Revue des Composites et des Matériaux Avancés-Journal of Composite and Advanced Materials
Vol. 32, No. 1, February, 2022, pp. 33-38
Journal homepage: http://iieta.org/journals/rcma

Moisture and Dry Density Influence on Compacted Clay and Clay-Sand Mixtures

Bahia Louafi[1*], Muawia A. Dafalla[2]

[1] Civil Engineering Faculty, Laboratory of Environment, Water Geomechanics and Structures, University of Sciences and Technology Houari Boumediene, Algiers 16111, Algeria
[2] Bugshan Research Chair in Expansive Soils, Civil Engineering Department, College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia

Corresponding Author Email: blouafi@usthb.dz

https://doi.org/10.18280/rcma.320105

Received: 3 January 2022
Accepted: 20 February 2022

Keywords:
clay soils, swelling, state parameters, water content, dry density, sand-clay mixture

ABSTRACT

The influence of initial moisture content and dry density on swelling clays was extensively investigated in the literature. In order to explore the relationships that exist between the swelling parameters of clay soils and the water content, initial dry density, and sand content, a series of experimental tests were conducted on pure clay and clay treated with 20% sand. The swelling pressure and the swell potential were also tested for sand-clay mixtures. The results showed a significant influence of the initial water content on the swell potential of bentonite and bentonite sand mixture. The increase in the dry density was found to boost the swelling pressure and swell potential. The rate of increase is related to sand content. For higher sand content, it was found that grain-to-grain contact reduces the compressibility of the mixture and thus causes the general swell trend to alter. The amount of clay particles within the mixture is an important factor affecting the swelling. The results demonstrated the effectiveness of the sand in the reduction of swelling parameters. This study provides a control measure for expansive soil materials using sand addition to achieve better soil for construction purposes.

1. INTRODUCTION

Swelling of compacted clays is a crucial problem, encountered in many regions, mainly in the tropical, arid, semi-arid, and hyper-arid regions. This problem is specific to certain types of clay soils and is mainly related to the variations in their moisture content [1]. As a response to the moisture gradient, expansive soils show alternating cycles of heave and settlement. The variation in volume results in differential ground movements, which is associated with distress and disorders.

It affects all types of structures, both for structures built on the surface (buildings, surface foundations, retaining structures, embankments, etc.) and for underground structures (tunnels, piles, pipelines, deep foundations, etc.). Examples of disorders related to the presence of swelling clay are numerous and varied [1-7].

This phenomenon of volume variation is not only proportional to the soil moisture content but also dependant on a number of other environmental and intrinsic parameters. For example, it depends on the mineralogical nature of the clays that make up the soil and its proportions. Clays with a phyllite structure are among the mineralogical species indicating expansion characteristics.

The swelling of clay soils is a vast subject whose complexity can be viewed by the number of books and publications devoted to studying and mastering its behaviour.

Several research works have been conducted to investigate the behavior of expansive soils and to combat the risk of damage associated with this type of clay [8-16].

The swelling pressures and the swell potential are considered the primary parameters defining the swelling in clays when subjected to moisture increase.

It is not only the clay content and type of clay that influence the behavior of swelling soils but many other placement conditions can be involved in the process.

The variation in water content is one of the most important factors affecting the swelling potential. An expansive soil, that is initially humid, swells less when it is in contact with water because its affinity to water has decreased. This affinity is explained by the direct relationship between water content and suction pressures [17].

This parameter combined with a second parameter, which is the density of the soil are the most influential on the level of volume change. The compactness state of an expansive soil affects its behavior. A dense clay develops a higher swelling rate than the less dense state at the same water content [17].

Daffala [14] showed that low-swelling clay soils could cause more damage to structures than highly plastic soils at specific placement conditions. Highly plastic clays close to ground water level are unlikely to show high swelling due to the hydration assisted by the capillary water all the time. An example for this is the green clay along the coastal areas in the eastern parts of Saudi Arabia. The swelling is directly related to the initial dry density and the state of confinement.

This study is focused on the impact of moisture and dry density on highly expansive clay and the study of the swelling parameters of clay-sand mixtures. The percentage increase of volume commonly referred to as swell potential and the swelling pressure are the main two parameters used to express and classify the expansiveness of the swelling clay. Experience has shown that these parameters are affected by many external and intrinsic factors.

Chen [1] stated that swelling pressure is independent of an initial surcharge or compression state and also stated that the expansion or shrinkage could be considered negligible when the initial moisture contents are slightly higher than the optimum.

Tay et al. [18] found that shrinkage of compacted bentonite sand mixtures increases with the increase of initial or molding moisture content.

Many predictive approaches for determining swelling based on soil index properties are presented in the literature. Works of Vijayvergiya et al. [19] can be referenced.

The equation used by Vijayvergiya et al. [19] is:

$$\text{Log } Sp=(0.44LL-Wc+5.5)/12 \qquad (1)$$

where, Sp is the swelling pressure, Wc is the water content, and LL is the liquid limit.

Dhowian et al prediction method [9] for clay gives a similar trend to that of [19]), but the swelling values are much lower.

$$Sp=0.25(0.43LL-Wc)^{0.51}+1.19\,PI^{0.4}-74(100-c)^{0.33.} \qquad (2)$$

where, C is the clay content defined as the percentage of material measuring <0.002 mm, and PI is the plasticity index.

The work presented in this research covered the experimental behavior of highly plastic clay subjected to two dominant factors affecting the swelling; these are the water content and the initial dry density followed by an investigation of the influence of the addition of sand to this typical type of clay when other parameters are kept constant.

2. TESTING PROGRAM AND TEST METHOD

2.1 Materials

2.1.1 Bentonite

The bentonite used in this study is pure clayey soil obtained from the Mostaghanem area. It is an artificial processed clay obtained from the region of M'zila in the northeast of the city of Mostghanem. This material is available as a commercial product and comes in the form of fine ground powder.

The physical and chemical properties are presented in a tabular form. Table 1 presents the chemical composition of Mostaghanem bentonite and Table 2 presents the physical characteristics of the same bentonite.

Table 1. Chemical composition of bentonite

SiO_2 [%]	58
AL_2O_3 [%]	19
Mg O [%]	1
Fe_2O_3 [%]	3
Ca O [%]	2
Sodium, as Na_2O_3 [%]	4
Loss on ignition [%]	13

The granulometric curve shows that it consists of more than 90% of fines. It is highly plastic with a liquid limit of 187% and a plastic limit of 47%. The typical plasticity index is 140%.

Table 2. Physical characteristics of bentonite

Property	Value
Specific gravity	2.6
Consistency properties	
Liquid limit [%]	187
Plastic limit [%]	47
Plasticity index (%)	140
Optimum moisture content (OMC) [%]	25
Maximum dry unit weight γ_d^{max} [kN / m^3]	1.6

2.1.2 Additive

Greyish beach sand from the region of Zemmouri was selected for the treatment of expansive soil. Zemmouri is located east of Algiers. The grain size distribution curve shows relatively medium sand, poor to graded material.

Figure 1 indicates that almost all of the bentonite material passes through a sieve size of 80 µm and 41% of the material is less than 2 µm.

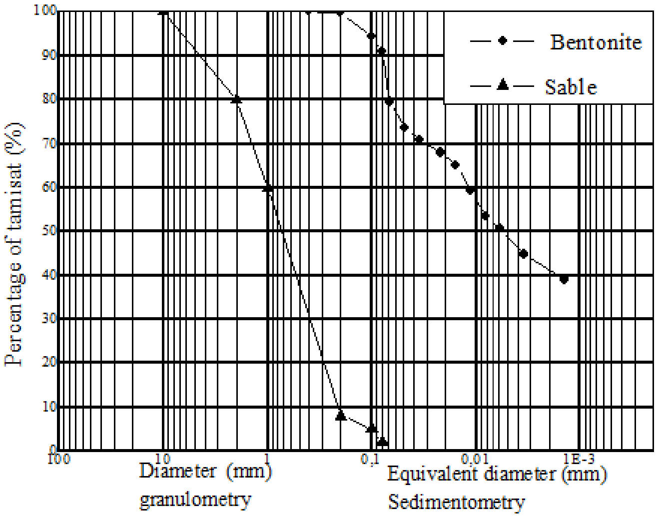

Figure 1. Curves of grain size distribution

2.2 Experimental procedure used

For all tests, the samples were prepared by hand mixing after computing the quantities required for the selected ranges of dry density and water content.

The sample needed to fill the oedometer ring was divided into three equal portions and each portion was placed in a ring of 19mm height and 70mm diameter. To ensure uniform dry density, the sample was statically compacted in three layers using a hand press with a diameter of 70-mm. The final sample height was 15 mm providing a 4 mm recess to allow for potential expansion. On each face of the sample, a filter paper and a porous stone were placed.

2.2.1 Oedometer swelling tests

Swell potential and swelling pressure tests were conducted using one-dimensional oedometer tests according to ref. [20] method A with a seating press of 7 k N/m^2 to examine the changes in the swelling of the soil.

After assembling the oedometer, it was mounted on the loading frame such that the load is applied to the specimen through the loading cap. Dial gauge reading was set to zero and an initial nominal surcharge of 7 kPa was applied.

The sample was inundated and allowed to swell vertically under the seating pressure until primary swelling was completed (until no noticeable change occurs over twenty-four hours period). The changes in dial gauge readings were taken at different intervals of time until equilibrium was reached.

Swell potential under any surcharge is taken as the ratio of the increase in thickness of the soil specimen to the original thickness of the sample and is expressed as a percentage [21].

$$S\,(\%) = \Delta H/H \times 100 \tag{3}$$

where, S is the swell potential expressed in percentage, ΔH is the increase in thickness of the specimen after swelling; H is the original thickness of the sample. The swell under a nominal surcharge of 7 kPa is taken as the oedometer free swell.

Swelling pressure is defined as the pressure required to keep a fully swollen expansive soil sample to its initial void ratio or volume [22].

2.3 Effect of the initial water content on swelling

To analyze the effect of the initial water content, samples of untreated bentonite and bentonite treated with 20% sand were prepared at different water contents (15%, 20%, 26.5%) and (10%, 15%, 20%, 25%) respectively. For sand-treated bentonite, the samples were compacted in three layers in the odometer cell to a dry density of 1.3 g/cm^3.

2.4 Effect of the initial dry density on swelling

In order to study the effect of the dry density on the swelling, four samples were prepared with bentonite alone and varying initial densities (0.8, 0.9, 1.0, and 1.3) and (1.3, 1.45, 1.5) for bentonite mixed with 20% sand material. All samples were prepared in the same optimum water content of the bentonite (26.5%).

2.5 Effect of sand on the swelling behavior of bentonite

In this part of the study, the free-swell test using an odometer was performed. A series of experiments testing the effect of sand addition on the swelling parameters were conducted to measure the swell potential and the swelling pressure. Samples of bentonite sand were prepared by manual mixing at a water content equal to the optimum moisture content (26.5%) and a dry density of 1.3 gm/cm^3. Static compaction was applied to the ring of the odometer (h = 19mm, d = 70mm) using a press machine.

3. RESULTS AND DISCUSSION

3.1 Effect of the initial water content

The curves shown in Figure 2 and Figure 3 indicate a clear influence of the initial water content on the swelling for the different samples (bentonite and bentonite treated with 20% of sand). It is found that the soil swelling decreases with the increase of the initial water content of the sample. The bentonite treated with 20% sand develops less swell than the untreated bentonite. It shows that the sand is reducing the swelling of the bentonite. It can also be noted that the two corresponding curves have the same shape and are almost parallel.

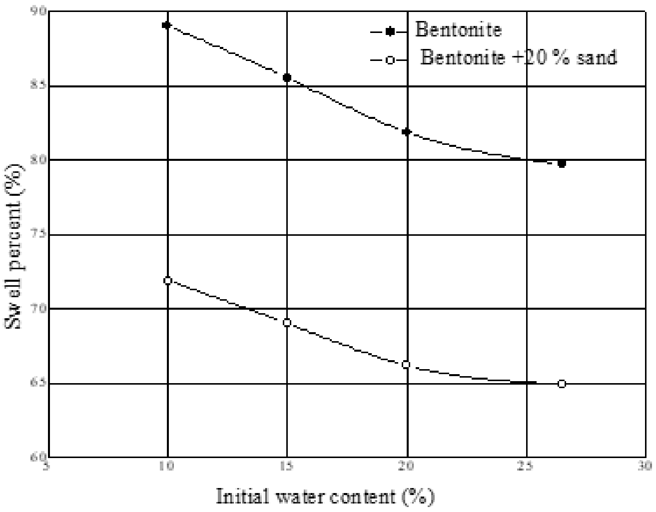

Figure 2. Swelling potential as a function of initial water content

This quasi-parallel expresses that the gain in swell potential and the swelling pressure are only a function of the sand dosage.

Figure 2 presents the swell potential as a function of initial water for a density of 1.3 and Figure 3 presents the swelling pressure function and initial water content at a density of 1.3.

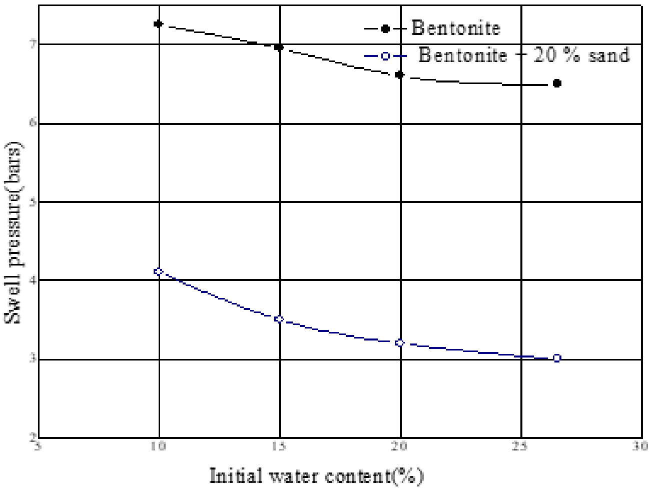

Figure 3. Swelling pressure function initial water content

The tendency to swell decreases with the increase of the initial water content and becomes of a negligible effect at high concentrations near the saturation water content. The swelling pressure was not found dependent on the initial water content. The results show that there is no clear trend in the evolution of swelling. Tests conducted in ref. [23] confirm these results.

According to Chen [1], the influence of water content on the swelling pressure is not significant for values of the initial water content higher than the optimum moisture content.

According to El-Sohb and Rabba [24], when the initial water content increases, the soil affinity to water decreases, and therefore its absorption capacity decreases.

The water in the soil sample has satisfied a part of this affinity and therefore the pressure remains the same as the swelling pressure. Increasing the water content of clay promotes the breaking of the bonds between the layers resulting in an increase in volume. Furthermore, the degree of saturation also increases with the water content of the samples, the soil decreases affinity to adsorption of water to reach saturation, which results in a decrease in swelling.

3.2 Effect of initial dry density on swelling potential and pressure

Examination of the results clearly shows that the state of compactness of soil affects its swelling behavior. The results presented in Figure 4 and Figure 5 show that the swelling and the dry density vary in the same direction. The densest ground indeed exhibits the highest swelling.

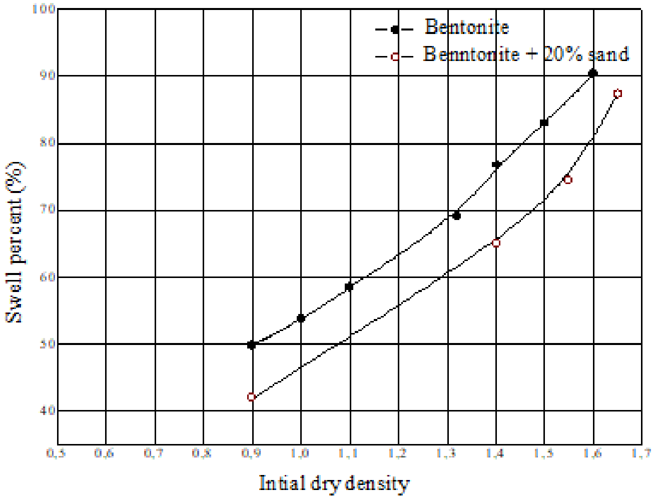

Figure 4. Swell percent as a function of initial dry density

Swelling developed in bentonite is greater than that developed in the bentonite treated with 20% sand. This difference reflects the effectiveness of this material in swell reduction. The difference in the swell percent between the two types is the same for almost all densities, showing that this difference is somewhat independent of the density of the soil.

Numerous research works confirmed the influence of the initial dry density on the swelling characteristics.

Chen [1] Reports that swelling pressure increases with increasing initial dry density. This is justified as heave can occur when compressing a swelling material in a smaller space.

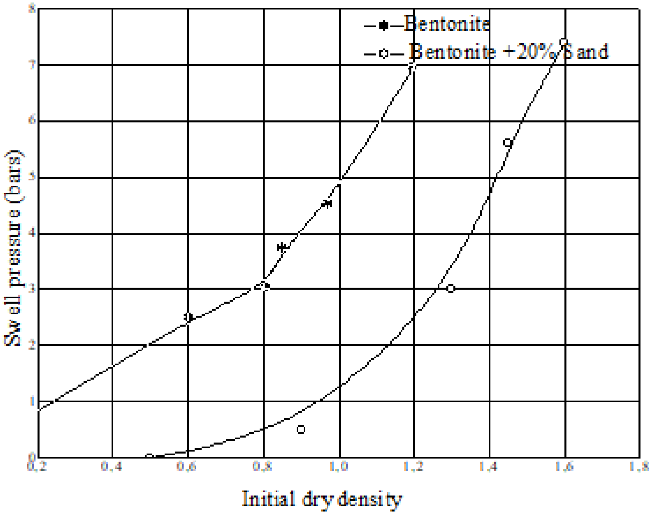

Figure 5. Swelling pressure versus initial dry density

Mollins [25] found that bentonite and sand–bentonite mixtures would swell to the same final clay void ratio regardless of the compaction method.

Jobs of El-Sohby and Rabba [24] tested natural expansive soils from Egypt and have shown that the potential swell and the swelling pressure increase with the increase of the initial dry density indicating a non-linear relationship. This result is confirmed in this study but can be described as close to a bilinear state (Figure 3, Figure 4). It seems that for low densities, the confinement of clay particles is not very tight but for higher dry densities the clay particles are tight and very well confined.

The works developed by Mrad [26] and works of Komine and Ogata [27] indicate that the swelling pressure is exponentially related to the dry density and the swell potential is linear depending on the initial dry density. Rao et al. [28] also confirms this linear relationship of the swell percent and the initial dry density. Many researchers refer to this increase in expansion to the large number of clay particles involved.

A reduction in the density will mean a reduction in the number of swelling particles. The voids within the system control the measured swelling. The corresponding relationship between density and swelling suggests that there are other phenomena that contribute to the development of the swell. The swelling pressures vary in the same way as for the potential swelling. For an initial dry density of 0.8, the pressure of swelling bentonite is 2.5 bars and increases to 6.5 bars for a 1.3density (Figure 5).

The curve presented in Figure 5 shows that there would be an initial dry density for which the untreated soil and the bentonite-sand mixture would give a zero swelling pressure which can be roughly estimated at 0.2 and 0.5 for the bentonite only and bentonite treated with 20% sand respectively.

3.3 Sand content and swelling bentonite

Based on the curves in Figure 6 and Figure 7 that illustrate the variation of the potential swell and swelling pressure with the sand content at a density of 1.3, we can see that both parameters swelling substantially decreases with the increase of the percentage of sand added.

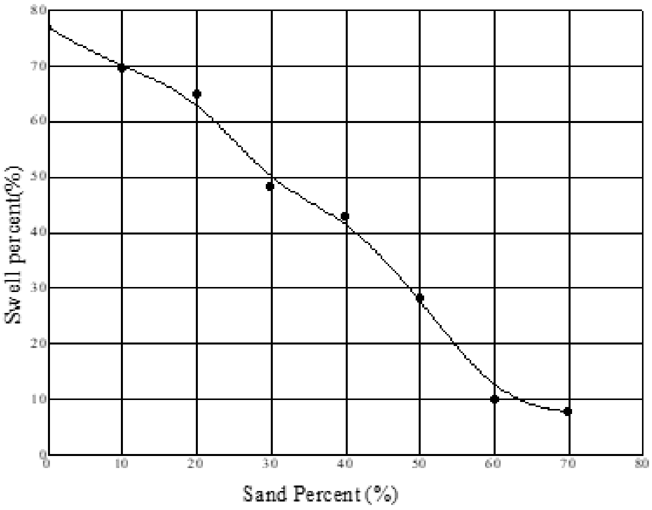

Figure 6. The swelling potential of bentonite-sand mixtures

Nevertheless, this variation in the three phases shows three separate inclinations or slopes that characterize the reduction in swell potential and swelling pressure. A steep slope characterizes the first part. The second part for percentages of sand (40% <Sand percentage <60%), is characterized by a medium slope which is less than the steep one.

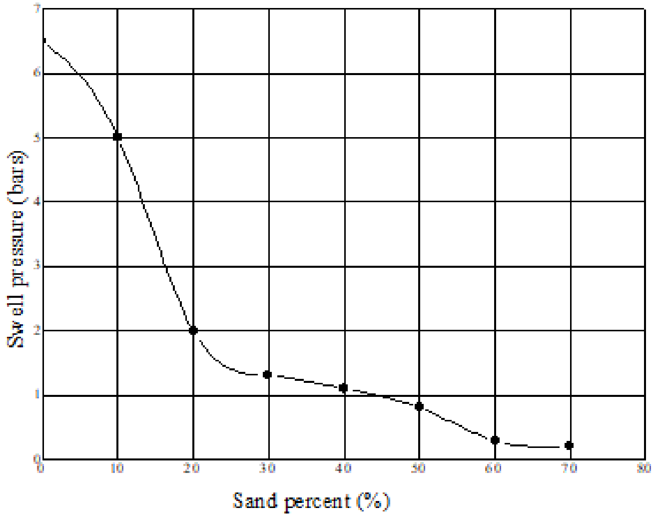

Figure 7. Swelling pressure of bentonite-sand mixtures

The last part is of a very low slope compared to other parts and tends towards being flat for very high sand content mixtures. This trend may reflect the change in the behavior of clay-sand mixtures and show that the decrease in swell is not resulting from the decrease in the clay fraction alone but other factors contribute to this reduction. Lowering the density of the clean dry clay in the mixtures at the same compaction effort can contribute to the reduction of swelling [29].

3.4 Analysis of the swelling evolution as a function of time under constant load

The succession of curves in Figure 8 representing the temporal evolution of the swelling potential shows the same shape for the different sand concentrations.

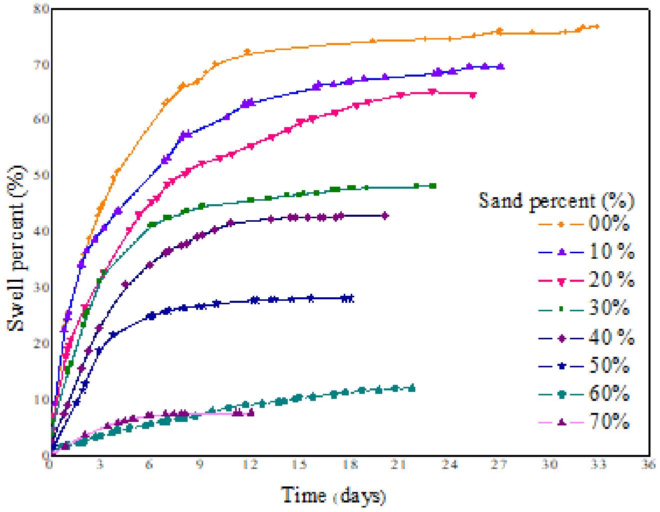

Figure 8. Swelling kinetics of bentonite sand mixture

The examination of the swelling curve as a function of the time of the untreated bentonite shows two distinct phases. A fast phase corresponds to the primary swelling and a slow phase which evolves in time. This secondary swelling phase can last three to four weeks for a bentonite sample.

Examination of the microstructure [30] has shown that in soil, particles tend to cluster together to form macroscopic grains or fragments, which can be as large as silt or even sand particles. In unsaturated soil, the pores between the grains are partially filled with capillary water. This water is subject to the effect of suction and movements governed by this suction. The water will be able to enter or leave the fragments, these movements will result in changes in the volume of the soil which are translated by swelling or a shrinking

The water in the soil is in equilibrium when the capillary suction in the inter-fragment pores is equal to the hydration potential of the particles.

It is noted that swelling varies with the amount of sand added. For the untreated bentonite, the swelling potential is very high and reaches 79%, the volume of the sample has almost doubled.

It can be seen that the addition of sand reduces the time of stabilization of the swelling of the mixtures. More precisely the first phase, which corresponds to the primary swelling, tends to disappear for high percentages of sand.

This change in the swelling kinetics may be due to the change in the permeability of the samples. The permeability increases as a result of the treatment. At percentages above 50%, the behavior of the mixtures changes and would resemble that of a gritty soil with high permeability. This new soil texture helps water to infiltrate quickly and fill the large pores from which secondary swelling will develop.

4. CONCLUSION

The results obtained from tests conducted in this study, form a set that shows the influence of two parameters governing the state of the swelling phenomenon excluding external factors. The effect of the addition of sand to bentonite material on the swelling behavior was examined and found dependent on the sand content. It can be concluded that there is no clear correlation between the initial water content and the swelling pressure. For increased values of dry densities, the swell potential and the swelling pressure are greater. The amount of clay particles is an important factor affecting the swelling.

The results showed the effectiveness of adding sand to highly plastic clay as an acceptable soil stabilization approach. It has been found that this stabilization is somewhat affected by the water content and initial dry density.

REFERENCES

[1] Chen, F.H. (1988). Foundation on Expansive Soil: Developments in Geotechnical Engineering. Elsevier Publishing Amsterdam.

[2] Mouroux, P, Margron P., Pinte J. (1988). Economic Construction on Swelling Soils. Rxcoop. Ed.

[3] Philipponat, G. (1991). Shrinking-swelling soils, methodology proposition. Revue Française de Géotechnique, 57: 5-22. https://doi.org/10.1051/geotech/1991057005

[4] Hachichi, A., Fleureau, J.M. (1999). Characterization and stabilization of some swelling soils in Algeria. Revue Française de Géotechnique, 86: 37-51. https://doi.org/10.1051/geotech/1999086037

[5] Bigot, G., Zerhouni, M.I. (2000). Shrinkage, swelling, settlement of fine soils. Bulletin des Laboratoires des Ponts et Chaussées France, 229: 105-114.

[6] Djedid, A., Bekkouche, A. (2001) Identification and prediction of swelling of some soils in the Tlemcen region (Algeria). Bulletin des Laboratoires des Ponts et Chaussées, 233: 67-75.

[7] Pedarla, A., Chittoori, S., Puppala, A.J. (2011). Influence of mineralogy and plasticity index on stabilisation effectiveness of expansive clays. Transportation Research Record: Journal of the Transportation Research Board, 2212(1): 91-99. https://doi.org/10.3141/2212-10

[8] Popescu, M. (1980). Behavior of expansive soils with crumb structure. In Vol. 1 of Proc., 4th Int. Conf. on Expansive Soils, New York, ASCE.

[9] Dhowian, A.W., Erol, A.O., Youssef, A. (1990). Evaluation of expansive Soils and Foundation Methodology in the Kingdom of Saudi Arabia. Final report, King Abdul Aziz City for Science and Technology, AT.

[10] Nelson, J., Miller, D.J. (1992). Expansive Soils Problems and Practice in Foundation and Pavement Engineering. New York, Wiley.

[11] Abduljauwad, S.N. Al-Sulaimani,G.J, Basunbul, I.A., Al-Buraim, I. (1998). Laboratory and field studies of response of structures to heave of expansive clay. Geotechnique, 48(1): 103-121. https://doi.org/10.1680/geot.1998.48.1.103

[12] Al-Mhaidib, A.I. (1998). Swelling behaviour of expansive shales from the middle region of Saudi Arabia. Geotech. Geol. Eng., 16: 291-307. https://doi.org/10.1023/A:1008819025348

[13] Muntohar, A.S. (2003). Swelling and compressibility characteristics of soil-bentonite mixtures. Civil Engineering Dimension, 5(2).

[14] Daffala, M.A. (2012). The Influence of placement conditions on the swelling of variable clays. Geotechnical and Geological Engineering, 30: 1311-1321. https://doi.org/10.1007/s10706-012-9544-z

[15] Daffala, M.A., Shamrani, M.A. (2013). Behaviour of walls and frames on expansive soils. In Proc., GeoMonterial /66th Canadian Geotechnical Conf. Richmond, BC, Canada.

[16] Dafalla, M.A., Shaker, A.A., Al-Shamrani, M. (2019). Influence of wetting and drying on swelling parameters and structure performance. Journal of Performance of Constructed Facilities, 33(1). https://doi.org/10.1061/(ASCE)CF.1943-5509.0001243

[17] Gromko, G. (1974). Review of expansive soils. Journal of the Geotechnical Engineering Division, 100(6): 667-687. https://doi.org/10.1061/AJGEB6.0000059

[18] Tay, Y.Y., Stewart, D.I., Cousens, T.W. (2001). Shrinkage and desiccation cracking in bentonite-sand landfill liners. Engineering Geology, 60(1): 263-274. https://doi.org/10.1016/S0013-7952(00)00107-1

[19] Vijayvergiya, V.N., Ghazzaly, O.I. (1973). Prediction of swelling potential for natural clays. In: Proceedings of the Third International Conference on Expansive Soils, Haifa, pp. 227-234.

[20] ASTM: D4546. (1996). Standard test method for one-dimensional swell or settlement potential of cohesive soils. D4546, Annual Book of ASTM Standards, Philadelphia.

[21] Seed, H.B., Woodward, R.J., Lundgren, R. (1963). Prediction of swelling potential for compacted clays. Journal of the Soil Mechanics and Foundations Division, 88(3). https://doi.org/10.1061/JSFEAQ.0000431

[22] Jennings, J.E. (1963). Discussion on the heaving of buildings and associated economic consequences with particular reference to orange free state gold fields. The Civil Engineers, 1963(5): 122. https://hdl.handle.net/10520/AJA10212019_17314

[23] Djedid, A., Ouadah, N. (2009). State parameters and swelling of clay soils, example of water content and initial dry density. International Symposium on Unsaturated Soils and the Environment. Tlemcen-Algeria.

[24] El-Sohby, M.A., Rabba, E.A. (1981). Some factors affecting swelling of clayey soils. Geotech. Eng. J., 12: 19-39.

[25] Mollins, L.H. (1996). The design of bentonite sand mixtures. Ph.D. Thesis, Department of Civil Engineering, University of Leeds, UK.

[26] Mrad, M. (2005). Modelling the hydromechanical behaviour of unsaturated swelling soils. PhD Thesis, National Polytechnic Institute of Lorraine, France.

[27] Komine, H., Ogata, N. (1994). Experimental study on swelling characteristics of compacted bentonite. Can. J. Geotec, 31(4): 478-490. https://doi.org/10.1139/t94-057

[28] Rao, A.S., Phanikumar, B.R., Sharma, R.S. (2004). Prediction of swelling listing of remolded and compacted expansive soils using free swell index. Quarterly Journal of Enginneering Geology and Hydrogeology, 37(3): 217. https://doi.org/10.1144/1470-9236/03-052

[29] Komornik, A., David D. (1969). Prediction of swelling pressure of clays. Journal of Soil Mechanics and Foundations Engineering Division, 95(1): 209-225. https://doi.org/10.1061/JSFEAQ.0001218

[30] Traolen, J.P., et al. (1985). Use of Meb to understand the swelling mechanisms of clay soils. Revue Française de Géotechnique, 29: 75-84.