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The Effect of Zeolite on Sandy-Silt Soil Mechanical Properties

Shahryar Aftabi, Saeed Fathi, Mohammad H. Aminfar

***Abstract*—It is well known that cemented sand is one of the best approaches for soil stabilization. In some cases, a blend of sand, cement and other pozzolan materials such as zeolite, nano-particles and fiber can be widely (commercially) available and be effectively used in soil stabilization, especially in road construction. In this research, we investigate the effects of CaO which is based on the geotechnical characteristics of zeolite composition with sandy silt soil. Zeolites have low amount of CaO in their structures, that is, varying from 3% to 10%, and by removing the cement paste, we want to investigate the effect of zeolite pozzolan without any activator on soil samples strength. In this research, experiments are concentrated on various weight percentages of zeolite in the soil to examine the effect of the zeolite on drainage shear strength and California Bearing Ratio (CBR) both with and without curing. The study also investigates their liquid limit and plastic limit behavior and makes a comparative result by using Feng's and Wroth-Wood's methods in fall cone (cone penetrometer) device; in the final the SEM images have been presented. The results show that by increasing the percentage of zeolite in without-curing samples, the fine zeolite particles increase some soil's strength, but in the curing-state we can see a relatively higher strength toward without-curing state, since the zeolites have no plastic behavior, the pozzolanic property of zeolites plays a much higher role than cementing properties. Indeed, it is better to combine zeolite particle with activator material such as cement or lime to gain better results.

***Keywords*—**CBR, direct shear, fall-cone, sandy-silt, SEM, zeolite.

I. Introduction

ZEOLITES are the result of hydration from alkaline aluminum silicates and alkaline earth metals, which have a crystalline structure consisting of a three-dimensional silica SiO^{+4} network and AlO^{+4} aluminate. These metal elements are surrounded by four oxygen atoms and interspersed with oxygen in the corners, creating a sieve-like hexagonal structure with holes and porous space. The same porous structure keeps larger particles in place, and smaller particles can easily pass; for this reason, zeolite is also called "sieve molecular". The surface of this particle is always negative due to the presence of Al^{+4} [1]. Zeolites will balance with other positive particles such as Na^{+}, K^{+}, etc., which make a high capacity exchange in zeolites, and due to this reason, the specific surface of zeolites is much higher that makes zeolites to be highly reactive material [2]. It can also remove toxic and heavier metal cations such as Ni^{+3} and Cd^{+2} in refining and sewage purification [3], and they have the same behavior as chitosan biopolymer in absorbing heavy metals and also reduce hydraulic conductivity and improve mechanical properties [4]. Previous studies have shown that the combination of zeolite with concrete tends to increase its cohesiveness and reducing segregation in pump-able concretes in 3D printing concrete devices [5]. Kaya has shown that because of the high exchange of cationic zeolites, bentonite-zeolite can be used instead of bentonite-sand in the landfill layer with less thickness, about half of its thickness and can have a much lower permeability coefficient [6]. Zeolites also have low compression index (Cc), which due to the high surface area have a very low Swelling Index, while its drained shear strength is relatively high [7]. In another study, the effect of zeolites in combination with cement showed that the properties and characteristics of dispersive soils and highly swollen clay soils can be improved [8]. Georgiannou also reported that zeolites are very close to the family of sandy soils, they not only have higher cations exchange capacity but also because of their pozzolanic properties, they will increase resistance toward sandy soils [9]. The chemical analysis XRD carried out shows that zeolites have CaO varying between 3% and 10%. As we know, CaO in the presence of water causes $Ca(OH)_2$ to be produced. If environmental conditions are available for pozzolanic reactions pH > 10.5, it can react with Si and Al in the base soil and form Calcium Silicate Hydrates cement gel (C-S-H) and Calcium Aluminum Hydrate (C-A-H) [10]. Therefore, this phenomenon was investigated by conducting tests such as direct shear, fall cone and also checking the CBR test on different weight percentages of zeolite from (5% to 35% of soil's weight) and SEM images to see the CSH structures between the particles, if available, and its effect on the mechanical properties of sandy silt soil.

II. Materials

The soil used in this study is sandy silt mix soil involve 70% Firoozkooh's sand and 30% silt, this soil yields better results toward the natural soil, and the physical properties of the soil and its grain size distribution have been shown in Table II and Fig. 2, respectively.

The natural zeolite has been provided from Negin Powder Co. of Semnan (Iran) and the type of zeolite is clinopetilolite that has passed through No. 200 sieve. Its chemical and physical characteristics are given in Tables I and III, respectively.

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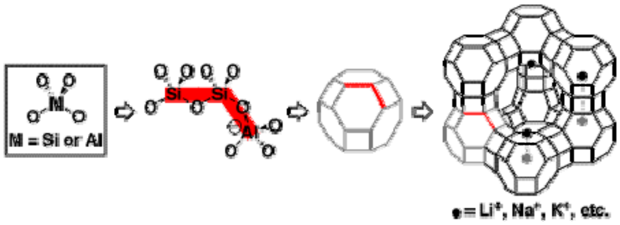

Fig. 1 The Zeolite Structure

TABLE I
ENGINEERING PTOPERTIES OF SOIL USED IN THE Study

Test NO.	Soil Properties	Values
1	Specific Gravity	2.68
2	Grain size analysis	
	2 - 0.075 mm	96%
	0.075-0.005 mm	1.56%
	< 0.005 mm	2.44%
3	Constrained Diameter	
	D10	0.091
	D30	0.31
	D60	0.52
4	Coefficient of Uniformity	5.71
5	Coefficient of Curvature	2.03
6	Classification based on USCS	SP
7	Compaction study	
	Optimum moisture content	6.60%
	Maximum dry density (gr/cm^3)	2.048

III. TEST PROCEDURE AND APPARATUS

The tests carried out by the soil listed with different percentages of zeolite was 5%, 10%, 15%, 20%, 25%, 30%, 35% weight percent of soil and combined with soil, and experiments like Density, Fall Cone, Drainage Direct Shear, and CBR had been carried out in two situations with 14-days curing and without curing at optimum moisture content and compared to elucidate composition mechanism.

A. Compaction Test

The standard proctor density test was performed according to the ASTM D698 [11]. Experiments show that by increasing the percentage of zeolite in the soil composition, it reduces the specific gravity of the soil ranging from 2.048 to 1.72. Because zeolites have a much higher specific surface area, the absorption of moisture in them will be higher, so we can see that the curvature of all samples is similar to each other, and also as the moisture content increases, the dry density is increasing until optimum moisture content and then decreases, so we can see that as the maximum dry density decreases, the optimum moisture content of all the soil samples increases. The results are presented in Table IV and Fig. 3.

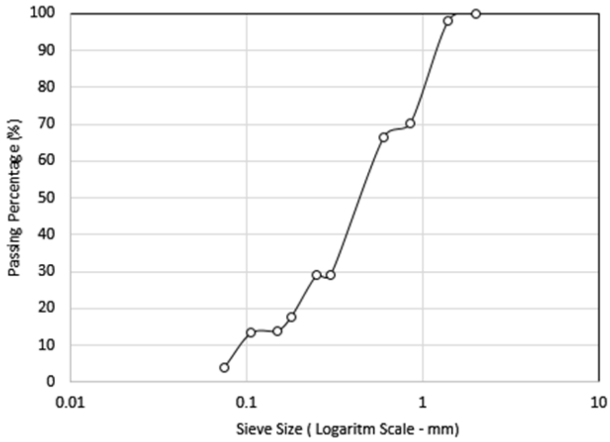

Fig. 2 Grain Size Analysis

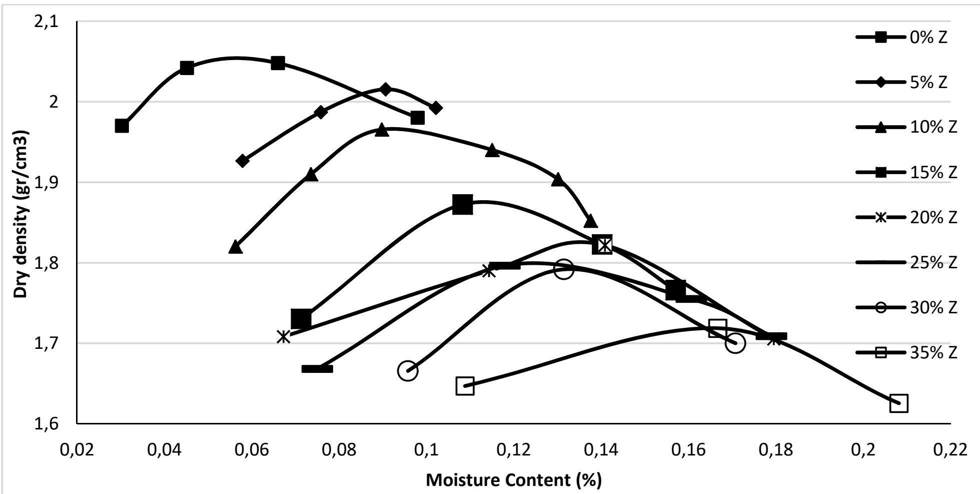

Fig. 3 Standard Proctor Compaction Curve of Soil with Different Percentage of Zeolite

TABLE II
CHEMICAL COMPOSITIONS OF THE ZEOLITE SAMPLE (WEIGHT %)

Samples	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	MgO	K_2O
Z102S	69.28	10.43	0.49	3.56	0.73	0.5	1.27

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TABLE III
PHYSICOCHEMICAL PROPERTIES OF THE ZEOLITE SAMPLE

Sample	Location	Clay fraction (< 2 µm)	Specific gravity (Gs)	Cation capacity (mEq/100 g)
Z102S	Semnan	80%	2.19	58.8

TABLE IV
EFFECT OF ZEOLITES ON OPTIMUM MOISTURE CONTENT AND MAXIMUM DRY DENSITY

No.	Zeolite %	OMC (%)	MDD (kN/m^3)
1	0	6.6	20.48
2	5	9	20.08
3	10	10.2	19.5
4	15	11.5	18.7
5	20	12.3	18.3
6	25	13	18
7	30	13.8	17.93
8	35	15.3	17.25

B. Investigating Liquid Limit & Plastic Limit Behavior by Feng and Wroth-Wood Methods

Since the tested soil (silty sand) has a low plastic range, determination of the consistency (Atterberg limits) of this soil is carried out using the fall cone test according to British Standard 1377 part-2 [12]. The reason for using this method is that the sand samples in the Casagrande cup show slippage when striking the cup. So it is practically impossible to determine the Atterberg limits with this device [13]. Also, the advantages of the fall cone test toward the Casagrande cup can be pointed out are: the convenience, speed of testing, better maintaining, and more reliable results in soils with low plastic [14]. And in the end, the calculations were compared with the Feng's method.

In accordance with the British Standard for determining the liquid limit, by recording the penetration rate in a specimen for 5 seconds by using a cone with 80 grams weight and repeating the test up to four times, and further by reading the moisture corresponding to each penetration, a straight line is obtained which the moisture content corresponds to the 20 mm penetration of the soils is Liquid limit [12]. By using the Wroth-Wood's theory which is based on critical state soil behavior [15], and by regarding the same repetitive process, but with a cone three times heavier (240 grams), in which a line is obtained which is almost parallel and below other one, soil plastic limit can be determined, which for by determining ΔW (vertical distance between the two parallel lines correspond to 20 mm penetration according to Fig. 5) and also using (1), Plastic Limit (PL) can be calculateD:

$$PL = LL - \frac{\Delta W}{\log_{10}\left(\frac{m_2}{m_1}\right)} \quad (1)$$

The second method is the calculation by Feng's method. In this method, after determining the liquid limit of the soil samples in the same manner as seen with the first method, just by determining the two parameters (m) line slope and (C) Y-axis intercept from Fig. 6 were obtained by (2), the soil's plastic limit and plasticity index can be calculated [16], [13].

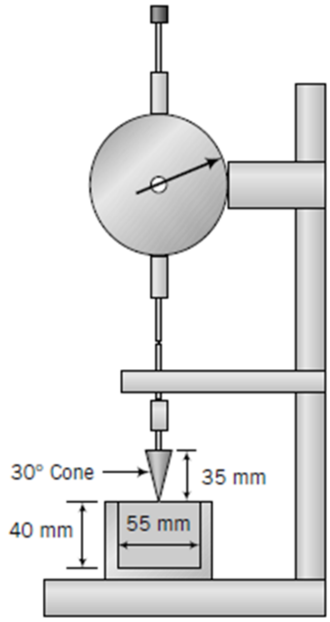

Fig. 4 Fall Cone Device

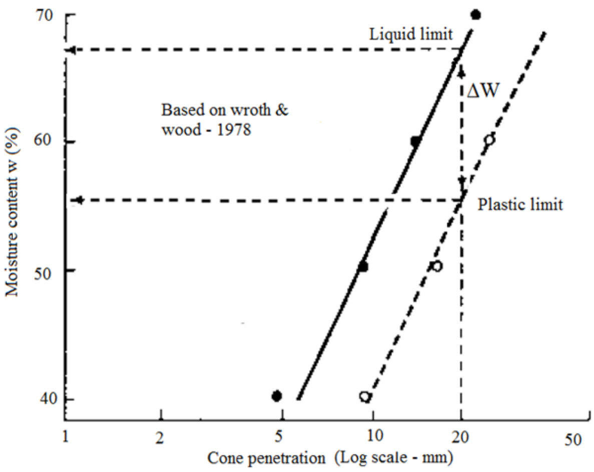

Fig. 5 Wroth and Wood 1978 - Schematic theory

The high numerical value of (m), which can vary up to 1, indicates the high rate of change in the sample's moisture decreasing compared to the depth of penetration. In other words, no matter how fine the grain is (like bentonite); this number is closer to 1 and vice versa. As can be seen, in sandy silt soils this parameter varies between 0.14 and 0.25 depending on fine grain zeolite in the soil.

The high (C) parameter indicates high soil plastic limit for which 47% for the Panama clay was reported [16]. The results obtained in this study, due to the lower percentage of fine-grained zeolites, are varying between 9.2% and 18.04% and represented in Tables V and VI. Also, the correlation between plastic limit and liquid limit by using two methods has been calculated and regressions were calculated as 0.987 and 0.951, respectively, and presented in Fig. 8.

$$\mathrm{PL} = C(2)^{m} \quad (2)$$

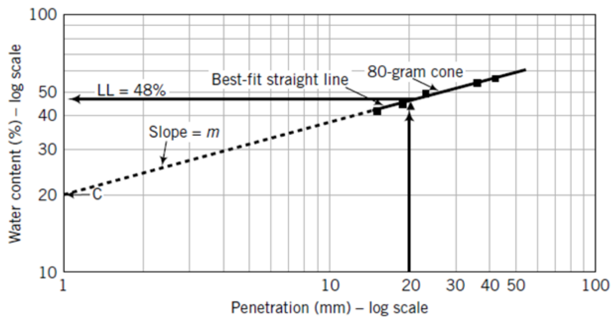

Fig. 6 Feng Method

The results shown in Fig. 8 and the comparison of the two methods mentioned above show a similar trend that by an increasing the amount of zeolites in the soil, the liquid limit and plastic limit of soil samples relativity for Feng's method change from 15.5 to 22.48 and plastic limit change from 10.99 to 21.03 which shows no plastic behavior.

TABLE V
RESULTS OF LIQUID LIMITS AND PLASTIC LIMITS OF SOIL SAMPLES BY WROTH-WOOD METHOD

Zeolite	Liquid Limit Measured%	Plasticity Index Computed%	Plastic Limit Computed%
0	14.35	3.897	10.453
5	15.35	3.85	11.5
10	16.6	3.848	12.752
15	18.4	3.328	15.072
20	19.03	3.08	15.95
25	19.5	2.92	16.58
30	21.5	3.84	17.66
35	22.5	4.16	18.34

Since the plastic index (PI) in the samples is almost constant, it shows no improvement in soil properties. This finding is consistent with the results of previous studies conducted by Metrenes and Perraki on pozzolans [17], [18].

TABLE VI
RESULTS OF LIQUID LIMITS AND PLASTIC LIMITS OF SOIL SAMPLES BY FENG

No	Zeolite %	LL (Measured)	C	m	PL = C(2)^{m} (Calculated)	PI (Calculated)
1	0	15.5	9.2019	0.2566	10.993	4.507
2	5	16	11.239	0.2045	12.951	3.049
3	10	16.7	13.419	0.1581	14.973	1.727
4	15	18	15.189	0.1397	16.733	1.267
5	20	20.35	15.41	0.2524	18.356	1.994
6	25	20.5	15.976	0.2213	18.625	1.875
7	30	21.5	17.007	0.225	19.877	1.623
8	35	22.48	18.041	0.2217	21.038	1.442

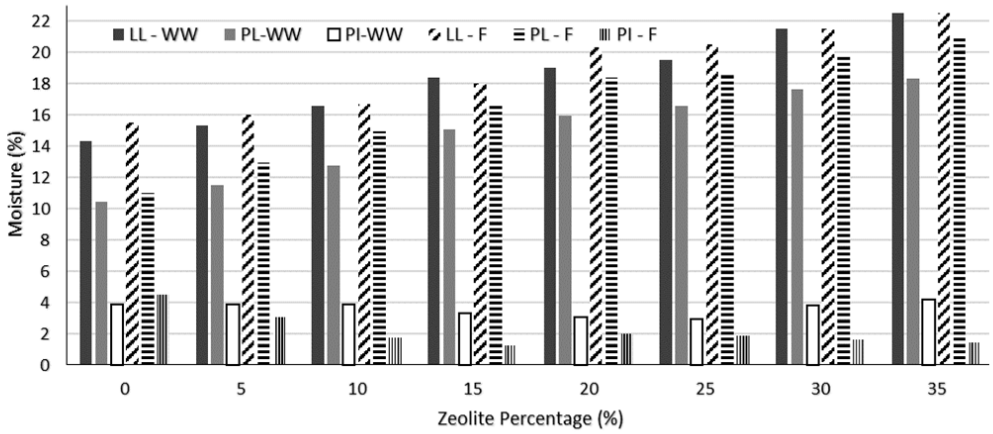

Fig. 7 Comparison Feng's Results with Wroth-Wood Results

B. Shear Strength Parameter

The effect of zeolite on sandy silt was investigated by using the direct shear test in optimum moisture condition and under three normal loads (49 KPa, 98 KPa, 196 KPa) in two situations without curing and 14-days curing in humidity room machine, in 95% humidity and 25 °C, usually after 3 days the pozzolanic reaction occurs [17]. To perform the tests in a drainage state, according to the ASTM D3080 standard, to

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determine the speed shear rate in which no water pore pressure being produced in the samples, it is necessary to act according to the recommendations of this standard. It is not easy to set these values, because it depends on the history of stress and the effective stress path, that is a time-consuming process for each sample, according to the standard shear speed rate, 0.5 mm/min will be sufficient for samples [19]:

$$t_f = 50 \times t_{50}$$
$$d_r = \frac{d_f}{t_f}, \left(\frac{mm}{\min}\right) \tag{3}$$

t_f = total estimated elapsed time to failure; t_{50} = time required for the specimen to achieve 50% consolidation under the specified normal stress.

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According to the results, it can be seen that zeolites do not have cementation properties, owing to lack of insufficient alkaline material such as CaO and according to ASTM C618 [20]. It is unsuccessful in supplying the basic environment pH > 10.5 to perform the pozzolanic reaction. However, by increasing the percentage of zeolite in the soil, the higher strength stresses with 14-days curing were obtained toward without-curing state, it is due to interparticle filling properties of zeolite and by increasing the amount of zeolites to 80%, the behavior of zeolites fine-grained particles overwhelms and governs on soil behavior. Maybe over longer curing, higher strength can be achieved but it does not mean that a successful stabilization has occurred. Similarly, researchers such as Mertens [17], Uzal [21], Massazza [22], Ahmadi [23], Ling [24] also pointed out that due to its lower amount of CaO in pozzolans, a successful stabilization would not occur without an activator. On the other hand, due to active materials such as SiO_2 and higher surface area in zeolites, the role of pozzolanic reaction with $Ca(OH)_2$ that was produced by combination with cement or lime which have a higher calcium amount will be helpful for stabilizing the soils [25].

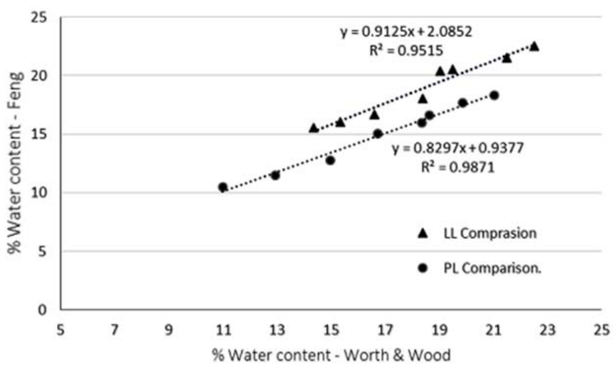
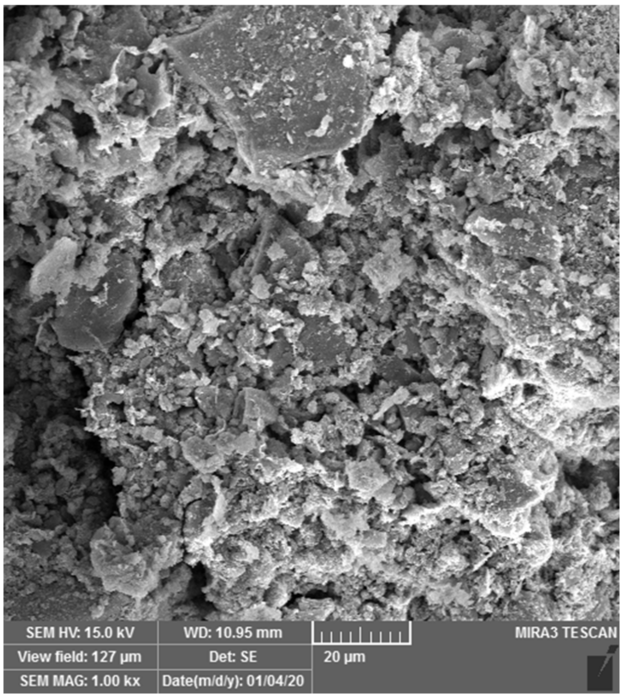
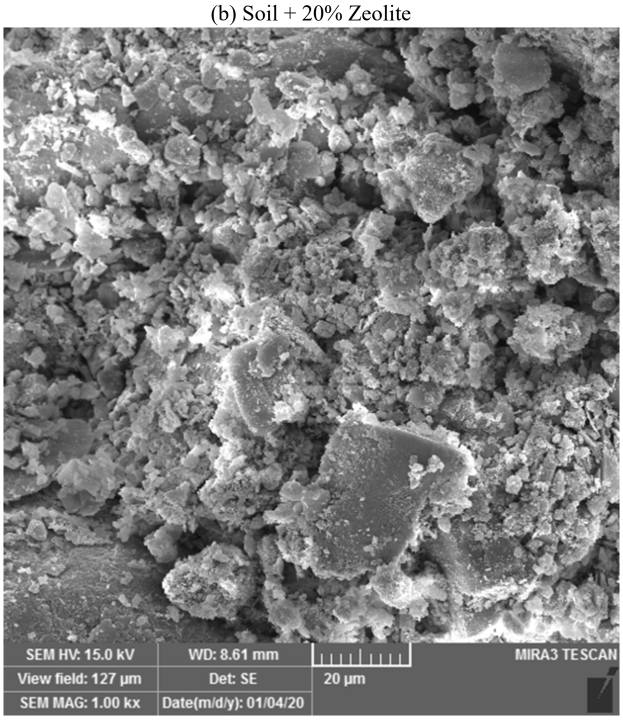


Fig. 8 Correlation between LL and PL of Two Methods



(b) Soil + 20% Zeolite



(a) Soil + 35% Zeolite

Fig. 9 SEM Images of Soil with Different Percentage of Zeolites

TABLE VII
INTERNAL FRICTION ANGLES RESULTED FROM DIRECT SHEAR TEST

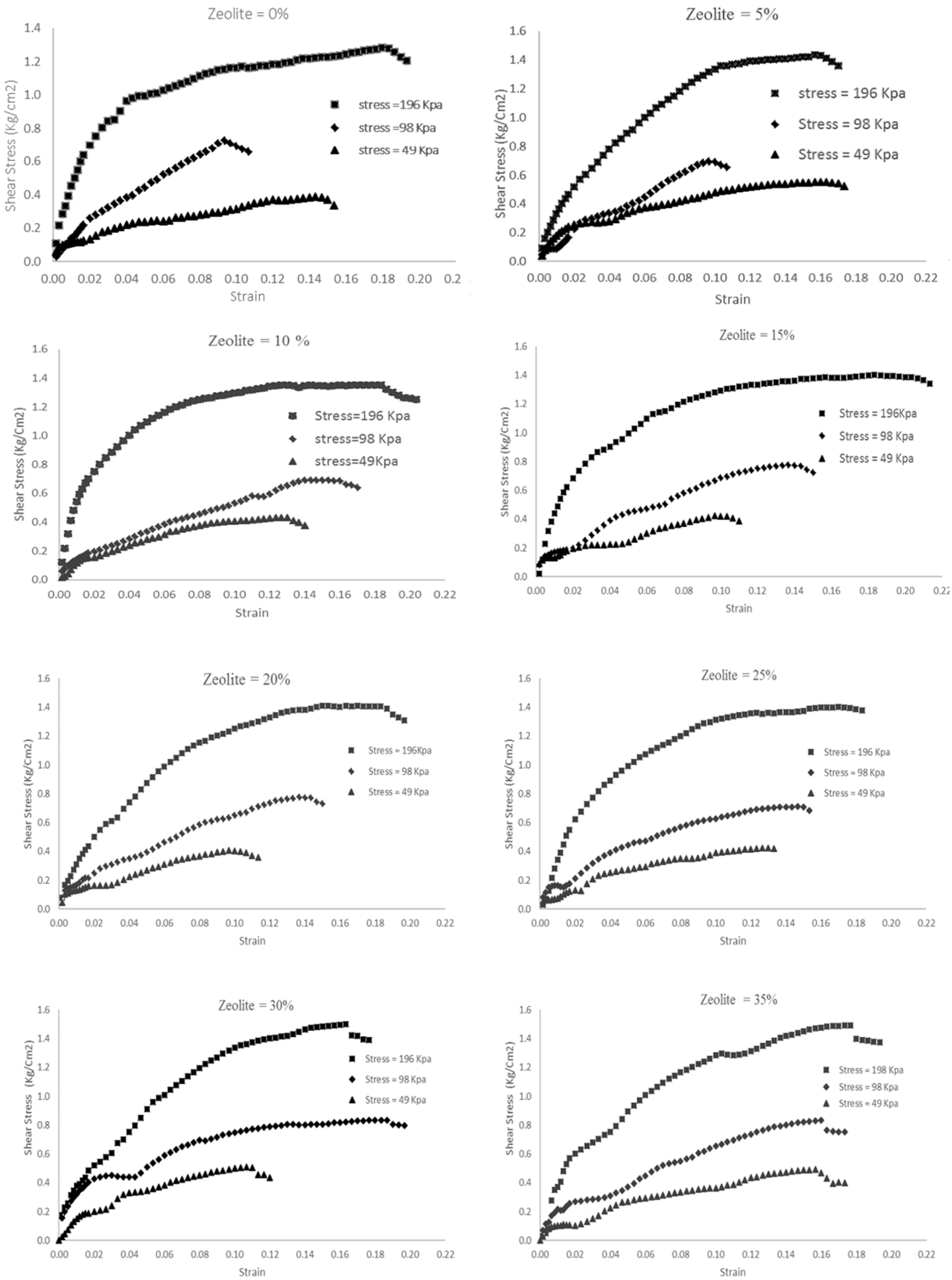
	Zeolite (%)	Without Curing	14 Days Curing	Enhancement
Effective Internal Friction Angel (φ')	0	30° 39"	30° 39"	0
	5	31° 23"	31° 18"	-0.29%
	10	31° 48"	31° 59"	0.63%
	15	32° 55"	33° 25"	1.52%
	20	33° 34"	35° 32"	5.87%
	25	33° 18"	34° 55"	4.89%
	30	33° 27"	34° 49"	4.09%
	35	33° 29"	34° 57"	3.86%

TABLE VIII
CBR RESULT TESTS

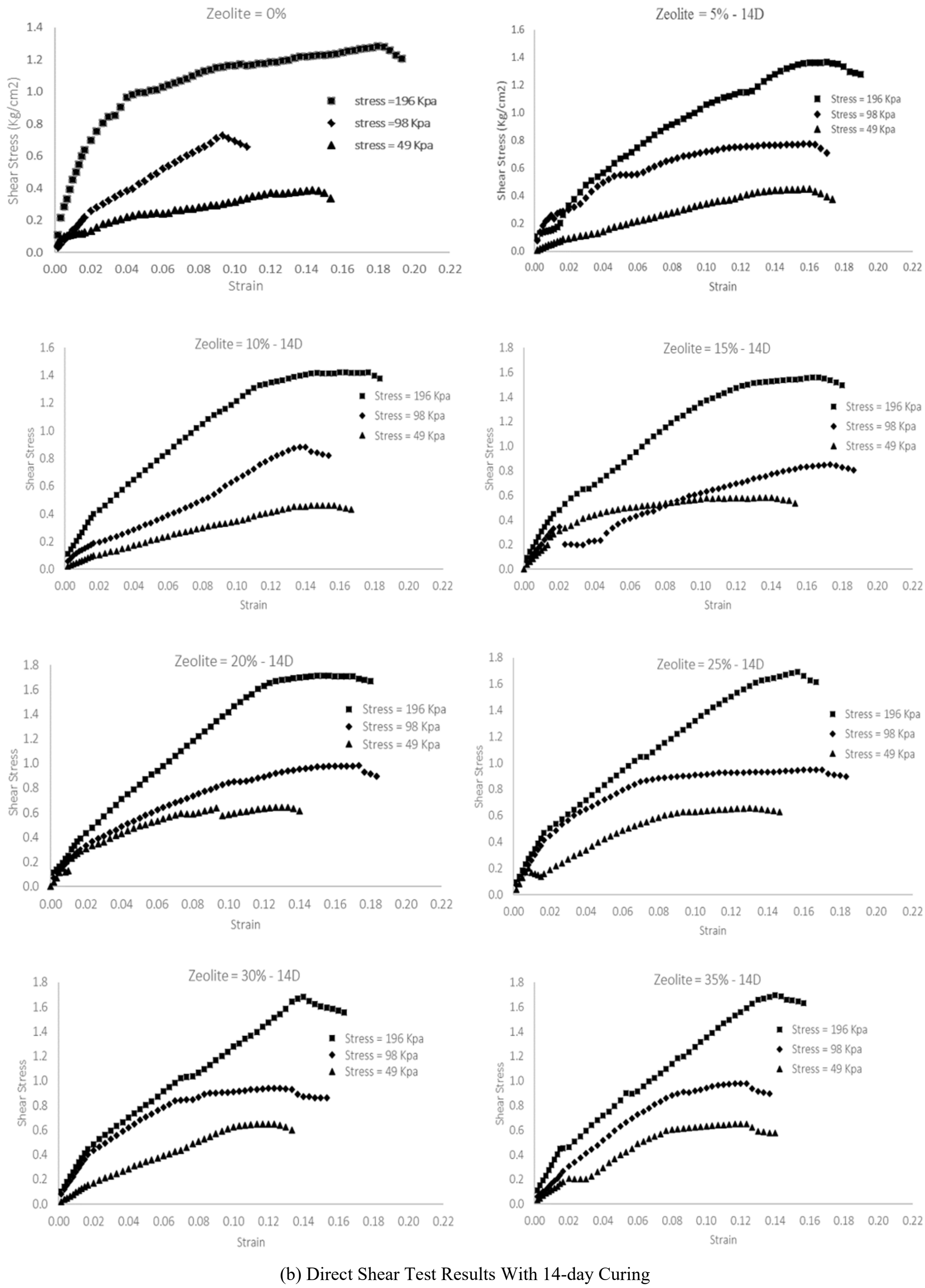
	Whit-out curing			14 Days Curing		
ZEOLITE	CBR 2.5	CBR 5	CBR7	CBR 2.5	CBR 5	CBR 7
0	10.48	9.90	9.37	10.48	9.90	9.37
5	10.89	10.42	9.91	11.52	11.10	10.98
10	12.28	12.05	11.79	13.31	13.16	12.99
15	13.57	12.99	12.32	16.01	15.90	15.81
20	15.62	15.47	15.01	18.45	18.30	17.83
25	16.39	16.24	15.81	20.89	16.76	15.01
30	16.91	16.76	16.08	23.46	22.92	19.71
35	17.93	16.93	16.48	25.90	20.18	17.02

TABLE IX
GENERAL RESULTS FROM DIRECT SHEAR TEST OF SAMPLES

Without Curing				14 Days Curing			
Zeolite (%)	Vertical Stress (KPa)	Failure Stress	Strain	Zeolite (%)	Vertical Stress (KPa)	Failure Stress	Strain
	49	0.5533	14.30%		49	0.5533	14.30%
0	98	0.6954	9.30%	0	98	0.6954	9.30%
	196	1.4357	18.00%		196	1.4357	18.00%
	49	0.5533	16.00%		49	0.4618	16.00%
5	98	0.6954	9.70%	5	98	0.8823	16.00%
	196	1.4357	15.70%		196	1.4200	17.00%
	49	0.4332	12.70%		49	0.4618	15.70%
10	98	0.6921	15.30%	10	98	0.8822	14.00%
	196	1.3530	18.30%		196	1.4212	17.70%
	49	0.4230	10.00%		49	0.5836	14.00%
15	98	0.7760	13.70%	15	98	0.8513	17.30%
	196	1.4000	18.30%		196	1.5608	16.70%
	49	0.4100	9.70%		49	0.6431	13.30%
20	98	0.7777	13.70%	20	98	0.9808	17.30%
	196	1.4110	16.30%		196	1.7101	17.00%
	49	0.4229	13.00%		49	0.6560	13.00%
25	98	0.7111	14.70%	25	98	0.9485	17.00%
	196	1.3998	17.00%		196	1.6917	15.70%
	49	0.5069	10.70%		49	0.6483	12.30%
30	98	0.8343	18.70%	30	98	0.9389	12.70%
	196	1.4974	16.30%		196	1.6799	14.00%
	49	0.4919	15.70%		49	0.6505	12.30%
35	98	0.8317	16.00%	35	98	0.9793	12.30%
	196	1.4915	17.70%		196	1.6944	14.00%



(a) Direct Shear Test Results With-out Curing



(b) Direct Shear Test Results With 14-day Curing

Fig. 10 Direct Shear Results

Kayabali had conducted some experiments on the shear strength of soil's compositions with zeolite behavior by triaxial shear test [26]. Also, Aksoy by the same experiments concluded that the effective friction angle of zeolite was between 34° to 36.5° [7]; the results of which are presented in Table VI.

The study of Mola-Abasi et al. examines the effect of zeolite on the stabilization of Babolsar sand with cement, which increases the resistance of single axial samples to 30% of zeolite. Also, the brittleness behavior of the stabilized samples increases with the increasing percentage of zeolite and decreasing its failure strain [27], which is obvious in the results obtained from the direct shear test which are presented in Figs. 10 (a) and (b). Unlike the above results without an activator, increase in zeolite content has decreased the failure strain, the results of which are presented in Table IX.

D. CBR

This experiment was performed according to ASTM 1883-06 [28]; here we obviously see that there is no improvement in the sample's strength and the zeolite grains just filling inter-particle. However, in samples with curing we can see an improvement, but, the main cause is the zeolite grains making agglomeration between soil particles and by curing samples, after two weeks, water in soil decreases and the soil grains stick together and make denser mass which gains strength, the results are presented in Table VIII.

E. SEM Images

Two samples (20%, 35%) were observed by SEM to validate the results obtained by direct shear test. Figs. 9 (a) and (b) represent the treated soil samples after 14 days curing, the zeolites particles just covered the particles and there is no evidence of cementitious material like (C-S-H) taking place.

IV. Conclusion

It is well known that utilizing cemented sand is one of the best approaches for soil stabilization. In some cases, a blend of sand, cement and other materials such as fiber, nanoparticles, and zeolite are widely available and can be effectively used in soil stabilization especially in road construction. In this research, the effect of zeolites on the soil behavior were investigated; in zeolites due to lower amount of alkaline material such as CaO, it was unsuccessful in supplying the basic environment (pH >10.5) and failed to perform the pozzolanic reaction. The results showed that by increasing the percentage of zeolite in the soil mix, the optimum moisture content will increase and the soil specific density decreases. The fall cone test by two methods, Feng and Wroth-Wood, was carried out and results showed that liquid limit increases as much as plastic limit, and also it is indicated that zeolites are not plastic. The SEM image results showed that there is no improvement in the soil, and the CSH gel has not been taken place due to low pH level in the solution and zeolite just plays the filler role between aggregates.

References

[1] T. Armbruster, M. E. Gunter, Crystal Structures of Natural Zeolites, Reviews in Mineralogy and Geochemistry 45(1)(2001)1{67. arXiv: https://pubs.geoscienceworld.org/rimg/articl-pdf/45/1/1/2940740/1ArmbrusterGunter.pdf,doi:10.2138/rmg.2001.45.1. URL https://doi.org/10.2138/rmg.2001.45.1

[2] N. Mostafa, S. El-Hemaly, E. Al-Wakeel, S. El-Korashy, P. Brown, Characterization and evaluation of the pozzolanic activity of Egyptian industrial by-products: I: Silica fume and delaminated kaolin, Cement and Concrete Research 31 (2001) 467{474. doi:10.1016/S0008-8846(00)00485-3.

[3] F. Helfferich, Ion exchange, Dover Publications, New York, 1995.

[4] N. Hataf, P. Ghadir, N. Ranjbar, Investigation of soil stabilization using chitosan biopolymer, Journal of Cleaner Production 170. doi:10.1016/j.jclepro.2017.09.256.

[5] N. Feng, G.-F. Peng, Applications of natural zeolite to construction and building materials in china, Construction and Building Materials - CONSTR BUILD MATER 19 (2005) 579{584. doi:10.1016/j.conbuildmat.2005.01.013.

[6] A. Kaya, S. Durukan, Utilization of bentonite-embedded zeolite as clay liner, Applied Clay Science 25 (2004) 83{91. doi:10.1016/j.clay.2003.07.002.

[7] Y. Yukselen-Aksoy, Characterization of two natural zeolites for geotechnical and Geoenviromental applications, Characterization of two natural zeolites for geotechnical and Geoenviromental applications 50. doi:10.1016/j.clay.2010.07.015.

[8] M. Turkoz, P. Vural, The effects of cement and natural zeolite additives on problematic clay soils, Science and Engineering of Composite Materials 20. doi:10.1515/secm-2012-0104.

[9] V. Georgiannou, D. Lefas, M. Konstadinou, M. Perraki, Geotechnical properties of a natural zeolite, Proceedings of the Institution of Civil Engineers - Geotechnical Engineering 170 (2017) 1{12. doi:10.1680/jgeen.16.00157.

[10] A. Ramezanianpour, Cement replacement materials: properties, durability, sustainability, Springer, Heidelberg, 2013.

[11] ASTM, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard E_ort, American Society for Testing and Materials, West Conshohocken, PA, 2012. doi:10.1520/D0698-12E02.

[12] B. Standard, Methods of test for soils for civil engineering purposes. Compressibility, permeability and durability tests, British Standard Institute, UK, London,389 Chiswick High Road,W4 4AL, BSI Customer Services, 2015.

[13] T. Feng, Fall-cone penetration and water content relationship of clays, Geotechnique 51 (2001) 819{821. doi:10.1680/geot.51.9.819.41032.

[14] A. S. A Rashid, K. Kassim, A. Katimon, N. Noor, Determination of plastic limit of soil using modified methods, Malaysian Journal of Civil Engineering 20 (2008) 295{305.

[15] C. Wroth, D. Wood, The correlation of index properties with some basic engineering properties of soils, Canadian Geotechnical Journal 15 (2011) 137{145. doi:10.1139/t78-014.

[16] M. Budhu, Soil mechanics and foundations, Wiley, New York, 2011.

[17] G. Mertens, R. Snellings, K. Van Balen, B. Bicer-Simsir, P. Verlooy, J. Elsen, Pozzolanic reactions of common natural zeolites with lime and parameters affecting their reactivity, Cement and Concrete Research 39 (2009) 233{240. doi:10.1016/j.cemconres.2008.11.008.

[18] T. Perraki, G. Kakali, F. Kontoleon, The e_ect of natural zeolites on the early hydration of portland cement, Microporous and Mesoporous Materials 61 (2003) 205{212. doi:10.1016/S1387-1811(03)00369-X.

[19] ASTM, Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions, American Society for Testing and Materials, West Conshohocken, PA, 2011.

[20] ASTM, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, American Society for Testing and Materials, West Conshohocken, PA, 2019.

[21] B. Uzal, L. Turanl_, H. Yucel, M. C. G onc uoglu, A. C_ ulfaz, Pozzolanic activity of clinopetilolite: A comparative study with silica fume, y ash and a non-zeolitic natural pozzolan, Cement and Concrete Research 40 (2010) 398{404. doi:10.1016/j.cemconres.2009.10.016.

[22] F. Massazza, Properties and applications of natural pozzolanas, Structure and performance of cements (2002) 326{352.

[23] B. Ahmadi, M. Shekarchi, Use of natural zeolite as a supplementary cementitious material, Cement and Concrete Composites 32 (2010) 134{141. doi:10.1016/j.cemconcomp.2009.10.006.

[24] F. Ling, K. Kassim, A. Abd Karim, J. Kan, Strength and stiffness of artificial organic soil admixed with lime zeolite, Applied Mechanics and Materials 773-774 (2015) 1422{1427. doi:10.4028/www.scienti_c.net/AMM.773-774.1422.

[25] S. Martinez-Ramirez, M. Blanco-Varela, I. Ere~na, M. Gener, Pozzolanic reactivity of zeolitic rocks from two different Cuban deposits: Characterization of reaction products, Applied Clay Science - APPL CLAY SCI 32 (2006) 40{52. doi:10.1016/j.clay.2005.12.001.

[26] K. Kayabali, Engineering aspects of a novel landfill liner material: bentonite-amended natural zeolite, Engineering Geology 46 (1997)

105{114. doi:https://doi.org/10.1016/S0013-7952(96)00102-0. URL http://www.sciencedirect.com/science/article/pii/S0013795296001020
[27] H. Mola-Abasi, I. Shooshpasha, Influence of zeolite and cement additions on mechanical behavior of sandy soil, Journal of Rock Mechanics and Geotechnical Engineering 8. doi:10.1016/j.jrmge.2016.01.008.
[28] ASTM, Standard test method for California bearing ratio (CBR) of laboratory-compacted soils, American Society for Testing and Materials, West Conshohocken, PA, 2014. doi:10.1520/D1883-16.