Evaluation and Mastery of the Risks of Swelling of Clayey Soils of the Khô Depression in the South-Benin

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Abstract: To find an adequate solution to master the risks of swelling is a more and more recurring question generally for the engineers and geo-technicians in particular. This study at first allowed to determine the physical characteristics of the soils of the district of Massi and allowed to summarize that the samples contain some strong proportion of clayey particles with a potential of variable swelling. Clays of the district of Massi are active and have an important pathological risk. So, the mechanical characteristics of the studied grounds, revealed that to fight against the swelling in the district of Massi, the works have to bring pressures of the order from 5 to 63 kPa when they are set up between 0.00 and 0.50 m; 3 to 111 kPa for 0.50-1.00 m; 56 to 136 kPa for 1.00-2.00 m; 151 to 265 kPa for 2.00-3.00 m. These pressures are inferior to the stress of pre-consolidation of the soils of the district of Massi and allow to limit the excessive subsidence of the massif of soil.

Key words: Potential of swelling, pathological risk, pressure of works, stress of pre-consolidation.

Nomenclature

C_2	Content in fines < 2 μm
W	Water content
C_{MO}	Organic material content
W_L	Liquidity limit
W_p	Plasticity limit
I_p	Plasticity index
A	Activity
C_c	Compression ratio
e_0	Voids ratio
C_g	Swelling pressure
C	Cohesion

Greek letters

γ_s	Voluminal weight of solid grains
γ_d	Dry voluminal weight
σ_{vo}	Vertical effective stress (kPa)
σ_g	Swelling pressure (kPa)
σ'_p	Pre-consolidation stress (kPa)
ϕ	Angle of internal friction

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1. Introduction

The achievement of infrastructures (buildings, roads) on swelling soils constitutes a major concern for the builders in general and the geo-technicians in particular because of the phenomena bound to the variation of the moisture content of the latter. Chretien [1] showed that the capacity in the retirement swelling of the clayey soils results from factors as the geologic history of these soils, which gives them a certain predisposition relative to their mineralogical composition and to their texture. According to Martin [2], the seasonal alternations of humidity/drying produce unceasing movements of the soil surface which swells when the moisture content of the underlying clayey material increases and which subsides when it decreases. According to Ejjaaouani et al. [3], the bulge of the footing foundations during the moistening of swelling soils develops when the vertical stress is inferior to the swelling pressure of the

ground at the same level.

The examples of disorders bound to the presence of swelling clays are numerous and varied [4, 5]. The phenomenon of retirement swelling of the clayey superficial formations so causes bulges which show themselves by the appearance of disorders, such as cracks, affecting mainly the works built in short depth. In these cases, the reference to the classic safe stress to plan the foundations is not thus suitable [2]. For the construction of buildings and works on swelling soils, the engineers must solve problems bound to the evaluation of the capacity of swelling or retirement of the soil, to the choice of technical and economic solutions allowing to stabilize the effects of the swelling or the retirement on the foundations, and to the definition of the optimal loads on the foundations so that they do not undergo dangerous or unacceptable deformations during the construction and the exploitation of these constructions [3].

These described phenomena are also present in Benin. They are mainly localized in the depression of Lama. Several authors [6-8] studied swelling soils of the depression of Lama and concluded that the studied soils were constituted of kaolinite, illite and montmorillonite clays, and that the content in swelling minerals in certain zones of the depression of Khô was important inferring a considerable activity. The present study aims at an appreciation of the behavior of the clayey soils in the locality of Massi located in the depression Center (depression of Khô) of Lama to estimate and master the risks of settlement and swelling.

2. Experimental Study

2.1 Presentation of the Environment of Study

Benin is a sub-Saharan country of western Africa endowed with a semi-arid climate. It is subdivided into 12 departments and counts 77 municipalities. Several of these municipalities are in the region of Lama where exist soils with swelling character covering an area estimated at more than 3,000 km^2. The region of Lama presents three depressions namely: Issaba in the East; Khô in the Center and Tchi in the West. The one of the center is our environment of study, exactly the municipality of Zogbodomey situated in the Atlantic and Zou departments where we note a preponderance of damages due to the phenomena of retirement swelling and the sinistrality relatively high caused in particular in the district of Massi [9].

For a better appreciation of the noticed strains at the level of bearing soils of the infrastructures of this locality of the depression of Khô, two sites were held: Massi-centre and Adjido (Fig. 1). It is at first, proceeded to the geotechnical analysis of eight (08) samples taken from both sites in depths from 0 to 0.5 m; 0.5 to 1.0 m; 1.0 to 2.0 m and 2.0 to 3.0 m with regard to the surface of the natural ground.

2.2 Methodology

Some tests were made according to the French standards on intact samples and remolded in particular the identifications tests: the grain size analysis by sieving (XP P 94-056, 1996) and by sedimentation (NF P 94-057, 1992), the Atterberg limits (NF P 94-051, 1993), the content in organic matter (NF P 94-055, 1993), the value in the blue methylene (NF P 94-068, 1998), the density of the solid grains (NF P 94-054, 1991) and mechanical tests namely the compressibility tests in the oedometer (NF P 94-090-1, 1997), the direct shear test in Casagrande box (NF P 94-071-1, 1994).

To master the risks of swelling, it is then proceeded to the determination according to the potential of swelling and the breaking stress of the ranges of applicable stresses at the level of bearing soils of the works to be set up. The NCTRPW (National Center of the Tests and Research in Public Works) of Benin and the LAB-TP laboratory of Lomé in Togo served as surroundings for the achievement of the different tests.
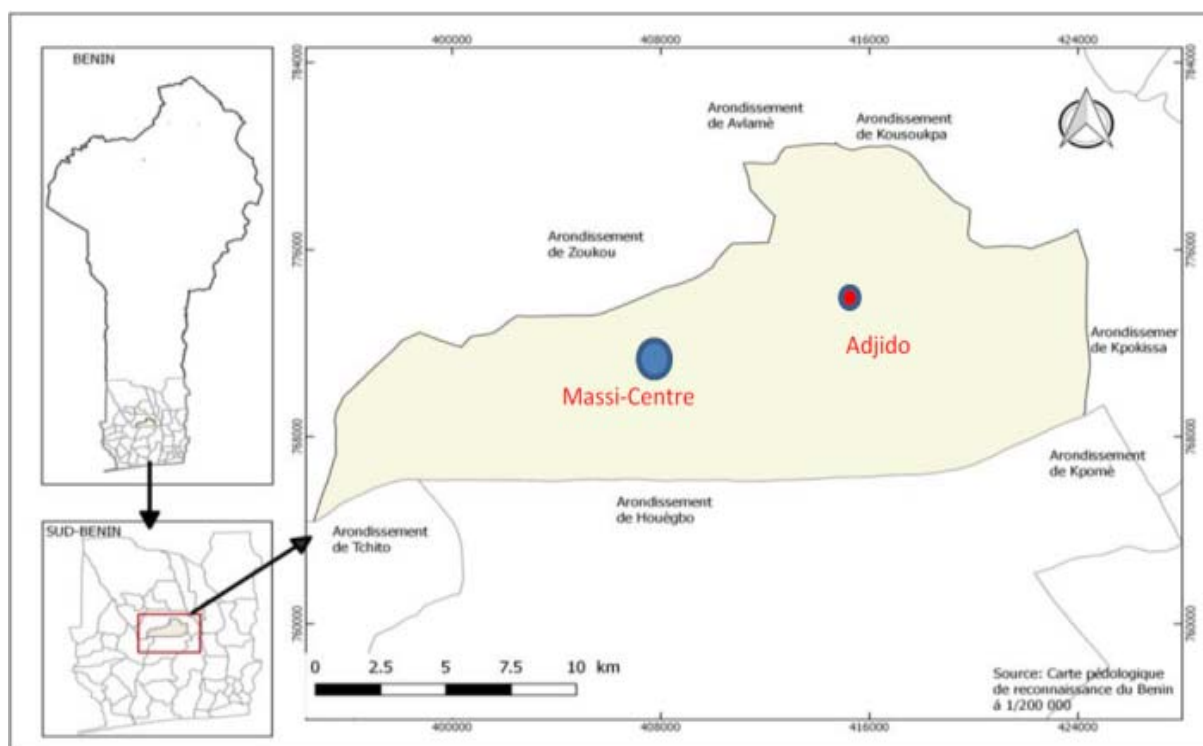
Fig. 1   Map of situation of the zone of study and positioning of the points of samplings.

3. Experimental Results

3.1 The Identification Parameters

The Tables 1 and 2 present the results of the identification tests of samples of soils of the locality of Massi-centre and Adjido.

The results of grain size analysis (percentages of passer-by in 80 μm and 2 μm) allowed on the basis of the classification of Taylor [15] classification to conclude that these samples contain clayey particles.

The plasticity index indicates according to Snethen's classification that the studied soils have a swelling potential which goes from average to very high [10]. The parameters such as the activity, the water content, the value in the blue and the voluminal weight of the solid grains allowed to confirm that it is really about a clayey soil. According to the classification GTR [11], the clayey soil is of class going from A2 (silt, clay, little plastic marl) to A3 (marly clay, very plastic silt) because the percentage of passer-by in the sieve 80 μm > 35% and the plasticity

index varies from 12 to 45.

3.2 The Results of Mechanical Tests

The Tables 3 and 4 recapitulate the results of mechanical tests of samples of soils of the locality of Massi-centre and Adjido.

The formula of Philipponnat [14] allows to have the pathological risk of clayey soils. The Table 5 presents the classification by using Philipponnat's formula [5].

Through this classification based on the form of Philipponnat, we notice that the pathological risks to which the soils of the localities of Massi-centre and Adjido are in from the big order to very big. From where the necessity of taking a particular attention on infrastructures set up in these localities. The swelling potential of the studied soils is not useless. It confirms that we are really in the presence of a swelling clayey soil.

The parameters such as the cohesion, the swelling pressure, the angle of internal friction will allow us to determine the intervals of applicable loads.

Table 1   Results of the identification parameters of samples of Massi-centre.

Parameters	Depths			
	0.0-0.5	0.5-1.0	1.0-2.0	2.0-3.0
C_2	77.6	89.0	86.5	88.0
W	24.6	27.3	26.6	31.3
C_{MO}	3.94	6.29	3.09	7.54
V_{BS}	4.50	5.20	6.12	2.54
W_L	69	89	68	49
W_P	56	46	45	25
I_P	13	43	23	24
γs	2.46	2.43	2.35	2.52
A	0.26	0.74	0.36	0.40
γ_d	19.50	17.9	18.46	18.30

Table 2   Results of identification parameters of the samples of Adjido.

Parameters	Depths			
	0.0-0.5	0.5-1.0	1.0-2.0	2.0-3.0
C_2	75.6	59.0	76,5	68.0
W	41.6	27.3	28.6	33.3
C_{MO}	7.94	1.29	4.09	7.984
V_{BS}	8.50	6.20	2.12	8.54
W_L	59	87	76	47
W_P	52	66	43	35
I_P	15	33	23	25
γs	2.36	2.51	2.63	2.16
A	0.28	0.75	0.37	0.48
γ_d	18.87	17.2	18.66	18.16

Table 3   Results of the mechanical characteristics of the soil of Massi-center.

Parameters	Depths			
	0.0-0.5	0.5-1.0	1.0-2.0	2.0-3.0
C_c	0.337	0.249	0.249	1.146
e_0	0.776	0.747	0.832	0.832
C_g	0.052	0.082	0.036	0.136
σ_{vo} (kPa)	9.75	17.90	36.95	54.90
σ_g (kPa)	5.18	3.44	56.63	151.57
σ'_p (kPa)	73	129	173	327
$C_c/1 + e_0$	0.190	0.143	0.136	0.626
C (kPa)	35	41	22	34
ϕ (°)	6	6.5	18	6.5

Table 4   Results of the mechanical characteristics of the soil of Adjido.

Parameters	Depths			
	0.0-0.5	0.5-1.0	1.0-2.0	2.0-3.0
C_c	0.117	0.293	0.274	0.418
e_0	0.853	0.832	0.913	0.724
C_g	0.026	0.043	0.067	0.092
σ_{vo} (kPa)	9.09	12.53	33.14	39.25
σ_g (kPa)	8.56	8.17	71.85	98.14
σ'_p (kPa)	72	122	156	193
$C_c/1 + e_0$	0.063	0.156	0.143	0.242
C (kPa)	34.85	29	34	24
ϕ (°)	9.83	8	10	14

Table 5   Pathological risk according to $\frac{C_c}{1+e_0}$ of Philipponnat [14].

$\frac{C_c}{1+e_0}$	Pathological risk
< 0.015	Low
$0.015 < \frac{C_c}{1+e_0} < 0.05$	Average
$0.05 < \frac{C_c}{1+e_0} < 0.2$	High
>0.2	Very high

3.3 Evaluation and Mastery of the Risks

3.3.1 Principle

To master the risks means to determine a range of applicable values of stresses by the works at every depth of the massif of soil such as there is neither swelling nor excessive settlements in a massif of soil constituted of elementary layers. The applicable stresses have to answer the conditions grouped in the system of following in equations:

$$\begin{cases} \Delta\sigma \geq \sigma'_g & (1) \\ \Delta\sigma < \sigma_p - \sigma'_{v0} & (2) \\ \Delta\sigma \leq \sigma_u & (3) \end{cases}$$

where,

$\Delta\sigma$: applicable pressure;

σ_g': the highest pressure of swelling at the level of the considered layers;

σ_p: pressure of pre-consolidation at the level of the considered depth;

σ_{v0}: effective stress at the level of the considered depth;

σ_u: limit breaking stress of footing foundations [12]; such as

$$\sigma_u = cN_c + qN_q + 1/2 \ B_\gamma N_\gamma \quad (4)$$

where, *c, q, B, ɣ*, express respectively the cohesion, the overload or the weight of the initial sol between the surface of the ground and the level of foundation, the width of a footing foundation, a voluminal weight of the foundation soil. N_c, N_q and N_γ are the factors of bearing capacity which represent the effect of the cohesion, the foundation depth and the voluminal weight of the foundation soil.

Indeed:

The limits of the values must be equal or slightly superior to the highest swelling pressure of all those taken at the level of every elementary layer of the massif of soil (Eq. (1)).

To prevent the excessive settlement of the soil, it will be necessary to stay below the pre-consolidation pressure (which is the maximal value of stress undergone by the massif in its geologic history) from where we would deduce the value of the effective stress (Eq. (2)).

Furthermore, the pressures to be applied must be limited to the break stress of soils in situ obtained by calculation with Terzaghi's formula [12]. This breaking stress is determined for every depth of the massif, by supposing a square footing of one (01) meter aside (Eq. (3)).

To finish, it is advisable to verify for every load applied to a given depth, the evolution of the stresses engendered on the depth, this to make sure to stay in the ranges of stresses proposed for the good performance of the works on the experimental site.

3.3.2 Results

By depth, the limit breaking stresses point determined from Eq. (4), are presented in Table 6:

The intervals of the values of the overload to be applied satisfying the laid conditions above (Eqs. (1)-(3)) appear in Table 7.

For all the depths, the planned applicable stress $\Delta\sigma$ is both inferior to the same safe stress of the soil (will not engender the breaking of the soil) and superior to the swelling pressure of the soil (will avoid the bulge of the massif of soil).

Table 6 Limit breaking stresses, by depth, for studied sites in the depression.

Depth (m)	Massi-centre	Adjido
	σ_u (kPa)	σ_u (kPa)
0.0-0.5	177	108
0.5-1.0	204	122
1.0-2.0	210	126
2.0-3.0	271	194

Table 7 Table of values interval of the pressures to be applied.

Localities	Depth (m)	σ_u (bar)	Interval of pressure values ($\Delta\sigma$) (kPa)
Massi-centre	0.0-0.50	1.77	[5.18; 63.5]
	0.5-1.0	2.04	[3.44; 111.1]
	1.0-2.0	2.10	[56.63; 136.]
	2.0-3.0	2.71	[151.57; 265.0]
Adjido	0.0-0.5	1.08	[8.56; 62.87]
	0.5-1,0	1.22	[8.17; 109.43]
	1.0-2.0	1.26	[71.85; 123.17]
	2.0-3.0	1.94	[98.14; 153.31]

4. Conclusions

The researches made on the capacity of the swelling soil showed that some tests were made in certain countries and the results are satisfactory. In the depression of Lama, in particular the one of Khô, the experimental study made on the intact soils taken at different depths at the level of Massi locality allowed:

To obtain that according to Snethen's classification [10], Massi soil has a swelling potential which belongs to the swelling range of "low-high".

To obtain that according to Costet and Sanglerat's classification [13], the site of Massi is constituted of illite, kaolinite and montmorillonite.

To determine the pressures of the works to be applied to the soil and which eliminate the bulge of the foundations.

It is then recommended to readjust the pressures derived of ordinary methods of dimensioning foundations by limiting them by the intervals of proposed pressures.

This will allow to minimize the risks to which are submitted the works achieved on swelling soils in this zone.

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