas M. – "Behavior of structures in the expansive clays of ln- Aménas". French Geotechnical Review, No. 89, 1999, p. 55-65.

[10] Chassagneux D., Stieljes L., Mouroux P., Ménilliet F., Ducreux GH (1996). Mapping of the soil shrinkage-swelling hazard (drought/rain) at the departmental scale. Methodological approach in the Alpes de Haute-Provence. Report BRGM/RR-39218-FR, 74 pages

[11] Mitchell J.K. (1993). Fundamentals of soil behavior, 2nd edition, John Wiley and sons, New York, 437 pp.

[12] Philipponnat G. "Shrinkage-swelling of clays, proposed methodology. » French Geotechnical Review, n" 57, 1991, p.5-22.

[13] Vandangeon P. "Examples of disasters in the Paris region". French review of geotechnics, no. 58, 1992, p.7-14.

[14] Cisse Ibrahima Khalil, (1985) -Characterization and construction methods on expansive soils: application to Rufisque marl (Senegal). Doctoral thesis from the National Polytechnic Institute of Lorraine. ENSG of Nancy (France).

[15] Maschenko A. (2001). Drought and clayey soils. Alpha Sol industrial project. École des Mines d'Alès,74 p., 9 ann.

[16] NF P 94-050 (1995). Soils: reconnaissance and tests - Determination of the weight water content of materials - Steaming method.

[17] XP P 94-056 (1996). Soils : Reconnaissance and tests. Particle size analysis. Dry sieving method after washing.

[18] NF P 94-057 (1992) Soils: recognition and tests - Particle size analysis of soils - Sedimentation method.

[19] NF P 94-051 (1993). Soils: recognition and tests - Determination of Atterberg limits - Liquidity limit with the cup - Plasticity limit with the roller.

[20] NF P 94-068 (1998). Soils: recognition and tests - Measurement of the methylene blue adsorption capacity of a soil or a rocky material - Determination of the methylene blue value of a soil or a rocky material by the test to the job.

[21] HORTON R., WIERENGA PJ, NIELSEN DR" A rapid technique for obtaining uniform water content distributions in unsaturated soil columns

[22] LAURENT, J.-P. (1984). Contribution to the thermal characterization of porous materials: Optimization of "in-situ" measurement tools of thermal parameters, application to the study of the thermal properties of earth material, National Polytechnic Institute of Grenoble.

[23] NF P 94-071-1 (1994). Soils: recognition and tests – Rectilinear box shear test – Part 1: direct shear.

[24] LCPC-SETRA (2000b). Guide to Road Earthworks, Creation of embankments and subgrade layers (GTR), Fascicles I and II.

[25] Magnan JP (1997). Description, identification and classification of soils. Engineering techniques.