Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 4, No. 4, April, 2018

Evaluation of Softening of Clayey Soil Stabilized with Sewage Sludge Ash and Lime

Kamyar Norouzian [a], Nader Abbasi [b*], Jahangir Abedi Koupai [c]

[a] *Department of Water Engineering, Isfahan University of Technology, Isfahan, Iran.*

[b] *Associate professor, Agricultural Engineering Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Alborz, Iran.*

[c] *Professor, Department of Water Engineering, College of Agriculture, Isfahan University of Technology, Isfahan, Iran.*

Received 14 January 2018; Accepted 30 March 2018

Abstract

Production of sewage sludge have raised increasing concerns due to negative environmental effect. Sewage Sludge Ash (SSA) is used as a new type of additive for clay. Laboratory tests were performed on clay samples to study the mechanism of sewage sludge ash (SSA) and Hydrated Lime (HL) soil stabilization. Different SSA contents (0, 5, 10, 15%) and hydrated lime (0, 1, 3 and 5%) were added to the soil samples. 288 samples were prepared, and unconfined compressive strength tests were carried out. The samples were tested under optimum water content and also saturated conditions with three replications. The results of the coefficient of softening indicated that by adding SSA and hydrated lime to clay soil simultaneously, the stabilized clay soils can be applied in the moist and saturated condition. According to the results, the samples of SSA contents 0% with hydrated lime 5% and SSA contents 10% with hydrated lime 5% can be placed in the vicinity of moisture.

Keywords: Soil Stabilization; Sewage Sludge Ash; Hydrated Lime; Unconfined Compressive Strength; Coefficient of Softening; Water Absorption.

1. Introduction

Soft clay soil is one of the problematic soils covering considerable parts of the earth including many low-land and coastal regions where many urban and industrial hubs are located and are frequently encountered in civil engineering projects. Some of the major behavioral and strength problems associated with these types of soils are low strength, excessive settlements, expansive, collapsible, liquefiable, soluble, dispersive, silty fine sands, highly organic weak soils, high plasticity, swelling, dispersivity, erodibility, high compressibility and sensitivity to environmental conditions. Generally, problematic soils such as soft clay soils were improved in order to improve their behavioral and strength properties [1, 2]. The methods of stabilization can be divided into ground improvement techniques, chemical, mechanical and biological techniques or a combination of them [3-5]. Chemical stabilization includes the addition of different natural and synthetic additives such as lime, cement, fly ash and different modern technologies such as nanoparticles to the soil [3, 5, 6]. One of the major techniques used to overcome the problems created by soft soils is the mixing with a cementitious binder. Traditionally, these binders are cement and/or lime, which 'glue' the soil particles together mainly through chemical and not physical reactions. Both binders share the fact that their reactions with water depend largely on their specific surface. Moreover, although the type of reaction is different for lime and cement, the final product is very much alike, based on calcium and silica compounds [7]. On the other hand, production of sewage sludge have raised increasing concerns due to negative environmental effect. So the management of sludge produced in

* Corresponding author: nader_iaeri@yahoo.com

http://dx.doi.org/10.28991/cej-0309129

wastewater treatment plants is necessary and inevitable. Sewage sludge ash (SSA) is also used as a new type of additive for clay.

Lin et al. (2007) investigated the impact of sewage sludge ash (SSA) and hydrated lime at a constant ratio of 1:4 to stabilize soft soils. The result showed that the unconfined compressive strength of specimens with the SSA/lime addition was improved to about 3-7 times higher than that of the untreated soil [8]. Chen and Lin (2009) evaluated the effects of sewage sludge ash and cement at a constant ratio of 1:4. The result showed that the unconfined compressive strength of specimens with SSA/cement was about 3-7 times higher than that of the untreated soil [9]. Sakr et al. (2009) showed that soft clay soil of high organic content of 14% can be stabilized satisfactorily with the addition of 7% lime [10]. Yilmaz and Civelekoglu (2009) showed that adding gypsum improves the unconfined compressive strength of bentonite [11]. Pradhan and Sahoo (2010) showed that the maximum strength of soil is obtained when it is treated with 8% hydrated lime with 14 days curing time [12]. Seco et al. (2011) studied the effects of various materials such as lime, Magnesium oxide (PC-7), Rice Husk Fly Ash (RHFA), Coal Fly Ash (CFA), polymer (CS) and Aluminatum filler (AF) on the mechanical behavior of swelling soils. They showed that adding 5% rice husk fly ash with 4% lime is most effective in increasing the compressive strength of the soil [13]. Maaitah (2012) showed that the strength of soil mixed with 4% hydrated lime and 2% sodium silicate was increased significantly [14]. Al Adili et al. (2012) showed that papyrus fiber can be considered an appropriate material for reinforcement of soils [15].

Cristelo et al. (2013) studied the effects of sodium-based alkaline activators and class F fly ash on soil stabilisation. The results showed a clear increase in strength with decreasing activator/ash ratio (up to a maximum of 43.4 MPa), which is a positive result since the activator is the most expensive component in the mixture. Finally, UCS results of the cement and AA samples, at 28 days curing, were very similar [2]. Tempest and Pando (2013) showed that the addition of SSA as a soil stabilizing material, can improve the bearing capacity and stiffness of the soil in comparison with the untreated soil [16]. Ahmed (2015) investigated the microstructure and mineralogical compositions of soft clay soil stabilized with bassanite that is produced from gypsum waste materials. Test results showed that the addition of recycled bassanite improves the strength of the tested soil [17]. Gao et al. (2015) tested the effects of nanometer magnesium oxide (NM) on a clay soil. The results show that the unconfined compressive strength of the soil samples increases with NM content and decreases with higher soil water content. They also showed that the addition of 6% NM to clay soil can significantly improve the strength and stability of the soil [18]. Modarres and Mohammadi Nosoudy (2015) resulted that the combination of coal waste materials with lime in considerably higher compressive strength and CBR especially in saturated condition [19]. Mousavi (2016) investigates the possibility of the use of cement and/or lime for improvement ground of shallow clay to support highway embankment. A novel approach to stabilize the clay is to use peat ash as a supplementary material in the compacted and stabilized soil. Test results showed that partial replacement of cement with 12% peat ash in the optimal mix design resulted in maximum unconfined compressive strength [20].

Estabragh et al. (2016) studied the effects of a contaminated clay soil and its treatment through a program of experimental tests. The contaminated soil samples were prepared with different percentages (3, 6, and 9%) of a glycerol solution with 40% concentration. Both the strength and stiffness of the contaminated soil are reduced by increasing the degree of contamination. The results of treated soil showed that adding cement to contaminated soil increases the strength and the amount of increase in strength is dependent on the percent of cement, curing time and degree of contamination [3]. Mousavi (2017) investigates the mechanical properties of compacted and stabilized clay with various proportions of cement and silica fume. Test results showed that the 28 day UCS of the stabilized soil with 2% partial substitution of cement with silica fume is almost 3.5 fold greater than that of the untreated [21]. Norouzian et al. (2017) showed that by the addition of both SSA and lime to clayey soil, the optimum water content of the treated samples (ω_{opt}) is increased and their maximum dry density ($\gamma_{d\ max}$) decreased considerably. So they concluded that the variation of ω_{opt} and $\gamma_{d\ max}$ are significant for the samples having different amounts of SSA and lime. Also they showed that simultaneously application of hydrated lime and sewage sludge ash could improve the compressive strength of the treated soil more efficiently. They found that the maximum compressive strength occurs with a certain combination of hydrated lime and SSA rather than their higher values. In this research the combination of 5% hydrated lime and 10% sewage sludge ash were determined as the most efficient combination [22]. Hamidi and Marandi (2018) showed that using epoxy resin increases strength parameters about 100 to 1000 times while UCS reaches to more than 50 MPa in some samples based on the clay mineral types in the soils [1].

As mentioned different pozzolans, especially sewage sludge ash has been used for improvement engineering properties of clayey soils. In this study, the interactive effects of hydrated lime and sewage sludge ash on the Softening of soft cohesive subgrade soil were investigated

2. Materials and Methods

2.1. Soil Samples and Additives

The soil used in the study is originated from Glolabar region located in Zanjan province of Iran. The physical and mechanical properties of the soil were determined based on the ASTM standard and are presented in Table 1 [23-26].

Figure 1 shows location of untreated clay soil in the plasticity chart. Also the particle distribution of untreated clay soil was showed in Figure 2.

Table 1. Index Properties of the soil

Properties	LL (%)	PL (%)	SL (%)	EC (dS/m)	G_s	Organic Material (%)	Classification (USCS)
Content	46.7	26.1	20.4	1.2	2.72	0.06	CL

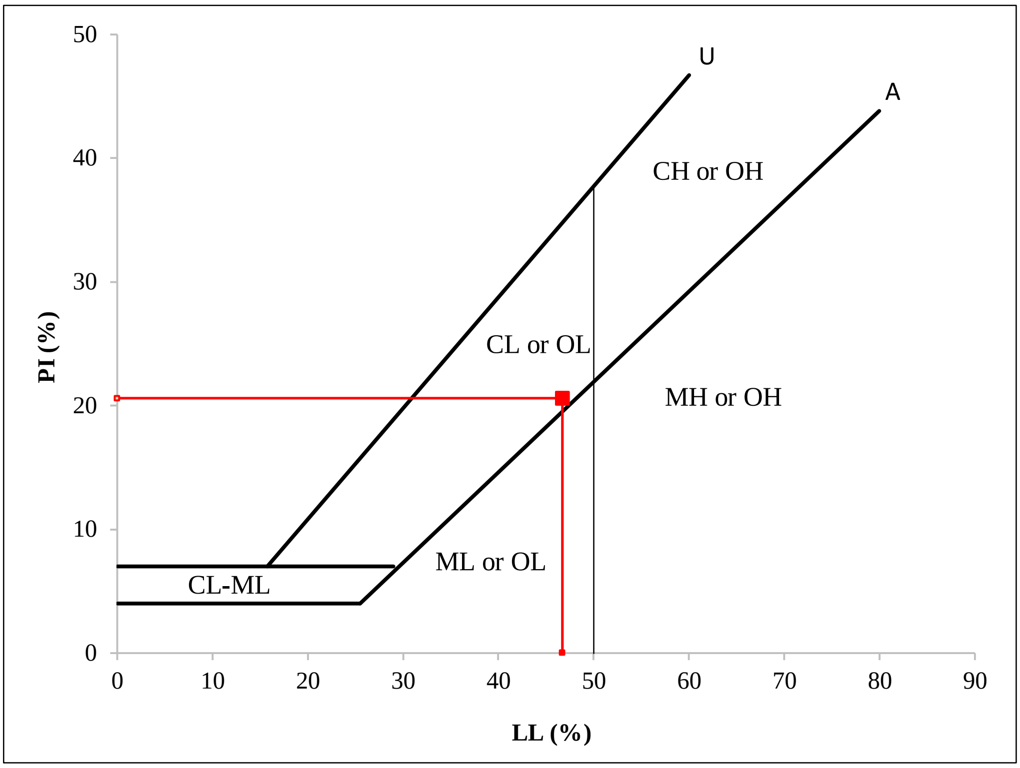

Figure 1. Location of untreated clay soil in the plasticity chart

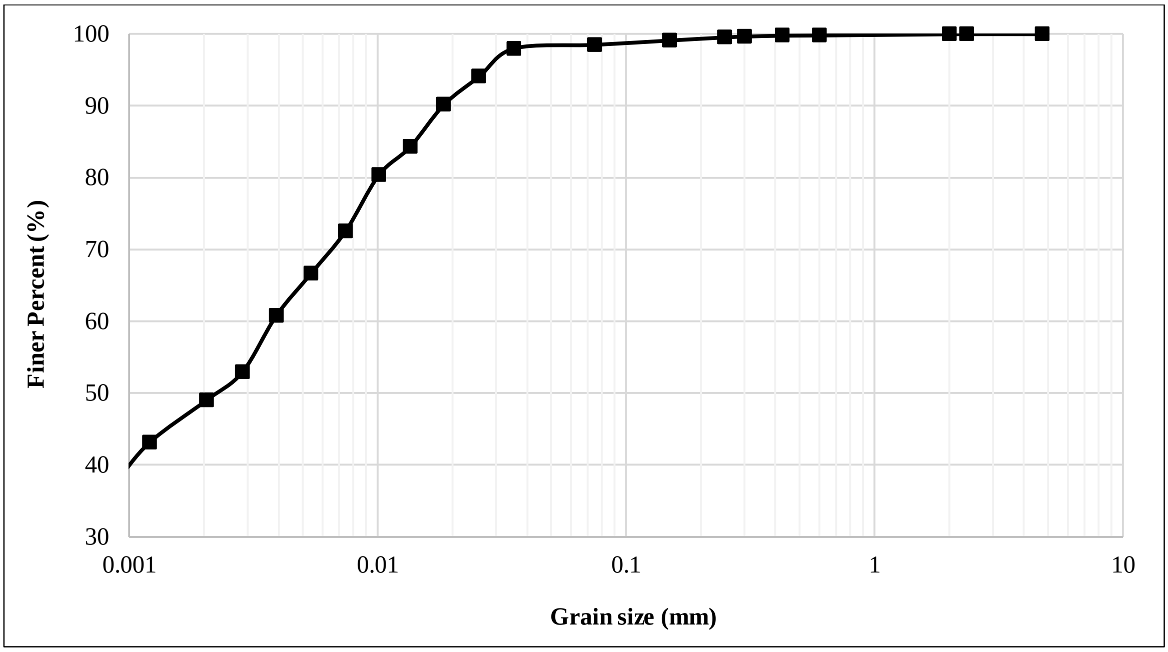

Figure 2. Particle Size Distribution of untreated clay soil

Hydrated lime was passed through No.40 sieve (0.42 mm). Sewage sludge to produce ash was obtained from a municipal wastewater treatment plant at Zanjan city. The method of water treatment in this plant includes sludge stabilization and thickening systems. In this method, the liquid sewage sludge is turned into pulp by heating and then dried in oven and finally the ash sludge is prepared by heating the sludge samples in a furnace at 800 °C for 1 hour and grinding the resulting aggregate. The burning and incineration of sludge shrinks its volume by about 90-95%. Different stages for preparation of SSA are presented in Figure 3. The sewage sludge ash was passed through No.200 sieve (0.075 mm) after grinding.

Figure 3. Different procedures of SSA production, a) Raw liquid sewage sludge; b) Plastic sewage sludge after predrying; c) Drying of sewage sludge in oven, d. Sewage sludge ash (SSA)

The results of X-ray fluorescence spectrometry (XRF) tests on the soil, lime and sewage sludge ash are shown in Table 2.

Table 2. XRF Characteristics of soil, lime and SSA

Compound concentration	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	K_2O	TiO_2	Na_2O	P_2O_5	SO_3	LOI*
Soil (%W/W)	45.70	12.80	11.95	7.98	4.07	2.91	0.82	0.45	0.18	0.08	13.06
Lime (%W/W)	2.55	0.66	61.62	0.43	3.82	0.23	0.04	0.06	0.03	0.81	29.75
SSA (%W/W)	27.19	8.32	19.94	5.55	2.34	2.35	0.73	0.52	11.40	7.42	12.24

*Loss of ignition (1000 C, 2 h)

2.2. Experimental Treatments

In order to study the effects of sewage sludge ash and hydrated lime on soil compressive strength and to determine the appropriate composition of the mixture, different amounts of sewage sludge ash and hydrated lime were mixed as experimental treatments. For this purpose, the clay soil was air-dried and then the desired mixtures were prepared with predefined proportions of SSA and hydrated lime. The ratios of sewage sludge ash and hydrated lime in the mixtures were defined as the ratio of dry weight of the additive to dry weight of the soil. Hence, four different SSA contents of 0, 5, 10, and 15% were considered and assigned the abbreviations S0, S5, S10 and S15 respectively. Also four hydrated lime contents of 0, 1, 3 and 5% were considered with abbreviations L0, L1, L3 and L5. Therefore, 16 mixture types, or in other words 16 experimental treatments, were prepared.

2.3. Preparation of Specimens

Harvard miniature compaction apparatus was used for preparation of experimental specimens. Harvard apparatus has

528 g hammer weight, drop height of 10.8 cm and mold volume of 61.09 cm^3. Figure 4 shows the Harvard apparatus used in this research which made by a local manufacture according standard specification. For this purpose, certain amount of additives were mixed and compacted in Harvard compaction cylindrical mold (length 71.52 mm with a 33.34 mm diameter) applying optimum water content and to reach maximum dry density according to Norouzian et al. (2017) compaction test results [22]. In such a way, for different treatments, first the SSA and hydrated lime were mixed with soil, and then water was added gradually to the mixture up to optimum moisture content and compacted by standard compaction effort. To do this, the prepared mixtures were placed in five layers and each layer was compacted by applying 15 strikes using a specified hammer and then the compacted specimen was extracted using special apparatus from the mold (Figure 5a). Then prepared specimens was placed in plastic and stored in airtight polystyrene containers under constant temperature until curing ages (Figures 5b and 5c). Thus, given the number 16 treatments, 3 curing ages (7, 14, and 28) and 3 replications for each treatment, totally 288 specimens were prepared stored and tested for compressive strength at the end of curing period.

Figure 4. Harvard compaction test apparatus and its accessories

Figure 5. Specimens prepared by Harvard compaction apparatus. a. A cylindrical specimen, b. Labeled specimens, c. Stored specimens in airtight polystyrene containers

2.4. Softening

This characteristic, which is specific to some water-sensitive building materials such as clay, gypsum mortar, lime mortar, rock and similar materials, indicates a decrease in material resistance due to water absorption and saturation. To express this sensitivity, a coefficient called the coefficient of softening, which is expressed by the following equation, is used [27]:

$$k_s = \frac{f_{sat}}{f_d} \tag{1}$$

f_{sat} = Unconfined compressive strength in saturated condition

f_d = Unconfined compressive strength in unsaturated condition

k_s = Coefficient of softening

To carry out compressive strength tests in saturated condition, after curing time, specimens were taken out of plastic cover, weighed and placed in water for 2 days. Then, the unconfined compressive strength tests were performed in strain control mode at a rate of 1.1 mm per minute on the specimens in saturated and unsaturated conditions. Tests were performed according to the standard ASTM D 2166-00 using compression test apparatus shown in Figure 6. The amounts of compressive stress were determined for different samples and then the stress-strain curves were plotted and the compressive strength was determined.

Figure 6. Unconfined compressive strength test apparatus

3. Results and Discussion

3.1. Water Absorption

In order to obtain the water absorption percentage according to ASTMD 4609-00, after curing the samples, their weights were recorded and they were kept in water for two days. The samples were then taken out of water and their surfaces were dried using a soft towel. Then, their weights were recorded again. Any increase in the weight due to water absorption was reported as a percentage of dry sample's weight. Water absorption percentages of all samples were calculated after 7, 14 and 28 days and the results are shown in Table 3. The results are presented as the mean of water absorption percentages of the three samples in each treatment.

Table 3. Water absorption in saturated condition

Treatment	Water absorption (%)		
	7 days	14 days	28 days
S0L0	6.32	6.9	6.71
S0L1	4.37	4.7	4.43

S0L3	2.39	2.43	2.27
S0L5	1.32	1.71	0.8
S5L0	4.45	4.84	3.98
S5L1	3.94	3.65	3.72
S5L3	3.24	2.8	2.8
S5L5	3.44	3.37	3.29
S10L0	4.48	5.39	3.85
S10L1	3.09	3.2	3.23
S10L3	4.79	4.24	3.69
S10L5	4.35	4.03	4.24
S15L0	3.99	4.23	3.75
S15L1	4.12	4.01	4.74
S15L3	4.57	4.1	3.72
S15L5	4.46	3.85	4.11

According to Table 3, by increasing of curing time, the water absorption percentage is slightly reduced in most samples. By increasing of curing time, pozzolanic reactions will probably develop which will result in hardening of the samples. Therefore, the water absorption percentage decreases. One of the reasons for the high water absorption percentage of sample S0L0 compared to other samples is the negative charges on the clay particles and their high water absorption capacity. By increasing the SSA content, the water absorption percentage of sample is reduced compared with the untreated soil but it is increased in comparison with the samples containing lime. In soils with only lime, by an increase in lime percentage, the water absorption percentage of samples decreases. The soil particles agglomerate and become hardened because of cation exchange with lime particles and as a result the water absorption percentage decreases.

3.2. Softening Results

Compressive strength tests were carried out on samples at curing times of 7, 14 and 28 days, in three replications in saturated and unsaturated conditions. Coefficient of softening of all samples were calculated after 7, 14 and 28 days and the results are shown in Table 4 and Figure 7 to 12. The results are presented as the mean of Coefficient of softening of the three samples in each treatment.

Table 4. Coefficient of softening.

Treatment	Coefficient of softening		
	7 days	14 days	28 days
S0L0	0.10	0.07	0.09
S0L1	0.21	0.20	0.21
S0L3	0.57	0.73	0.59
S0L5	0.82	0.82	0.93
S5L0	0.20	0.25	0.28
S5L1	0.31	0.39	0.33
S5L3	0.52	0.65	0.52
S5L5	0.66	0.69	0.75
S10L0	0.28	0.30	0.39
S10L1	0.45	0.57	0.47
S10L3	0.39	0.54	0.53
S10L5	0.75	0.74	0.82
S15L0	0.36	0.45	0.39
S15L1	0.47	0.45	0.40
S15L3	0.37	0.52	0.51
S15L5	0.73	0.76	0.59

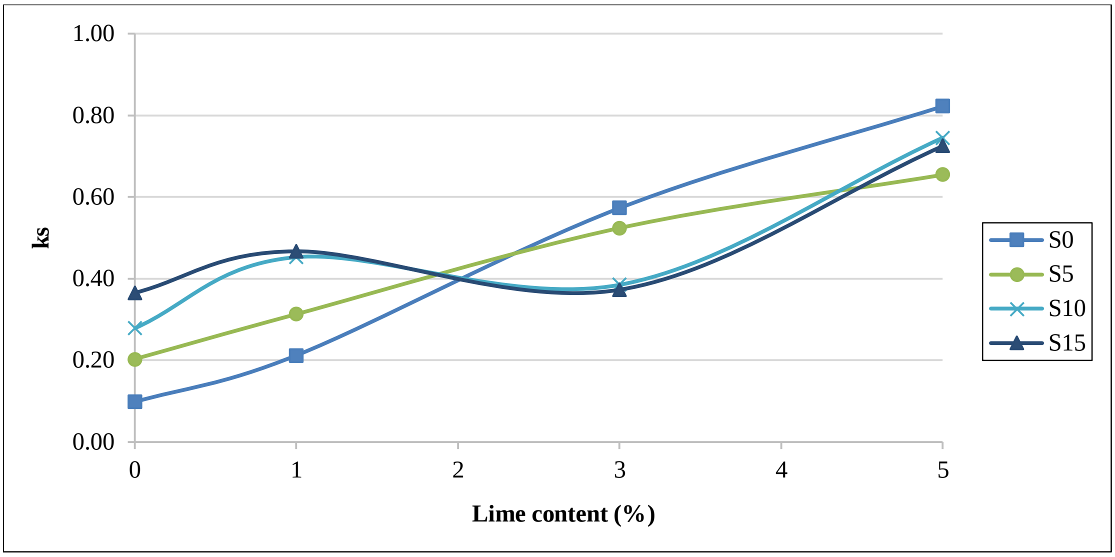

Figure 7. Effect of lime on the coefficient of softening of 7-day samples

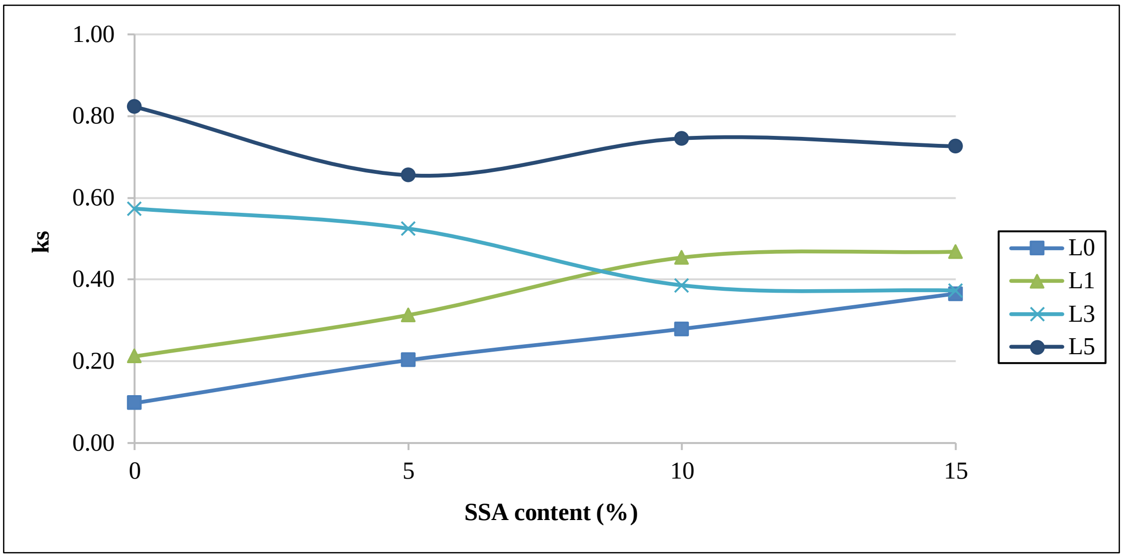

Figure 8. Effect of SSA on coefficient of softening of 7-day samples

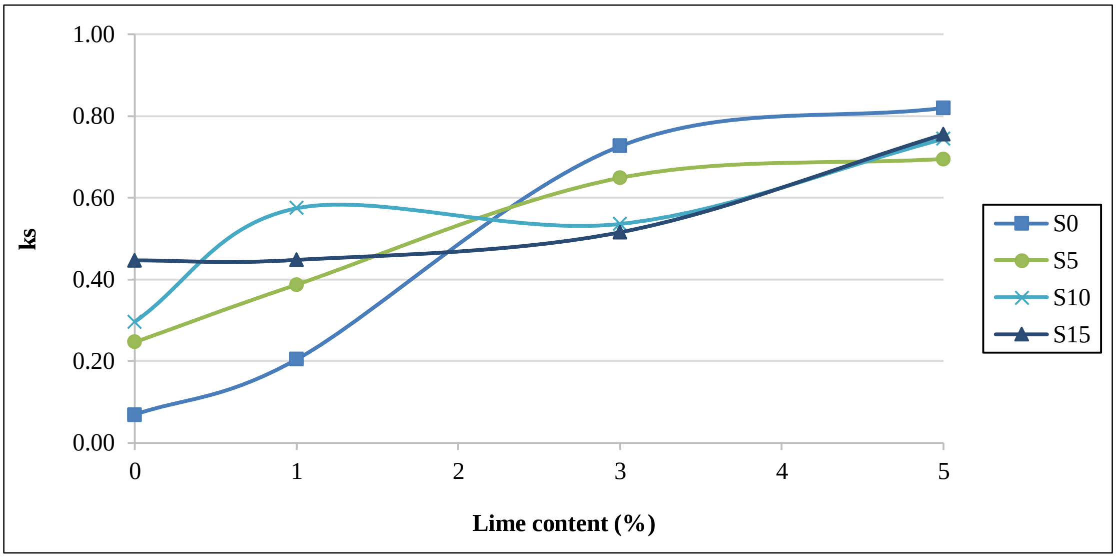

Figure 9. Effect of lime on the coefficient of softening of 14-day samples

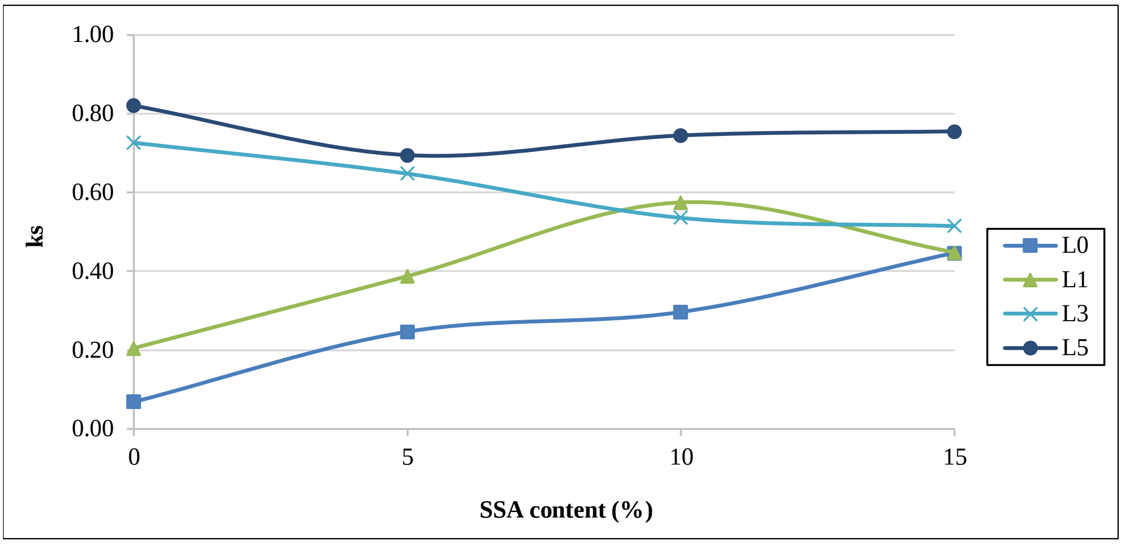

Figure 10. Effect of SSA on coefficient of softening of 14- day samples

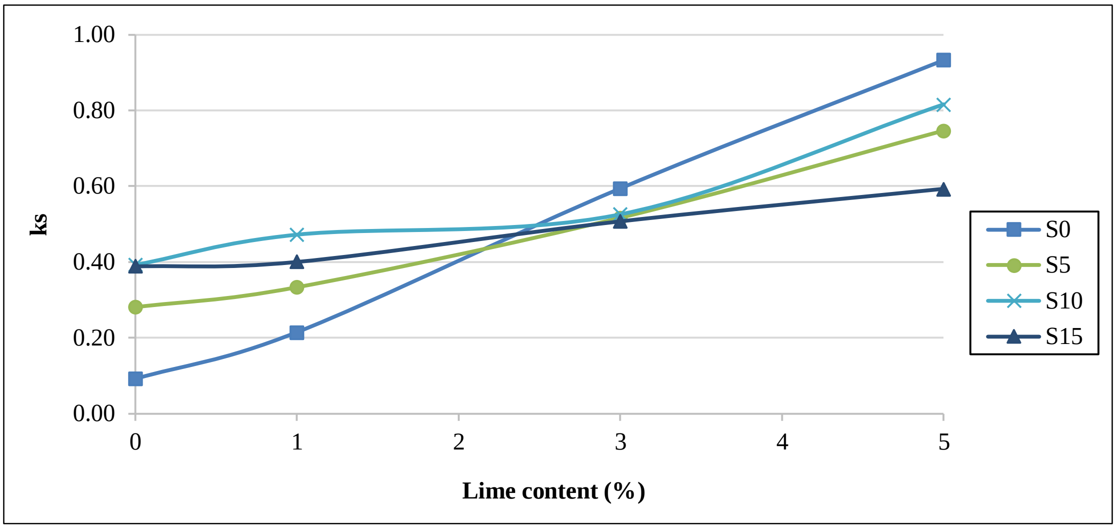

Figure 11. Effect of lime on the coefficient of softening of 28- day samples

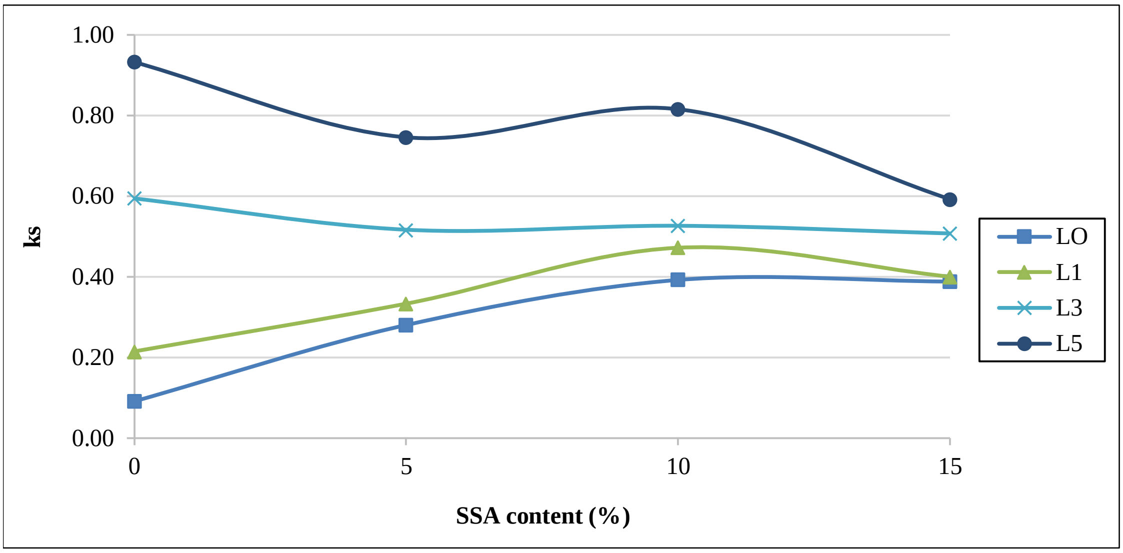

Figure 12. Effect of SSA on coefficient of softening of 28- day samples

The coefficient of softening is proportional to the sensitivity of the material to the water, and the amount of resistance is reduced due to the absorption of water and the saturation between zero to one variable, and the more the material is more sensitive, the coefficient becomes closer to zero. Some building materials such as glass and metals are not sensitive to water, and this factor is about one, while some materials such as clay, gypsum mortar and some of the stones are sensitized, and these factors are less than One. Based on existing criteria, if the material has a coefficient of softening less than 0.8, the material should not be placed in the vicinity of moisture [27]. From Table 4 and Figure 7 to 12, the results of the coefficient of softening showed that, in general, the addition of sewage sludge ash and lime to clay soil, increases the coefficient of softening of the soil. However, the increase is more significant for the soil specimens treated with HL. From Figure 7 to 12, it can be observed that curing time leads to an increase in coefficient of softening for both SSA (except the sample stabilized by 15% SSA) and HL stabilization. The reason for increasing the coefficient of softening can be related to the increasing of pozzolanic reactions. The pozzolanic interactions between a pozzolan's silica or aluminates silica components occurs in the presence of calcium hydroxide in water and exhibits the adhesion and cementation properties. Calcium Hydroxide Products (CSH) and Calcium Hydro Aluminates (CAH), are generally obtained after silica and alumina compounds in sewage sludge ash with calcium hydroxide in the lime. Using SSA and lime simultaneously increased the coefficient of softening. Using lime and sewage sludge ash simultaneously, increased the coefficient of softening of the natural soil 8 times. Based on the results, the most significant influence on the coefficient of softening happened to be from a 28 day test specimen corresponding to the addition of 5% HL, 0% SSA and 5% HL, 10% SSA. According to the results, the samples of S0L5 and S10L5 can be placed in the vicinity of moisture.

The stress–strain curve of S0L0, S0L5 and S10L5 samples for a 28- day curing time in saturation condition and optimum moisture content condition are shown in Figure 13.

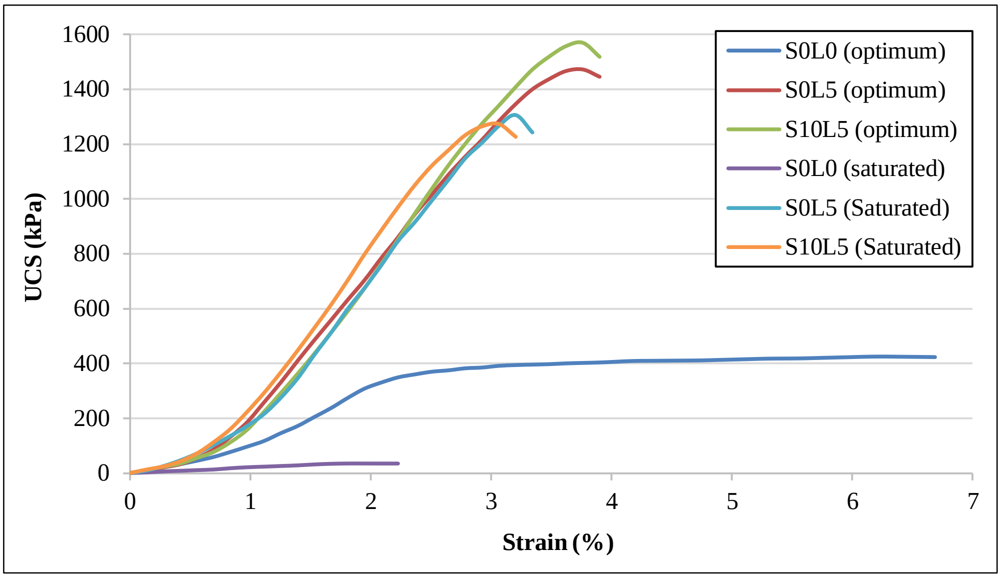

Figure 13. The stress–strain curve of S0L0, S0L5 and S10L5 samples for a 28- day curing time in saturation condition and optimum moisture content condition.

Figure 13 shows the stress-strain curves for the soil, S0L5 and S10L5. As shown in this figure, adding water to the soil resulted in decreasing its strength. The strength of the soil sample in optimum moisture content condition before failure was 416 kPa, but for the S0L5 and S10L5 the strength changed to 1404 and 1565 kPa, respectively. The strength of the soil sample in saturation condition before failure was 38 kPa, but for the S0L5 and S10L5 the strength changed to 1310 and 1277 kPa, respectively. The results show that although adding water caused a reduction in strength. As shown in this Figure 12 the strain for S0L5 and S10L5 is less than the soil. Also saturation condition has a low failure strain compared to optimum moisture content condition. The initial slope of the stress-strain curves was increased by adding SSA and HL to the soil which shows increase in stiffness of the untreated soil. This is due to the brittle behavior that develops in the soil by adding SSA and HL or increasing the curing time that causes the failure occur at small strains.

4. Conclusion

Based on the results of the present study, the following conclusions can be drawn:

- The amount water absorption decreased with curing time, increased with SSA content and decreased with lime content.
- The addition of sewage sludge ash and lime to clay soil, increases the coefficient of softening of the soil.

- Using SSA and lime simultaneously increased the coefficient of softening.
- Curing time leads to an increase in coefficient of softening for both SSA (except the sample stabilized by 15% SSA) and HL stabilization. It can be concluded that pozzolanic reaction is a time-dependent process and with increasing curing time, the greater amounts of lime and sewage sludge ash participate in the pozzolanic reactions.
- The most significant influence on the coefficient of softening happened to be from a 28 day test specimen corresponding to the addition of 5% HL, 0% SSA and 5% HL, 10% SSA.
- The samples of S0L5 and S10L5 can be placed in the vicinity of moisture.
- The results show that although adding water caused a reduction in strength.
- Saturation condition has a low failure strain compared to optimum moisture content condition.
- The initial slope of the stress-strain curves was increased by adding SSA and HL to the soil which shows increase in stiffness of the untreated soil.

5. Acknowledgements

This research has been carried out in soil mechanics and construction materials laboratories of Iranian Agricultural Engineering Research Institute, Tak Azmaye Zanjan Consulting Company, and Sanaye Mese Novin Company. Hereby, the authors express their thanks to the staff and management of the mentioned companies and institute.

6. References

[1] Hamidi, S., and Marandi, S. M. “Clay concrete and effect of clay minerals types on stabilized soft clay soils by epoxy resin.” Applied Clay Science (2018): 92- 101. DOI: 10.1016/j.clay.2017.10.010.

[2] Abbasi, N., and Nazifi, M. H. “Assessment and Modification of Sherard Chemical Method for Evaluation of Dispersion Potential of Soils.” Journal Geotechnical and Geological Engineering (2013): 337-349. DOI: 10.1007/s10706-012-9573-7.

[3] Estabragh, N., Khatibi, M., and Javadi, A. A. “Effect of Cement on Treatment of a Clay Soil Contaminated with Glycerol.” Journal of Materials in Civil Engineering (2016): 241- 247. DOI: 10.1061/(ASCE)MT.1943-5533.0001443.

[4] Rahimi H., Abbasi N., and Shantia, H., “Application of geomembrane to control piping of sandy soil under concrete canal lining (case study: Moghan irrigation project, Iran),” Journal of Irrigation and Drainage (2011): 330-337. DOI: 10.1002/ird.574

[5] Abbasi N., Bahramloo R., Movahedan N., “Strategic planning for remediation and optimization of irrigation and drainage networks: a case study for Iran.” Agric. Agric. Sci. Procedia (2015): 211–221. DOI: 10.1016/j.aaspro.2015.03.025.

[6] Abbasi, N., Farjad, A. and Sepehri, S., “The use of nanoclay particles for stabilization of dispersive clayey soils.” Geotechnical and Geological Engineering (2017). DOI: 10.1007/s10706-017-0330-9.

[7] Cristelo, A., Glendinning, S., Fernandes, L., and Teixeira Pinto, A. “Effects of alkaline-activated fly ash and Portland cement on soft soil stabilisation.” Acta Geotechnica (2013): 395- 405. DOI: 10.1007/s11440-012-0200-9.

[8] Lin, D.F., Lin, K. L., Hung, M. J., and Luo, H. L. “Sludge Ash/Hydrated Lime on The Geotechnical Properties of Soft Soil.” Journal of Hazardous Materials (2007): 58- 64. DOI: 10.1016/j.jhazmat.2008.05.087.

[9] Chen, L., and Lin, D. F. “Stabilization Treatment of Soft Subgrade Soil by Sewage Sludge Ash and Cement.” Journal of Hazardous Materials (2009): 321- 327. DOI: 10.1016/j.jhazmat.2008.05.060.

[10] Sakr, M. A., Shahin, M. A., and Metwally, Y. M. “Utilization of Lime for Stabilizing Soft Clay Soil of High Organic Content.” Geotechnical and Geological Engineering (2009): 105- 113. DOI:10.1007/s10706-008-9215-2.

[11] Yilmaz, I., and Civelekoglu, B “Gypsum: An Additive for Stabilization of Swelling Clay Soils.” Applied Clay Science (2009): 166-172. DOI: 10.1016/j.clay.2009.01.020.

[12] Pradhan, P. K., and Sahoo, J. D. P. “Effect of Lime Stabilized Soil Cushion on Strength Behaviour of Expansive Soil.” Geotechnical and Geological Engineering (2010): 889- 897. DOI:10.1007/s10706-010-9332-6.

[13] Seco, A., Ramírez, F., Miqueleiz, L., and García, B. “Stabilization of Expansive Soils for Use in Construction.” Applied Clay Science (2011): 348-352. DOI: 10.1016/j.clay.2010.12.027.

[14] Maaitah, O. N. “Soil Stabilization by Chemical Agent.” Geotechnical and Geological Engineering (2012): 1345- 1356. DOI:10.1007/s10706-012-9549-7.

[15] Al Adili, A., Azzam, R., Spagnoli, G., and Schrader, J. “Strength of Reinforced with Fiber Materials (Papyrus).” Soil Mechanics and Foundation Engineering (2012): 241- 247. DOI: 10.1007/s11204-012-9154-z.

[16] Tempest, Q. B., and Pando, M. A. “Characterization and Demonstration of Reuse Applications of Sewage Sludge Ash.” International Journal of Geomate (2013): 552- 559. DOI: 10.21660/2013.8.1620.

[17] Ahmed, A. “Compressive strength and microstructure of soft clay soil stabilized with recycled basanite.” Applied Clay Science

(2015): 27- 35. DOI: 10.1016/j.clay.2014.11.031.

[18] Gao, L., Ren, Zh., and Yu, X. "Experimental Study of Nanometer Magnesium Oxide-Modified Clay." Soil Mechanics and Foundation Engineering (2015): 218- 224. DOI: 10.1007/s11204-015-9331-y.

[19] Modarres, A., and Mohammadi Nosoudy, Y. "Clay stabilization using coal waste and lime- Technical and environmental impacts." Applied Clay Science (2015): 281- 288. DOI: 10.1016/j.clay.2015.03.026.

[20] Mousavi, S. E. "Stabilization of compacted clay with cement and/ or lime containing peat ash." Road Materials and Pavement Design (2016): 1304- 1321. DOI: 10.1080/14680629.2016.1212729.

[21] Mousavi, S. E."Utilization of Silica Fume to Maximize the Filler and Pozzolanic Effects of Stabilized Soil with Cement." Road Materials and Pavement Design (2016): Geotechnical and Geological Engineering (2017): 77- 87. DOI: 10.1007/s10706-017-0305-x.

[22] Norouzian, K., Abbasi, N., and Abedi Koupai, J. "Use of Sewage Sludge Ash and Hydrated Lime to Improve the Engineering Properties of Clayey Soils," Geotechnical and Geological Engineering (2017). DOI:10.1007/s10706-017-0411-9.

[23] ASTM D 422-63. "Standard Test Method for Particle Size Analysis of Soils." Annual book of ASTM standards, ASTM international, Philadelphia (2007).

[24] ASTM D 854-10. "Standard Test Method for Specific Gravity of Soils." Annual book of ASTM standards, ASTM international, Philadelphia (2012).

[25] ASTM D 2487-11. "Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)." Annual book of ASTM standards, ASTM international, Philadelphia. (2012).

[26] ASTM D 4318-10. "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils." Annual book of ASTM standards, ASTM international, Philadelphia. (2012).

[27] Rahimi, H. "Building Materials", University of Tehran Press, Tehran, Iran (2017).

[28] ASTM D 2166-00. "Standard Test Method for Unconfined Compressive Strength of Cohesive Soil." Annual book of ASTM standards, ASTM international, Philadelphia. (2012).

[29] ASTM D 4609-00. "Standard Guide for Evaluating Effectiveness of Admixtures for Soil Stabilization." Annual book of ASTM standards, ASTM international, Philadelphia.