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Influence of Nanozeolite Particles on Improvement of Clayey Soil

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Abstract**—**The problem of soil stabilization has been one of the important issues in geotechnical engineering. Nowadays, nanomaterials have revolutionized many industries. In this research, improvement of the Kerman fine-grained soil by nanozeolite and nanobentonite additives separately has been investigated using Atterberg Limits and unconfined compression test. In unconfined compression test, the samples were prepared with 3, 5 and 7% nano additives, with 1, 7 and 28 days curing time with strain control method. Finally, the effect of different percentages of nanozeolite and nanobentonite on the geotechnical behavior and characteristics of Kerman fine-grained soil was investigated. The results showed that with increasing the amount of nanozeolite and also nanobentonite to fine-grained soil, the soil exhibits more compression strength. So that by adding 7% nanozeolite and nanobentonite with 1 day curing, the unconfined compression strength is 1.18 and 2.1 times higher than the unstabilized soil. In addition, the failure strain decreases in samples containing nanozeolite, whereas it increases in the presence of nanobentonite. Increasing the percentage of nanozeolite and nanobentonite also increased the elasticity modulus of soil.

Keywords**—**Nanozeolite particles, nanobentonite particles, clayey soil, unconfined compression stress, specific surface area, cation exchange capacity, Atterberg limits.

I. INTRODUCTION

REGARDING to implementation conditions of each construction project, soil improvement and strengthen will always be considered with the lowest cost, as well as considering environmental issues and the feasibility.

Fine grained soils, due to their chemical and physical properties are particularly important. The resistance of fine grained clayey soils is mainly due to the cohesion created by surface water absorption or electric charges and the internal friction angle between the soil grains is low, so it is important to be able to improve the soil in construction projects such as building, road and dam construction.

There are several methods for stabilizing the fine grained soils and various studies have been carried out using various additives to treatment the soils [1]-[7]. These additives can be cement, zeolite, silica, lime and other materials. Each of these additives has its own advantages and disadvantages as well as considerations during implementation and curing time. Considerations such as cost, easily execution, availability, environmental issues etc. can be mentioned.

New technologies always bring new horizons to different sciences. Geotechnical science, which is an important part of these sciences, also follows this principle. The application of nanotechnology in civil engineering is a very new technique that is the basis of the present research. After obtaining the desired nanomaterial, it can be used as a stabilizer in soil improvement. Because of their size, nanoparticles can affect the soil behavior and exhibit different physical and chemical behaviors.

A nanoparticle is defined as a particle has at least one dimension at nanometer scale (i.e., 1 to 100 nm) [1]. Nanotechnology is the technology of change in the properties of the molecules that make up the material, and that is why nanoscale is the best definition for this technology. Humans are trying to alter the properties of molecules using nanotechnology until they are physically made to have all the properties of these molecules (and the main material).

The nanomaterials have larger surfaces than the same materials on a larger scale. As the surface area increases, more particle can be in contact with the particles surrounding it and thus, affecting its reactivity. The application of nanotechnology in geotechnical engineering can be described in two areas: (1) study of soil structure at the nanoscale and thus gain a better understanding of soil nature along with study of the soils performance with different nanostructures and (2) applying soil at the atomic and molecular scale by adding nanoparticles as an external agent. Soil is inherently a grain material that covers a wide range of particles from 1 nm to 2 mm [2]. Such a wide range of particle size has made soil one of the most sophisticated materials to study and use.

Generally, when the particle size of the soil is reduced to the nanoscale, it generally exhibits very different behaviors compared to the same material in larger dimensions. This change in behavior is due to two main reasons: increased surface area and the dominance of quantum effects on particles. Therefore its surface properties (such as physical, chemical, electrical and reactivity properties) become more important and even dominant, while the importance of soil mass properties is greatly diminished. Because of the high surface area of the active surfaces with electrical charges (specific surface area), the nanoparticles interact with the constituents of the soil (including liquid phase, cations, organic matter and clay minerals) very actively. Therefore, they have complex effects on the microstructural, physical, chemical, and engineering properties of the soil, even at low weight percentages. The following is an evaluation of research on using the nanomaterials as a stabilizer for improving the

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geotechnical characteristics of the soils.

Ghazi et al. [3] conducted a series of Atterberg limits test on clayey soils with low plasticity stabilized with different percentages of modified montmorillonite nanoclay (MMN). Similar tests were also performed on mixtures of soil and bentonite, which mainly contain unmodified montmorillonite, in order to evaluate the effect of stabilizer particle dimensions. The MMN did not significantly change the value of plastic limit, but increased the liquid limit significantly. The addition of 8% wt of MMN to clayey soil increased the plasticity index of the soil about 68%, which can be very useful in embankment dams with clayey core. The tests on the soil-bentonite mixtures confirm the increasing trend of plasticity index, but this change is less than of modified montmorillonite-soil mixtures. This phenomenon can be considered as the effect of montmorillonite particles size. Therefore MMN can be a suitable material for soil improvement where higher plasticity properties are required. Also, the effect of different amounts of MMN on the compression strength of the soil was investigated. With increasing MMN, the unconfined compression strength increased and at its highest content, 34.2% improved compared to the unstabilizd condition.

Kananizadeh et al. [4] conducted a research by adding nanoclay to the soil around the landfill in Kahrizak to prevent the penetration of the landfill leachate in three neutral, acidic and alkalinity modes. The soil was MH type. The results showed that soil permeability decreased in all three conditions. They investigated the effect of three types of nanomaterials on the shrinkage and swelling behavior of four various mixed soils. These three types of nanomaterials were nanoclay, nano-alumina, and nanocopper. The soil sample had different percentages of bentonite. By adding nanomaterials, geotechnical characteristics of soil (i.e., compaction characteristics, volumetric shrinkage strain, volumetric swelling strain) were improved. Adding some nanomaterials, such as nanoclay, did not improve the soil properties significantly and by increasing its content from a certain value, this nanomaterial had a negative effect on the soil. The induced improvements in the swelling and shrinkage strain by using nanocopper were greater than of nano-alumina. SEM images were taken to show the nanoparticles sizes after the crushing process by ball mill.

Mohammadi and Niazian [5] investigated the effect of nanoclays on geotechnical properties of Rasht clay. Increasing the percentage of nanoclay increases the plastic and liquid limit. Increase in plastic limit is more than increase in liquid limit, so sample plasticity index decreases. They also investigated the effect of nanoclay on shear strength of Rasht clay using direct shear and unconfined compression strength tests. By increasing the nanoclay to 1.5%, the shear strength of the soil increases significantly. No further increase in shear strength was observed after 1.5%. Also, the results of unconfined compression strength test show that increasing the nanoclay up to 0.5% has no effect on the soil strength, but when the nanoclay is up to 1.5%, the sample exhibits maximum resistance. By increasing the nanoclay in the sample from 1.5% to 2%, the ultimate strength of the sample decreases.

The study by Firoozi et al. [6] investigated the effect of adding various percentages of nanozeolite on the Atterberg limits of kaolinite-silty sand and illite-silty sand mixed soils. They showed that by increasing the percentage of nanozeolite in each soil, the plastic limit was reduced, while the Atterberg curve increased to 0.5% nanozeolite and began to decrease after this value.

Hareesh and Vinothkumar [7] investigated the effect of adding different percentages of nanozeolite and nanosilica on free swelling, Atterberg limits, compaction properties, and unconfied compression strength of clay with high (CH) and low (CL) plasticity. Nanozeolite was added to the soil with contents of 0.4%, 0.8%, 1.2%, 1.6% and 2%. Evidence has shown that the shrinkage of the soil decreases with increasing percentage of nanozeolite. They also concluded that with the increase of nanozeolite, the Atterberg limits decreased. In addition, the optimum moisture content of the soils increased and the maximum dry unit weight decreased with increasing nanozeolite content. They also assessed the effect of various nanozeolite contents on the soil unconfined compression strength with 14 days curing time. The soil shear strength increased with the nanozeolite stabilizing.

In present paper, the effect of nanozeolite on the engineering properties of fine grained soil from Kerman (Iran) was investigated. Nanozeolite is one of the materials that contain clay minerals and can be used as stabilizers. In addition, nanobentonite has also been used to compare its behavior with nanozeolite. For the purpose of study, nanomaterials were added to the soil in three different dry weight percentages (3, 5 and 7%) as a colloidal suspension (33% concentration, 1 unit nanomaterial to 3 unit water) with three various curing time (1, 7 and 28 days) and after preparing the samples, the Atterberg and unconfined compression strength tests was performed and the results were discussed.

II. MATERIALS

A. Fine-Grained Soil

The soil used in this study was from a region of Kerman province with a fine-grained soil. The grain size distribution curve obtained from the sieve and hydrometric tests on this soil are shown in Fig. 1. Base soil properties are also presented in Table I. This soil is considered CL in the unified classification.

TABLE I
PROPERTIES OF KERMAN CLAYEY SOIL

Property	Value
Specific gravity, G_s	2.75
Liqiud limit, LL (%)	32
Plastic limit, PL (%)	15
Plasticity index, PI (%)	17
Maximum dry unit weight, $(\gamma_d)_{max}$, (kN/m^3)	18
Optimum moisture content (%)	16
USCS classification	CL

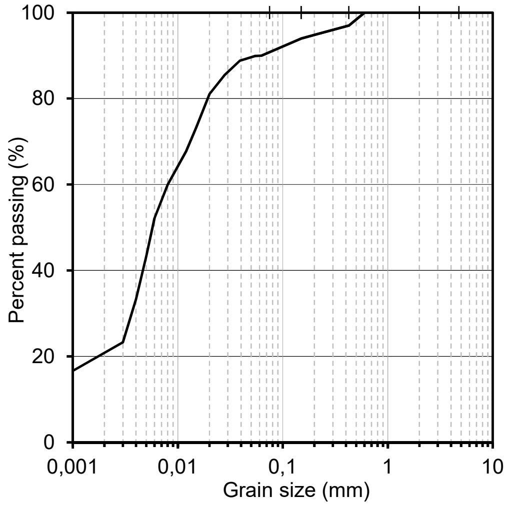

Fig. 1 Grain-size distribution curve of the Kerman soil (Iran)

B. Nanomaterials

In this research, the effects of nanobentonite and nanozeolite on the clayey soil were evaluated. Zeolite is a mineral rich in aluminosilicate and its major commercial use in industries is as an adsorbent. The word zeolite was first coined in 1756 by the Swedish mineralogist Axel Friedrich Kronstedt [6]. In terms of origin, the zeolites are divided into sedimentary and volcanic rocks. Most zeolites are colorless or white. In the sedimentary type zeolites, the ratio of silicon to aluminum is larger than the volcanic zeolites.

Unlike the rest of the world, zeolites in Iran are sedimentary. Generally, the zeolites are open and crystalline, with special surfaces similar to those of silicate minerals showing that water absorption in each cell unit is relatively high. Zeolites usually have a density between 2 and 2.3 gr/cm^3. The cation exchange capacity (CEC) of a zeolite is essentially a function of the degree of substitution of Al^{3+} and Fe^{3+} instead of Si^{4+} in the zeolite framework polyhedra. Reducing the amount of alumina to silicate leads to reduced CEC. The nanozeolite used in this study is clinoptilolite.

The chemical formula for this type of zeolite is $(NaKCa)_{2-3}[Al_3(AlSi)_2Si_{13}O_{36}].12H_2O$. The properties of clinoptilolite can be described as crystalline and clear white. This type of zeolite has an uneven fracture and is classified in silicate. The specific gravity of this zeolite is between 2.2 and 1/2 gr/cm^3. The nanomaterials used in this study were provided by Sigma-Aldrich Company and their properties are summarized in Table II. Result of X-ray Fluorescence Spectroscopy (XRF) test on nanozeolite and nanobentonite is presented in Table III.

TABLE II
Properties of Nanomaterials

Property	Nanomaterial	
	Nanozeolite	Nanobentonite
Average particle size (nm)	1-2	1-2
Specific surface area (m^2/g)	200-220	250-280
Density (g/cm^3)	0.22	0.35

TABLE III
Chemical Properties of Nanobentonite and Nanozeolite

Property	Value	
	Nanozeolite	Nanobentonite
SiO_2	69.12	52.24
Al_2O_3	10.79	25.68
Fe_2O_3	0.73	6.72
CaO	4.2	1.97
K_2O	1.09	0.96
Na_2O	0.84	0.85
MgO	0.65	0.6
TiO_2	-	0.78
LOI	-	10.2

III. Methods

A. Sample Preparation

Nanomaterials can be added to soil in both dry and colloidal suspension form. Wei et al. [8] investigated the effect of nanomaterials in both dry and suspension states and reported that the nanomaterial particles would be better dispersed in the solvent (water). On the other hand, in the process of nanomaterial solubilization, colloidal suspension homogeneity is of particular importance which should not be overlooked because of its direct influence on the results of subsequent tests. In this study, ultrasonic bath apparatus was used to obtain a homogeneous colloidal suspension as shown in Fig. 2.

The ultrasonic bath is actually a metal container with some water inside it. The device connected to this container generates ultrasound. One of the uses of the ultrasonic bath is to disperse the particles into the solvent and thus make the solution uniform. These waves can break links between the agglomerated particles and increase the quality of the suspension. The nanomaterials are added to the water to a certain extent and then mixed initially with an electric mixer at a speed of 1000 rpm. Then, the colloidal suspension obtained from the ultrasonic bath was subjected to waves to prevent agglomeration. The concentration of colloidal suspension was considered about 33% (1 nanomaterial: 3 water).

Fig. 2 Ultrasonic bath apparatus

For the preparation of untreated sample, the optimum moisture content of the clayey soil, which was determined from modified proctor compaction test, is sprayed layer-by-layer to the all soil surface and then, mixed thoroughly. Preparation of stabilized specimens with nanomaterial suspension such as untreated specimens, but initially, based on the contents intended for the stabilizer, it is necessary to calculate the amount of colloidal suspension to be added to the soil (depending on the suspension concentration). The dry weight percent of nanozeolite particles is also one of the effective parameters in this study. For the tests, the amount of nanomaterials was selected as 3, 5 and 7% dry weight. The procedure and timing of mixing are important. In fact, the optimum moisture content that is mixed with the soil is the amount of water available in the suspension and, if needed, the extra water.

The mixing of the colloidal suspension and the soil will continue until the sample reaches homogeneity, which requires about 30 minutes. For this purpose, a low speed electric mixer was used for homogenization of the colloidal suspension-soil mixture [9]. After initial mixing, a homogenizer was used to integrate the particles. The optimum parameters obtained from the compaction test were used for the preparation of the specimens. After the specimens are prepared, for the purpose of unconfined compression strength testing, the plastic protective coatings are laid on around the specimen and they are placed in plastic bags where the air is completely discharged with a suction device for curing. Also, the curing time of samples is considered 1, 7 and 28 days after preparation.

IV. RESULTS AND DISCUSSIONS

A. Cassagrande Test

In order to prepare the sample to perform the Cassagrande test, the soil was mixed with various contents of nanozeolite and nanobentonite (3, 5, and 7%) and to homogenize the nanomaterial-clayey soil mixture, the turbo mixer was used. Then, for the Cassagrande tests, the soil-nanomaterial mixture was stored for 24 hours in the insulation environments. Atterberg limit tests on the soil samples with different contents of nanomaterials, according to Standard ASTM D 4318-87 [10] were conducted and the results are shown in Fig. 3.

According to Fig. 3 (a), by increasing the nanozeolite content in the soil, liquid and plastic limits increase due to high surface area to volume ratio of nanozeolite particles and the increased water absorption capacity in the sample. The results showed that the rate of increase in the value of plastic limit was higher than the liquid limit and the plasticity index decreased with increasing the content of nanomaterials. Similar processes occur in samples containing nanobentonite (Fig. 3 (b)). By observing Table III which summarizes the results of the Atterberg Limit test, it is found that the samples containing nanobentonite have a higher liqiud and plastic limits than the nanozeolite-clay mixture, which may be due to the higher specific surface area of the nanobentonite particles and the difference in the amount of their surface charge.

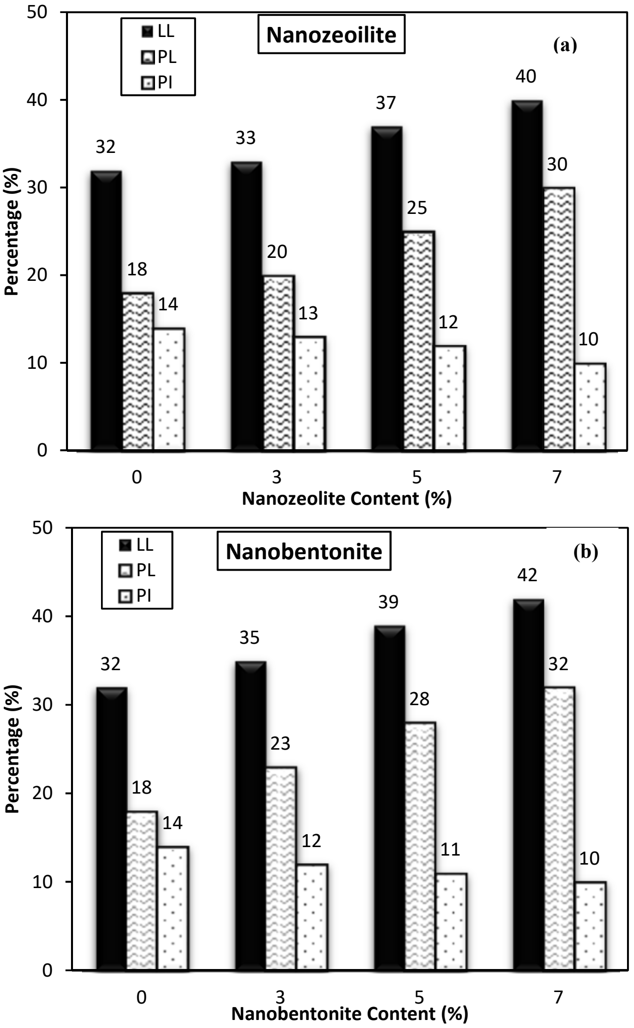

Fig. 3 Effect of various content of (a) nanozeolite (b) nanobentonite on Atterberg limits

TABLE IV
SUMMARY OF CASSAGRANDE TEST RESULTS

Property	Value (%)		
	Liqid limit	Plastic limit	Plasticity index
soil	32	18	14
Soil + 3% NZ	33	20	13
Soil + 5% NZ	37	25	12
Soil + 7% NZ	40	30	10
Soil + 3% NB	35	23	12
Soil + 5% NB	39	28	11
Soil + 7% NB	42	32	10

B. Unconfined Compressive Test

One of the most important tests to be carried out on stabilized soils with different materials is the unconfined compression strength test. In fact, the parameters obtained from this test, such as compression strength, failure axial strain and elastic modulus, play an important role in the stabilizer evaluation.

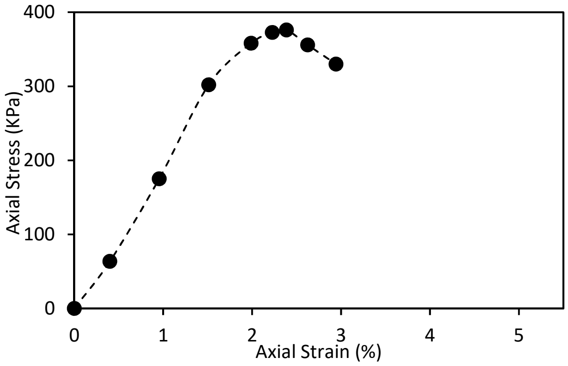

Fig. 4 Stress-strain curve for natural soil

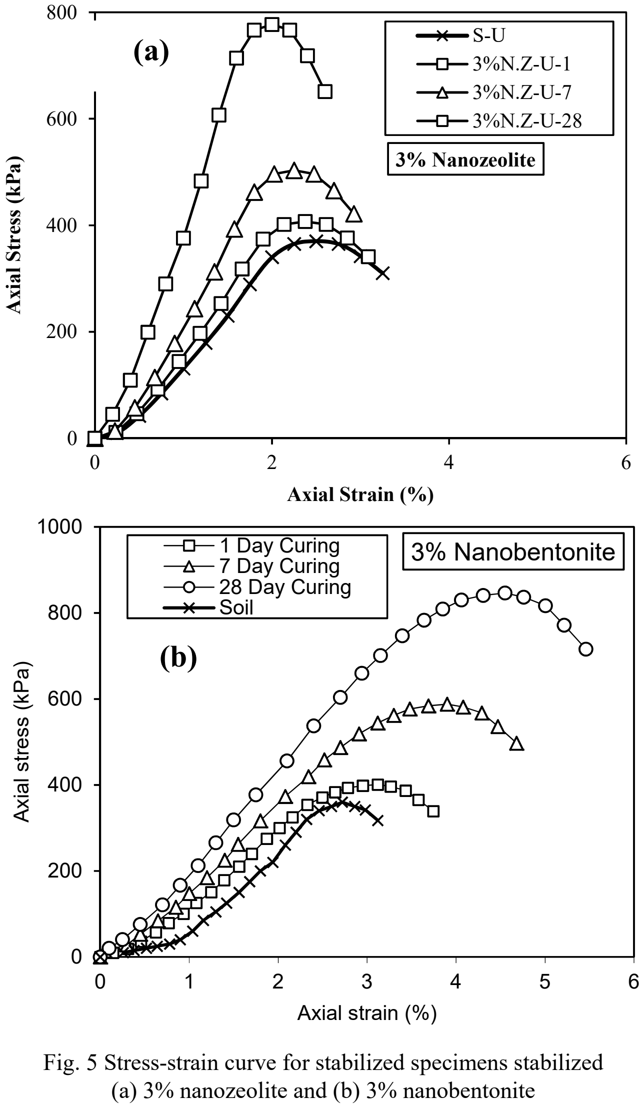

Fig. 5 Stress-strain curve for stabilized specimens stabilized (a) 3% nanozeolite and (b) 3% nanobentonite

The specimens were prepared according to the sample preparation section and the specimens were made in cylindrical stainless mould with a diameter of 38 mm and a height of 88 mm. All samples were made with optimum moisture content obtained from standard compaction test (according to standard ASTM D 698-78 [11]) and loading rate of 0.5 mm/min. Unconfined compression strength of Kerman clay (according to standard ASTM D 2166-87 [12]) was obtained in unstabilized conditions, 375.9 kPa (Fig. 4).

Fig. 5 (a) is presented to investigate the behavior of the stress-strain curve for specimens stabilized with nanozeoilite. As can be seen, the presence of only 3% of nanozeoilite has led to an increase in the failure point in the curve. In addition, the failure axial strain decreased with the addition of nanozeoilite compared to the unstabilized conditions. In fact, with increasing resistance and decreasing failure axial strain, the elastic modulus also increases and the specimens exhibit more brittle behavior. In Fig. 5 (b), it can be seen that nanobentonite also results in an increase in unconfined compression strength. Unlike nanosheolite, in the presence of nanobentonite, the fracture strain increases. This could be due to the high plasticity of the sample due to the high water retention properties of the nanoclay. The water retention property can also be due to the high specific surface area of the nanobentonite.

The effect of various percentages of nanomaterials on the unconfined compression strength with different curing times is shown in Fig. 6. According to this figure, increasing the nanozeoilite percentage leads to increase in unconfined compression strength at all curing times. In fact, it can be stated that by increasing the nanozeoilite content from 3% to 7% with 1 day curing, the compression strength also increases from 407 kPa to 444 kPa. However, for nanobentonite these values are 420 kPa and 790 kPa, respectively. Nanobentonite samples have higher unconfined compression strength due to their higher reactivity and cohesion properties. In fact, nanomaterials by interconnecting between the soil particles, due to their cation exchange properties and high specific surface area, reduce the thickness of the diffused double layer and bring the soil particles closer together. The proximity of the soil particles to each other results in agglomeration of the soil particles and with the formation of the flocculate structure, the unconfined compression strength increases with increasing nanomaterial percentage. Nanobentonite has a higher impact on the soil structure than nanozeolite and provides higher strength in clayey soil. The passage of time also affects the unconfined compression strength of the specimens. In fact, as time passes and chemical reactions are completed, a stronger bonding between the soil-nanomaterials particles is formed. On the other hand, the effect of nanomaterials on the strength of clayey soil is presented in Fig. 7. As can be seen, the normalized unconfined compression strength (ratio between the unconfined compression strength in the stabilized specimens with different contents (at 28 days curing time) to the unconfined compression strength of the soil in unstabilized conditions) increases with increasing nanozeolite and nanobentonite percentages. This ratio was 2.06, 2.15, and 2.32 in samples containing 3, 5, and 7% nanozeolite, respectively, while these values were 2.26, 3.19, and 4.27 for nanobentonite, respectively (in 28 days curing). In fact, nanobentonite has a greater impact on compression strength of the soil than nanozeolite. Similar trends can be observed at other curing times.

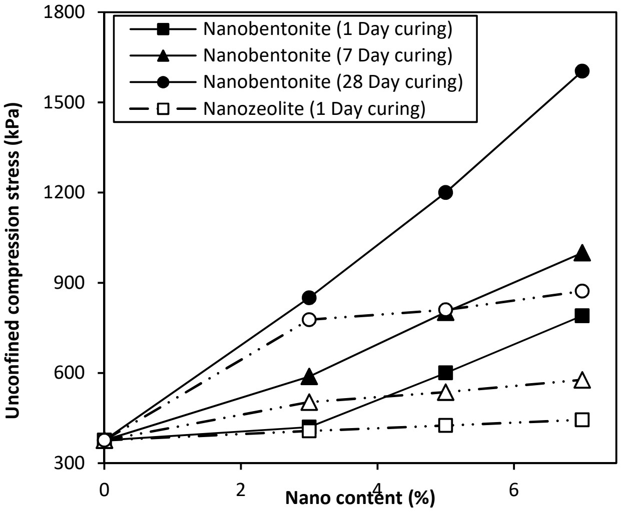

Fig. 6 Effect of different content of nanomaterials on UCS of stabilized specimens

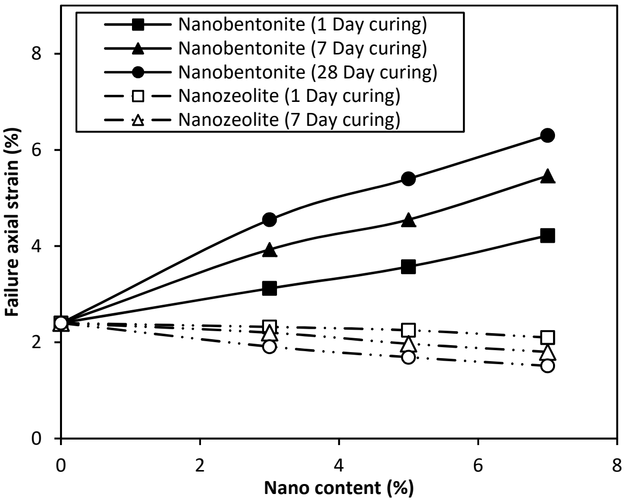

Fig. 7 Normalized unconfined compression strength for treated specimens

The presence of nanomaterials in clayey soil also affects the failure axial strain due to soil structure change. The presence of nanozeolite decreases the failure axial strain and as the nano content increases, the failure strain decreases further (Fig. 8). In fact, as the nanozeolite percentage increases, the sample ductility decreases and tolerates fewer axial strains until the breakthrough moment. The increase in failure axial strain is such that, for example, after 7 days, this parameter in stabilized samples with 3, 5, and 7% nanozeolite is 2.2, 1.97, and 1.8%, respectively (Fig. 8). Unlike nanozeolite, in nanobentonite-containing samples, these values were 3.9, 4.5, and 5.4%, respectively, indicating that the nanobentonite increases the failure axial strain.

According to Fig. 9, which presented the normalized failure axial strain versus nano content for various nanomaterials with 28 days curing time, it can be seen that the ratio between the failure axial strain of nanobentonite-stabilized specimens to the unstabilized soil is greater than 1. It means that the nanobentonite increased the failure axial strain and ductility of clayey soil. In the nanozeolite-containing samples, this ratio is less than 1, which in fact indicates a decrease in the failure axial strain of the unstabilized soil. Normalized failure axial strain is 0.63 in the stabilized samples with 7% nanozeolite, while this value for clayey soil with 7% nanobentonite is 2.62. Curing time also affects the ductility or brittleness of the stabilized specimens, so that by increasing the curing time, the failure strain in nanobentonite increases, whereas in nanozeolite, this parameter decreases.

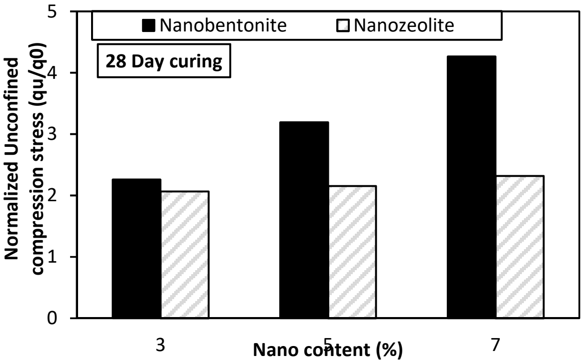

Fig. 8 Failure axial strain values of stabilized specimens with nanomaterials and natural soil

The effect of different percentages of nanozeolite particles on the secant elastic modulus (E_{50}) of the stabilized samples is shown in Fig. 10. As can be seen, as the nanozeolite content increases, the elastic modulus increases as compared to the unstabilized soil, which can be due to the increase of the flocculate and integrated structure (by increasing the specific surface area and CEC and decreasing the diffuse double layer thickness) between the sample particles.

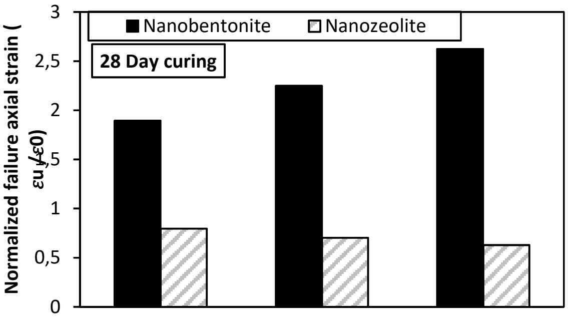

Fig. 9 Normalized failure axial strain for stabilized specimens

In the samples with nanobentonite, an increase in the elastic modulus was observed with increasing nano percent. However, because of the higher formation of flocculate structure and agglomeration in the presence of nanobentonite, these samples have a higher elastic modulus and have higher elastic properties. The variations of the elastic modulus is such that in samples with 3, 5 and 7% nanozeolite with 7 days curing time, E_{50} values are 21.9, 24.3 and 26.6 MPa, respectively. However, these values for nanobentonite-containing specimens are 30.11, 36.4 and 44.1 MPa, respectively, which is indicative of higher elastic modulus than nanozeolite specimens in the same content and curing time.

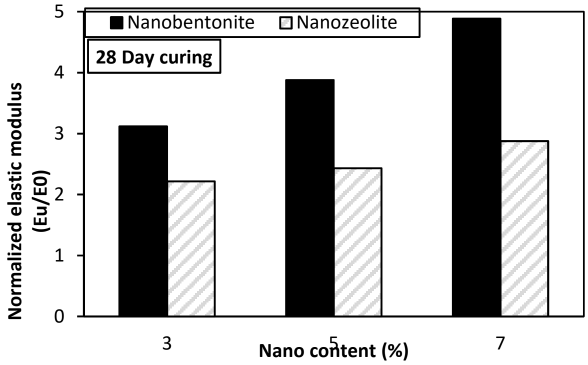

Fig. 10 Effect of various contents of nanomaterials on E_{50}

Increasing the duration of the curing time may also affect the elastic modulus. In fact, the elasticity of the soil increases with the passage of time and the formation of stronger bonds between the particles by reducing the thickness of the diffuse double layer in the presence of nanomaterials. As shown in Fig. 10, by increasing the curing time in samples containing 7% nanozeolite and nanobentonite, the value of E_{50} increased and reached to its maximum value in 28 days.

With the increase in the time of curing to 28 days, a sudden increase in the elastic modulus of soil is observed in both nanomaterials, which shows the effect of time. For the samples stabilized with 3, 5 and 7% nanozeolite particles with 28 days curing, the normalized elastic modulus $[(E_{50})_s/(E_{50})_0]$ values were 2.21, 2.43 and 2.88, respectively. On other hand, for the stabilized specimens with nanobentonite, this ratio $[(E_{50})_s/(E_{50})_0]$ obtained 3.12, 3.88 and 4.88, respectively (Fig. 11).

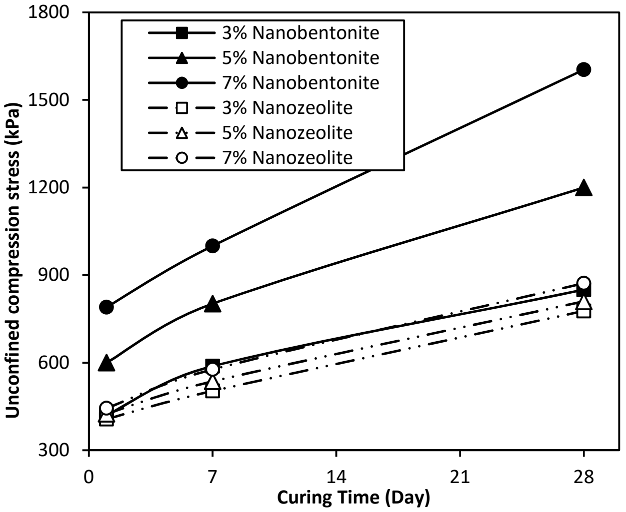

Fig. 11 Normalized E_{50} for stabilized specimens (28 Day curing)

The curing time also has a great impact on unconfined compression strength. As the curing time increases, the unconfined compression strength also increases, which can be due to the completion of the cation exchange process and reduction of the diffuse double layer thickness leading to the formation of flocculate structure and the unconfined compression strength increases. Fig. 12 shows that in the first 7 days of curing time, the trend has a higher slope (unconfined compression strength increases with a higher slope) and decreases the slope of the trend until the 28 days curing which indicates a greater formation of inter-particle bonds up to 28 days. Fig. 13 shows a sample containing 3% nanozeolite after loading in unconfined compression strength test.

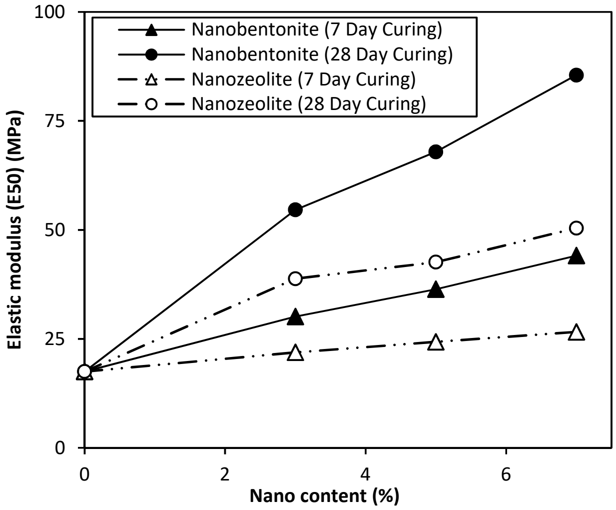

Fig. 12 Effect of curing time on UCS of nano-stabilized specimens

Fig. 13 Specimen failed on unconfined compression strength test

As a general conclusion, it can be stated that the presence of nanomaterials (nanozeolite and nanobentonite) in clayey soil leads to changes in its resistivity parameters. These nanomaterials increase the unconfined compression strength due to the formation of flocculate structure between the soil particles. This process has been observed in the results of other researchers. For example, [7] evaluated the effect of nanozeolite on soil (CL) strength. As the nanozeolite percentage increased, the strength increased. Tabarsa et al. [13] and Asakereh and Avazeh [14] also investigated the effect of montmorillonite nanoclay on clayey soil and their research results showed that with increasing nanoclay content, unconfined compression strength, failure axial strain and elastic modulus increase. In addition to the strength, the elastic modulus and failure strain are also affected by the presence of nanoparticles.

V. CONCLUSION

In the present study, the effect of using nanozeolite as stabilizer on clay in Kerman (Iran) was investigated. Also, nanobentonite was used as a nanoclay for comparison with nanozeolite. Percentages of nanoparticles considered 3, 5 and 7% of soil dry unite weight. Samples were subjected to unconfined compression strength and Cassagrande tests after 1, 7, and 28 days curing time. The summary of results is as follows:

1. The values of liquid and plastic limits of Kerman soil were obtained 32% and 18%, respectively. Also, the plasticity index is 14%. Nanomaterials due to their high specific surface area have higher water absorption due to their high volume-to-surface ratio and as a consequence their addition to clay results in variations of the soil Atterberg limits. Addition of 3% nanozeolite increases the liquid and plastic limits to 33% and 20%, respectively. However, similarly in samples containing 3% nanobentonite, these values reached to 35% and 23% due to the higher particle specific surface area in nanobentonite and their higher water reactivity. Created nanopores in the presence of nanomaterials also influence Atterberg limits. By increasing the nanozeolite content to 5%, LL and PL increased to 37% and 25%, respectively. However, due to a greater increase in PL than LL, the plasticity index decreases with increasing nanoparticles content.
2. Unconfined compression strength parameter is one of the important parameters obtained from unconfined compression test. The unconfined compression strength of the unstabilized sample is 375.9 kPa. By adding 3, 5, and 7% by dry weight nanozeolite, the strength of the soil after just 1 day is obtained as 407, 425 and 444 kPa, respectively. These changes indicate that the addition of nanozeolite to clayey soil increases the strength. Increasing the content of nano also improves the unconfined compression strength. In the samples containing nanobentonite, these values are 420, 600, and 790 kPa, respectively. These results indicate that at the same time of curing and nano percentage, nanobentonite had a greater effect on nanozeolite as a stabilizer on natural soil. For example, the unconfined compression strength of stabilized samples with 7% nanozeolite and nanobentonite at 28 days curing was 2.3 and 4.3 times of untreated soil, respectively.
3. The curing time also has a great effect on the strength and elastic modulus, so that by increasing the sample specific surface area and the CEC during curing time, the unconfined compression strength and elastic modulus increase. The unconfined compression strength of the stabilized specimens with 7% nanozeolite and 1, 7 and 28 days curing were 1.2, 1.5 and 2.3 times the unstabilized conditions, respectively. These values indicate that the curing time has a significant impact on the strength of the stabilized samples. By observing the results of the samples containing nanobentonite, it is found that this process also occurs in the samples stabilized with nanobentonite and these values are 2.1, 2.6 and 4.3, respectively. These variations show that the passage of time has more impact on the formation of the flocculate structure in the presence of nanobentonite. In addition to unconfined compression strength, the failure axial strain and elastic modulus also change over time. By increasing the time of curing, the axial strain at failure moment decreased in nanozeolite samples whereas it increased in nanobentonite samples. Also in the presence of both nanomaterials, the elastic modulus increases with time.
4. Decreasing the thickness of the diffused double layer leads to the closure of the soil and nanoparticles to each other. By forming the flocculate structure, in addition to increasing the unconfined compression strength, the E_{50} of the nanozeolite-stabilized specimens was greater than of the natural soil. The elastic modulus for untreated soil was 17.5 MPa indicating that the soil has a low elastic modulus. The elastic moduli in the samples stabilized with 3, 5, and 7% nanozeolite (28 days curing) were 2.21, 2.43 and 2.88 times of natural soil, respectively. The results indicate that the inter particle bonding is higher in the presence of nanobentonite and, therefore, the elasticity property in this sample is higher than that of nanozeolite.

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