Using Compression and Swelling Indices to Characterize Expansive Soils

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Abstract Expansive soils are a worldwide problem. The volume variation of this soil is depended on its moisture content. A new approach to characterize this kind of soil is based on the oedometer test results, performed on compressible soils, either expansive or non-expansive. The C_c/C_s ratio is determined, where C_c is the compression index and C_s is the swelling index. Zones delimited by a C_c/C_s value and a swelling pressure (σ_s) value are identified to differentiate expansive soils from non-expansive soils. When C_c/C_s ratio is higher or equal to 15, the swelling pressure is practically equal to zero.

Keywords Expansive soils · Characterization · Oedometer test · Compression index · Swelling index

1 Introduction

Expansive soils are globally widespread geological and natural hazard. This type of soil is currently found in arid or semi-arid areas. It can cause several damages to constructions. Clays, in particular the montmorillonite, are belong to the expansive soils. The shrink-swell behavior of this latter develops according to the variation of water content. Therefore, the expansive soils topic is of high interest for the six continents: Africa, Asia, Europe, Oceania, North and South America.

To understand the behavior of this category of soils, researchers are looking to suitable approaches to characterize it and to mitigate the swelling phenomenon.

The change in volume of expansive soils depends on the water content. The clay structure and the saturation of soils take a major place in this phenomenon. The liaison between montmorillonite clay particles is weak. During the swelling process, the water molecules and other cations carried by the water force the passage between

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clay particles by pushing them apart. This leads to an increase in swelling pressure [6].

Several buildings are constructed on swelling clays and represent damages that are due to the swelling phenomenon in the North of Africa, in particular in Tunisia and Algeria. Therefore, a research program to characterize expansive soils suitably and to formulate countermeasures and construction methods is needed to help civil engineers in the safe design and construction of foundations on the swelling soils [1].

2 About Expansive Soils

The shrink-swell behavior of clays is an extremely destructive phenomenon and leads to huge repair costs. Therefore, it is crucial to find methods to characterize expansive soils.

First, expansive soils are one of the most hazardous natural disaster [2]. Slope instability, tunnel collapse, differential heavy and buckling of building, fissures on structures and destruction of hydraulic structures can result from the presence of swelling soils [6].

Second, around the world, a lot of money is wasted due to extensive damage to buildings caused by the effect of swelling phenomenon every year. In many countries, financial assessment of the extra-costs, like repairing and maintenance, due to swelling soil problems has not yet been carried out. In Sudan, the cost of damage to buildings and light structures due to swelling soils is estimated more than 6 million dollars [14]. Many countries are affected by the damage of this problematic soil: in United States, losses due to expansive soils are about 13 billion dollars in damage to buildings, roads, airports and other infrastructures each year [15]. In United Kingdom and Saudi Arabia, this cost varies in the range of 300 to 450 million dollars [5, 16].

Third, to deal with this type of soil, there are some improvements proposed, like the use of granular materials, chemical and soil mixture treatments. The granular piles technique is a practical and promising technique. Their installation is possible at any season. The reduction in swelling provided by the use of a granular piles varied from 10 to 45% [10]. The use of a granular material as a separation layer between the foundation and an expansive soil revealed a potential solution to reduce the swelling effect [1]. In addition, noted also that chemical treatments revealed of interest as well. According to Mahamedi and Khemissa [12], mixture of swelling clay with respectively cement and lime in an amount of 10% reduces the swelling potential and decreases liquid limit by 41 and 43% respectively. Soil sensitivity to water has been reduced by the lime treatment. This is due to decrease of moisture content after lime hydration [11]. As cement contains about 60% lime, mixing with cement gives approximately the same result as mixing with lime. Moreover, according to Gueddouda et al. [7], about the soil mixture, the addition of dune sand leads to an important reduction of the swelling parameters. With 45% sand, for the swelling potential, this reduction is about 65% and for the swelling pressure exceeds 85%.

This addition is involved in the increase of the pore size in the swelling soil mass that is owed to the reduction of these expansion effects. The evolution of suction is proportional to that of shear strength. Further, Tiwari et al. [18] recommended the use of coir geotextile which reduces the swelling pressure by about 27% and also reduces the speed of swelling. It is noted that, approximately, the same results are found with a silica fume treated coir geotextile. A reduction of 55% for the swelling pressure and 79% for the percentage of expansion are observed when using a coir geotextile treated with lime. Finally, according to Kalantari [9], the three most commonly used techniques are the soil substitution, use of enough strong structures and the separation between the structure and the swelling clay.

3 Characterization Methods

Due to damages caused by expansive soils, several researchers made an effort to develop approaches to characterize this type of soil in order to know it better and to prevent the problems it can cause. Sridharan and Prakash [17] proposed two kinds of characterization methods:

- by identifying the soil mineralogy using X-ray diffraction analysis, differential thermal analysis, dye adsorption, chemical analysis and scanning electron microscopy;
- by inferential testing using indirect or direct methods.

There are some indirect methods: clay fraction method, Atterberg limits tests and activity A_c method. Some classifications are referred to direct methods like the oedometer swell test, free swell tests and suction method.

4 Approach to Characterize Expansive Soils from Oedometer Test Results

Compression index (C_c) and swelling index (C_s) are currently determined from oedometer tests, which performed with submerged specimens to ensure a full saturation during the experiments. By an oedometer test, both indices C_c and C_s, can be measured for any compressible soil, either expansive or non-expansive.

The data used for this study are oedometer test results provided by specialized geotechnical engineering offices or published by researchers in technical papers. The method to characterize expansive soils using the C_c/C_s ratio relied on data collected from four case studies, comprising twenty-nine specimens from Tunisia, Algeria, Canada and United States. These data are presented in Table 1. The C_c/C_s ratio is an indicator of the change in volume quantifying the degree of soil compression versus swelling [1]. This volume variation is linked the swelling pressure (σ_s).

Table 1 Oedometer test results (update of Bouassida et al. [1])

Country	Site	Sample	Cc	Cs	Cc/Cs	σ_s (kPa)	Expansive	Non-expansive
Tunisia	Béja	BH1	0.160	0.024	6.667	110	x	
		BH2	0.140	0.026	5.385	230	x	
		BH3	0.150	0.018	8.333	90	x	
		BH4	0.180	0.037	4.865	120	x	
		BH5	0.160	0.035	4.571	140	x	
		BH6	0.140	0.010	14.000	40		x
		BH7	0.150	0.012	12.500	40		x
		BH8	0.130	0.019	6.842	140	x	
		BH9	0.220	0.030	7.333	130	x	
		BH10	0.180	0.039	4.615	80	x	
		G109-BH1-2	0.226	0.086	2.628	204	x	
		G109-BH1-3	0.176	0.035	5.029	108	x	
	Centre Urbain du Nord—Tunis	BH1-US1-1	0.158	0.012	13.167	0		x
		BH1-US1-2	0.123	0.009	13.667	0		x
		BH2-US2-1	0.129	0.008	16.125	0		x
	Tunis El Manar University*	BH1-US11	0.097	0.022	4.409	90	x	
		BH1-US12	0.040	0.004	10.000	95	x	
		BH1-US13	0.124	0.021	5.905	220	x	
		BH1-US14	0.114	0.027	4.222	185	x	
		BH2-US21	0.173	0.009	19.222	0		x
		BH3-US31	0.055	0.003	18.333	0		x

(continued)

Table 1 (continued)

Country	Site	Sample	Cc	Cs	Cc/Cs	σ_s (kPa)	Expansive	Non-expansive
		BH3-US33	0.156	0.040	3.900	275	x	
	Jardin El Menzah 1—Tunis	BH1-US1	0.140	0.017	8.235	160	x	
		BH1-US2	0.140	0.025	5.600	190	x	
		BH2-US2	0.140	0.017	8.235	150	x	
		BH3-US2	0.140	0.011	12.727	20		x
		BH4-US1	0.190	0.041	4.634	70	x	
		BH4-US3	0.200	0.061	3.279	180	x	
Algeria	Médéa[a]	S-1-1	0.140	0.045	3.111	400	x	
		S-4-1	0.400	0.100	4.000	70	x	
		S-4-3	0.350	0.140	2.500	80	x	
		S-10-1	0.150	0.100	1.500	420	x	
		S-10-2	0.080	0.070	1.143	800	x	
USA	Louisiana	–	0.360	0.110	3.273	170	x	
Canada	Lake Agassiz	B	0.73	0.23	3.174	54	x	
	Northen Alberta	C	0.12	0.07	1.714	429	x	
	Regina[a]	D	0.17	0.05	3.400	965	x	
		E-1	0.1	0.04	2.500	547	x	
		E-2	0.08	0.04	2.000	526	x	

[a] Updated; BH: borehole; US: undisturbed sample; S: sample

The variation of swelling pressure with respect to the Cc/Cs ratio from the data, given by Table 1, is shown in Fig. 1. From this figure, non-expansive soils are in the side where C_c/C_s ratio is above 10 and the swelling pressure is under 50 kPa. The swelling pressure of expansive soils belong to the side where C_c/C_s ratio is under 10, is higher than 50 kPa. This approach is approved by Chen [3] and Coduto [4] who affirmed that when the swelling pressure is under 50 kPa, the swell potential is low, hence insignificant. Furthermore, when C_c/C_s ratio is higher than 15, the swelling pressure is practically equal to zero. A classification between expansive and non-expansive soils is shown in Table 2. If the compression index (C_c) is about 10 times larger than the swelling index (C_s), then the swelling potential of this soil is low. For Tunisian non-expansive soils, the swelling index is around or lower than 0.010. So, this value represents the low degree of soil to swell in North Tunisia. Note that all non-expansive Tunisian soils in Table 1 or in Fig. 1 are sandy or silty clays which may approve that the mixture of sand or silt with a swelling clay can reduce the soil swelling potential.

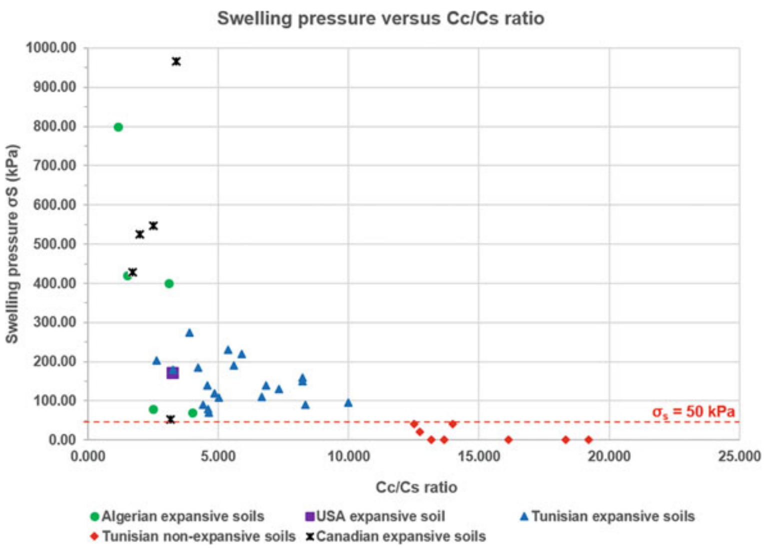

Fig. 1 Swelling pressure versus C_c/C_s ratio (updated from Bouassida et al. [1])

Table 2 Classification of expansive soils using oedometer test results [1]

Type of soil	C_c/C_s	σ_s (kPa)
Expansive	<10	>50
Non-expansive	>10	<50

5 Conclusion

The objective of this work is to characterize expansive soils using oedometer test results. This method is related to compression and swelling indices and carried out with thirty-nine (39) data from two continents, North America and Africa. The soil is considered to be non-expansive when the swelling pressure is under 50 kPa. If the C_c/C_s ratio is less than 10, Civil engineer should not underestimate the swelling pressure of the soil and should take it into their calculations. And, they should not forget the shrink—swell behavior of the soil.

The perspective of this work is to collect a lot of oedometer test results to have more precision in this characterization method and also to estimate the swelling pressure of a soil from these data.

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Since 2019, the launch of the You Tube channel « Mounir Bouassida" gained lot of interest from than 1430 subscribers. Fifty nine uploaded videos, in English and French, to this channel cover themes focusing on soil mechanics, modelling and the study of the behavior of geotechnical engineering structures.