Experimental researches

PHYSIC-MECHANICAL CHARACTERIZATION OF THE CLAYEY SOILS OF ISSABA DEPRESSION IN THE SOUTH-EAST OF BENIN

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The instability of soils due to the swelling phenomenon is among others at the origin of enormous damages in civil engineering works, such the deformations, the cracking, the tearing, the wear of the rotation surface and the destruction of the foundations observed at the infrastructures level (housing, socio-community centers, covered road or not). This phenomenon is a very complex and particularly threatening situation for the different construction projects, in a lot of regions of the world where these types of soilsare met and at the level of which we note premature damages of the works. It urges then to make specific arrangements during the execution of infrastructures. The phenomenon described above is also present in Benin mainly in the depression of Lama.

KEY WORDS: physic-mechanical characterization, soil, clay, the south-east of Benin.

1. Introduction

The depression particularly interested some researchers who consecrated some studies.

SLANSKY M. (1950) did very precise stratigraphical studies on the coastal pond of the Dahomey at that time and detailed synthetic study of the whole coastal sedimentary pond of Togo and Dahomey. After a high number of drilled wells, he leadsto the conclusion that the pond receives from the quartz and the clayey minerals where the kaolinite is very widely dominant. So as it is noted the presence of attapulgite and montmorillonite.

ADJATI A., (1986) working on the establishment of the constructive criteria of the clay of Lama Depression lead in his conclusions that the zone contains some Kaolinite, montmorillonite and illite.

The results of the chemical composition by X-ray fluorescence of the works of KIKI Yvette (2003-2004)on Onigbolo clay, located in the East depression of Lama reveal a strong proportion of silica (45 %) compared to the one the alumina (17 %), values comparable to those of illites and montmorillonites.

In 2008 HENDRIKS Kirsten (2008) studied the swelling soils of Lama Depression and concluded that all the studied soils are made of clays of Kaolinite and montmorillonite type. Her work remains however to perfect, in view of the number very restricted by points of taking in all the depression of Lama and the differences observed in the results stemming from thetests carried out.

Further to the works of HENDRIKS Kirsten, GBAGUIDI V. et al (2010) studied the swelling soils of Lama Depression. On the six points of taking made at the level of the aforementioned depression, only two points in Onigbolo and Issaba-South were realized in East of Lama. The tests allowed concluding that all the studied soils are made clays of Kaolinite and montmorillonite type and that the percentage in swelling minerals in Onigbolo is also very important with a normal activity whereas the clay obtained in Issaba has a low activity.

Although the study on all the zone of Lama depression turns out very interesting, we shall circumcise our work only in the East zone (one of the three parts of the depression) to comprehend it better and be more precise in our results.

The present study aims at an improvement of the physico-mechanical behavior of these clayey soils and at a proposal of preventive solutions for the good behavior of the works.

2. Environment of study

The sites, object of the present study, are located in Issaba depression in East of Lama depression. According to IGUE MOUINOU, WELLER ULRICH (2000) – Geology and geomorphology of the South Benin quoted by KIKI Yvette (2003-2004).This depression of Lama is formed by a directed band WSW - ENE of maximal width 25km. It covers an area which extends from East (Pobè, Issaba, etc.) to the West (Allada, Toffo, etc.) and is estimated at a surface more than 3000km ².

The depression of Lama forms a wide drill of a length of 130km and of a variable width from 5km (Tchi) to 25km (Issaba). It is divided into three zones to know the depression of Issaba in East, the depression of Ko in the center and the depression of Tchi on the West, by A. BIO YESSOUFOU, (2002).

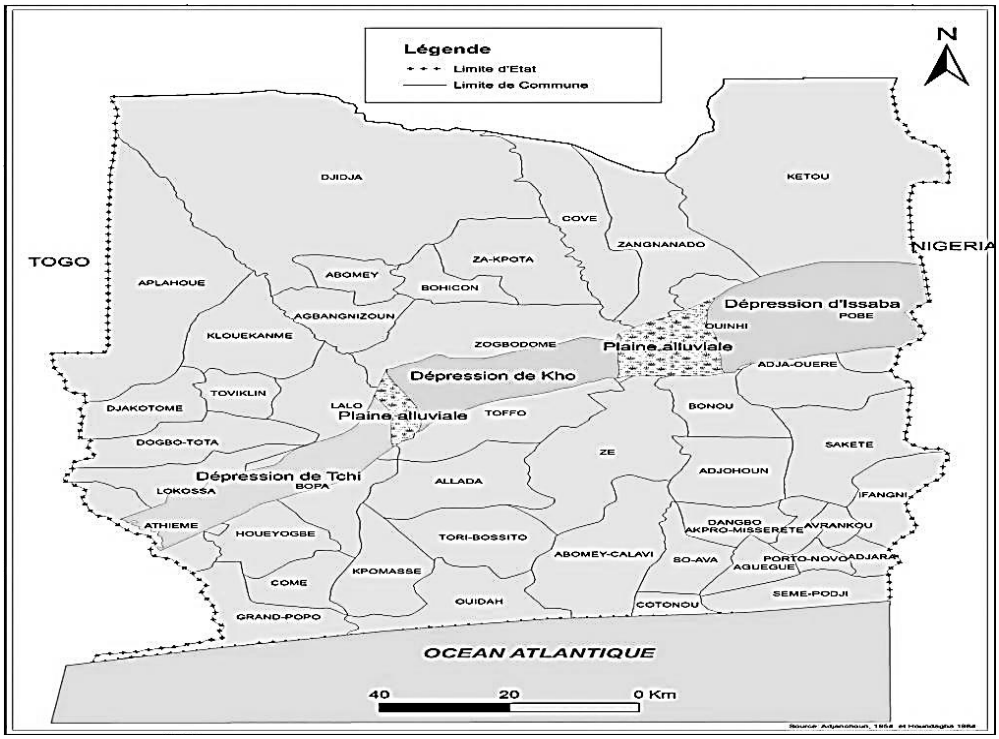


Fig. 1: Southern regional Map of Benin

3. Methodology

The methodology used then this study is at first based on the document research, then the field works finally tests of laboratory and their treatment.

The main objective of this document research is to make a bibliographical synthesis to list in general the documents approaching the studies on clays and in particular those linked to our zone of study. As regards the field works, we made at first the sampling in the environment of study, in second time located the sites of taking by a GPS to pass finally at the third time in the various takings.

So, for a better understanding of the physico-mechanical behavior of soils located in the East depression of Issaba, we realized some takings on nine (09) sites (*Fig. 2*). On every site, remolded and intact samples were extracted from 0m to 0,40m; 0,40m to 1,00m; 1,00m to 2,00m and from 2,00m to 3,00m of depth. The National Center of Test and Researches in Public works (NCTRPW) of Benin, the laboratory LAB-TP of Lomé in Togo and the Laboratory of the Sciences of Soil Waters and

Environment (LSSWE) of the National Institute of the Agricultural Researches of Benin (NIARB) served as surroundings for the achievement of the different and mechanical identification tests on samples. The results of these tests were the object of analysis and discussions.

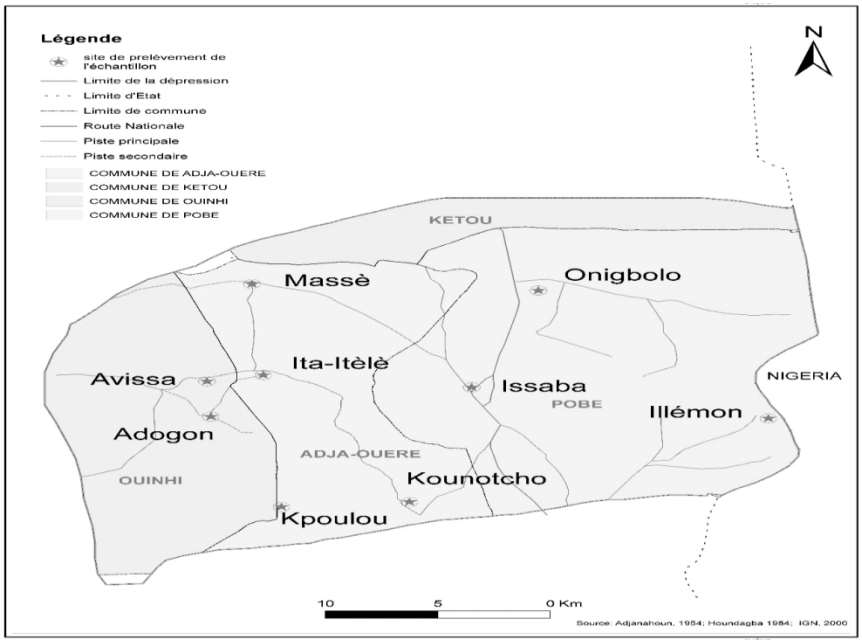


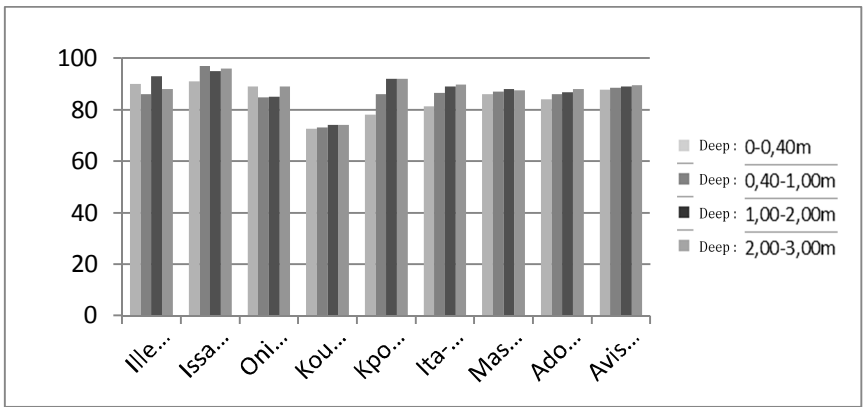
Fig. 2: Location of the taking sites

4. Results and analysis

4.1. Physical characteristics and classification

➢ ***Particle analysis by sieving***

It is achieved according to the specification NF P 94-056 and allowed us to determine the percentage of undersizein the sieve (<80µm).

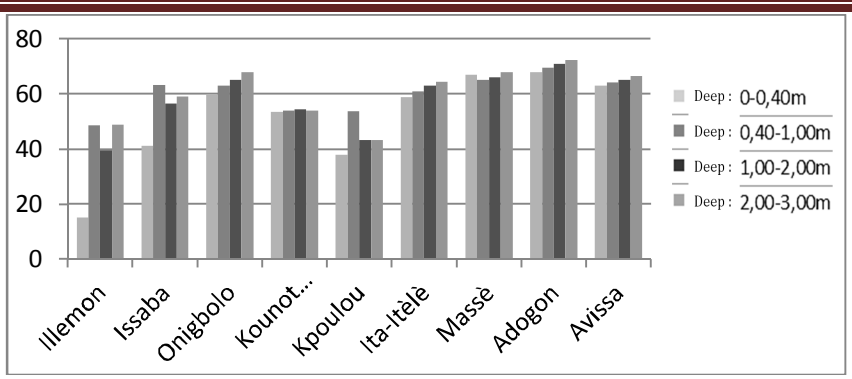


Graph 1: Undersize in the sieve80 µm

We notice a high percentage of undersizein the sieve (<80µm) varying from 72,50 to 97 %. This analysis lets conclude, for every site, the presence until a depth of three (03) meters of a material constituted essentially of fine particles (<80µm) for every site. We shall then make a particle analysis by sedimentation for every sample to know the portion of clayey particles.

➢ ***Particle analysis by sedimentation***

This test was ledaccording to the specification NF P 94-057 to determine the weight distribution of the present fine particles in the samples of studied soil.

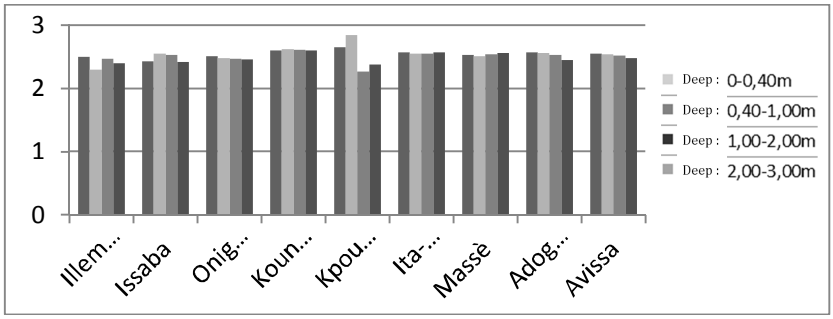


Graph 2: Undersize in the sieve2µm

Except for the site of Illemon where the rate of clay is 15 % in the depth of 0,40 m, we note that the rate of clay for all the samples in the different depths varies from 38 to 72 %. So it draws that our samples contain clayey particles.

➢ ***Specific Weights***

The specific weight of the solid grains was determined according to the French specification NFP 94 - 054. The found values are summarized on the following graph:

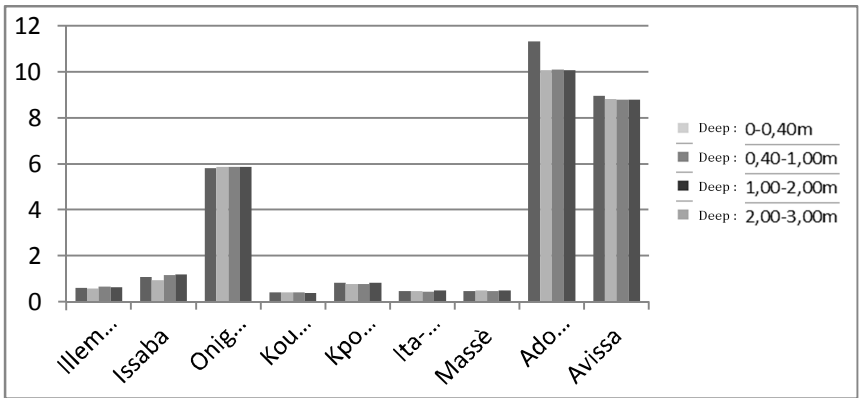


Graph 3: Specific weights

The found values are of the order of 2,27 - 2,84 and allow us to conclude that the taken samples are of clayey nature,J. LERAU, (2006).

➢ ***Organic matters***

The organic matters (OM) content is the quotient of the mass of organic matters contained in a sample of ground by the total mass of solid particles. The obtained results are put down on the graph below:



Graph 4**:** Organic matters

Through these fluctuations, we notice a variation going from 0,39 to 11,3. So we can say that the soils of Illemon, Issaba, Kounotcho, Ita-Itèlè and Massè sites are not organic with, in Issaba, a maximal content in organic matters of 1,187 < 3.

The soils of the other sites (Onigbolo, Adogon and Avissa) are weakly organic except the depth of 0,00m-0,40m of Adogon, fairly organic (Confer table below).

Table 1: Classification of soils in soil mechanics according to their organic matters content,(1999)

Organic matters content(%)		Qualifying
$C_{M0} \leq 3$	not organic	
$3 < C_{MO} \leq 10$	Weakly organic	
$10 < C_{MO} \leq 30$	Fairly organic	inpassive organic matrix
		insemi-fibrous organic matrix
		infibrous organic matrix
$C_{M0} > 30$	Very organic	in passive organic matrix
		insemi-fibrous organic matrix
		infibrous organic matrix

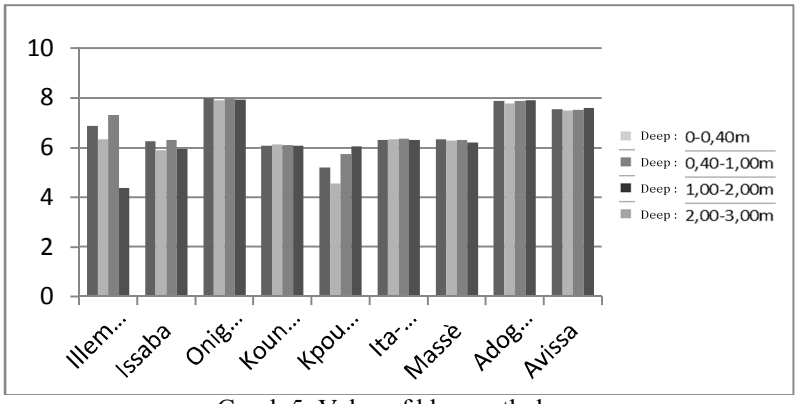
- ***Test in the blue methylene***

According to the Guide of the Road Excavations (GRE 92) French **[10]**, six categories of soil are defined from the value in the blue methylene.

Table 2: Value in the methylene blue according to the GRE

Value in the methylene blue(V_{BS})	Type of soil
$V_{BS}<0,1$	insensitivesoilto water
$0,2 <= V_{BS}<1,5$	sandsilty soil, sensitive to water
$1,5 <= V_{BS}<2,5$	sand clayey soil, little plastic
$2,5 <= V_{BS}<6$	silty soilof fair plasticity
$6 <= V_{BS}<8$	clayey soil
$V_{BS}> 8$	Very clayey soil

The results of the test in the blue methylene on sites are recapitulated on the graph below.



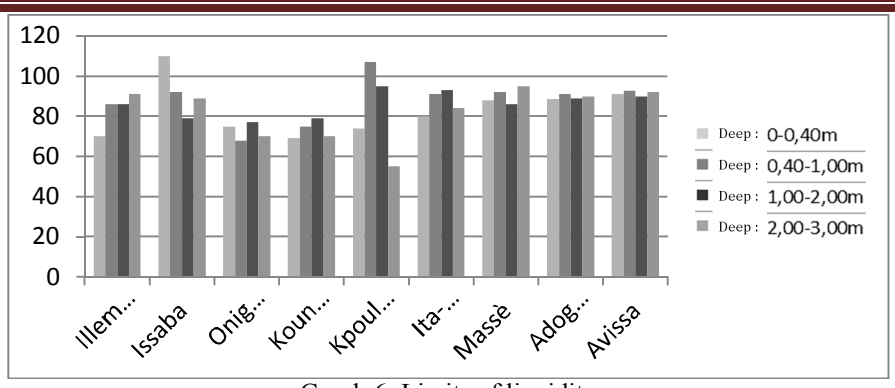
Graph 5: Value of blue methylene

According to the board of classification according to the value of V_{BS} stemming from the French guide of excavation higher notified, we can conclude that the soils of Onigbolo, Kounotcho, Ita-Itèlè, Massè, Adogon and Avissa sites are clayey soils($6< V_{BS}<8$). On the other hand the soils of Illemon, Issaba and Kpoulou sites are a mixture of clayey and silty soils with fair plasticity. Illemon for example presents some clayey grounds until a depth of 2,00m and some silt atfair plasticity from 2,00m to 3,00m.

- ***Limits of Atterberg (NF P 94-051)***
  - ✓ *Limits of liquidity*

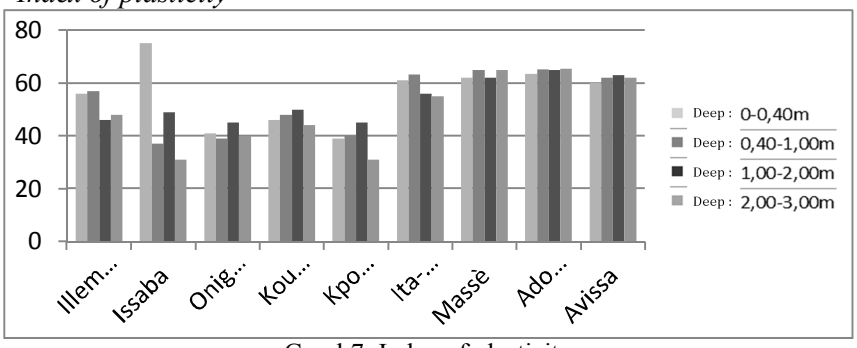
The limits of liquidity for the studied soils vary from 47 to 110 %.

As for the indexes of plasticity the obtained values go from 30 to 75 %.



Graph 6: Limits of liquidity

✓ *Index of plasticity*



Graph7: Index of plasticity

➢ ***AASHTO Classification***

Table 3: AASHTO Classification (1978)

Sites	AG	Limits		Subgroups (AASSTO)
		WL	IP	
Illemon	90	70	43	A-7-6
	86	86	57	A-7-6
	93	86	46	A-7-5
	88	91	48	A-7-5
Issaba	91	110	75	A-7-5
	97	92	37	A-7-5
	95	79	49	A-7-5
	96	89	31	A-7-5
Onigbolo	89	75	41	A-7-5
	84,7	68	39	A-7-5
	85	77	45	A-7-5
	88,9	70	40	A-7-5
Kounotcho	39,92	69	46	A-7-6
	40,78	75	48	A-7-6
	41,54	79	50	A-7-6
	38,76	70	44	A-7-6
Kpoulou	78	74	39	A-7-5
	86	107	40	A-7-5
	92	95	45	A-7-5
	92	55	31	A-7-6
Ita-Itèlè	81,33	80	61	A-7-6
	86,6	91	63,2	A-7-6
	89	93	56	A-7-6
	89,7	84	55	A-7-6
Massè	86	88	62	A-7-6
	87	92	65	A-7-6
	87	86	62	A-7-6
	87,5	95	65	A-7-5

Adogon	71	46,4	26,3	A-7-5
	72,5	50	27	A-7-5
	72	45	26,8	A-7-5
	76	50	25	A-7-5
Avissa	87,8	91	60	A-7-6
	88,5	92,7	62	A-7-6
	89	89,78	63	A-7-6
	89,5	92	62	A-7-6

It emerges from this classification that all the taken samples are clayey soils of A-7-5 and A-7-6.

➢ **Casagrande's chart of Plasticity**

Casagrande suggested asimplified approach, based on the limits of liquidity and plasticity. This chart of plasticity allows having so much relevant information as the mineralogical identification tests, (1991).

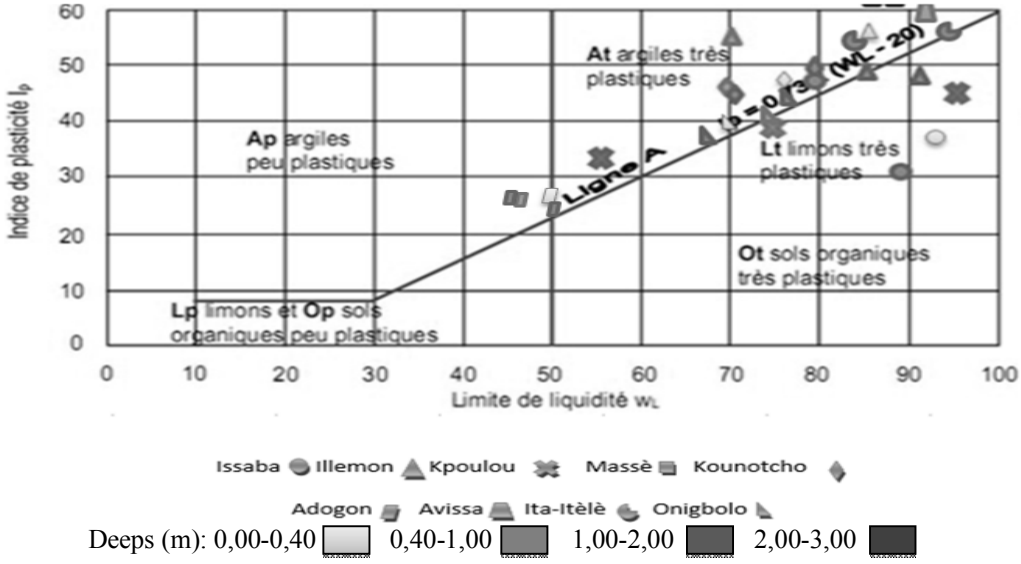


Fig. 3: Casagrande's chart of plasticity (1953)

According to this chart, the soils of Onigbolo, Massè, Ita-Itèlè, Kounotcho sites, Adogon and Avissa are over the Line A; so they are some very plastic clay. The soils of Issaba, Illemon and Kpoulou sites are a mixture of very plastic of clay and silt because these samples are both above and below the line A. That confirms the results of the value of blue methylene.

➢ ***Activity of the clay***

The activity coefficient « A » of an aggregate (known on the name of SKEMPTON coefficient) was defined in 1953 by SKEMPTON, as being the quotient of the index of plasticity (IP) of this aggregate in its content in elements of diameters lower than 2 micrometers (2µm) «the clayey fraction (FA)», (1981).

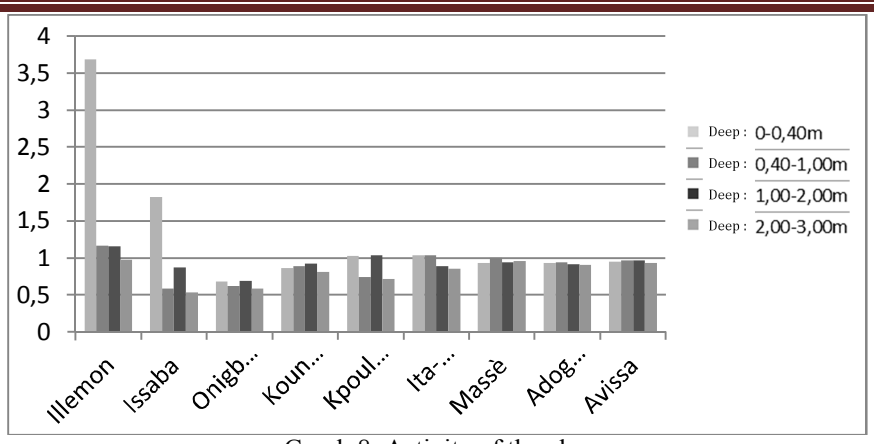
$$A = \frac{I_p}{\%<2\mu m}, \quad (1)$$

where A is the activity of the aggregate and IP is the index of plasticity.

Table 4: Activities of the main families of clays (Skempton, 1953)

Activity Ac	Type of sol
0,50 – 0,75	inactive soil
0,75 – 1,25	normal soil
1,25 – 2,00	activesoil
>2	Very activesoil

The diagram below presents the results of the activity of the clay out of various studied takings.



Graph 8: Activity of the clay

It draws from these results that all the soils taken until the depths of 3,00mm are inactive (Ac<0,75) except for the level from 0 to 0,40 m for the one of Issaba where the clay is active and very active for Illèmon always for the same thickness.

➢ ***Potential of swelling***

Table 5: Classification of SANGLERAT, (1981).

Potential of swelling	**IP (%)**
Weak	<15
Fair	15 – 25
High	25 – 55
Very high	>55

By referring to the Graph 7, the values of IP are between 31 and 75 %. According to Guy SANGLERAT's chart, we can conclude that studied clays have a «High to Very High» potential of swelling.

Table 6: Classification of the swelling of the different soils studied according to the G. SANGLERAT Chart, (1981).

Sites	**DEPTHS (m)**			
	0,00-0,40	0,40-1,00	1,00-2,00	2,00-3,00
	Type of swelling			
Illemon	Very High		High	
Issaba	Very High	High		
Onigbolo, Kounotcho, Kpoulou	High			
Ita-Itèlè, Massè, Adogon, Avissa	Very High			

4.2. Mechanical characteristics

➢ ***Direct shearing***

From the results of the direct shearing test for the soils of the studied sites, we made a classification of these lastones according tothe permissible stress.

Table 7: Classification of soils following the permissible stress

Sites	**DEPTHS (m)**			
	0,00-0,40	0,40-1,00	1,00-2,00	2,00-3,00
	Contrainte Admissible du Sol			
Illemon	VeryWeak	Weak	Weak	Weak
Issaba, Onigbolo	Weak			
Kounotcho	VeryWeak	VeryWeak	VeryWeak	VeryWeak
Kpoulou	Weak			VeryWeak
Ita-Itèlè, Massè, Adogon, Avissa	VeryWeak			

➢ **Oedometrical tests**

The results obtained during the oedometrical tests are recapitulated in the table below.

Table 8: Summary of the results of the oedometrical tests

Sites	Depth (m)	Index of compression Cc	Index ofvoids	Indexofswelling Cg	$\frac{c_c}{1+e_0}$
Illemon	0,00-0,40	0,820	0,840	0,060	0,470
	0,40-1,00	0,352	1,028	0,028	0,170
	1,00-2,00	0,359	0,902	0,027	0,190
	2,00-3,00	0,357	0,856	0,026	0,192
Issaba	0,00-0,40	0,345	0,757	0,032	0,196
	0,40-1,00	0,355	0,590	0,026	0,160
	1,00-2,00	0,327	0,860	0,022	0,176
	2,00-3,00	0,340	0,970	0,020	0,172
Onigbolo	0,00-0,40	0,560	1,103	0,017	0,270
	0,40-1,00	0,490	1,087	0,018	0,235
	1,00-2,00	0,590	1,098	0,016	0,281
	2,00-3,00	0,480	0,980	0,0165	0,240
Kounotcho	0,00-0,40	0,270	0,857	0,024	0,140
	0,40-1,00	0,310	0,744	0,023	0,180
	1,00-2,00	0,320	0,783	0,024	0,180
	2,00-3,00	0,290	0,731	0,023	0,167
Kpoulou	0,00-0,40	0,375	1,020	0,023	0,185
	0,40-1,00	0,358	0,906	0,022	0,170
	1,00-2,00	0,363	0,957	0,024	0,185
	2,00-3,00	0,416	0,912	0,021	0,220
Ita-Itèlè	0,00-0,40	0,280	0,933	0,012	0,145
	0,40-1,00	0,270	0,945	0,013	0,140
	1,00-2,00	0,250	0,892	0,014	0,132
	2,00-3,00	0,270	0,905	0,011	0,142
Massè	0,00-0,40	0,290	0,975	0,012	0,147
	0,40-1,00	0,280	0,912	0,013	0,146
	1,00-2,00	0,260	0,868	0,015	0,140
	2,00-3,00	0,280	0,857	0,010	0,150
Adogon	0,00-0,40	0,310	1,430	0,0092	0,127
	0,40-1,00	0,290	1,162	0,009	0,134
	1,00-2,00	0,330	1,510	0,009	0,131
	2,00-3,00	0,350	1,340	0,0094	0,150
Avissa	0,00-0,40	0,280	1,523	0,0047	0,110
	0,40-1,00	0,285	1,433	0,0051	0,120
	1,00-2,00	0,300	1,311	0,005	0,130
	2,00-3,00	0,297	0,980	0,0053	0,150

- **Index of compression Cc**

Table 9: Index of compression of some clayey minerals by COSTET and SANGLERAT, (1981)

Sand	0,01 < Cc < 0,1
Stiff clay (kaolinite)	0,1 < Cc < 0,25
Fair clay (illite)	0,25 < Cc < 0,80
Soft clay (montmorillonite)	0,80 < Cc < 2,5

From the *Table 9*, we can deduct that the soilis by nature ‘‘fair clay (illite)’’in Kpoulou, Issaba, Massè, Kounotcho, Adogon, Avissa, Ita-Itèlè and Onigbolo. But in Illèmon the soil is not uniform. From 0 to 0,40m we meet some soft clay (montmorillonite) " and from 0,40m to 3,00m the soil is by nature ‘‘fair clay (illite)’’.

- Formula of PHILIPPONAT$\frac{C_c}{1+e_0}$, (1997)

Table 12: Pathological risk according to $\frac{C_c}{1+e_0}$

$\frac{C_c}{1+e_0}$	**Pathologicalrisk**
< 0,015	Weak
0,015<$\frac{C_c}{1+e_0}$<0,05	Fair
0,05<$\frac{C_c}{1+e_0}$<0,2	Big
>0,2	Very Big

Table 13: Board translating the pathological risk of studied soils following the formula of PHILIPPONAT, (1997)

Sites	**DEPTHS** (m)			
	0,00-0,40	0,40-1,00	1,00-2,00	2,00-3,00
	Risque pathologique			
Illemon	Very Big	Big		
Issaba, Kounotcho, Ita-Itèlè, Massè, Adogon, Avissa	Big			
Onigbolo	Very Big			
Kpoulou	Big			Very Big

5. Proposals for a good behavior(performance) of the works

The studied soils being some clay constituted essentially by Montmorillonite and by illite with a high and very high swelling so causing a «Big – Very Big» pathological risk of the beach, we suggest:

- ***For the road constructions***

A general scraping of the soil is at least at a thickness of 40 cm.

Replace the part of the soils craped by selected materials whose characteristics answer the specifications allowing a good behaviourof the road.

Isolate the layer of foundation of the soil support by materials as geotextiles and geogrids to avoid the water rise.

- ***For the buildings***

As regards the light structures, in view of the character swelling some clay with a pressure of variable swell in all the studied depths, we recommend a scraping of the clay soil and its replacement by adequate materials. So, the foundations will be anchored in a ground bistratum: it’s a system of blob foundations resting on a backfilling in pulverulent materials (granular sand) which will act as mattress distributor of stresses. For the big constructions, we recommend the design of the deep foundations on piles to anchor on the good soil. The maximum of depth reached for the takings within the context of this study being only three (03) meters, an analysis of soils in bigger depth in proving necessary to appreciate better their natures in order to make the best options.

6. Conclusion

The present study reported in this paper allowed us to draw from conclusions about the soils of our sites of research.

The soils of all the studied sites except Illemon are constituted by silt and by clay of the family of illite and montmorillonite, having a potential of swelling from «high»

to «very high» with an activity of the clay varying from «inactive» to «very active». In Illemon, the soil is only constituted by clay of the family of montmorillonites, whose activity is «active» with a «Very High» potential of swelling.

The mechanical tests confirmed our conclusions made from the identification tests. Kpoulou, Massè, Ita-Itèlè, Avissa and Kounotcho are characterized by a soil of «fair» clay. The soils of Illemon, Issaba contains some «soft» and «fair» clay. On the other hand the soils of Adognon and Onigbolo contain some «fair» clay. As for the pathological risk, according tothe formulaof Philipponnat, the studied grounds have a pathological risk going from «big» to «very big».

Bibliographical references

[1]- M. SLANSKY, (1962).Contribution à l'étude géologique du bassin sédimentaire côtier du DAHOMEY et du TOGO. Technip, Paris, France.

[2]- A. ADJATI, (1986).Etablissement des critères constructifs de l'argile de la Lama : Contribution à l'étude du gonflement. Thèse d'agrégation de l'Enseignement Supérieur de l'Université Libre de Bruxelles, Belgique.

[3]- Y. KIKI, (2003 – 2004).Contribution à la mise au point de méthodes de stabilisation des sols gonflants : application aux sols argileux de la région de la Lama (Bénin). Thèse de doctorat de 3ème cycle de l'Ecole Supérieure Polytechnique de THIES.

[4]- K. HENDRIKS, (2008). Etude et analyse des sols gonflants au Bénin. Travail de fin d'études en vue de l'obtention du grade d'Ingénieur Civil des Constructions. Université de Liège. Université d'Abomey-Calavi - Laboratoire d'Essais et de Recherche en Génie Civil,.

[5]- V. GBAGUIDI et al, (2010).Etude du phénomène de gonflement des sols argileux du bassin sédimentaire côtier au Bénin.

[6]- I. Mouinou, W. Ulrich, (2000).Géologie et géomorphologie du sud Bénin.

[7]- A. BIO YESSOUFOU, (2002). Analyse organisationnelle de la fédération béninoise de football : stratégie des acteurs.

[8]-J.LERAU, (2006).Géotechnique,Tome 2.

[9]-P.REIFFSTECK, (1999). Les sols gonflants en génie-civil.Laboratoire Central des Ponts et Chaussées.

[10]-Le Guide des Terrassements Routiers (GTR 92).

[11]- R. HOLTZ, W. KOVACS et T. SHEAHAN, (1991).Introduction à la géotechnique, Montréal, Editions de l'Ecole polytechnique de Montréal.

[12]- O. COUSSY, (1981). Mécaniques des milieux poreux,Editions Technip,Paris.

[13]- J. COSTET et G. SANGLERAT, (1981). Cours pratique de mécanique des sols, Tome 1: Plasticité et calcul des tassements, 3ème édition, Dunod, Paris.

[14]- G. PHILIPPONNAT et B. HUBERT, (1997). Fondations et ouvrages en terre, 3ème édition, Eyrolles, Paris.

ФИЗИКО-МЕХАНИЧЕСКИЕ ХАРАКТЕРИСТИКИ ГЛИНИСТЫХ ГРУНТОВ РАЙОНА ИССАБА НА ЮГО-ВОСТОКЕ БЕНИНА

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Неустойчивость грунта под основанием из-за выпучивания, как и многие другие явления, вызывает огромные разрушения в строительных работах из-за деформирования, растрескивания, образования трещин и разрушения фундаментов инфраструктур (жилищных, социально-общественных центров, дорог асфальтированных или не асфальтированных).

Это явление очень сложное и особенно вызывает угрожающие ситуации для различных строительных проектов во многих регионах мира, где эти типы основания существуют и на уровне которых отмечаются преждевременные нарушения работ. Эти явления требуют введения конкретных мероприятий по ходу выполнения строительных работ. Описанное выше явление присутствует в Бенине в основном в ложбине Лама.

КЛЮЧЕВЫЕ СЛОВА: физико-механические характеристики, грунт, глина, юго-восток Бенина.