Effect of Bentonite on Shear Strength of Bushehr Calcareous Sand

Arash Poordana, Reza Ziaie Moayed

Abstract**—**Calcareous sands are found most commonly in areas adjacent to crude oil and gas, and particularly around water. These types of soil have high compressibility due to high inter-granular porosity, irregularity, fragility, and especially crushing. Also, based on experience, it has been shown that the behavior of these types of soil is not similar to silica sand in loading. Since the destructive effects of cement on the environment are obvious, other alternatives such as bentonite are popular to be used. Bentonite has always been used commercially in civil engineering projects and according to its low hydraulic conductivity, it is used for landfills, cut-off walls, and nuclear wastelands. In the present study, unconfined compression tests in five ageing periods (1, 3, 7, 14, and 28 days) after mixing different percentages of bentonite (5%, 7.5% and 10%) with Bushehr calcareous sand were performed. The relative density considered for the specimens is 50%. Optimum water content was then added to each specimen accordingly (19%, 18.5%, and 17.5%). The sample preparation method was wet tamping and the specimens were compacted in five layers. It can be concluded from the results that as the bentonite content increases, the unconfined compression strength of the soil increases. Based on the obtained results, 3-day and 7-day ageing periods showed 30% and 50% increase in the shear strength of soil, respectively.

Keywords**—**Unconfined compression test, bentonite, bushehr calcareous sand.

I. Introduction

IMPROVING soil's mechanical characteristics has always been one of the most important concerns of geotechnical engineers. Using admixtures to gain the requirements needed for projects is a common method of soil improvement. Cemented soils have long been considered a soil-improvement method, but it has its environmental impacts and replacements are being studied to minimize the contamination of soil. The montmorillonite-based clay, bentonite is being used in several civil projects. Bentonite is an absorbent aluminum phyllosilicate. In present study, unconfined compression test is performed to determine the mechanical properties of this soil.

As described by Mollins et al. [1], bentonite only swells to a limit. Sand-bentonite mixtures were tested to investigate the hydraulic conductivity. For this, 5%, 10%, and 20% of bentonite by dry weight of sand were examined with vertical effective stresses of up to 450 kPa. Swelling and hydraulic conductivity tests were performed. It was concluded that a threshold stress which is a function of clay content controls the swelling behavior of the specimens. The behavior of the mixtures and pure clay showed similar behavior at low effective stresses and therefore, the applied effective stress is governed by the clay. When the applied effective stress goes higher than a limit, it loses its effectiveness and no remarkable change in the clay void ratio can be seen. Furthermore, a relationship between bentonite content, sand porosity, tortuosity and the vertical effective stress can give us a schematic overview of the hydraulic conductivity of the mixtures.

Variation of percentages of sand-bentonite mixtures were tested by Pakbaz et al. [2] in two, confined and unconfined states. Measures of 10%, 30%, 50%, 70%, and 80% of bentonite by dry weight of sand were compacted after adding optimum moisture content. The results indicated an increase of unconfined strength of specimens until 50% bentonite samples but afterwards the trend was declining and a loss of strength was obvious. The logic for this behavior is the deficiency in confinement of specimens, while the sand has no cohesion between its grains.

Tensile strength of different sand-bentonite mixtures was investigated by Kim et al. [3]. Contaminated and compacted sand-bentonite mixtures were examined to determine the effect of disk diameter, leading rate, and pH level on tensile strength. An improved unconfined penetration was done and it was concluded that alignment, friction, slippage, and stress concentration were improved. The stress-strain curve achieved during the tensile tests and the stress-strain curve achieved from triaxial test had similar behavior.

Sun et al. [4] have proposed that the main reason for the swelling of bentonite is montmorillonite water absorption. A unique relationship between the void ratio of montmorillonite and vertical pressure is formed following the water absorption and it is independent of the percentage of bentonite.

Dynamic properties of sand-bentonite mixtures were studied by Khan et al. [5]. Resonant column test and cyclic triaxial test were used to measure the shear modulus as a function of frequency. The viscoelasticity of sands increased with the presence of plastic fines. Sand-bentonite mixture with 32% of bentonite-water saturation showed similar behavior in shear modulus increase percentage of pure clay. Also, it was indicated that the increase in shear modulus was significantly larger in RC tests in comparison with CT tests, because of the nature of lower shear strain levels in resonant column apparatus.

Wayal et al. [6] tested the stabilization of sand-bentonite-lime mixtures using unconfined compression test. The immediate amelioration by base exchange and flocculation

A. Poordana is with the Department of Civil Engineering at Imam Khomeini International University, Qazvin, Iran (e-mail: arashpoordana@rocketmail.com)
R. Ziaie Moayed is with the Department of Civil Engineering, Imam Khomeini International University, Qazvin, Iran (Corresponding author, e-mail: Ziaie@eng.ikiu.ac.ir).

was the result of adding lime to the specimens. The pozzolanic reaction of the added lime increased the strength of the mixture while the added bentonite gave the specimens an adequate amount of cohesion. Therefore, the addition of bentonite and lime increased the unconfined compression strength of the soil.

Salem et al. [7] studied the static and cyclic behavior of calcareous sands. Monotonic and cyclic undrained triaxial tests were performed and it became clear that the development of excess pore pressure was the main factor in failure under cyclic loading. The importance of the different shapes of the sand particles became obvious in higher cyclic strength of the tested soil compared to other calcareous sands. This characteristic gave the specimen more stable interlocking making it resistant to liquefaction; though, the effect of particles interlocking was less governing in denser specimens. Reaching liquefaction required more cycles as the relative density of the soil increased. It was also concluded that with the increase in confining pressure, the initial relative density on the cyclic behavior was less effective.

Cement as an additive to sand-bentonite mixture and the ageing period was evaluated by Iravanian et al. [8]. Ageing increased the strength gained by bentonite and bentonite-cement additives, while the effectiveness of ageing was more apparent in cement added specimens. Unconfined compression strength reached a peak value in 90 days in both combination of mixtures. In addition, it became clear that 90% of the peak strength of the specimens is reached after 28 days of ageing.

Fig. 1 Microscopic image of Bushehr calcareous sand

II. Material Properties

In the present study, Bushehr calcareous sand and bentonite powder were assessed. Based on the indicators given by Krumbein [9], Bushehr calcareous sand is sub-angular. A microscopic image of the assessed sand is given in Fig. 1. It could be seen that the skeletal fossil of marine creatures in the microscopic image. The specific gravity (Gs) of the tested sand is 2.78. In Fig. 2, the site where the soil was taken from is shown. In the south-western part of Iran and the coast of Persian Gulf with longitude of 50.816856 and latitude of 28.907930. Based on ASTM D2487 [10], this sand is classified as SP (Poorly graded Sand). The particle size distribution diagram is presented in Fig. 3. The bentonite used in this study, obtained from Iran Barite Co., is considered as CH (High plasticity Clay) according to the Unified Soil Classification System (USCS).

Fig. 2 Satellite image of coastal region of Bushehr, Iran

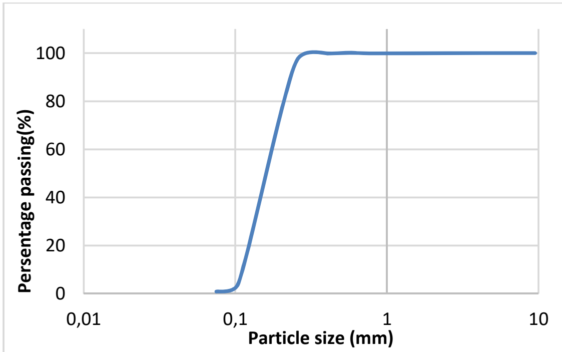

Fig. 3 Particle size distribution curve of Bushehr Calcareous Sand

Table I presents the chemical compositions of bentonite used in this study. The specific gravity (Gs) of bentonite is 2.79, liquid limit (LL) and plasticity index are equal to 420% and 385%, respectively. The properties of bentonite are displayed in Table II.

III. Test Procedure and Apparatus

A. Sample Preparation

Generally, there are several common methods for preparing remolded samples. Wet tamping is the chosen method for this study. Three percentages of bentonite (5%, 7.5%, and 10%) were dry-mixed with sand and then optimum moisture content (19%, 18.5%, and 17.5%), respectively, were added to the mixture. Each specimen was compacted in five layers to reach the desired relative density of 50%. The ageing considered for this study consists of five periods (1, 3, 7, 14, 28 days). After carefully preparing the samples, they were kept in sealed storage bags so they would not lose their moisture.

B. Unconfined Compression Test

The Unconfined compression test apparatus of Wykeham Farrance was used for this study. The rate of axial strain of this apparatus was set to 0.76 millimeters per minute.

TABLE I
CHEMICAL COMPOSITIONS OF BENTONITE

Properties	Values
Mineral composition in decreasing abundance	Montmorillonite, Calcite, Quartz
Carbonate content	8%
Organic content	1.4%
CEC, cmol/kg soil	68.2
Exchangeable Na^+	48.5
Exchangeable Ca^{2+}	14.2
Exchangeable K^+	3.4
Exchangeable Mg^{2+}	2.1
pH(1:10, soil-water ratio)	8.5

TABLE II
PROPERTIES OF BENTONITE

Properties	Values
Liquid limit (LL) %	420
Plastic limit (PL) %	35
Plasticity index (PI) %	385
Clay %	76
Silt %	23
Sand %	1
Activity %	0.37
Water content %	7.10
Specific Surface m^2/kg	413

IV. RESULT AND DISCUSSION

A total number of 15 unconfined compression tests were completed in this study to evaluate the effect of bentonite percent and ageing on the shear strength of Bushehr calcareous sand. The Unconfined Compression Strength (UCS) of the specimens were calculated and compared. The effect of adding bentonite on the shear strength of specimens in five periods of ageing can be observed in Fig. 4. In all the three percentages of bentonite, there is an upward trend in the UCS, which clearly shows the strengthening influence on the specimens of 50% relative density. The strength of samples with 5% bentonite (B5) and 10% bentonite (B10) after 1 day of ageing, differentiate by almost 20%, while this amount reaches to about 80% after 28 days of ageing for the same percentages of additive. In Fig. 5, the effect of ageing on the UCS of the specimens in different percentages of bentonite is presented. For B5 specimens, the strength increase from 1 day of ageing to 3 days, 7 days, 14 days, and 28 days of ageing was 2%, 4%, 14%, and 34%, respectively. These increments were 4%, 23%, 49%, and 90% in the same order for B7.5 specimens. As for B10 specimens, the increasing percentages are 26%, 29%, 51%, and 99%, which means that in B10 specimens, the UCS almost doubled after 28 days of ageing. As it was earlier discussed by Iravanian [8], 90% of peak shear strength of sand-bentonite specimens was achieved after 28 days of ageing; hence, in this study, 28 days of ageing is considered as the efficient period of ageing. It can also be seen that 3 days and 7 days of ageing showed almost the same UCS in variation of bentonite and there were no sizeable discrepancy.

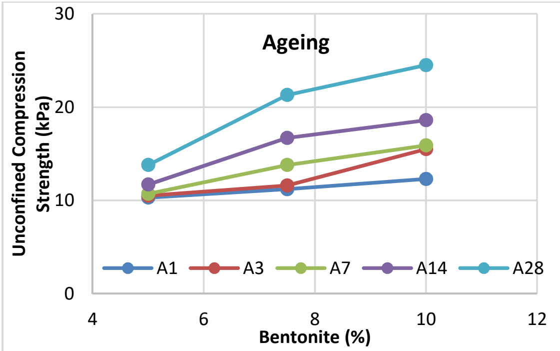

Fig. 4 Unconfined compression strength of Bushehr calcareous sand with 5%, 7.5%, and 10% bentonite

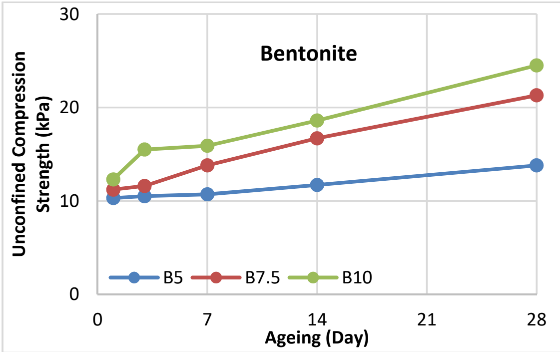

Fig. 5 Unconfined compression strength of Bushehr calcareous sand in ageing periods of 1, 3, 7, 14, and 28 days

V. CONCLUSION

In the present study, 15 unconfined compression tests were conducted to investigate how the two main factors of bentonite addition and ageing, affects the shear strength of Bushehr calcareous sand. The specimens were compacted with a relative density of 50% and mixed with 5%, 7.5%, and 10% of bentonite and then were sealed until their ageing periods of 1 day, 3 days, 7 days, 14 days, and 28 days. The results show that the addition of bentonite increased the shear strength of sand. Increasing the bentonite content from 5% to 7.5% increases the shear strength by 54%, while increasing bentonite from 7.5% to 10% in specimens increases the shear strength by 15%. Ageing from 1 day to 28 days also increased the UCS of specimens with 5% bentonite by 34%. In 7.5% bentonite-sand specimens this amount was 90%, and in samples with 10% bentonite content, this number was up to 100%.

REFERENCES

[1] Mollins, L. H., D. I. Stewart, and T. W. Cousens. "Predicting the properties of bentonite-sand mixtures." Clay Minerals 31.2 (1996): 243-252.
[2] Pakbaz, Mohammad C., and Navid Khayat. "The effect of sand on strength of mixtures of bentonite-sand." Engineering Geology for Infrastructure Planning in Europe. Springer, Berlin, Heidelberg, 2004. 316-320.
[3] Kim, T. H., et al. "Tensile strength characteristics of contaminated and compacted sand-bentonite mixtures." Environmental geology 52.4 (2007): 653-661.

[4] Sun, De'an, Hongbin Cui, and Wenjing Sun. "Swelling of compacted sand–bentonite mixtures." Applied Clay Science 43.3-4 (2009): 485-492.
[5] Khan, Zahid, M. H. El Naggar, and Giovanni Cascante. "Frequency dependent dynamic properties from resonant column and cyclic triaxial tests." Journal of the Franklin Institute 348.7 (2011): 1363-1376.
[6] Wayal, A. S., N. K. Ameta, and D. G. Purohit. "Dune sand stabilization using bentonite and lime." J Eng Res Stud 3.1 (2012): 58-60.
[7] Salem, Manal, Hussein Elmamlouk, and Shehab Agaiby. "Static and cyclic behavior of North Coast calcareous sand in Egypt." Soil Dynamics and Earthquake Engineering 55 (2013): 83-91.
[8] Iravanian, Anoosheh, and Huriye Bilsel. "Strength Characterization of Sand-Bentonite Mixtures and the Effect of Cement Additives." Marine Georesources & Geotechnology 34.3 (2016): 210-218.
[9] Krumbein, William Christian. "Measurement and geological significance of shape and roundness of sedimentary particles." Journal of Sedimentary Research 11.2 (1941): 64-72.
[10] ASTM Committee D-18 on Soil and Rock. Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) 1. ASTM international, 2017.