Int. J. of GEOMATE, June, 2013, Vol. 4, No. 2 (Sl. No. 8), pp. 528-532
Geotec., Const. Mat. & Env., ISSN:2186-2982(P), 2186-2990(O), Japan

Evaluation of Soil Water Characteristic Curves of Sand-Clay Mixtures

T. Y. Elkady[1 2], M. A. Dafalla[2], A. M. Al-Mahbashi[2] and Mosleh Al Shamrani[2]
[1]Cairo University, Egypt [2]King Saud University, Saudi Arabia

ABSTRACT: This paper presents an experimental investigation performed to evaluate the soil water characteristic curves of sand/Al-Qatif clay mixtures. Al-Qatif clay is natural expansive clay widely spread in the eastern province of Saudi Arabia. Detailed mineralogical and physical tests were performed on Al-Qatif clay for characterization. Mixtures of sand and Al-Qatif clay were prepared with sand being the base material and with different clay contents (0%, 5%, 10% and 15%). Test results indicate that the shape of SWCC curves changes from the unimodel to the bimodal form of soil water characteristic curve with the increase in clay content indicative of changes in sand/clay mixture micro-and macro-pores.

Keywords: Soil water characteristic curve, Sand- clay mixture, Soil suction

1. INTRODUCTION

Hydraulic barriers are integral components of various engineering systems such as waste containment facilities, earth dam, and water conservation practices. The purpose of these barriers is to preclude the migration of water or leachate. Compacted sand-bentonite barriers have proven to be a suitable material for hydraulic barriers. Several researchers [1]-[6] reported that the amendment of sand with bentonite (ranging between 4 and 20 percent) yielded hydraulic conductivity values acceptable to engineering standards. In addition, sand mixed with bentonite yielded a composite material with satisfactory characteristics in regards to shear strength, susceptibility to desiccation cracking, and ease of construction.

The Kingdom of Saudi Arabia (KSA) is one of the countries which have considerable areas of expansive soil formations. These formations cover vast area of KSA estimated to be about 800,000 km^2 [7] (Fig. 1). This study evaluates the hydraulic characteristics of compacted sand/Al-Qatif expansive clay hydraulic barriers. Al-Qatif clay represents a natural expansive clay that is abundant in the Arabian Gulf coastal region (Fig.1). This over-consolidated clay is extremely fissured in its natural unsaturated state and exhibits significant volume changes when water content is altered. The volume change potential is due to the high amount of expansive clay minerals such as smectite and illite [8].

The hydraulic characteristics and proper simulation of water flow through compacted sand-clay barriers require consideration of unsaturated liquid flow principles. One of the main unsaturated soil parameters required for modeling is the soil water characteristic curve (SWCC). SWCC is defined as the relationship between soil suction and water content (whether gravimetric or volumetric).

Previous studies [9]-[11] focused on the evaluation of SWCC of compacted sand-bentonite mixtures. Results of these studies revealed that the retention capacity increased with increase in bentonite content. Reference [9] indicated that the SWCC possessed a hysteresis effect depending on the wetting and drying paths. In addition, the initial density had a markable effect on the air entry value of SWCC.

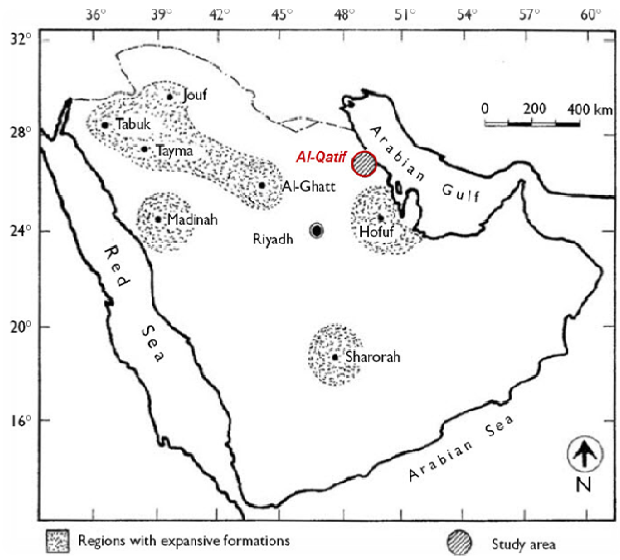

Fig. 1 Distribution of expansive soil formations in Saudi Arabia [7].

Review of technical literature showed a possible trend regarding the shape of SWCCs of sand-bentonite mixtures. SWCCs with unimodel shape were reported for sand-bentonite mixtures with high bentonite content (greater than 30%) [10]-[12]. However, SWCC with bimodal form were observed in case of low bentonite content-sand mixtures. References [13], [14] reported that the SWCC of sand-bentonite mixture with 8% bentonite content revealed a bimodal shape (i.e., curve with four bending curves). This was attributed to pore water trapped between both the larger, interaggregate pores between the sand particles and bentonite platelets and the smaller, intra-aggregate pores.

This paper aims at evaluating the effect of Al-Qatif clay content on the SWCCs of sand/Al-Qatif clay mixtures. Clay content considered were 0%, 5%, 10%, and 15% per dry mass mix. This was achieved by measuring the soil water characteristic curves over a suction range that captures the main features of the curves.

2. MATERIAL AND METHODS

This section describes the material used for the compacted sand/Al-Qatif expansive clay mixtures. Initially, the geotechnical properties of each of the sand and clay material are presented. Finally, the effect of clay content on the geotechnical characteristics of sand-clay mixture is highlighted.

2.1 Soil Used

The expansive clay used in this study was obtained from the city of Al-Qatif located on the Arabian Gulf shoreline at a distance of 400 km from Riyadh, the capital of Saudi Arabia. Several researchers investigated the swelling characteristics of Al-Qatif expansive clay [8], [15], [16]. Based on these investigations, Al-Qatif clay was characterized as highly expansive soil due to the presence of high montomorillonite mineral content.

Soil samples were obtained from open pits excavated to a depth of 1.5 - 3.0 m below ground surface. Samples were transferred to laboratory and complete mineralogical and geotechnical characterization was performed. A summary of geotechnical characterization results is presented in Table 1.

Table 1. Soil Characterization Data for Al-Qatif Soil

Test	Value
Specific Gravity, G_s	2.70
Liquid Limit, w_L (%)	137 %
Plastic Limit, w_P (%)	60 %
Shrinkage Limit, w_{sh} (%)	12 %
% passing Sieve No. 200	99 %
Unified soil classification	CH
Standard Proctor Compaction Test	
Maximum dry unit weight (kN/m^3)	12 kN/m^3
Optimum water content (%)	40 %
Swelling potential (ASTM D4546)	16-18%
Swelling pressure (ASTM D4546)	550-600 kN/m^2

Mineralogical characterization of Al-Qatif clay was performed using Bruker D8 Advance system. Samples were scanned from 2° to 60° (2θ) using 2.2kW Cu anode long fine focus ceramic X-ray tube at a scanning rate of 1 degree per minute. The X-Ray diffraction analysis shown in Fig. 2 depicts that Al-Qatif clay consist of montmorillonite and palygorsite which are typical swelling minerals.

Uniform sand was used in this study with grain size ranging from 0.6 to 0.1 mm. The grain size distribution of sand used is shown in Fig. 3. According to unified soil classification system (USCS), the sand was classified as poorly graded sand (SP).

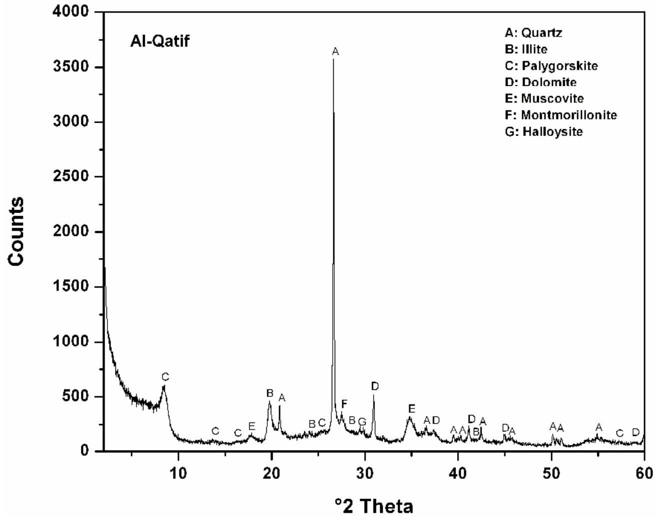

Fig. 2. X-Ray diffraction analysis.

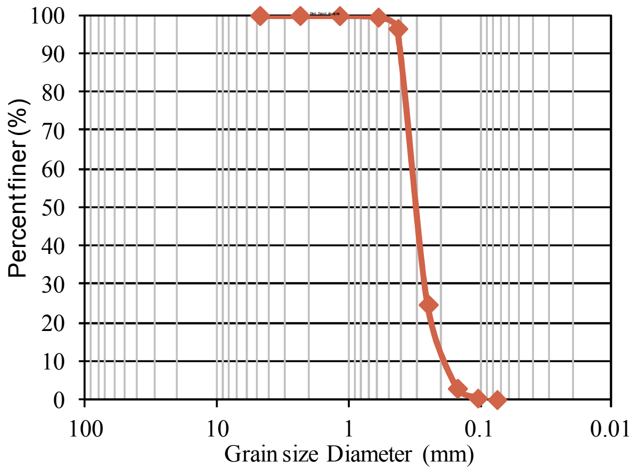

Fig. 3 Grain size distribution of sand.

3 EXPERIMENTAL PROGRAM

3.1 Sample Preparation

Samples of Al-Qatif expansive clay obtained from the field were air dried, pulverized and sieved using sieve No. 40. The oven dried sand and Al-Qatif clay were mixed thoroughly and then optimum water content corresponding to each mix was added, mixed and stored in plastic bags for 24 hours to mellow. Compacted samples of sand/Al-Qatif clay mixtures were prepared for the determination of the soil water characteristic curves. Samples were statically compacted in a stainless steel ring to maximum dry unit weight obtained from Fig. 4. All samples were 50 mm in diameter and 20 mm thick.

3.2 Compaction Curves of Sand-Clay Mixtures

Standard compaction tests were performed in accordance with ASTM D 698 [17] to evaluate the compaction characteristics of sand-clay mixtures. The results of the tests are presented in Fig. 4 revealed that the maximum unit weight and optimum water content increased with increase in clay content.

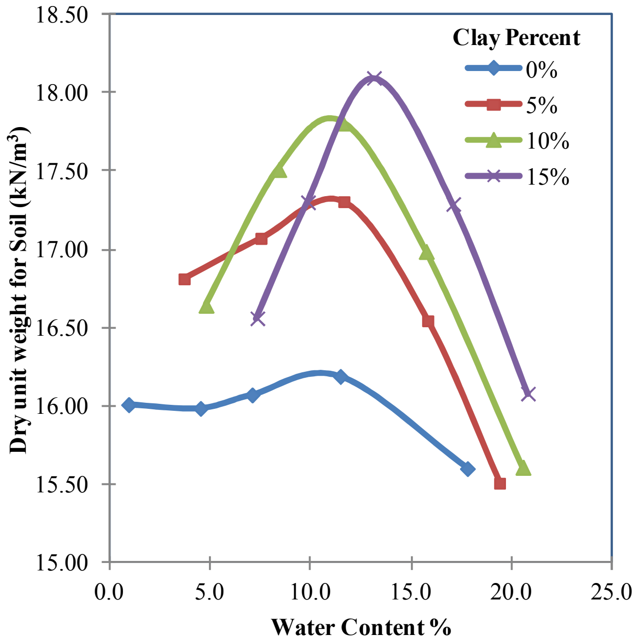

Fig. 4 Compaction curves for sand/Al-Qatif clay mixtures with different clay contents

3.3 Soil water characteristic Curves

The drying curve of the SWCCs of sand/Al-Qatif clay mixtures were evaluated using pressure plate test and hanging column technique. Pressure plate extraction apparatus is based on the principle of axis translation technique [18] and was used to apply suction ranging from 5 kPa to 1500 kPa. The hanging column technique was used to evaluate the SWCC for the suction levels less than 5 kPa. All tests were performed according to ASTM D6836 [19].

For the pressure plate extractor test, samples were placed in confined compartment with a ceramic disc base of air entry value of 5 or 15 bars. Prior to the test, the ceramic disk was saturated by soaking in water of 24 hours. Suction on samples was applied in increments and water exiting from the compartment below the ceramic disc was monitored. Equilibrium under each suction level was assumed to be attained when no water egress was observed. After equilibrium under each suction level, the amount of water lost from tests samples was determined by weighing the samples using a balance with a 0.0001 resolution. At the end of the test, the final water content of the sample was calculated using gravimetric methods. The water content at each suction level was back-calculated based on the final water content and the amount of water loss recorded at each suction level.

The hanging column apparatus comprise of a glass Buchner funnel with a porous plate and two graduated burette system connected to the outflow end of the funnel as shown in Fig. 5. The purpose of these burettes is to apply suction and measure water outflow during the test. The "suction application" burette contains a valve to seal the top of burette from the atmosphere. Suction was applied by raising the Buchner funnel such that base of the sample is above the water level in the suction application burette when the valve is closed. Suction is calculated as the difference between water level multiplied by unit weight of water. The "water outflow" burette was used to monitor and record the amount of water expelled or entered during the test. Equilibrium was attained when no change in water level was observed. Water content at each suction level was calculated based on final water content of sample and amount of water expelled at each suction level.

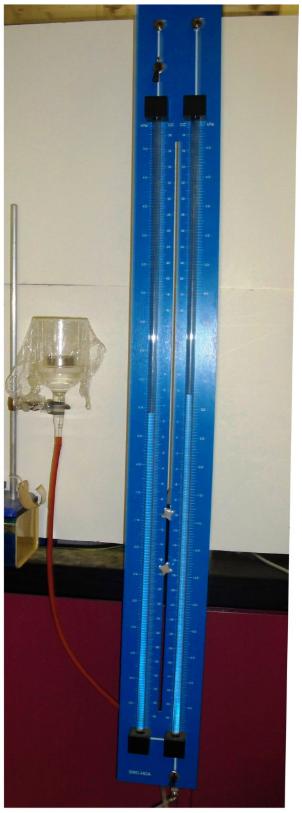

Fig. 5 Hanging column apparatus

4 RESULTS AND DISCUSSIONS

The SWCCs for sand-expansive clay mixtures under different clay contents are illustrated in Fig. 6. In Fig. 6, a gradual transition from a unimodel SWCC to a bimodal SWCC was observed as clay content increases. The unimodel SWCC is characterized by having two bends in the curve defining the air entry value and residual water content (Fig. 6). The air entry value is defined as the matric suction above which air commence to enter the soil pores. The residual water content is defined as the water content beyond which no significant decrease in water content occurs. The bimodal SWCC is characterized by having four distinct bendings: two air entry values and two residual water contents. For clay content equal to or less than 5 percent, the SWCC show a unimodal form of SWCC. With the increase of clay content greater than 5%, the SWCC show a bimodal form.

It is further observed from Fig. 6 that the residual water content increases with the increase of the clay content. In addition, the air entry value increases with the increase in clay content. These observations are attributed to the presence of smaller pore size developed as a result of clay particles filling the voids between sand particles.

Bimodal SWCC are generally observed for gap-grade grain size distribution soils [20] as well as soils that includes two levels of pore sizes defined as macropores and mesopores/micropores [21]. Therefore, it can be inferred that the increase of clay content for resulted in the formation of mesopores/micropores within the sand-clay mixtures compacted at optimum water content conditions. The portion of the soil water characteristic curves representing macropore size ranges between matric suction 0.1 to 100 kPa. Whereas, the portion of the SWCC representing mesopores/micropore sizes lies between matric suction 200 and 1500 kPa.

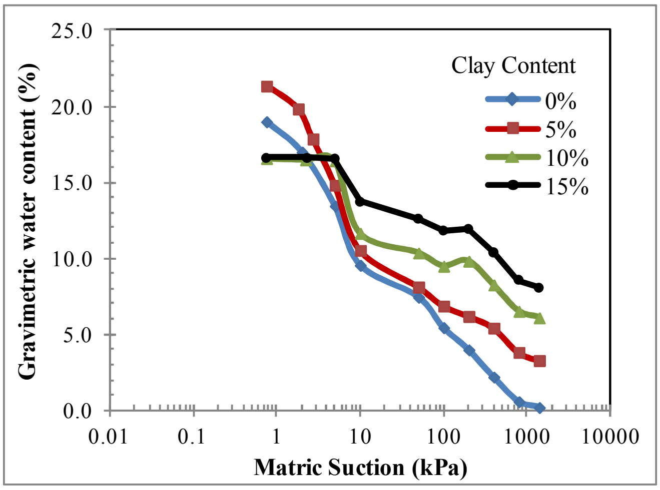

Fig. 6 Soil water characteristic curves of sand/Al-Qatif clay mixtures

5 SUMMARY AND CONCLUSIONS

In this study, the effect of clay content on the soil water characteristic curves of compacted sand/Al-Qatif clay mixtures were evaluated. Clay contents considered include 0%, 5%, 10%, 15%. Results from this study indicated that, as the clay content increased, the shape of the SWCC of sand-clay mixtures transforms from a unimodal form to a bimodal form.

Furthermore, the air entry value and residual water content were observed to increase with increase in clay content signifying increase in water retention capacity.

The bimodal form of the SWCC indicates the presence of two levels of pore sizes; namely macropores and mesopores/micropores. For 10% and 15% clay content, the macropores are considered the dominant pore size covering a broad range of the SWCC from 0.1 kPa to 100 kPa. Therefore, it is inferred that the SWCC of sand-clay mixtures compacted at optimum water content conditions are strongly related to the texture and pore size distribution of the sand/Al-Qatif clay mixture which in turn, has a significant impact on its hydraulic characteristics.

6 ACKNOWLEDGMENT

This paper is a part of a research project supported through NPST program by King Saud University, Project No. ENV 1183. The authors thank the staff of Bugshan Research Chair in Expansive Soils and especially Eng. Abdulla Shaker for his works in constructing the soil compaction curves for sand clay mixtures.

7 REFERENCES

[1] Cho WJ, Lee, JO and Kang, CH,. "Hydraulic conductivity of compacted soil-bentonite mixture for a liner material in landfill facilities", Korea Society of Environmental Engineers, Environ. Eng. Res. Vol. 7. No. 3, 2002, pp. 121-127.

[2] Komine H, “Simplified evaluation on hydraulic conductivities of sand–bentonite mixture backfill”, Applied Clay Science , vol. 26, 2004, pp. 13– 19

[3] Chalermyanont T and Arrykul S, "Compacted sand-bentonite mixtures for hydraulic containment liners,” J. Sci. Technololgy, Vol. 27, No.2, Mar - Apr 2005.

[4] Ameta NK and Abhay S W, "Effect of bentonite on permeability of dune sand", EJGE, Vol 13, 2008.

[5] Akgün H, “Geotechnical characterization and performance assessment of bentonite/sand mixtures for underground waste repository sealing”, Applied Clay Science, Vol. 49, 2010, pp. 394–399.

[6] Gueddouda MK, Lamara MNA, and Taibi S, "Hydraulic conductivity and shear strength of compacted dune sand - bentonite mixtures”, in Proc. International conference on construction and building technology, ICCBT, 16-20 June, 2008, pp. 139 – 150.

[7] Ruwaih IA, “Experiences with Expansive Soils in Saudi Arabia”, in Proc. 6th Int. Conf. on Expansive Soils, New Delhi, India, 1987, pp. 317-322.

[8] Azam S, "Influence of mineralogy on swelling and consolidation of soils in eastern Saudi Arabia", Canadian Geotechnical Journal, Vol.40, No. 5, 2003, pp. 964–975.

[9] Montanez JEC, "Suction and volume changes of compacted sand-bentonite mixtures", Ph.D. Dissertation, Imperial College of Science, 2002

[10] Agus SS and Schanz T, "wetting, drying, suction characteristic curves of bentonite sand", in Proc. of the Fourth International Conference on Unsaturated Soils, 2-6 April, 2006, Carefree, AZ, pp. 1405-1414.

[11] Pei-yong L and Qing Y, "Test study on soil-water characteristic curve of bentonite-sand mixtures", EJGE, Vol. 14, 2009, pp. 1-8

[12] Sun D et al., "Hydro-mechanical behaviors of highly compacted sand-bentonite mixture", Journal of Rock Mechanics and Geotechnical Engineering, Vol. 2, No. 1, 2010, pp. 79–85.

[13] Stoicescu JT, " Soil water characteristics and pore size distribution of a sand-bentonite mixture", in Proc. 49th Canadian Geotechnical Conference, St. John's Newfoundland, September 23-25, Vol. 2, 1996, pp. 721-728.

[14] Stoicescu JT et al., "Soil water characteristics of sand-bentonite mixtures used for liners and covers", in Proc. Second International Conference of Unsaturated Soils, Beijing, China, 27-30 August, Vol. 1, 1998, pp. 143-148.

[15] Abduljuawad SN, Hameed RA, Al-Sulaimani GJ, Basunbal IA, Safar MM, “Expansive soils in Eastern Province of Saudi Arabia”, in Proc. of 7th International Conference on Expansive Soils, Dallas, TX, vol. 1, 1992, pp. 426-431.

[16] Azam S, Abduljauwad SN, Al-Shayea NA, Al-Amoudi OSB, “Expansive characteristics of gypsiferous/anhydritic formations”, Engineering Geology, Vol. 51, 1998, pp. 89-107.

[17] ASTM D698 - 02 Standard Test Methods Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft lbf/ft3 (600 kN m/m3) , Vol. 15.09, Annual book of ASTM Standards, West Conshohocken, PA.

[18] Hilf JW, "An investigation of pore-water pressure in compacted cohesive soils", Ph.D. Thesis, Tech. Memo No. 654, U.S. Dept. of interior Bureau of Reclamation, Design and Construction Div., Denver, Colorado, 1956

[19] ASTM D6836 - 02 Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using a Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, and/or Centrifuge, Vol. 15.09, Annual book of ASTM Standards, West Conshohocken, PA.

[20] Durner W, "Hydraulic conductivity estimation for soils with heterogeneous Pore Structure", Water Resources Research, Vol. 30, No. 2, 1994, pp. 211-223.

[21] Burger CA and Shackelford CD, "Soil-Water Characteristic Curves And Dual Porosity of Sand–Diatomaceous Earth Mixtures”, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 127 No. 9, September 2001, pp. 790-800.

Int. J. of GEOMATE, June, 2013, Vol. 4, No. 2 (Sl. No. 8), pp. 528-532.
MS No. 246 received June 17, 2012, and reviewed under GEOMATE publication policies.

Pertinent discussion including authors’ closure, if any, will be published in the June 2014 if the discussion is received by Dec., 2013.
Corresponding Author: T. Y. Elkady