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Determination of Mechanical Properties of Compressible Soil in Littoral's Region of Cameroon: Depths Study of Soils Bordering the Wouri River in Douala

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Abstract

This work deals to the determination of the expansion ratio (C_r) and compression index (C_c) of soil samples taken at several points around the Wouri coast river of Cameroon. These parameters are the most important soil parameters, necessary to be known before each building project. The undisturbed soils samples are taken at nine different points labeled as P1, P2... P9 at the depths varying from 5m to 9.5 m and distanced around 10 to 15 meters. These studies are motivated by the fact that in this region, mechanical properties of soil have huge effects on buildings. By plotting the void ratio as a function of the logarithm of the pressure, these mechanical parameters are found and compared to that obtained from the inner land of Cameroon, Yaoundé town chosen as an example. As a result, this comparison has allowed us to classify the soil and give some practical advantages when carrying out civil engineering works such as buildings, bridges in coastal area.

Keywords: Clays; Oedometer test; Compression index; Expansion ratio; Compressible soil.

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1. Introduction

Generally, in civil engineering, all construction projects have soil for support, leading it to take the weight of the structures. This is why the soil's behavior is always an important element that creates a great concern for all engineers [1]. The soil testing in order to know its properties before construction is first and important step for many reputed construction companies. The properties of soil such as swelling, compressibility or strength (cohesion and internal friction angle) of soil always affect the design in constructions [2-4]. The soil must be able to withstand the load of the building otherwise the loss of property and life can occur. The soil investigations or analysis determine not only the bearing capacity of the soil, but also its rate of settlement [3, 4], that is the rate of the structure stabilization on the soil. Lack of understanding of the properties of the soil can lead to construction errors that are pricy in effort and material. Soil testing is primarily done to test the bearing capacity of the soil. It also shows its physical and chemical compositions. These characteristics may vary from layer to layer of the same soil [4]. Within a small area, weather, climate change and man activity can modify the soil and indirectly the bearing capacity of the soil. The suitability of a soil for a particular use should be determined based on its mechanical characteristics and not on visual inspection or apparent similarity to other soils. The soil testing also determines the length and depth of the pillars put in the soil to lay the foundation of the building. The selection of suitable construction technic, and knowing the possible foundation problems all are based on the results of the soil testing. Understanding Geotechnical investigation of the soil helps to take better decisions leading to the achievement of the construction project. The structure engineers can also decide whether there is need to go for soil stabilization or increase the depth of foundation for better stability of the building. Information about the surface and sub-surface features is vital for the design of structures and for planning construction methods. When buildings impose very heavy loads and the zone of influence is very deep, it would be desirable to invest some amount on sub-surface exploration than to overdesign the building and make it costlier. For complex projects involving heavy structures, such as bridges, dams, multi-storey buildings, it is essential to have detail exploration, allowing to engineers to determine properties of soils for different strata [5]. Particularly in the country Cameroon, various studies have been done concerning the soil properties found in littoral region. However, no research (analysis) has been carried out in other to know the influence of mechanical properties such as compression index, and expansion ratio at the Wouri's boarder coast. However, inside the land, researches about soil compressibility and shearing of sandy clay for building project were already carried out [6]. Only two points were chosen for collecting samples and this cannot be significant for the entire region, but remains until now, a good tool for general analysis for engineers. The great constraint is create a same environment in the lab that will keep the undisturbed samples to the conditions in the field and this test is limited for the small loads. From the above obvious reasons, we aim in this work to bring out a direct tool for engineers working in the Douala city of the Littoral's Region of Cameroon, which can be extended to other littoral region along the coast. Our particular attention being carried on soils bordering the Wouri River, based on the determining of mechanical properties that refers to One-Dimensional Consolidation (Oedometer) test to find the compression index (Cc) and the pre-consolidation pressure ($\sigma_p{}'$). The Oedometer test in one hand is complex, time consuming and costly, in contrast to other soil tests.

2. Materials and methods

The quality and the increasing of the civil engineering structure, such as roads, stadiums and buildings, has always been one of proofs of development or richness of any country. This is why in the concern of being emerging in year 2035, the Cameroonian government undertook vast building construction sites on all the extent of the country. Pointing to ensure the security of works, the soil test in laboratory or in situ is necessary, in order to have the qualitative and quantitative geotechnical reconnaissance, including all the phenomena related to the possible presence of water in the ground. In ref [5], the general studies of geotechnical parameters of the Cameroonian soil are shown. This need to be compared from other area in the region because many geotechnical studies have shown that the properties of soil in the region can vary according to seasons and sensitive works, we need to go into details. In this section, materials and methods applied to conduct field and laboratory test are presented.

2.1 Fieldwork and localization of the site of study

The challenge in the field is to collect undisturbed sample that retain the structural integrity of the soil and having a high recovery rate within. Collecting a perfectly undisturbed sample is difficult and the samples may contain a small portion of undisturbed soil at the top and bottom along its length. Samples have been taken at tributary of the river Wouri in Cameroon in a neighborhood of Bonamtoumbé. The area location is shown on the map of Figure (1), the topographic survey of the area, figure (2) and geodetic coordinates table (1).

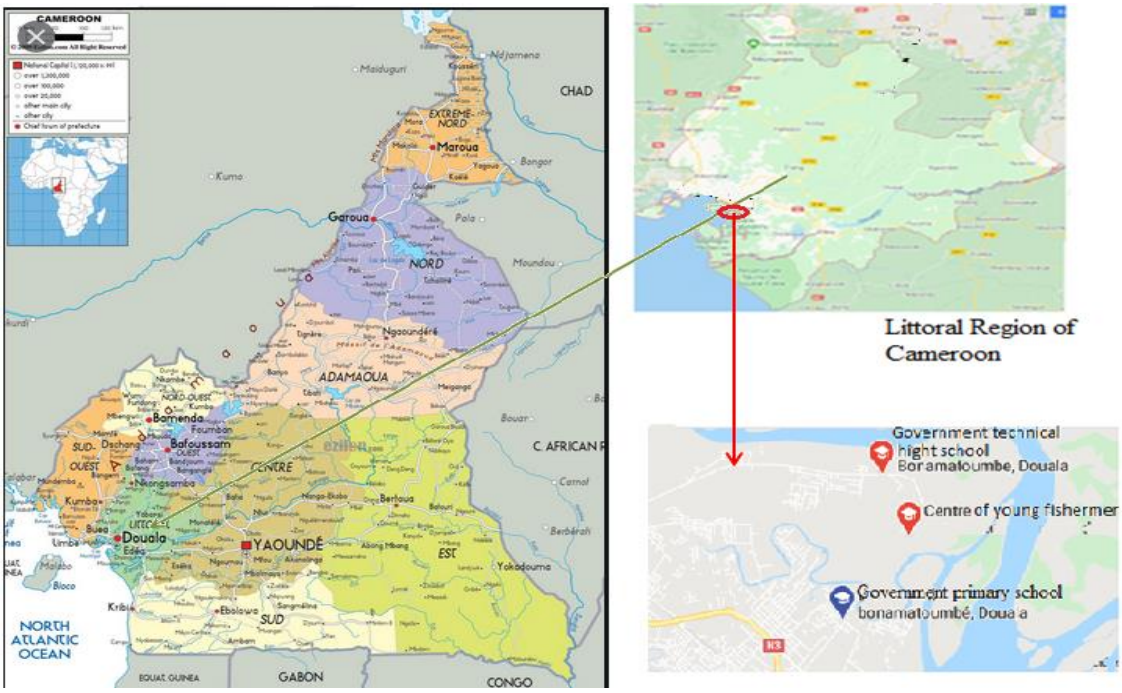

Figure 1: Location of the study area in the Littoral region of Cameroon

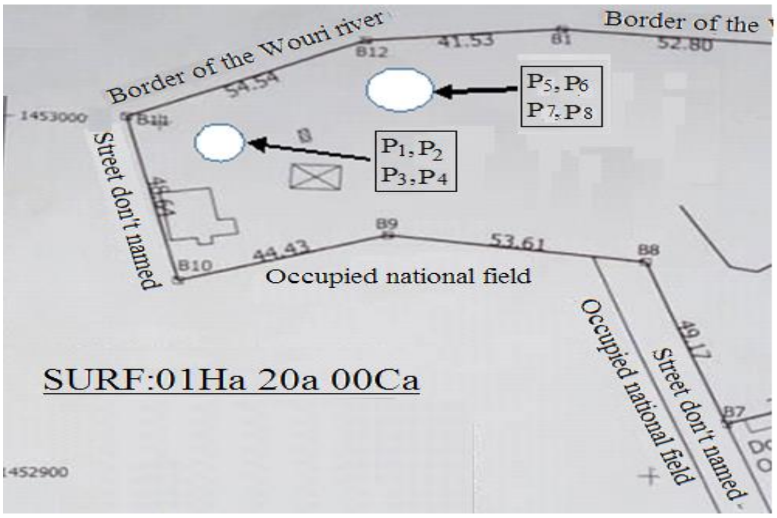

Figure 2: Topographic survey with collecting points P1…P9

Table 1: Geodetic coordinates of the site location

Points	**Geodetic Coordinates**	
	X	Y
B1	574385,842	453192,507
B2	574438,544	453189,306
B3	574461,837	453186,142
B4	574479,913	453180,613
B5	574439,645	453089,746
B6	574448,873	453086,019
B7	574418,699	453075,667
B8	574402,942	453122,245
B9	547349,751	453128,885
B10	574307,644	453114,699
B11	574296,251	453161,986
B12	574344,663	453187,108

2.2 Materials and sampling

Several types of augers are available; due to the depth of collecting sample, continuous flight (screw) was used. The system consists of a trier and a "T" handle. The auger is driven into the soil to be sampled and used to extract a core sample from the appropriate depth. The steps and procedure can easily be found in [7]. The highest depth can be up more than 10 meters. For the present investigation, nine of undisturbed soil sample are taken on an area of 01ha 20a 00ca near the Wouri coast. It consists of clay and mixed with sand at low percentage. For each point$P_i, with(\ i = 1, .., 9)$, the undisturbed soils samples are taken at different depths. The experimental procedure is based on BS1377 (1990) [8-10]. It is relevant for the sample to require classification, soil index and properties, a chemical testing before sending for consolidation tests. Mechanical property, namely compression index **Cc** is determined by conducting one-dimensional consolidation test (Oedometer Test). It is the method to determine consolidation characteristic of low-permeability soils when subjected to vertical load. In theory, the soil in this test specimen is loaded axially in increment of applied stress. Each increment of stress is held constant until the primary consolidation has ceased [11, 12]. Then the results incorporated into the reading formula that will show the value of void ratio, e. After the void ratio, e obtained plot log graph pressure versus void ratio (log scale) to find C_c . Then Cc is equal to the slope of the graph [13].

$$C_c = \left|\frac{\Delta e}{\Delta \log(\sigma)}\right| \tag{1}$$

It is one of the most important parameters in soil mechanics to calculate the settlement of different geotechnical structures. On the same graph, the expansion ratio Cr is equal to the slope of graph obtaining during the loading.

$$C_r = \left|\frac{\Delta e}{\Delta \log(\sigma_{p'})}\right| \tag{2}$$

Where $\sigma_p{}'$ is the pre-consolidation pressure, and is also an important parameter. It is the stress at which the transition or "break" occurs in the curve of (e-log) graph. It designates the maximum vertical overburden stress that a particular soil sample has sustained in the past. If soil is loaded beyond $\sigma_p{}'$, the soil will unable to sustain this load and the structure will collapse. Graphically it is the intersections of the two lines tangent to the plot (e-logσ) (For example: See Figures 3-6).

2.3 Experimental overview

To study the deformation of the sample of soil taken in the coastal area, nine samples have been brought in the lab. Experimental studies were carried out in the laboratory of consulting GEOTECH STUDIES AND PLANNING Sarl. The first and essential step before any construction activity on compressible soils is to assess the degree of compressibility and his impact on the structure in order to adopt preventive measures when dimensioning structural elements. To assess the characteristics of the soil many procedures, both simple and elaborate including laboratory methods of determining soils parameters have been developed by geotechnical researchers and engineers (e.g. [11,12].). A number of factors influencing expansive and compressibility behavior have been reported in the past ([11, 12, 13]). Among the identified factors that influence the compressibility behavior type and percentage of clay, initial placement conditions, stress history and stress path, nature of pore fluid, size and thickness of the sample are found to be more essential. The consolidation pressure of compressible soil is primarily dependent on the initial dry unit weight (γ_s) or void ratio (e) and on the moisture content (w).

3. Results and discussions

3.1 Preliminary

The one-dimensional consolidation test (Oedometer test) is an experiment usually used to seek the mechanical characteristics of soil from diagrams found by plotting the parameter "e" representing the void ratio, as a function of the logarithm of the applied pressure ($\log\sigma$) on the soil mass (see Figures 3…6). With these obvious parameters, the other parameters are defined as:

- The Recompression Index C_{rc}, defined as ;

$$C_{rc} = \frac{C_c}{1+e_0}, \quad (3)$$

which is the slope of the (e- log(σ)) diagram obtained along the hysteresis path .

- **T**he final settlement **(s)**

$$s = \Delta H = \frac{\Delta e}{1+e_0} H_0 = \frac{H_0}{1+e_0}\left[C_s log\left(\frac{\sigma_p{'}}{\sigma_{v0}}\right) + C_c log\left(\frac{\sigma_{vf}{'}}{\sigma_p{'}}\right)\right]. \quad (4)$$

Where $\sigma_p{'}$ on the diagram is materialized by the first changing of the slope. σ_{v0} being the initial compression strain, while $\sigma_{vf}{'}$ is the final compressive strain. ν is the Poisson ratio, difficult to obtain. Its good approximation can be taken as $\nu = 0.33$ (which is usually used in literature for the majority of soils), for our investigations .

- The young modulus of the soil E_s; which can be evaluated at the coast zone with the formula:

$$E_s = E_{oed}\frac{(1+\nu)(1-2\nu)}{1-\nu} \quad (5)$$

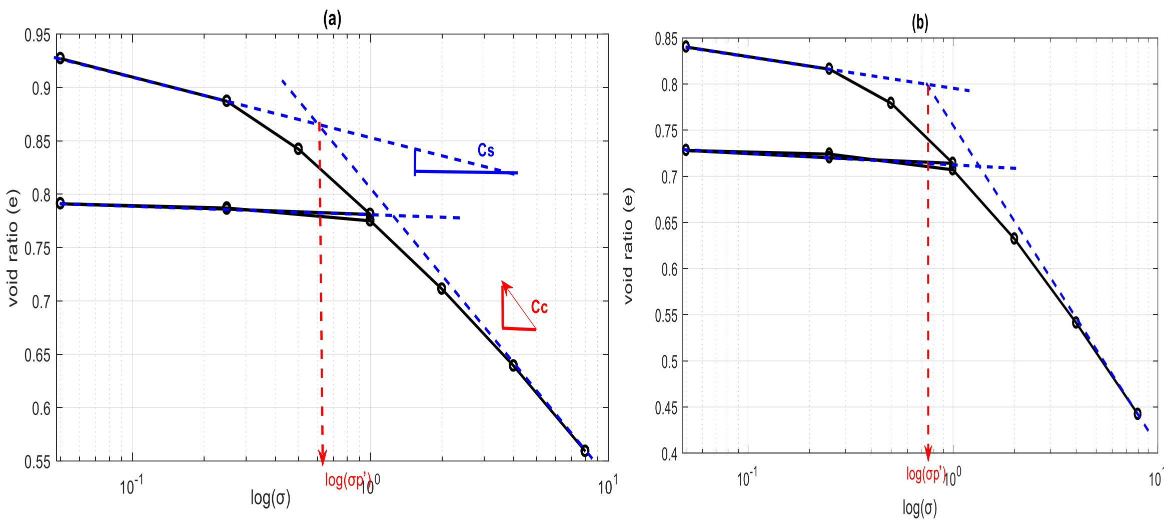

Figure 3: Compressibility curve, void ratio (e) as a function of $\log(\sigma)$. (a): At point P1, with $e_0 = 0.929, Cc = 0.251, Cr = 0.006, \sigma_p = 0.35$. (b): At point P2, with $e_0 = 1.010, Cc = 0.325, Cr = 0.004, \sigma_p{'} = 0.510$, (where the curvature is near to that obtained at point P3 $e_0 = 0.920$, Cc=0.251,Cr=0.006, $\sigma_p{'} = 0.510$)

3.2 Interpretations of results

In Tables. (2 and 3), we have sketched the means values of the characteristic of soil of the boarder coast obtained from nine arbitrary points.

Table 2: Results of oedometer test

Points / Results	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	Means values	vari-ance	Standard deviation
h(m)(Sampling depth)	5,00	7,20-7,70	5,00-5,50	7,50-8,00	4,30-4,80	7,40-7,90	5,00-5,40	9,00-9,50	5,00-5,300	**6,36**		
e (Voice ratio)	0,92	0,82	0,92	0,83	0,85	1,67	1,01	1,01	1,01	**1,004**	0,06	0,25
Pre-consolidation pressure (σ_p')	0,35	0,490	0,510	0,318	0,410	0,338	0,360	0,320	0,324	**0,422**	0,02	0,16
Cc(Compression ratio)	0,25	0,23	0,25	0,32	0,14	0,67	0,37	0,39	0,33	**0,327**	0,02	0,14
Crc(Recompression Index)	0,13	0,12	0,13	0,17	0,08	0,25	0,19	0,19	0,16	**0,158**	0,0022	0,05
Cr (Expansion ratio)	0,006	0,0040	0,0060	0,0090	0,0290	0,0240	0,0030	0,0050	0,0040	**0,01**	0,0001	0,009
σ_{vf} (Final compressive strain)	1,80	1,80	1,80	1,80	1,80	1,80	1,80	1,80	1,80	**1,8**	0,00	0,00
s(Final settlement) (mm)	3,85	2,77	3,85	4,35	2,76	6,60	6,65	6,29	5,26	**4,709**	2,14	1,46
σ_{ov}' (initial compressive strain)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	**0,05**	0,00	0,00

Table 3: Interpretations and analysis of Table 2

Mechanical properties	**Parameter (Symbol)**	**Value**	**Range**	**classification**	**Compressibility**
Compression ratio	Cc	0.327	$0,25 \leq Cc \leq 0,8$	Medium clay	Highly compressible (illites)
				Boston Clay	
Expansive ratio	Cr	0,01	< 4%	non expansive soil	
Pre-consolidation pressure	σ_p'	0,346 kPa	$\sigma_p' > \sigma_0$	Normally consolidated clay (NC)	
Oedometer modulus	E_{oed}	1,010MPa	1< Eoed < 30Mpa	Fine-grained soil	
Young Modulus	Es	0,681Mpa			

In order to seek the mean value of the pre-consolidation pressure, which is very important in geotechnical engineering, Casagrande [14] suggested a simple graphic construction to find it from laboratory **e- log (σ)**, which helps engineers to predict the settlement of a structure after loading. This is required for any construction project such as new building, bridges, larges roads and railroad tracks.

For the present work, the mean value Oedometer module, which is a characteristic data to evaluate the settlement, is obtained from Table 3:

$$E_{oedm} = 1.010MPa\ , \qquad (6)$$

which allowed us to deduce, by taking the Poisson ratio $\nu = 0.33$, the average value of the young modulus of the soil :

$$E_{sm} = 0.6810MPa \qquad (7)$$

But this value, which is just an indication seeing that the variance and standard deviation of data for each nine points at different depths are too high. Standard deviation and variance for other properties are in a good range to validate the results. Figures (3 to 6) present the conventional void ratio *e* versus the logarithm of the effective pressure (log σ), for the nine arbitraries points selected in the area. As one could expect the (e–logσ) curves of samples with initial water content as liquid limit water content is placed much upper than the one which is initially compacted and saturated for all the nine points. All the samples with initial water content as liquid limit water content, the slope relationship is initially curled concave downward, which approaches a straight line as pressure increases soils. With loading and unloading, the hysteresis phenomenon could be seen for all the nine points. We then have a slight slope which can be concluded that the clay in this area is not expansive (illites clay) and we are out of the phenomenon of *shrinkage swelling* clay that creates differential settlement on construction. For compacted and saturated soils, and soils with lower initial water content than their liquid limit, the (e–log(σ)) relationship is curved and curved in downwards throughout the pressure ranges. The compression index calculated C_c for each pressure increment increases as pressure increases. Similar behavior has been reported in the literature for many natural undisturbed and saturated soils with initial water content less than the liquid limit. Unloaded and reloaded samples also showed ''concave downward'' behavior in their ($e - log\sigma$) relationship [11, 12]. Figures (3-6) illustrate the compression index; which is equal to the slope of the pressure graph versus void ratio. Compression index **Cc** for clay is in the range 0.258 to 0.968 that has been proved by these studies.

3.3 Discussions

This test provided engineers with useful data about the soil near the Wouri river. These data as outlined in Table 2 are:

- ***The pre-consolidation pressure: ($\sigma_{p'}$)= 0.422 Mpa, which i***s the effective stress that marks the boundary between stiff and soft deformation response of a soil to loading and usually gives and indication of high loading in the past that the soil has been subjected. Having this value at a lower scale gives a clear idea of the kind of footing can bear the soil.
- ***The compression index Cc = 0.327,*** indicating how the soil will change the volume (settle) under load greater than the pre-consolidation pressure.
- ***The final settlement $s \approx 4.12\ mm$,*** which elucidates to the engineers the behavior of the building on soil and which plays important role while dimensioning the structural elements. Any construction in which the admitted compaction will be more than 4.12 mm, appropriate measures need to be taken.

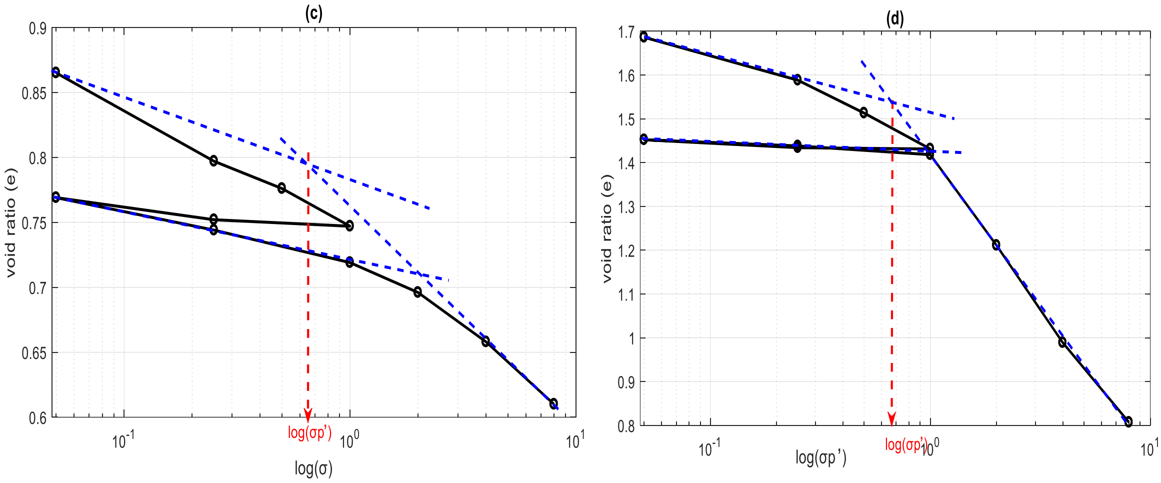

Figure 4: Compressibility curve, void ratio (e) as a function of log(σ). (c): at point p4 $e_0 = 0.830,\ Cc = 0.316,\ = 0.009,\ \sigma = 0.290$. (d) At point P5 $e_0 = 0.850,\ Cc = 0.142,\ Cr = 0.029,\ \sigma p' = 0.310$

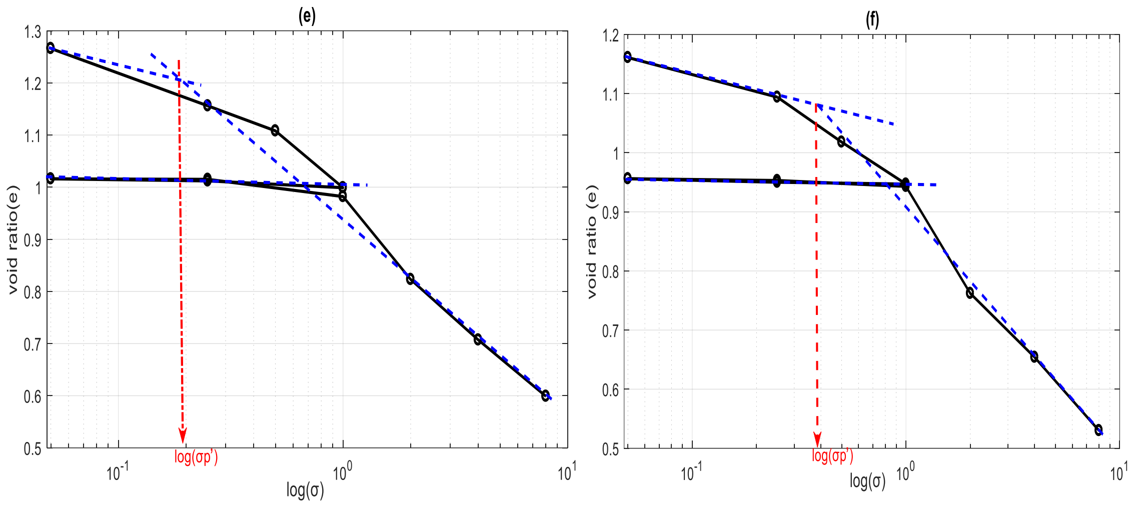

Figure 5: Compressibility curve, void ratio (e) as a function of log(σ). (e): at point P6 $e_0 = \mathbf{1.670}$, $\mathbf{Cc} = 0.670$, $Cr = 0.024$, $\sigma p' = 0.150$ (f) At point P7 $e_0 = 1.010$, $Cc = 0.373$, $Cr = 0.003$, $\sigma p' = 0.270$

3.4 Comparison with the results of inner land

In this sub-section our goal is to compare the mechanical properties found above with results found earlier for some important cities inside the country, not subjected daily to the influence of water. Our choice been carried on results found in [15,16] for the Yaounde's city, that is the capital of Cameroon, and this due to the fact that one can find there the majority of tallest engineering structures of the country, that are built after several geotechnical tests. The mechanical properties for Yaounde are shown in the right hand side of Table 4, while on left, those found in present work are shown.

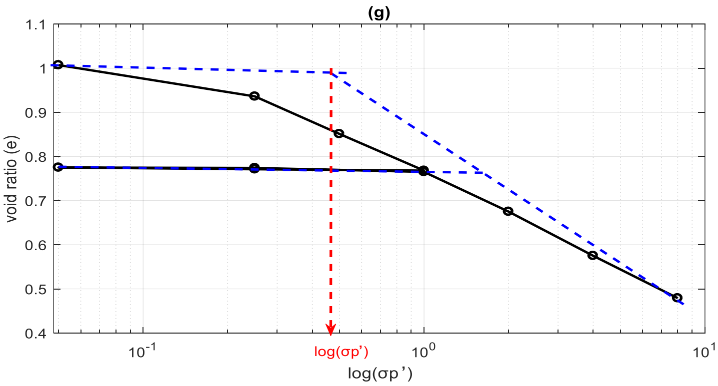

Figure 6: Compressibility curve, e-log at point P8 $e_0 = 1.010$, $Cc = 0.386$, $Cr = 0.005$, $\sigma p' = 0.20$. The curvature of this curve is near to that obtained at point P9: $e_0 = 1.010$, $Cc = 0.325$, $Cr = 0.004$, $\sigma p' = 0.215$

Table 4: Comparison of mechanical properties of sample of soil located at the littoral zone (Wouri) and in the inner land (Yaoundé)

Littoral area (Bands of Wouri river)				Inner area (Yaoundé Town)				
Points	Pre-consolidation pressure ′ (kPa)	Compression Index (Cc)	Expansion ratio (Cg)	Area	Number of points	Pre-consolidation pressure $\sigma'(kPa)$	Compression Index (C_c)	Expansion ratio (C_g)
P_1	0,31	0,251	0.006	Northen sub-zone	5	73.2 − 99	0.117 − 0.268	0.05 − 0.06
P_2	0,68	0,225	0,004					
P_3	0,31	0,251	0.006	Western sub-zone	5	56 – 86	0.196 − 0.323	0.05 − 0.07
P_4	0,5	0,316	0,009					
P_5	0,2	0,142	0,029	Southern sub-zone	5	65-105	0,119 − 0,290	0.05 − 0.06
P_6	0,46	0,67	0,024					
P_7	0,22	0,373	0,003	Central sub-zone	5	56 - 86	0,182 − 0,223	0.05 − 0.07
P_8	0,22	0,386	0,005					
P_9	0,22	0,325	0,004	Eastern sub-zone	5	56 - 86	0,181 − 0,279	0,05 − 0,06
Normally consolidated clay and highly compressible (Illites)				*Over-consolidated soil and average compressible*				

It comes out considering Table (4) that :

- Accounting to values of the pre-consolidation pressure, the Wouri boarders soil is highly compressible comparatively to soil of Yaoundé town, leading to the fact that expect settlement of foundations and embankments in this area will be more important.
- Accounting to values of the compression Index (Cc), the Wouri boarders soil is normally consolidated comparatively to Yaoundé soil which is over-consolidated. Precautions need to be taken while building in the area around the Wouri borders, which can be subjected to the immediate settlement.

4. Conclusions

In this work, we have determined certains mechanical parameters of soil borders of the Wouri coast river of Cameroon. The compression index, expansion ratio and the pre-consolidation pressure were calculated. We also through the oedometer modulus got an idea of the range of young modulus of this soil. These values obtained have been compared with others same parameters took in literature, inside the land not subjected to the same conditions, and it comes out that the mechanical properties totally differ and have a great influence of the stability of structures. Through our analysis, we noted that the soil at the boarder of Wouri River is highly compressible and not expansive. We also deduced from the e-log graph compression index (C_c) and expansion ratio value. Such correlation will bring many conveniences to engineers of geotechnical field whenever they tend to do quick and simple identification of the compressibility of soil. It will also help civil engineers to plan the construction of an appropriate structure with the soil conditions without having to make all tests for determining soil properties. Thus also profit from all aspects such as cost and energy. The parameters found in this paper will also help geotechnical engineers anticipate soil properties and behavior and find out how to adjust mechanical properties moving from inner land to the border coast. It is a tool of quick evaluation. Above all, the use of this soil as foundation stone requires special attention to the risk of endangering the building structure.

5. Recommendations

The oedometer test is important, but not sufficient when carry out a building construction. Other tests as direct shear at Casagrande box and sieve analysis adding to this will be a full and adequate geotechnical database for the mechanical properties of the soil boarding all coasts in general and particularly soil at borders of the Wouri river. Works in these lines is already under consideration and will enable us to evaluate the bearing capacity of soils and give cleared indications for constructions in order to avoid settlement.

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