Scientia Iranica A (2015) 22(2), 367–372

SCIENTIA IRANICA

Sharif University of Technology
Scientia Iranica
Transactions A: Civil Engineering
www.scientiairanica.com

Oedometric response of an artificially prepared sand-bentonite mixture improved by potassium silicate

M. Ajdari[a,*] and H. Bahm Yari[b,1]

a. *Department of Civil Engineering, School of Engineering, Fasa University, Moallem BLVD, Fasa, Fars, Iran.*
b. *Department of Civil Engineering, Azad University, Branch of Marvdasht, Marvdasht, Fars, Iran.*

Received 17 September 2013; received in revised form 13 January 2014; accepted 31 May 2014

KEYWORDS
Expansive clay;
Oedometric behavior;
Potassium silicate.

Abstract. In this paper, artificially prepared sand-bentonite samples with different bentonite contents were employed to investigate the role of the clay content in the swelling potential, swelling pressure and oedometric behavior of expansive clays. Specimens were also dynamically compacted utilizing an identical compaction effort at various initial water contents to study the effect of the initial fabric of the soil on its volume change behavior and also to find the moisture content corresponding to the minimum drying-wetting induced swell and shrinkage of the material. Furthermore, commercially available Potassium Silicate is evaluated as a potential stabilizer in improving the volume change features of the sand-bentonite mixtures. Three dosage levels of the Potassium Silicate solutions were utilized to stabilize the expansive clayey soil. Free swelling, drying-wetting and consolidation tests were conducted on the stabilized soil samples. The results indicate that the swelling potential of the improved soil specimens are much lower than those of the non-stabilized soils. Also, Potassium Silicate eliminates the shrinkage behavior of the expansive clay. Besides, the mechanical oedometric behavior of the stabilized and non-stabilized soils is similar and Potassium Silicate does not change the response of the soil samples to the mechanical loading.

1. Introduction

Following the hypothesis that swelling clays are in abundance where the annual evapo-transpiration exceeds the precipitations, south west of Iran is among the regions of reported examples of expansive clays. Hence, understanding the behavior of saturated and unsaturated expansive clays is essential in the design and construction of light structures, embankments and roads in this region. Considerable experimental researches have been done to investigate the hydro-mechanical behavior of these soils [1,2]. Alonso et al. [3] showed that the pre-consolidation stress of expansive clays is significantly affected by initial dry density and hydraulic loading. Similar results were reported by Liangton [4].

Shuai [5] investigated the swelling pressure of the expansive soils. The experimental data from the loaded swell oedometer tests indicated that total heave has a linear relationship with logarithm of the surcharge load. Besides, different values of swelling pressure were measured from different test procedures. The rate of the swelling was significantly dependent on the permeability of the soil. Also, low hydraulic conductivity results in a slow swelling process and vice versa.

Rao et al. [6] studied the swelling behavior of desiccated soils. The results of the tests indicated

1. *Present address: Department of Civil Engineering, School of Engineering, Fasa University, Fasa, Fars, Iran.*
*. *Corresponding author. Tel.: +98 917 3196516*
E-mail addresses: ajdari@fasau.ac.ir (M. Ajdari), hossein.bahmyari.eng@gmail.com (H. Bahm Yari)

that the ultimate void ratio of the compacted clays subjected to drying-wetting cycles is independent of the initial compaction condition. Further, his investigation showed that the vertical deformation, void ratio and water content after four cycles of drying-wetting are reversible in the oedometer test.

Attom et al. [7] conducted a set of swell tests on both undisturbed and three soils compacted employing different methods namely: dynamic, static and kneading compaction. Dynamic compaction provides the highest value of swell potential and swelling pressure followed by the static and kneading compaction. This behavior is probably due to the flocculated structure of the dynamically compacted soil resulting in providing samples with more capability to absorb water.

Day [8] Tripathy et al. [9] and Lloret et al. [10] have shown that the swelling and shrinkage path of a single structure expansive soil occurs as a part of an S-shaped curve and in three different phases. Moreover, it has been stated [9] that the swelling and shrinkage path is reversible in terms of void ratio and water content after several drying-wetting cycles. The results showed an increase in the swelling with an increase in the initial dry density.

Sridharan and Gurtug [11] studied the swelling behavior of Cyprus expansive clay with variation in compaction energies from standard Proctor compaction to modified Proctor. The results demonstrated that there is a linear relationship between the swelling pressure and swelling potential irrespective of the level of compaction energy. Swelling potential increases linearly with the compaction energy. Besides, the time vs. percent swell has the shape of a rectangular hyperbola and percent swell vs. log of time relationship has essentially three phases namely: initial, primary, and secondary portion.

Avsar et al. [12] performed some swelling pressure and swelling potential tests on the Ankara clay. The results showed that the swelling parameters determined in the vertical direction are greater than those determined in the horizontal direction. Besides, microstructural study showed that the direction of the sheeting of the clay particles play a significant role in the swelling parameters of the soil. Employing the conventional swelling test and Mercury Intrusion Porosimetry (MIP) method, Ferber et al. [13] examined the coupled influence of the initial dry density and moisture content on the swelling potential and microstructure of the expansive clay. The results indicated that sample preparation method affects the micro and macro-pores leading to the different swelling behavior. Such that, initial dry density governs the macro-pores and initial moisture content directs the micro-pores.

In this study, a comprehensive experimental investigation of the volume change behavior of the expansive sand-bentonite mixtures was performed. Soil specimens were blended with different amount of distilled water to reach various moisture contents resulting in different initial soil fabrics. Then, wetted samples were dynamically compacted in the oedometer ring. Free swelling, consolidation and drying-wetting tests were performed subsequently and the role of initial fabric in the hydro-mechanical behavior of the samples is discussed. Details of the test program and results are considered in subsequent sections.

Furthermore, estimated damages that occur around the world due to expansive clays volume change is about a few billion dollars per year. Structures founded on this type of material bear damages from the minor cracking of pavements or interior finishing of buildings, irreparable displacement of footings and superstructure elements [14-16]. Therefore, finding suitable methods to stabilize the material and reduce the hydraulic loading induced volume change of the expansive clays is essential. Consequently, numerous studies have been performed to investigate the various improvement techniques [5,17-20]. Al-Rawas et al. [21] compared the suitability of the different stabilization methods and indicated the superiority of the lime in the reduction of swelling potential and swelling pressure of the soil. However, Guney et al. [22] showed that the drying-wetting cycles increase the swelling pressure of the lime-stabilized clays.

In this paper, commercially available Potassium Silicate (PS) is considered as a stabilizer material. Different PS solutions were prepared by solving various amount of PS in unit volume of distilled water. The solutions were then blended with dry sand-bentonite mixture and the hydro-mechanical behavior of the stabilized soil was studied employing the free swelling, consolidation and drying-wetting tests. The comparison between the behavior of the stabilized and non-stabilized soils are presented and discussed in detail.

2. Materials and experimental procedure

Sand-bentonite mixtures are usually utilized as a liner for municipal waste disposal facilities. In this study, two types of artificially prepared sand-bentonite mixtures with different percentages of bentonite content were taken to investigate the hydro-mechanical behavior of the expansive clays. Several classification tests were performed employing ASTM code procedure. Atterberg limits of the material were determined and specific gravity of the sand-bentonite was calculated. Maximum dry density and optimum moisture content were determined using the standard Proctor compaction test (Figure 1). Table 1 shows the index properties of the materials.

Sand and bentonite, taken from Shiraz bentonite mine, were separately oven-dried at the temperature of 105°C for 24 hours. Coarse grain particles of the sand

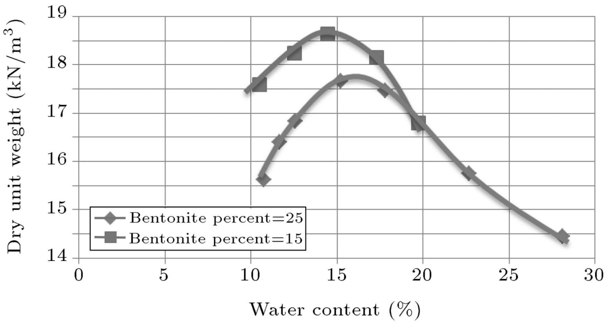

Figure 1. Compaction curves of studied sand-bentonite mixtures.

Table 1. Physical properties of the studied materials.

Parameter	Bentonite content	
	15%	**25%**
LL (%)	52	79
PI (%)	21	41
G_s	2.63	2.61
OWC (%)	14	16.5
$\gamma_{d,\max}$ (kN/m^3)	18.7	17.7
USCS classification	SM	SM

were removed by passing the soil through the 0.425 mm sieve. Bulk soil samples were prepared by blending a predetermined percentage of sand and bentonite with the desired water contents (Optimum Water Content (OWC), OWC-5% and OWC+5%) and stored in a humid chamber. After 48 hours, samples were dynamically compacted using the identical standard Proctor energy per unit volume of soil. In other words, samples were compacted such that three different points of compaction curve were achieved.

Additives usually improve the hydro-mechanical behavior of clays through the flocculation process in which absorbed water is substituted by cations (e.g. Ca^{++} in lime, Na^+ in Sodium Chloride or K^+ in Potassium Silicate) resulting in a change in the soil texture and chemical reactions in which cations are added to the clay mineral and change the chemical composition of the clay particles.

As previously mentioned, drying wetting cycles increase the swelling pressure (vertical stress at which the initial void ratio is reached) of the lime stabilized soils [22]. Also, sodium chloride may lead to an increase in the dispersion capability of the soil. Hence, in this study, distilled water was utilized for preparing the non-stabilized samples, and Potassium Silicate (PS: K_2SiO_3, Batch Number: 123-44) solutions were employed for providing the stabilized specimens. PS solution was prepared employing the distilled water and exposed to the environment for two days. Three dosages of the PS solution (6, 9 and 12%) were blended with dry soil (25% bentonite and 75% sand) to prepare the moist specimens, and wetted samples were stored for 48 hours to homogenize the moisture content between the soil particles. These specimens were used to determine the hydro-mechanical behavior of stabilized sand-bentonite mixture.

As previously mentioned, twenty one cylindrical specimens, five centimeter in diameter and one centimeter in height were compacted at various points of compaction curve to perform the oedometric tests. Free swelling tests under the vertical stress of five kPa followed by the conventional consolidation tests were done on the stabilized and non-stabilized samples. In consolidation experiments, the load was held on the sample for twenty four hours or until all excess pore pressure was dissipated. During this time, the change in height was measured and the change in void ratio was determined. The load was doubled at the end of the 24 hour period and the process was repeated. The measurements were then used to determine the relationship between the vertical effective stress and void ratio. In the free swelling test, water was introduced to a sample that was laterally restrained in the oedometer cell and the one-dimensional volume change was measured with time. Readings of the vertical displacement of the sample were taken at sequential time intervals. To keep the sample submerged in water, distilled water was added if necessary.

Drying-wetting cycles were imposed to the specimens followed by the consolidation under the applied vertical loads: Samples were air-dried in a thermal control chamber (temperature of 21°C) for six days and then introduced to the distilled water for twenty four hours to do the wetting procedure. The suitable duration of the drying process was determined through a trial procedure by increasing the time of the drying and monitoring the rate of the shrinkage of the samples. The flowchart of the oedometric tests is shown in Figure 2.

3. Results and discussion

3.1. Oedometric response of non-stabilized soil

Figure 3 compares the oedometric behavior of the saturated soil samples and their volume change during the free swelling test. As is clear from these figures,

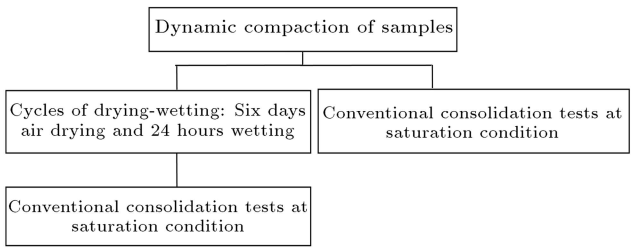

Figure 2. Layout of the oedometric tests.

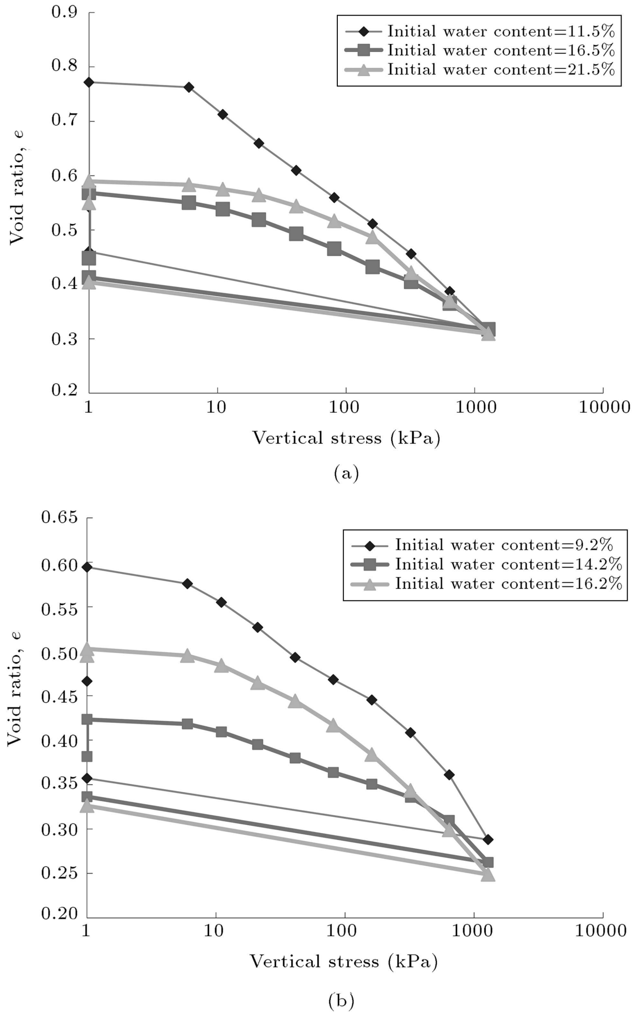

Figure 3. Consolidation curves of saturated sand-bentonite mixtures: (a) Bentonite percent = 25; and (b) bentonite percent = 15.

swelling pressure and swelling potential of the samples decrease with an increase in the initial water content (Table 2). Obviously, it is due to the higher capacity of the dry specimens to absorb water during the saturation process. Besides, samples compacted in the dry side of the OMC have a flocculated texture. Absorbed water increases the thickness of the double layer water and changes the structure of the samples to the dispersed one resulting in a high amount of the volume increase. Therefore, more effort should be taken to reach the initial volume of the samples.

Also, these figures show that the samples compacted at OMC have lower coefficients of compressibility. High initial unit weight of these specimens can explain this behavior. Furthermore, mechanical loading leads to the de-structuring of the samples approaching asymptotically to a unique normal consolidation line at high applied net stresses. It is worth mentioning that, in general, more bentonite content results in a higher swelling pressure and swelling potential.

3.2. Responses of the stabilized and non-stabilized soils upon drying-wetting cycles

Figure 4 indicates the volume change behavior of non-stabilized soils during wetting-drying cycles. Clearly,

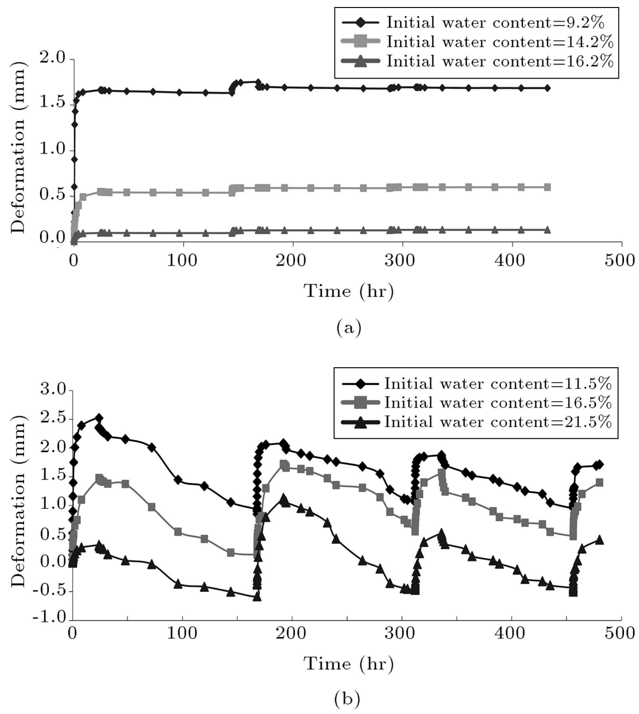

Figure 4. Wetting-drying cycles at constant vertical stress of 5 kP. (a) Bentonite percent = 15 (b) bentonite percent = 25.

Table 2. Swelling and oedometric properties of the sand-bentonite mixture.

Bentonite (%)	Initial void ratio	Initial water content (%)	C_c	C_s	Swelling potential (%)	Swelling pressure (kPa)
15	0.49	9.2	0.1902	0.02	8.7	90
15	0.37	14.2	0.15	0.025	3	40
15	0.46	19.2	0.15	0.025	0.5	7
25	0.55	11.5	0.234	0.048	14.9	120
25	0.45	16.5	0.15	0.029	7.8	110
25	0.46	21.5	0.12	0.03	2.6	35

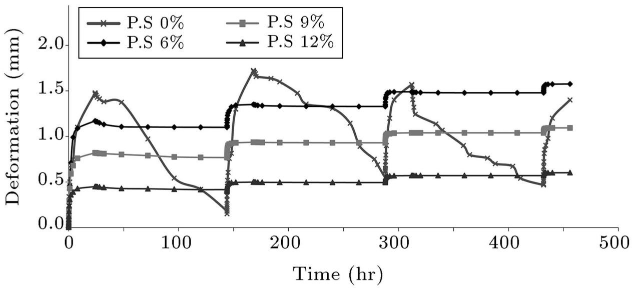

Figure 5. Wetting-drying cycles of the non-stabilized and PS stabilized samples at constant vertical stress of 5 kP; bentonite percent = 25, initial water content = 16.5%.

samples compacted at lower water contents show more volume change during hydraulic loading and the amount of the volume change decreases with an increase in hydraulic loading cycles. It is worth mentioning that the capability of the clay particles to absorb water depends on the initial structure of the soil sample: Specimens compacted at lower water content, possess a flocculated structure and have a considerable swelling potential. Moreover, samples compacted at higher water content, have a dispersed structure and their volume change during the wetting process is insignificant. Also, the more bentonite contents, the more the volume change of samples. Besides, while, drying induced shrinkage of samples with bentonite content of 15% is negligible, specimens with bentonite content of 25% show a significant amount of the shrinkage during the drying processes.

The variation of the volume of the stabilized samples with time is re-plotted in Figure 5. Clearly, PS reduces the amount of the wetting induced swelling and removes the drying induced shrinkage. The more concentrations of the PS, the less soil expansion. Also, in contrast with the lime stabilized soils [22], PS stabilized samples are stiffened by drying-wetting cycles and their volume change decreases with an increase in the drying-wetting cycles. Based on these results, this stabilization method is more suitable for arid areas and effectively eliminates the drying induced shrinkage of the soil media.

3.3. Oedometric response of stabilized soil

Figure 6 indicates the oedometric response of the non-stabilized and PS stabilized soils before and after hydraulic loading. Visibly, the mechanical behavior of stabilized and non-stabilized samples is similar. In other words, an identical load step results in a similar change in void ratio in all specimens. Therefore, PS does not change the oedometric behavior of expansive sand-bentonite mixture and in contrast with the behavior of lime stabilized soils [22], PS stabilized samples are stiffened by drying-wetting cycles and their swelling pressure decreases with a drying-wetting cycle.

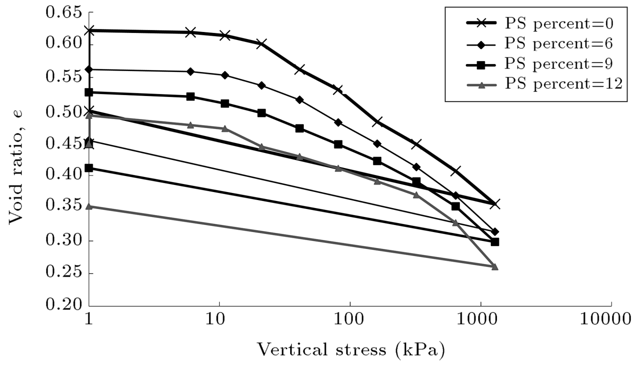

Figure 6. Consolidation curves of non-stabilized and PS stabilized sand-bentonite mixture after hydraulic loading, bentonite percent = 25, initial water content = 16.5%.

4. Conclusion

Oedometric results showed that the initial water content and bentonite content change the oedometric behavior of the soil samples. Potassium Silicate was introduced as a stabilizer of expansive clays. Consolidation and wetting-drying tests were performed on the stabilized and non-stabilized samples. Although PS does not change the oedometric parameters of the plastic clay (compressibility index, C_c, and re-compressibility coefficient, C_s), wetting induced swelling of the stabilized soil is less than that of non-stabilized samples and drying induced shrinkage of stabilized specimens is negligible.

To stabilize thick layers of expansive clays in engineering practice, shallow thin layers of the soil can be mixed with PS. Vertical flow of the rain washes the stabilizing material into the deeper parts and the deeper portion is improved by PS solution. More field tests are needed to verify the applicability of this method to treat thick layers of swelling clays.

References

1. Ajdari, M., Habibagahi, G. and Masrouri, F. "The role of suction and degree of saturation on the hydro-mechanical response of a dual porosity silt-bentonite mixture", *Applied Clay Science*, **83**, pp. 83-90 (2013).
2. Ajdari, M., Habibagahi, G., Nowamooz, H., Masrouri, F. and Ghahramani, A. "Shear strength behavior and soil water retention curve of a dual porosity silt-bentonite mixture", *Scientia Iranica*, **17**, pp. 430-440 (2010).
3. Alonso, E.E., Romero, E., Hoffmann, C. and Garcia-Escudero, E. "Expansive bentonite-sand mixtures in cyclic controlled-suction drying and wetting", *Engineering Geology*, **81**, pp. 213-226 (2005).
4. Liangtong, Z. "Field and laboratory study of an unsaturated expansive soil associated with rain-induced slope instability", PhD Thesis, Hong Kong University (2003).

5. Shuai, F. "Simulation of the swelling pressure measurements of expansive soils", PhD Thesis, Saskatchewan, Canada (1996).
6. Rao, S.M., Reddy, B.V.V. and Muttharam, M. "The impact of cyclic wetting and drying on the swelling behaviour of stabilized expansive soils", *Engineering Geology*, **60**, pp. 223-33 (2001).
7. Attom, M.F., Abu-Zreig, M.M. and Obaidat, M.T. "Changes in clay swelling and shear strength properties with different sample preparation techniques", *Geotechnical Testing Journal, GTJODJ*, **24**(2), pp. 157-163 (2001).
8. Day, R.W. "Swell shrink behavior of compacted clay", *Journal of Geotechnical Engineering, ASCE*, **120**(3), pp. 618-623 (1994).
9. Tripathy, S., Rao, K.S.S. and Fredlund, D.G. "Water content-void ratio swell-shrinkage paths of compacted expansive soils", *Can. Geotech. J.*, **39**, pp. 938-959 (2002).
10. Lloret, A., Villar M.V., Sanchez, M., Gens, A., Pintado, X. and Alonso, E.E. "Mechanical behaviour of heavily compacted bentonite under high suction changes", *Geotechnique*, **53**(1), pp. 27-40 (2003).
11. Sridharana, A. and Gurtug, Y. "Swelling behavior of compacted fine-grained soils", *Engineering Geology*, **72**, pp. 9-18 (2004).
12. Avsar, E., Ulusay, R. and Sonmez, H. "Assessments of swelling anisotropy of Ankara clay", *Engineering Geology*, **105**, pp. 24-31 (2009).
13. Ferber, V., Auriol, J.C., Cui, Y.J. and Magnan, J.P. "On the swelling potential of compacted high plasticity clays", *Engineering Geology*, **104**, pp. 200-210 (2009).
14. Chen, F.H., *Foundations on Expansive Soils*, Elsevier Scientific Publication Company (1975).
15. Nelson, J.D. and Miller, J.D., *Expansive Soils: Problems and Practice in Foundation and Pavement Engineering*, Wiley, New York (1992).
16. Fityus, S.G., Smith, D.W. and Allman, M.A. "Expansive soil test site near Newcastle", *J. of Geotech. and Geoenviron. Eng., ASCE*, **130**(7), pp. 686-695 (2004).
17. Cokca, E. "Use of class C fly ashes for the stabilization of an expansive soil", *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, **127**(7), pp. 568-573 (2001).
18. Kumar, B.R.P. and Sharma, R.S. "Effect of fly ash on engineering properties of expansive soils", *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, **130**(7), pp. 764-76 (2004).
19. Cai, Y., Shi, B., Ng, C. and Tang, C. "Effect of polypropylene fiber and lime admixture on engineering properties of clayey soil", *Engineering Geology*, **87**, pp. 230-240 (2006).
20. Yilmaz, I. and Civelekoglu, B. "Gypsum: An additive for stabilization of swelling clay soils", *Applied Clay Science*, pp. 1-7 (2009).
21. Al-Rawas, A.A., Hago, A.W. and Al-Sarmi, H. "Effect of lime, cement and sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman", *Building and Environment*, **40**, pp. 681-687 (2005).
22. Guney, Y., Sari, D., Cetin, M. and Tuncan, T. "Impact of cyclic wetting-drying on swelling behavior of lime-stabilized soil", *Building and Environment*, **42**, pp. 681-688 (2007).

Biographies

Mohsen Ajdari is an Assistant Professor in Fasa University. He received his Ph.D. from Shiraz University in 2010. He has published more than 25 papers in the field of unsaturated soil mechanics, engineering of embankment dams and slope stability in respected journals and international conference proceedings.

Hossein Bahm Yari received his MSc in Geomechanics in 2010. He has published a few papers in international conferences. His research interests include soil improvement and unsaturated soil mechanics.