Effect of swelling mineral on geotechnical characteristics of clay soil

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Abstract. The shrinking and swelling is a very common phenomenon in the world, mainly in arid and semi-arid areas. The construction on these soils often requires a study of the risk of swelling, in advance. The emergence of this phenomenon in soils is caused primarily by the presence of swelling clays and water. The risk is most significant when the rate of the expansive minerals, such as bentonite, is important. Several researchers have studied the relationship between the percentages of swelling minerals and soil swelling potential. The researchers have shown the difficulty of characterization, because of the complexity of the phenomenon under natural conditions, where several other phenomena occur, and which are not considered in laboratory experimentation. This article addresses the characterization of several soils, with different swelling rates from the physical, chemical and mechanical tests. It shows the relationship between the quantity of swelling minerals and some site conditions, such as water content and consolidation stress, on the ability of soil to swell. This work aims to establish empirical relationships between the percentage of swelling minerals and soil swelling potential.

1 Introduction

The shrinking - swelling of soils is one of the geotechnical problems. It is observed on the plastic clay soils under the various environmental conditions. This phenomenon affects all the weight construction realized on these soils without the knowledge of their properties. The damages resulting from this phenomenon are expensive in repairing damaged structures [1].

The swelling characteristics of expansive soils are due to several parameters associated to the initial soil conditions (initial dry density and initial moisture content) [2, 3], the granularity and clay content. Nonetheless, the first factor which conditions the swelling of a clay soil and affects these physical-chemical and mechanical properties is the mineralogical composition; the quantity and type of minerals present in clay soils. It's known for example, that the phenomenon of swelling depends not only on the granularity, but also on the superficial activity of the clay itself which will be all the more intense as the specific area of particles will be high.

A montmorillonite will swell more than illite and this exhibits for such phenomenon more than the kaolinite; the properties of the soil will be all more marked as the percentage of expansive minerals (montmorillonite) will be higher [4, 5, 6, 7, 8].

But in nature, the soil is very heterogeneous; its composition depends on other elements in addition to

swelling minerals. Several mineralogical researches on natural soils show the considerable presence of swelling clay and non-swelling clay in addition to the presence of bentonite and silt [4, 5, 6, 7, 8, 9].

Therefore, the objective of this study is to highlight and quantify the influence of swelling minerals on the different properties of studied soils.

2 Test procedures

The materials used in this study are: Bentonite delivered by the treatment company "ENOF", the Kaolinite delivered by the treatment company "SOALKA", the silt and the fine sand from the Algiers region. Table 1 and 2 summarize the physical-chemical properties of used materials.

The preparing of tested mixtures was performed following the same procedures in order to optimize the repeatability between the prepared samples. The four materials were dried in oven at 105 °C for 24 h, then samples were prepared by manual mixing in different weight proportions, by varying percentage of bentonite, kaolinite and keeping the rate of the Silt and fine sand fixed as shown in table 3.

The mixtures prepared were kept in closed plastic bags and conserved more than 24 h; this allowed moisture in the soil to distribute evenly throughout the mass of soil (for compaction and oedometer tests). The granulometric distribution by

sedimentation of studied mixtures is presented in figure 1, soil geotechnical and physical-chemical properties are presented in table 4.

Table 1. Physical - chemical properties of used materials.

Properties	Materials			
	Bentonite	Kaolinite	Silt	fine sand
Liquid Limit (%) (ASTM D 4318 00)	149,39	63,40	30,84	/
Index Plastic (%) (ASTM D 4318 00)	119,59	26,94	9,98	/
Bleu Value (g/100g)	12,84	2,00	0,24	0.12
Activity of Skempton	2.84	0.84	/	/
pH	8,58	6,01	6,75	6,03
Sst (m ² /g)	269,50	42,00	4,98	2,63

Table 2. Chemical composition of the materials used.

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	SO ₃	Cl
Bentonite	60,80	17,33	1,72	3,62	3,00	1,89	4,45	0,29	0,06
Kaolinite	53,04	31,98	1,83	2,93	0,00	3,31	0,01	0,00	0,02
Silt	49,43	16,19	11,46	4,83	7,82	2,14	1,55	0,16	0,06
Fine sand	48,78	7,39	8,49	15,36	0,83	0,87	0,91	0,09	0,04

Table 3. Mineralogical composition of the studied soils.

Index of soil Material	5B/60K	10B/55K	20B/45K	30B/35K	40B/25K	50B/15K
Bentonite (%)	5	10	20	30	40	50
Kaolinite (%)	60	55	45	35	25	15
Silt (%)	20	20	20	20	20	20
Fine sand (%)	15	15	15	15	15	15

Table 4. Physical - chemical and geotechnical properties of the studied soils.

Index of soil Properties	5B/60K	10B/55K	20B/45K	30B/35K	40B/25K	50B/15K
Liquid Limit (%)	49,60	55,80	75,44	88,85	92,54	101,81
Index Plastic (%)	20,34	26,34	45,91	56,46	57,21	69,07
Activity	0,48	0,61	1,00	1,04	1,08	1,17
Classification (UCSC)	CL	CH	CH	CH	CH	CH
Max. Dry unit weight (KN/m ³) (ASTM D 698 12)	15,06	14,95	14,90	14,90	14,72	14,47
Optimum Moisture Content (%) (ASTM D 698 12)	14,33	15,13	17,38	17,66	21,82	23,78
Specific Area (m ² /g)	45,50	59,50	77,00	115,50	136,50	154,00
Swelling Potential (%) (ASTM D 4546 03)	1,02	2,08	8,10	11,25	15,60	17,90
Pressure swelling (KPa) (ASTM D 4546 03)	34,54	77,47	193,72	214,94	321,49	470,80

Fig. 1. Grain size distribution of the studied mixtures.

3 Results and discussion

3.1. Effect of minerals on the Atterberg limits

The results presented in figure 2 show that the liquidity limit increases from 50 to 100%, with an increase of nearly 50% for the rate of bentonite ranging from 5 to 50%, due to the increase in fine particles of the bentonite and their swelling characters, which further favors water absorption.

The plasticity index has been evaluated for all studied mixtures and the results represented in of figure 2. A proportional relationship between bentonite content (between 5 and 50 %) and the plasticity index of studied

mixtures were observed, rising from 20 % to 70 %, an increase of nearly 70 %. This fact due to the total surface area of water adsorption of samples that depending on grains size of bentonite.

Fig. 2. Variation of Atterberg limits versus mineral contents (bentonite / kaolinite).

3.2 Effect of minerals on the activity and total surface area

From the figure 3, it can be seen that the activity and the total surface area are proportional to the bentonite rate and evolving at the same intensity. The lowest values are obtained for mixtures with high levels of kaolinite (5B/60K and 10B/55K) with an activity ranging from 0,48 to 0,61 and a specific area between 45,50 and 59,50 m²/g, respectively. On the other hand, when bentonite

contents increase from 5 to 50%, the activity rises from 0,48 to 1,17 and the specific surface area from 45,50 to 154 m²/g respectively. The increase of more than 60 % is observed. These results show the activity and the development of specific area is much higher when the rate of active clay (bentonite) is important. There is a direct impact on the swelling potential of these mixtures, which is in accordance with other researchers work studies [10, 11, 12, 13, 14] between mixtures and swelling potential.

Fig. 3. Variation of the activity and total surface area versus mineral contents (bentonite / kaolinite).

3.3 Minerals effect on compaction characteristics

The effect of minerals percentage (bentonite / kaolinite) in studied mixtures on compaction parameters (optimal water content and dry density) are shown in figure 4. The dry density decreases slightly for a high rate of bentonite from 5 to 50%, a reduction of 4% is observed which is not significant.

Fig. 4. Variation of compaction parameters as a function of mineral content (bentonite / kaolinite).

The optimal water content is very sensitive to the percentage of bentonite, a proportional relationship is found between the optimal water content and the bentonite rate, which increases from 14,33% for the mixture with 5% of bentonite compensate by 65 % Kaolinite (5B/65K) up to 23,78% for mixing with 50% bentonite compensate by 15% kaolinite (50B/15K), this variation is caused by the increase in the amount of water

adsorbed by the bentonite particles present in the mixtures.

3.4 Effect of minerals on swelling parameters

Figure 5 shows the kinetics of free swelling as a function of logarithm of time. It is noted that the swelling kinetics have a conventional form with an initialization phase, a primary swelling phase and a secondary swelling phase, which evolve differently as a function of the minerals percentages (bentonite / kaolinite);

reconstituted soils (5B / 60K and 10B / 55K) with high rates of kaolinite (60 and 55% respectively) and low percentages of bentonite (5 and 10% respectively) show a rapid initialization phase; at the moment that studied mixtures are in contact with water they swell immediately, this phase corresponds to swelling of macrostructure that depends on the permeability and suction of tested samples. In the second swelling phase, minor variations in volume are noted, the equilibrium is established rapidly (after 48 h).

Reconstituted soils (20B / 45K, 30B / 35K, 40B / 25K, and 50B / 15K) with considerable percentages of bentonite 20,30, 40, and 50%, respectively, indicated very slow kinetics of swelling initialization phase, this may be due to a low permeability [15, 16, 17]. Then primary swelling phase begins. It can be noticed that an important deformation occurs which correspond to swelling of microstructure, that depending on the degree of hydration of bentonite minerals and cation exchanges.

In the secondary phase of swelling low deformations were recorded, this phase is slow and gradual; the stability is established only after 360 hours.

Fig. 5. Evolution of free swelling as a function of time.

The variation of swelling parameters as a function of minerals percentage contained in the studied mixtures is shown in figure 6. A proportional relationship between the bentonite content and swelling parameters is observed, and inversely proportional to kaolinite percentages. This is associated to the nature and rates of active minerals present in mixtures, which is in accordance with work of many researchers [2, 4, 5, 8, 14], The swelling potential increases from (1,02 to 17,90%) for bentonite contents ranging from (5 to 50%),

at the same time swelling pressure increases from (34,54 to 470,80 KPa), reaching a value of more than 90%.

Fig. 6. Variation of swelling rate and pressure versus mineral contents (bentonite / kaolinite).

4 Conclusion

The present researchers show the impact of nature and rate of minerals present in various reconstituted soils. The following conclusions can be drawn from these results:

Limits of Atterberg are strongly influenced by the variation of mineral contents (bentonite / kaolinite), they have a proportional relationship with the percentage of bentonite, an increase of nearly 50% for the Bentonite contents ranging from 5 to 50% is noticed.

The development of the specific area is as higher as the level of active clay (bentonite) contained in studied mixtures is greater; There is an increase of 70% when bentonite contents range from 5 to 50%.

Results obtained for dry density of studied soils as a function of mineral content show a slight variation, there was a decrease of only 4% for bentonite rate ranging from 5 to 50%. However, the optimal water content is highly sensitive and proportional to bentonite levels, where an increase of 40 % is recorded for bentonite contents varying from 5 to 50%.

Kinetics of swelling progress differently according to the rate and type of minerals; For mixtures with high rate of kaolinite compensated by low bentonite content (5B / 60K, 10B / 55K and 20B / 45K) the primary swelling phase occurs at the instant of contact with water and stabilization is established, swelling is due only to deformations caused by the macrostructure, in case of mixtures with high bentonite contents compensated by a low percentage of kaolinite (30B/35K, 40B/25K and 50B/15K), swelling tendency is very slow and progressive, the greater deformations are recorded during the second swelling phase which correspond to deformations caused by microstructure hydration.

Swelling parameters are highly sensitive to the bentonite content; swelling potential is higher at rates of 1,02 to 17,90% for bentonite percentages ranging from 5 to 50%, at the same time swelling pressure increases from 34,54 to 470,80 KPa, where an increase of more than 90% is noted.

We find that with a bentonite level beyond 30% the swelling potential becomes dangerous with demanding values (Liquid Limit = 88%, Ac = 1,04, Specific Area = 115,05 m²/g and Pressure swelling = 214,94 KPa).

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