Geotechnical and Geophysical Site Characterisation 5 – Lehane, Acosta-Martínez & Kelly (Eds)
© 2016 Australian Geomechanics Society, Sydney, Australia, ISBN 978-0-9946261-2-7

Prediction of swelling potential of Sudanese clayey sand (SC) soils

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ABSTRACT: Although some Clayey sand soils were classified as (SC) soil still have appreciable high values of Atterberg limits, swelling pressure (SP) and/or settlement as change in their moisture content. Many structures in Sudan were situated in areas dominated by (SC) soil reported damages. Consolidation test was conducted on clay-sand and sand-bentonite mixtures having different sand contents to study the expansive behavior of such (SC) soils. Soil parameters were calculated to study the impact of expansiveness on sandy soil structure and fabric. Test results were analyzed and presented in MS excel charts and verified by SPSS package to obtain simple prediction methods between soil parameters. Soil samples showed decreasing in volume change characteristics with increase of sand fraction. New prediction methods with good correlation coefficients, near to 1.0, were obtained between sand content, Atterberg limits and (SP) for clay-sand and sand-bentonite mixtures to predict the swelling potential of (SC) soils.

1 INTRODUCTION

Unified Soil Classification System (USCS) describes clayey sand (SC) soils varying to great extent in percentages of clay fraction and consistency limit (i.e. LL, PL and PI). These Soils of sand content greater than 50% and percentage finer less than 50% can have very high values of Liquid Limit (LL) and Plasticity Index (PI). Clayey sand (SC) soils are known to exist in different areas in Sudan, especially in the eastern and center of Sudan. These soils tend to have relatively high values of Atterberg limits and noticeable variations of volume change when its moisture content varied. The expansive clay in (SC) soil tends to increase with the increase of its colloidal contents. Although these soils are identified as clayey sand (SC) they can have considerable volume change characteristics that will affect the safety of the foundations and the floors of the buildings. The specifications for fill material under foundations and floors of building must comply with the requirement of strength and settlement limits. It's well known that expansive clay soil swells when wetted and shrinks when dry and usually results in ground movement and depending on its severity, swelling can cause structural damage to low-rise buildings (e.g. foundation movement, cracks in walls…etc.). Upon expansion, the soil exerts an upward pressure on foundation and structures founded on it.

The interaction between coarser and finer grain matrices affects the overall stress–strain behavior of (SC) soils (Monkula, Ozdenb, 2005). Soils that contain platy particles are more compressible than those composed entirely of bulky grains. In some models proposed for compression behavior of cohesionless soils such as those by Hardin (1987) and Pestana and Whittle (1995); effects of initial void ratio, relative density, particle shape, mineralogy, structure and applied stress conditions were mentioned. These factors were also prominent in the experimental researches related to the compression of sands (Yamamuro et al. 1996, Chuhan et al. 2003). Skempton (1985) indicated for the clayey soils that if the clay fraction is less than about 25%, the soil behaves much like a sand or silt, whereas residual strength is controlled almost entirely by sliding friction of the clay minerals when the fraction is above 50%. Georgiannou et al. (1990) concluded that up to a fraction of 20%, clay does not significantly reduce the angle of shearing resistance of the granular component.

Several factors can influence the swelling potential of clay soils; these factors include the amount and type of clay minerals, cation exchange capacities of clay minerals, availability of moisture, initial water content and other factors related to clay deposition history such as fabric and overburden pressures. Both gradation and grain shape affect the compressibility of a cohesionless soil (United States (US) Army 1992 - Field Manual FM 5-410). Therefore, gradation and grain shape are main factors in swelling behavior of a clayey sand soil.

2 MATERIALS AND SAMPLES PREPARATION

Sand-bentonite mixtures (i.e. artificial soil samples and clay-sand mixtures (i.e. natural soil samples) were used to clarify the effect of sand fraction on the volume change behavior of sand-clay mixture. Artificial soil samples were made by combining sodium bentonite with different standard sand contents. Natural soil samples are clayey soils mixed with standard sand in various ratios. The effect of increasing sand fraction on soil was determined on different types of clay minerals, i.e. sodium bentonite (pure montmorillonite) and highly expansive natural soil, and various mixing ratios.

Relatively high plastic clay soils were obtained from (Soba) district, south of Khartoum, Sudan. Tests pits were excavated, disturbed soil samples were obtained. Field moisture content and field density were recorded using the standard procedures. The samples have relatively high natural moisture contents (NMC) (ranging from 17% to 23%). Standard sand was washed and passed through #40 sieve (0.425 mm) and retained in #200 sieve (0.075 mm).

Percentage of bentonite in artificial samples by weight was varied from 10%, 15%, 20%, 25%, and 30% by weight. On the other hand, natural samples were mixed with standard sand in percentage of the total weight of mixture. Sand percentages varied from 17 % (as origin sample), 25%, 40%, 55%, 60%, and 65% from the total weight. Classification, compaction, Consolidation and swelling tests were performed. Laboratory testing carried out according to the BS 1337 - 1990 and classification of soil samples results were established in accordance to Unified Soil Classification System (USCS).

Table 1. Physical properties of testing materials

Material	LL (%)	PL (%)	PI (%)	Specific Gravity
Standard Sand		None plastic		2.59
Sodium betonies	395	45	350	2.86

3 EXPERIMENTAL WORK RESULTS

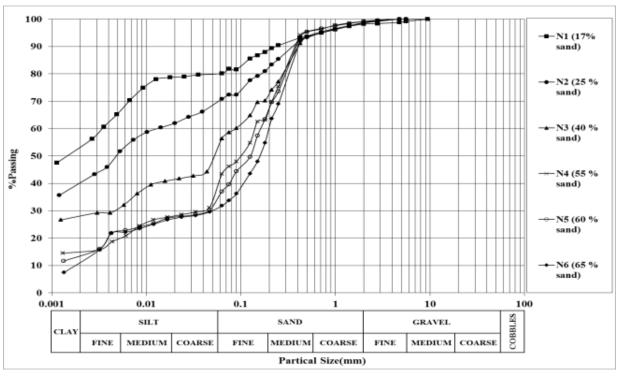

Figure 1. Grain size distribution curves for natural soils samples

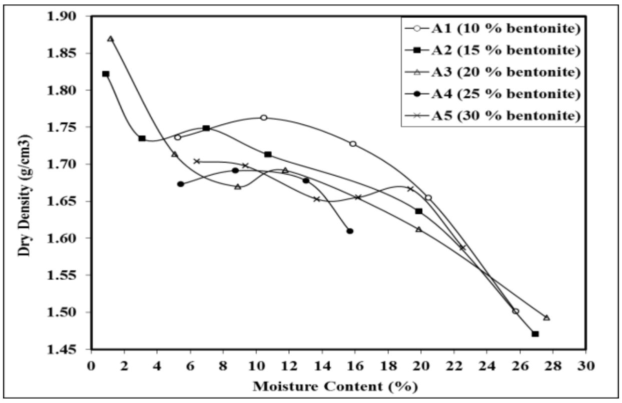

Figure 2. Moisture-density relationships (artificial soil samples)

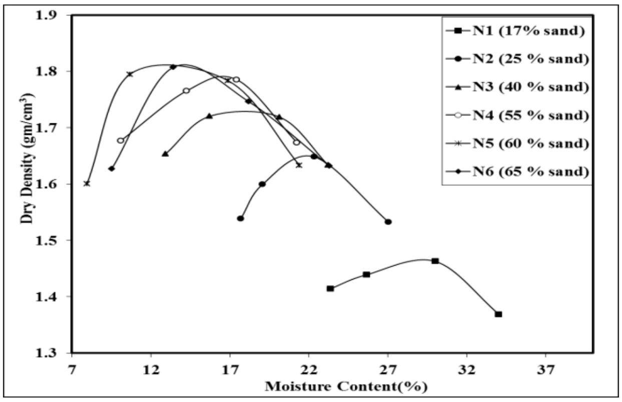

Figure 3. Moisture-density relationships (natural soil samples)

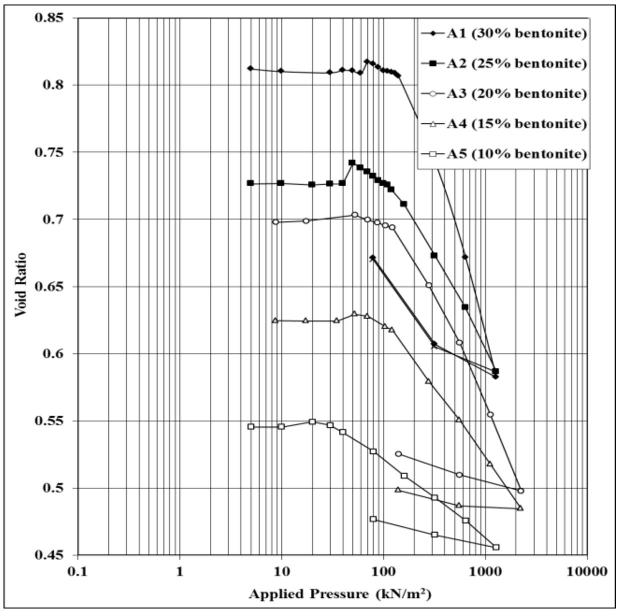

Figure 4. Consolidation curve results (artificial soil samples)

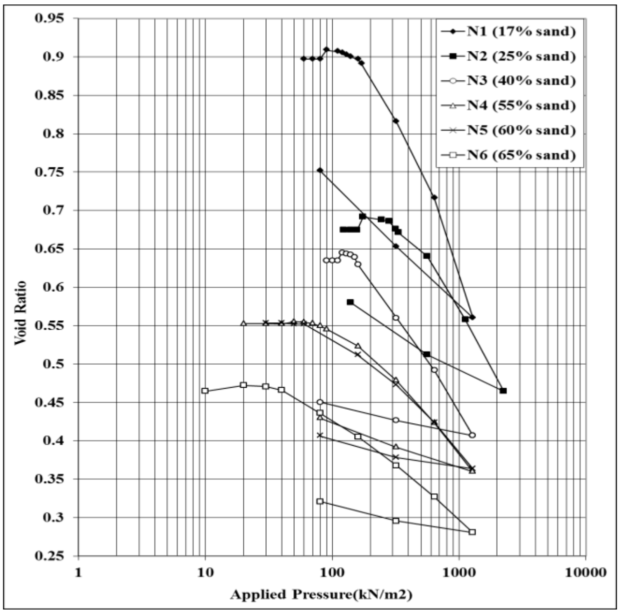

Figure 5. Consolidation curve results (natural soil samples)

Table 2: Index properties for artificial and natural soil samples

Soil code	Sand content	LL	PL	PI	LS*	Clay fraction (< 2µm)	Activity
(%)	(%)	(%)	(%)	(%)	(%)	(%)	
A1	70	115	21	94	19.3	30	3.13
A2	75	95	17	78	15.7	25	3.12
A3	80	78	20	58	12.4	20	3.0
A4	85	64	19	45	8.6	15	2.9
A5	90	46	21	25	5.0	10	2.5
N1	17	78	23	54	14.7	53	1.02
N2	25	77	25	52	13.6	40	1.30
N3	40	66	19	40	10.6	28	1.43
N4	55	52	18	34	7.9	16	2.13
N5	60	37	14	23	7.1	13	1.77
N6	65	35	14	21	6.2	11	1.91

* LS= Linear Shrinkage

Table 3: Compaction & swelling test results for artificial and natural soil samples

Soil code	Sand content	MDD*	OMC**	Free swelling	Swelling pressure
(%)	(%)	(g/cm^3)	(%)	(%)	(kN/m^2)
A1	70	0.48	0.81	0.296	0.079
A2	75	0.33	0.72	0.158	0.069
A3	80	0.24	0.70	0.188	0.023
A4	85	0.14	0.62	0.110	0.012
A5	90	0.06	0.54	0.066	0.018
N1	17	0.35	0.89	0.517	0.154
N2	25	0.32	0.67	0.309	0.079
N3	40	0.27	0.63	0.282	0.052
N4	55	0.18	0.55	0.210	0.033
N5	60	0.16	0.55	0.199	0.025
N6	65	0.14	0.47	0.154	0.024

* MDD = Max. Dry Density
** OMC = Optimum Moisture Content

Table 4: Consolidation test results for artificial and natural soil samples

Soil code	Sand content	Swelling potential	Initial void ratio	C_c	C_r
	(%)	(%)	(e_o)		
A1	70	0.48	0.81	0.296	0.079
A2	75	0.33	0.72	0.158	0.069
A3	80	0.24	0.70	0.188	0.023
A4	85	0.14	0.62	0.110	0.012
A5	90	0.06	0.54	0.066	0.018
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4 ANALYSIS AND DISCUSSIONS

4.1 *Atterberge Limits*

Increasing bentonite content from 10% to 30% made LL and PI to increase from 46% to 115% and from 25% to 94% respectively (see Table 2). This is due to the mineralogy of sodium bentonite having physical properties almost dictated by the smectite minerals (Grim and Guven, 1978). In natural samples, Atterberg limits results showed that LL decreased from 78% to 35% and PI decreased from 54% to 21% (see Table 2). Soil sample designated (N4) showed high values of LL and PI despite the sand fraction is more than 50%. This soil sample presents the object of this study.

4.2 *Classification and identification of expansiveness*

Sand-bentonite mixtures were classified as having very high swelling potential, except samples (A4) and (A5) which showed high and medium swelling behavior, respectively. Four samples were classified as (CH) according to (USCS) and one sample classified as (CL) (i.e. A5 sample). Classification and identification of expansiveness for natural samples results were shown in table (5). Soil samples (N1) and (N2) were classified as having very high swelling potential soils and sample (N3) was classified as having high to very high swelling soil. Soil samples (N4), (N5) and (N6) with sand contents greater than 50%, represent (SC) soils. These were noted to have medium to high swelling behaviour. From Table (5), sample (N4) exhibits expansive soil with medium to high swelling potential from several classifications. Although soil sample (N4) contains sand content more than 50%, but significantly it has an expansive behaviour. This behavior attributed to mineralogy composition, particles shape, texture and particles size distribution of the sand-clay mixture.

Table 5: Classification and identification of expansiveness for natural soil samples

→ Soil Code ↓ Classification	N1	N2	N3	N4	N5	N6
USCS classification	CH	CH	CH	SC	SC	SC
Skempton's method (1953)	N	N	A	A	A	A
Swelling potential (Chen, 1975)	VH	VH	VH	M	M	M
Potential expansiveness (Dakshanamurthy & Raman, 1973)	CV	CV	CH	CH	CI	CI
Swelling potential (Snethen, 1980)	VH	VH	VH	H	Mo	Mo
Potential expansiveness (Van der Merwe,1964)	VH	VH	VH	M	L	L
Degree of expansion (Holtz & Gibbs,1956)	VH	VH	H	M	M	M
Swelling potential (Seed,1962)	VH	VH	H	M	L	L

*Where:
CH = High plasticity clay
SC = Clayey Sand
N = Normal
A = Active
VH = Very high
H = High
M = Medium
CV = Very high swelling
CH = High swelling
CI = Medium swelling
L = Low swelling
Mo = Moderate

4.3 *Compaction test results*

Artificial soil samples results for compaction tests are shown in Table 3 and Figure 2. They showed increasing in OMC with increase of bentonite content. Santucci de Magistris (1998) was working with relatively low bentonite contents and reported that a general tendency for OMC to increase with high contents of bentonite.

Natural soil samples results present increasing in MDD with the increasing of sand fraction (see Table 3 and Fig. 3). It's postulated that the sand will fill the voids between soil grains and that will result increasing dry density. Many authors (Sorochan, 1991; Elarabi, 2004; Nelson and Miller, 1992) were conducted many experiments and concluded that the swelling rate increases when the density of soil is increased. From density results and conclusions of the mentioned authors it can be extracted that the problem of (SC) soil will come bigger when it is dense because this will increase the swelling rate of soil.

4.4 *Consolidation and swelling test results*

Swelling pressure (SP) results, of artificial soil samples, are directly proportional to PI and gave correlation coefficient value of 1.0 (see Fig. 6). This correlation indicated that a new equation can be derived to predict SP of sand-bentonite mixtures from PI. Good relationship was presented for PI results with C_c with correlation coefficient of 0.88 (see Fig. 7).

Generally, natural soil samples showed reduction in swelling and compressibility characteristics as the percentage of sand fraction was increased (see Tables 3, 5 and Fig. 5). The initial void ratio (e_o) decreased from 0.89 for sample (N1) to 0.47 for (N6) which indicated that sand grains fill the void of the clay (see Table 4). Very good correlation coefficient was obtained between LL, PI with SP (R^2= 0.96) (see Fig. 8). Samples (N4) and (N5) have almost the same values of initial void ratio, swell potential and (C_c) (see Table 4).

In expansive soils, larger change in moisture implies higher degree of volume change (swelling and settling) in soil structure. The influence of volume change on the consolidation characteristics of expansive soil is not similar to non-expansive clay soils. In non-expansive clays, it shows flatter e-log P curves (Mesfin Kassa, 2005). Whereas, the laboratory test results of artificial samples and some natural samples including soil sample (N4) have shown that the soil exhibit a steeper e-log P plot (see Figs 4 and 5). Consolidation is the property of the soil mass that is highly dependent on permeability which depends on the structural arrangement of soil particles. On the other hand, swelling is the property of the soil particle, which depends on the mineralogy of soil particle. In effect, both phenomena bring about volume change in the soil mass. As can be seen from the test results, the factors that affect the swelling characteristics of expansive soils (i.e. moisture content variation and density) have also affected the consolidation characteristics of expansive soil and consequently affect the characteristics of expansive (SC) soils.

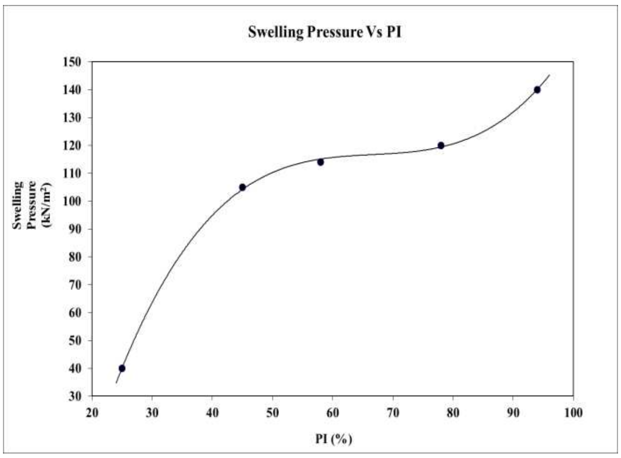

Figure 6. Relationship between SP and PI (artificial soil samples)

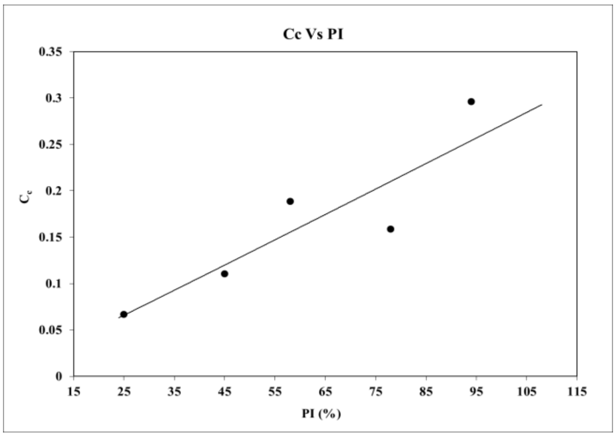

Figure 7. Relationship between C_c and PI (artificial soil samples)

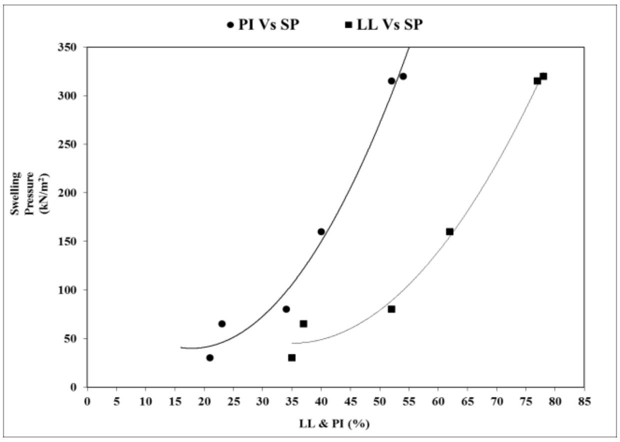

Figure 8. Relationship between SP, PI and LL (natural soil samples)

5 CONCLUSIONS

Mineralogy and density of clay are essential parameters to predict the behavior of (SC) soils and to classify its expansiveness. New methods were derived to predict the expansiveness of the clay-sand mixtures. All soil samples showed decreasing in volume change characteristics with increase of sand fraction. Increasing sand fraction from 7% to 10% for (SC) soil will give considerable strength and low volume change materials to use in construction.

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