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Effect of zeolite and cement additives on the mechanical behavior and dispersion characteristics of clay soil

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ABSTRACT: Due to their weak characteristics and low strength properties, dispersive soils can cause great damages to various geo-structures. Therefore, geotechnical engineers have attempted to modify and stabilize these soils in different ways. Although chemical stabilization with cement or lime is the most common method to improve the dispersion and swelling features of problematic soils, various environmental issues such as the emission of greenhouse gases for the production of cement or lime have made engineers replace them with sustainable and eco-friendly stabilizers. In this paper, the effect of replacing a part of cement with zeolite (as an environmentally-friendly additive) to stabilize a type of clay and modify its dispersion potential has been evaluated. The results of this study showed that by replacing a part of cement with zeolite, the maximum dry density increases and the optimum moisture content decreases; the trends which are different compared to the conventional cement stabilization. Also, the behavior of the sample in the unconfined compressive test was observed to be highly influenced by the percentage of replacement of cement with zeolite. The results of the double hydrometer test also showed that the combination of cement and zeolite reduces the potential of soil dispersion. It was also observed in the sedimentation experiments that with the increase in the zeolite portion, the sedimentation rate increases, which can be justified by the decrease in the thickness of the diffuse double layer (DDL) of clay and confirms the decrease in the dispersion potential. SEM microstructural analysis also indicated the formation of hydrated calcium silicate gel in the mixture, which improved the mechanical and strength characteristics and reduced the dispersion potential of clay soil.

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1- Introduction

Soils that easily and quickly separate and disperse when exposed to low salt water known as divergent soils. These soils usually contain sodium cations and have high surface absorption. Divergent soils generally have high shrinkage and swelling potential, low permeability, and high erosion potential.

Adding cement and lime to clay by changing the Atterberg limits, reduces swelling and shrinkage, changes the surface texture, and increases the shear strength as well as the durability of the soil [1]. The main components of cement include calcium oxide (CaO), silicon oxide (SiO_2), iron oxide (Fe_2O_3), and aluminum oxide (Al_2O_3), In proper processing conditions, the phenomenon of cementation and growth of compressive strength occurs [2]. Chemical reactions between cement and water compounds, which are called hydration, by producing calcium silicate hydrate (C-S-H) gel, improve the properties of the soil mixture [3]. On the other hand, zeolite has large amounts of aluminum, silicon, and oxygen, which loses its water with heat, and it, can predicted that the alkaline compounds of the soil will have a reaction and a suitable replacement with zeolite and cement [4].

By adding zeolite and cement to the swelling clay, Turkoz and Vural colleagues found that by adding 3% of cement and zeolite between 6 and 10% of the dry weight of the soil, the swelling potential as well as the divergence of the soil decreased significantly and the uniaxial compressive strength increased [5]. Iswarya and Beulah showed that zeolite due to its high porosity, can reduce the density of the mixture and increase the time setting of cement [6]. Kriptavičius et al. showed that zeolite is effective in controlling destructive expansion and swelling caused by the silicate-alkaline reaction of aggregates [7]. Soil divergence is a physicochemical process that is mainly influenced by mineral substances and the chemical properties of water in soil holes [8]. Savas investigated the effect of two percentages of lime by replacing different percentages of zeolite on the swelling and divergence potential of clay. The results of the research showed that by adding these additives, a significant improvement in the swelling and divergence potential of the stabilized samples was achieved [9].

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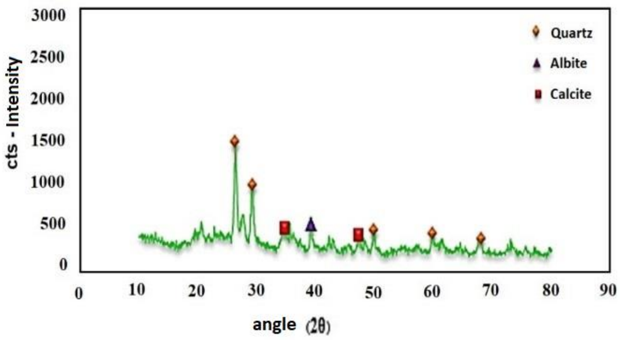

Fig. 1. X-ray diffraction graph of clay

Table 1. Chemical Compositions of clay, cement and zeolite

Chemical compounds	Zeolite	cement	Clay
LOI	6.89	24	12.11
P_2O_5	0.052	0.329	0.239
TiO_2	0.015	0.162	0.664
MnO	0.188	0.086	0.114
MgO	0.56	2.437	3.8
K_2O	2.68	0.989	2.569
Na_2O	1.89	0.783	1.805
CaO	1.53	45.654	12.371
Fe_2O_3	1.29	1.918	5.387
Al_2O_3	11.63	3.646	11.803
SiO_2	72.98	19.031	49.062

The results of a study show that sodium cations are the main factor in the divergence process. Negatively charged sodium cations are in equilibrium on the clay particles, and the clay particles surrounded by these cations and increase the thickness of the double layers. Therefore, the repulsive forces between the clay particles exceed the attractive forces and this causes the soil to diverge [10].

Another research shows that pozzolan reactions between lime and clay particles increase soil resistance and reduce soil divergence [11]. The research of Mohanty et al. colleagues showed that it is possible to improve the characteristics of soil dispersion by adding 15% fly ash and 2% lime [12]. Zhu et al. showed that soil mineralogical composition and alkaline environment are important for the chemical stabilization of divergent soils on convertible cations [13].

2- Material

The soil investigated in this study is in the CL category based on the unified classification system, which was sampled from a mine in the Shahriar area of Tehran. This soil has low plasticity, and the X-ray diffraction diagram of the soil sample is available. The chemical composition of the soil using spectroscopic analysis (XRF) was determined.

Table 2. Mixing plan and weight ratio of materials (weight percentage)

The replacement ratio of zeolite with cement	Cement	Soil
0	0	100
0, 15, 30, 60	2.5	97.5
0, 15, 30, 60	5	95

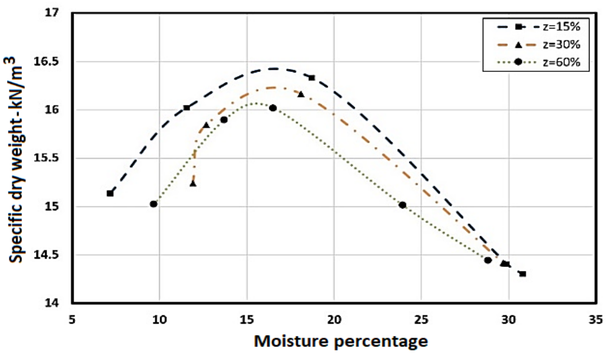

Fig. 2. Compaction curve of soil stabilized with 5% cement and different replacement ratios of zeolite

The cement used in this research is cement type 2 of Tehran Cement Factory. The used zeolite is Clinoptilolite zeolite with 98% purity and sampled from a mine in Semnan The chemical characteristics are reported in Table 1 are based on XRF analysis.

3- Making samples and testing program

In this research, first by conducting preliminary tests, the optimal soil moisture was determined by dry method. Since chemical stabilization with cement requires moisture, the amount of moisture needed in the soil-cement and soil-cement-zeolite mixture was added to the optimum moisture, proportional to the weight percentage of cement with a ratio of 50% (w/c=0.50).

Adding cement increases the optimal moisture content and decreases the maximum density. In the compaction test, due to the presence of false, initial, and final setting effects of cement during the test period, causes errors in the soil compaction process. Meanwhile, part of the moisture is involved in the chemical reaction of cement (about 25% of cement weight). Therefore, in this research, the optimal moisture percentage increased by half the weight of cement (the ratio of water to cement is about 50%).

Stabilization and mixing of materials done by the dry method, and the plan of weight ratios in mixture preparation and prototyping, including weight percentage of clay, percentage of cement, and percentage of zeolite, are reported in Table 2.

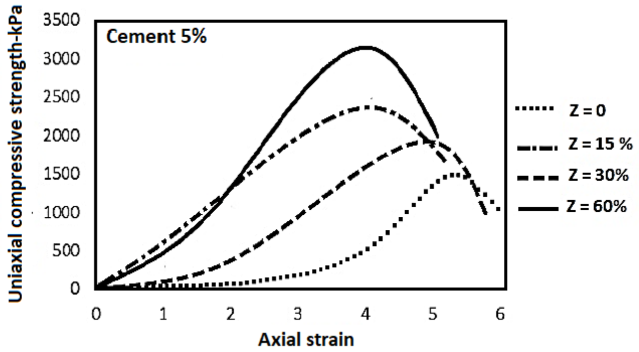

Fig. 3. Stress-strain behavior of clay-cement-zeolite mixtures after 7 days of curing

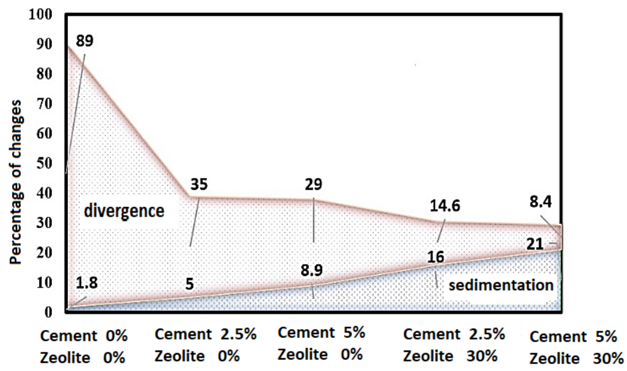

Fig. 4. Effect of sedimentation percentage on the reduction of dispersion potential

The tests carried out in this research included uniaxial compressive strength (to evaluate mechanical characteristics), standard Proctor (to determine optimal moisture and maximum density), double hydrometric, and sedimentation (to evaluate divergence), which was followed by the interpretation of electron microscope photos. (SEM), gel formation structure and chemical bonds were also investigated.

4- Discussion and interpretation of results

The results show that, in general, adding cement to the soil will increase the dry specific gravity and increase the optimum humidity. This behavior can be justified by considering the process of cementation and consolidation of the mixture along with the effect of the higher specific weight of cement compared to the base soil. The increase in optimum humidity also caused by the need of cement to absorb more water for hydration reactions and the homogeneous structure of the soil and cement mixture. The heat of hydration reaction is influential in this process (Figure 2).

The results of the uniaxial test on stabilized and unsterilized samples are given in Figure 3. These results show that the combination of cement and zeolite increases the strength of the sample, and the most suitable result was obtained in 5% cement with 30% zeolite replacement.

In samples stabilized with cement and zeolite up to 30%, the mechanism of lateral deformations of the sample was observed in the condition of rupture and failure (like a barrel); while increasing the amount of zeolite more than 30%, the appearance of several wide vertical cracks was observed with a decrease in lateral expansion.

The results of the double hydrometric test on the base soil and soil-cement-zeolite combination show that by adding 2.5% of cement to the base soil, the divergence potential of the soil decreases. Although this mixture failed to meet the "Sherrard" criterion for non-divergence, the decrease in the percentage of divergence is significant. It is worth mentioning that according to the "Bell" criterion, this soil has medium divergence. In addition, the results of this study show that replacing 30% of zeolite instead of cement in the mixture has reduced soil divergence, which classified as non-divergent soil based on both "Sherard" and "Bell" criteria. This change in failure mode confirms the downward trend of brittleness and reduction of failure strain of the sample with increasing percentage of zeolite replacement.

By sedimentation test to evaluate the potential of soil divergence, found that adding cement increases the percentage of sedimentation. Substitution of part of cement with zeolite shows that this replacement causes a further increase in sedimentation. This behavior can be attributed to the reduction of the thickness of the double layer of clay, which provides more reactive conditions. Chemical stabilization causes clay particles to approach each other and change their structural nature from dispersed to aggregated state. This issue will reduce the potential of divergence.

5- Summary and conclusion

- Chemical stabilization of clay with cement and cement-zeolite combination increases the density and decreases the optimal humidity, which is due to the high density of the additive compared to soil, as well as the need for water for chemical reactions.
- Chemical stabilization by cement or cement-zeolite combination will increase the uniaxial strength, reduce the fracture strain and change the behavior of the sample to a brittle state.
- Adding a small percentage of cement or cement-zeolite combination leads to the reduction of soil divergence potential in the double hydrometric test.
- By increasing the amount of cement and zeolite, the settling percentage of the mixture increases and then the divergence potential decreases by 90%.
- The results of the research showed that in chemical stabilization with cement at the rate of 5% by weight of the soil and replacing zeolite at the rate of 30%, the soil becomes non-divergent. The divergence index reduced by 90% based on standard criteria.
- Chemical stabilization of cement-zeolite with the formation of C-S-H gel reduces the volume of pores and cavities, and the soil particles take on a unified state, which results in the improvement of mechanical characteristics and also the reduction or elimination of divergence potential.

- Substituting 30% of zeolite causes the $Ca(OH)_2$ compound to form a pozzolan reaction with silica and alumina, and these compounds are used to produce C-S-H and C-A-H gels, and the result is improved mechanical properties.

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