Vol. 36, No. 03, pp. 383-403/Junio 2023

ISSN-E 1995-9516
Universidad Nacional de Ingeniería

http://revistas.uni.edu.ni/index.php/Nexo
https://doi.org/10.5377/nexo.v36i03.16461

Improvement of collapsing problematic soils on the sabzevar-mashhad railway route (northeast of Iran) using traditional additives

Mejora de suelos problemáticos de colapso en la vía ferroviaria sabzevar-mashhad (noreste de Irán) utilizando aditivos tradicionales

Hamid Hashemi[1], Abdollah Yazdi[1*], Ebrahim Sharifi Teshnizi[2]

[1]Department of Geology, Kahnooj Branch, Islamic Azad University, Kahnooj, Iran
[2]Department of Geology, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran

[*] Corresponding author: yazdi_mt@yahoo.com

(recibido/received: 05-febrero-2023; aceptado/accepted: 08-mayo-2023)

ABSTRACT

Collapsing soils are among the problematic soils in geotechnical engineering. These soils have a relatively good resistance in their natural state with low humidity, but in case of saturation without change in the incoming load or subjected to vibration force, they settle a lot and in many cases, it will cause cracking or destruction of foundations, roads, railway lines, dams, pipelines and other existing structures. Collapsing soils are scattered in many regions of the world, in Iran these soils are mostly observed in the central and eastern regions. In this research, according to the samples taken from Khorasan-Razavi province in the area of Sabzevar-Mashhad, these samples have been shown to be in the category of collapsing soils based on the tests performed according to ASTM standards. In order to improve this soil, cement and lime additives with percentages of 5 and 10 percent have been used, which has improved the shear properties of the soil due to the addition of lime and cement, so that it causes an increase in the friction angle in the soil, which indicates an improvement in the soil parameters. The results obtained with regard to the addition of cement and lime to the compacted soil show that the index of compaction in the addition of lime is better than that of cement and the results show that with the increase of lime, the soil has a 68% and 78% decrease in the soil compaction index, respectively, but when cement is added to the soil, it causes the percentage of raking index to improve by 34 and 37%.

Keywords: Collapsing Soil, Traditional Additives, Collapsing Index

RESUMEN

Los suelos colapsados se encuentran entre los suelos problemáticos en la ingeniería geotécnica. Estos suelos tienen una resistencia relativamente buena en su estado natural con baja humedad, pero en caso de saturación sin cambio en la carga entrante o sometidos a la fuerza de vibración, se asientan mucho y en muchos casos provocarán agrietamiento o destrucción de cimientos, carreteras, vías férreas, presas, oleoductos y otras estructuras existentes. Los suelos colapsados están dispersos en muchas regiones del mundo, en Irán estos suelos se observan principalmente en las regiones central y oriental. En esta investigación, según las muestras tomadas de la provincia de Khorasan-Razavi en el área de Sabzevar-Mashhad, se ha demostrado que estas muestras se encuentran en la categoría de suelos colapsados según las pruebas realizadas de acuerdo con las normas ASTM. Para mejorar este suelo se han utilizado aditivos de cemento y cal con porcentajes de 5 y 10 por ciento, lo que ha mejorado las propiedades de corte del suelo por la adición de cal y cemento, de forma que provoca un aumento del ángulo de fricción. en el suelo, lo que indica una mejora en los parámetros del suelo. Los resultados obtenidos con respecto a la adición de cemento y cal al suelo compactado muestran que el índice de compactación en la adición de cal es mejor que el del cemento y los resultados muestran que con el aumento de cal el suelo tiene un 68% y 78% de disminución en el índice de compactación del suelo, respectivamente, pero cuando se agrega cemento al suelo, hace que el porcentaje de índice de rastrillado mejore en un 34 y 37%.

Palabras claves: Suelo colapsado, Aditivos tradicionales, Índice colapsado

1. INTRODUCTION

Collapsing soils are among the problematic soils in geotechnical engineering. These soils have relatively good resistance in their natural state with low moisture, but in the case of saturation without change in the applied load or subjected to vibration force, they settle a lot and in many cases it will cause cracking or destruction of foundations, roads, railway lines, dams, pipelines and other existing structures. Collapsing soils are scattered in many regions of the world, in Iran these soils are mostly observed in the central and eastern regions. These soils are mostly composed of young sediments deposited in arid and semi-arid areas. These deposits include;

• Materials accumulated due to gravity or washing at the bottom of slopes (deposits)

• Accumulation of sediments in rivers or large floods (alluvium)

• Wind deposits caused by dust, silt and fine sand of Dante (wind drift)

These soils have low dry specific gravity and are mostly loam, fine-grained silty soils (ML), silty clay (ML-CL) and clay with low plasticity (CL). These soils have low specific gravity and are sensitive to changes in humidity.

Damages to construction projects are happened due to landslides in loess; This phenomenon has become one of the most dangerous geotechnical phenomena in the last century (Jefferson et al. 2005; Sharifi Teshnizi et al. 2022). Collapsing soils are those problematic soils that are dry, stable and strong in their normal state; However, with the increase of moisture percentage and loading of large deformations, rapid settlement and a large decrease in porosity ratio are observed in them (Jefferson et al. 2008a; Al-Obaidi et al. 2013). Large areas of the world - a surface equivalent to 10% of the continental masses are covered by these soils. These areas include continuous deposits from North China to Southeast Europe and scattered areas from North and South America and New Zealand (Jefferson et al. 2008b; Abbeche et al. 2010). In Iran and its surrounding areas, there are thick deposits of silty materials, which are described as loess. The distribution of Los in Iran can be divided into two parts: desert loess and northern loess. The loess of northern Iran has an area equal to 388 thousand hectares; 74 thousand hectares of this area belong to the border areas of Iran and Turkmenistan (Babanejad et al. 2022; Sharifi Teshnizi et al. 2022).

These soils are the cause of many geotechnical challenges and structures in different regions of the world. The collapse phenomenon occurs not only in natural deposits, but also in artificial embankments that have been compacted with a moisture percentage lower than the optimum moisture percentage. The collapse phenomenon occurs not only in natural deposits, but also in artificial embankments that have been compacted with a moisture percentage lower than the optimum moisture percentage. With the expansion of the construction industry, many structures and roads are built on collapsing soils. If these soils are not improved, the resulting settlement will impose many costs on the project (Rollins and Kim 2010; Al-Obaidi et al. 2013).

During the improvement process, suitable conditions are created for the implementation of the project on the ground. The result of improvement is the reduction of construction cost and project implementation time. Although the history of land improvement dates back to Babylonians and ancient Greece, this technology was considered a new technology until 1960 (Munfakh 2003). For construction on collapsing soils, the structure must be designed in a resistant way to be stable against large settlements; Otherwise, the soil should be improved in some way to eliminate its sensitivity to moisture (Abbeche et al. 2010).

The extent of the areas covered by these soils, the high costs of replacing them with suitable soil, and the increasing cost of materials, have increased the need for more investigations about the available materials, as well as investigating the possibility of using waste in soil improvement (Sariosseiri and Muhunthan 2008). The improvement methods of these soils include pre-construction improvement and post-construction improvement methods. The choice of remediation method depends on the needs of a project and the characteristics of the land, the most important of which is the amount of collapse and the depth of the region with the potential for erosion (Jefferson et al. 2008a; Karimizad et al. 2020; Sharifi Teshnizi et al. 2022).

In some areas, it is possible to use improvement methods before construction; In this way, either the collapse of the soil is completely prevented or by applying conditions, the soil collapses before the construction of the building (Murthy 2007; Cui et al. 2019). One of the common methods of designing a foundation on collapsed soils is soil removal and replacement of these soils. In this method, the soil is excavated to a depth that affects the foundation. Then it is replaced by a non- collapsed soil (Houston and Nelson 2012). Pre-moistening means flooding or moistening the soil before the construction of the structure; In this way, the collapse of the soil after the construction of the structure is reduced to the minimum possible amount. Moistening of the soil is done by means of ditches and ponds dug in it.

This method is suitable for channels and communication paths that are not under the effect of very large loads; Because pre-moistening leads to the settlement of the foundation under the existing overhead and applying more load will involve the subsequent settlement of the foundation; Therefore, pre-moistening without pre-loading is not a suitable method to prevent foundation settlements. Another way to improve the soil is to prevent the entry of moisture. This method includes measures such as controlling irrigation conditions, building sealed areas, limiting areas with vegetation near the structure, using geomembrane and building suitable drainage structures. One of the most effective and practical methods of reducing soil collapse is the use of compaction. This method is used for both shallow reaming soils and deep deposits. The most effective efficiency in this method is observed in the first five meters. The design of deep soil mixing 5 is aimed at improving the properties of unsuitable soils located in the upper layers and transferring the foundation load to hard clay layers in the depths. Deep mixing columns are implemented in a network to improve the properties of the soil as well as to apply remote stress to the soil. The distance between the columns and their density is determined according to the load from the foundation. Making changes in the soil in order to increase the carrying capacity and resistance to physical and chemical stresses caused by the environment is called soil stabilization. This process is done with or without additives. By means of various methods of stabilization, the characteristics of the soil can be changed, such as resistance, hardness, compressibility, permeability, efficiency, swelling tendency, and sensitivity to water and tendency to volume change. The scope of these methods can include changes in soil granularity and density to the use of various compounds or thermal and electrokinetic methods (Bell et al. 2007; Karimiazar et al. 2020, 2021; Mirzababaei et al. 2021; Johari et al. 2022; Opukumo et al. 2022; Seiphoori and Zamanian 2022; Khodabandeh et al. 2023).

In the process of soil stabilization, the bonds between particles are changed. This change leads to the creation of a new structure that has more adhesion than the previous soil structure. In some of these methods, the previous structure of the soil is broken, but in others, by injecting materials, this structure is strengthened and its resistance increases. Soil stabilization can be done on the surface or in depth. In the fixations that take place on the surface, the soil is combined with the desired materials on site using mixing equipment; After that, the desired compaction is obtained by using road-making rollers, small drums or other vibrating equipment. Stabilization with cement, lime and other waste products is widely used in road construction. Also, researches have been done on compounds obtained from soil with salt, acid and base. The obtained results showed that these materials lead to the reduction of leakage in the soil (Evstatiev 1988; Bell et al. 2007; Zhang et al. 2021).

The history of bed soil improvement with various compounds such as lime and cement goes back decades. Nowadays, improvement based on cement compounds is widely used all over the world. Also, some researches have been done on some salts and their effect on reducing the ability to grind. In most of the researches conducted in the field of soil stabilization, the samples have been reconstructed with optimal moisture percentage and maximum dry weight; then, the changes in resistance, optimal moisture content and maximum dry weight of the handmade samples have been investigated. The main goal of this research was to investigate the amount of changes in compaction index in the case of stabilization of compacted soil, to investigate the effect of cement and lime in weight percentages and different density ratios. In addition, the effect of applying suitable processing conditions on the smoothness index of samples stabilized with lime and cement is investigated. Due to the importance of this problematic soil on the railway line, investigating the effects of improving this soil will be of great importance to reduce the risks of the route.

2. MATERIALS AND METHODS

2.1. Physical and mechanical characteristics of collapsing soil

Collapsing soils are among the problematic soils, which cover large areas of the earth's surface equivalent to 10% of continental masses. These areas include continuous deposits from North China to Southeast Europe and scattered areas from North and South America and New Zealand (Jefferson et al. 2008a). Due to the presence of weak cement joints and loamy structure, these soils, especially in the unsaturated state in dry or semi-arid regions, naturally have a specific weight and a low moisture content. In addition, large deformations, rapid settlement and a large decrease in porosity ratio are observed in unstable soils during the increase in moisture content and loading. These soils may be seen in various forms both naturally and artificially made by humans. In order to reduce the effects of these soils, it is necessary to collect information about the locations of these types of soils, the geological characteristics of these areas, as well as the geomorphology of these areas (Al-Obaidi et al. 2013). In Iran and its surrounding areas, there are thick deposits of layered materials that are described as loess (Rahimi et al.; Babanejad et al. 2022; Sharifi Teshnizi et al. 2022).

Collapsing refers to the sudden fall of soil due to the loss of resistance of the binding agent of soil particles, and the amount of looseness created depends on the initial porosity of the soil. They are when saturated (moistened). The main features that make soils show collapse characteristics are (Pells et al. 1975; Sharifi Teshnizi et al. 2022):

• High porosity (more than 40%)

• Low degree of saturation (below 60 percent)

• High amount of litter (more than 30% and sometimes up to 90%)

• Fast softening in water (opening time of windblown samples with high collapse is less than 1 minute).

Collapsing soils are spread in many parts of the world, including Iran. According to the available statistics, collapsing soils occupy approximately 16% of the total area of the earth. Figure 2-3 shows the approximate map of the spread of this type of soil in Iran. Since collapsing soils mostly have a loose and semi-dense or non-dense structure, the existence of these types of soils should generally be expected in areas covered with wind deposits. Experiences from geotechnical studies conducted in different regions of Iran also confirm this and indicate the presence of silty soils in many plains covered with wind-blown sediments such as Gorgan, Mughan, Saveh, central regions and southeastern plains of the country (Fig. 1).

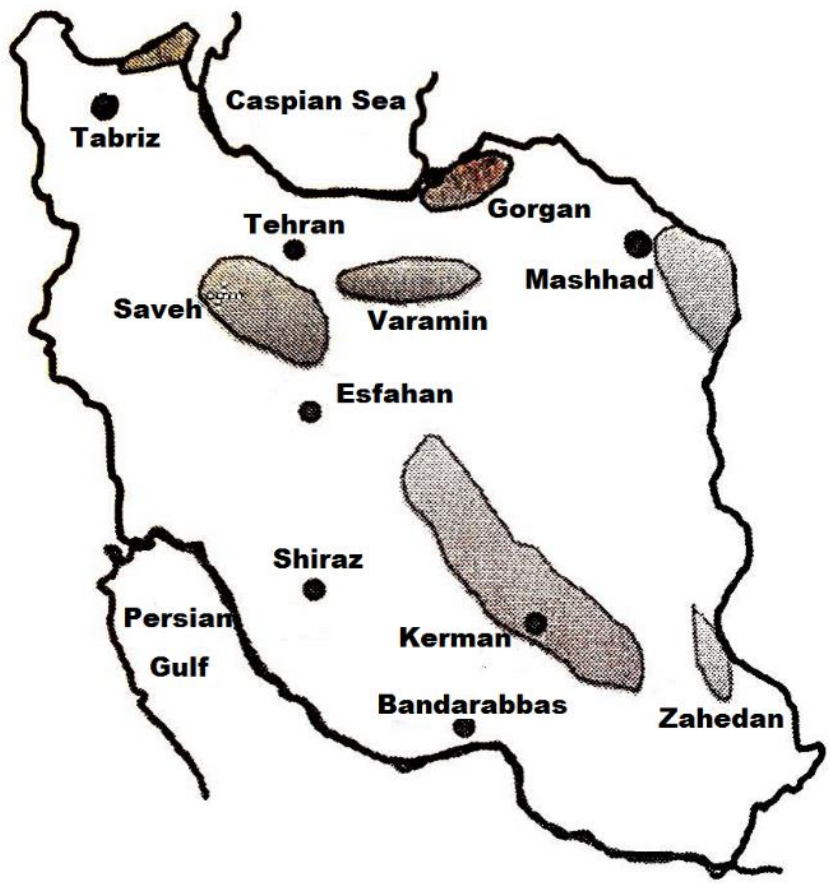

Fig. 1. The spread of collapsing soils in Iran

Collapsing soils are known as loess soils. The word loess comes from the German word meaning loose, which was first used by von-Leonhard to describe a friable layered deposit along the Rhine Valley near Heidelberg. Pye (1995) listed ten criteria to identify loess as follows (Gibbs and Bara 1962; Pye 1995).

A loose deposit with a high percentage of layer particles, without layering, porous, permeable, forming stable vertical walls, easily eroded by water, pea-yellow color (due to scattered particles of limonite), Quartz as the main constituent mineral (40 to 80 percent), feldspar as a secondary mineral, varying percentage of clay (5 to 20 percent) and carbonates (1 to 20 percent). According to him, for most scientific purposes, it is enough to define loess in the following simple way:

A detrital deposit, consisting of layer-sized particles, necessarily formed by the accumulation of wind-borne particles (Clevenger 1958).

• Granulation of collapsing soil:

The particle size distribution curve for loess soils shows that loess are layered soils (lay percentage between 50 and 90%) which also has a small percentage of fine sand and clay.

Loess can be divided into true loess, pseudo- loess, and sandy loess, or in another classification, they can be classified into layered loess, sandy loess, and flat loess (Clevenger 1956). Based on the research conducted on the results of granulation and hydrometric tests on the loess of Sabzevar province, it has been reported that the percentage of silt is between 42 and 85%, which sometimes has a small percentage of fine sand and clay.

• Permeability of collapsing soils:

The permeability of loess in the vertical direction is much higher than its permeability in the horizontal direction, and the reason for this is the increase in the presence of long vertical holes in the structure of loess, which are considered as traces of fossilized plant roots. Loess deposits are better than real clay deposits in terms of drainage (their permeability varies from 10-8 to 10-5 m/s). Unlike clay, loess is not susceptible to frost. The reason for this is their permeability to clay, but like clay, they can show rapid conditions and its compaction is very difficult if not impossible (Clevenger 1956).

• Density of solid particles of collapsing soils:

In loess soils, the range of solid particle density values is limited. For example, loess of this density varies from 2.65 to 2.7 (Bell 2013).

• Specific dry weight of collapsing soils:

The initial dry specific gravity is an effective factor on soil collapse, and with the increase of the initial dry density, as seen in Fig. 6-2, the collapse potential decreases.

The range of dry density varies from very low to low (for example, in Los Camlapes, British Columbia, dry density ranges from 1.4 to 1.46 grams per cubic centimeter), the low density is reflected in the ratio of porosity. Lunger found that the density of undisturbed loess in the Missouri Basin ranges from 1.2 to 1.36 g/cm3. Also, if these materials become wet or dense, the density increases and sometimes reaches 1.6 grams per cubic centimeter (Clevenger 1956, 1958).

• Porosity ratio:

In the case of some Chinese loess, the ratio of porosity varies from 0.81 to 0.89 and porosity from 45 to 55% (Thornton 1972).

• Paste properties:

In loess soils, the pasty property varies from low to medium, the pasty property in these soils increases with the increase in clay percentage. The limits of flow range from 25 to 35% and exceptional values for clay loess vary up to 45%. The reported pulp index values are between 5 and 22%. Fig. 7-2 shows the pasty properties of Missouri Basin loess (Clevenger 1956, 1958).

• Fluidity limit:

The fluidity limit of soil was first defined by Etterberg as follows: The fluidity limit is the amount of moisture at which the soil moisture changes from a semi-solid state to a liquid state. A more recent definition of the soil's fluidity limit is the degree of humidity at which the soil particles maintain their natural state, but there is no binding force between the particles. The new definition better explains what is happening in collapsing soils. In general, in collapsing soils, especially in loess with low clay percentage, if the natural soil moisture is close to the psychological soil moisture, it will cause the soil skeleton to collapse and lose its strength. If the soil moisture is more than the psychological limit, the soil will be subjected to an external load and will undergo compaction. This type of soil instability can be explained by the psychological index (Gibbs and Bara 1967; Handy 1973). In this case, when LI is equal to or greater than unity, the soil will be compacted. A criterion has been suggested for areas where the thickness of the soil is more than ten meters (Clevenger 1958; Gibbs and Bara 1967).

• Shear strength:

The shear resistance of loess is significant in the percentage of natural moisture, so that even if their volumetric weight is low, they can remain stable as a vertical wall at a height of 15 to 24 meters without support. At low humidity, loess has high shear resistance coefficients due to the locking of soil particles and cementation (Clevenger 1958; Gibbs and Bara 1967). The apparent stickiness of the soil cannot reach kg/cm2, which decreases to 0.75 kg/cm2 due to wetting.

2.2. The study area

The sampling site was in Semnan province, in the area between Damghan and Sabzevar, near the railway tracks. Fig. 2 shows the location of sampling in this research. According to the visits made, this area was selected as the study area in this research. Fig. 3 shows the condition of the soil in the region and the grooves caused by the effects of the soil, and Fig. 4 shows the location of the sampling site and the position of the railway station in relation to the position of the problematic soil.

It is worth mentioning that the sampling was done in two ways, sampling in the form of disturbed soil, which was used using a shovel to determine the physical characteristics of the soil, and sampling in the form of intact soil, that this method was used using 30 x 30 x 30 cm boxes. In the intact sampling method, sampling was done in such a way that the percentage of soil moisture did not decrease or change and the soil texture was not damaged, so these samples were used for mechanical and shear tests as well as for improvement time. It is worth mentioning that aluminum foil along with paraffin was used around this sample, the purpose of this work was to prevent the change of the moisture percentage of the sample.

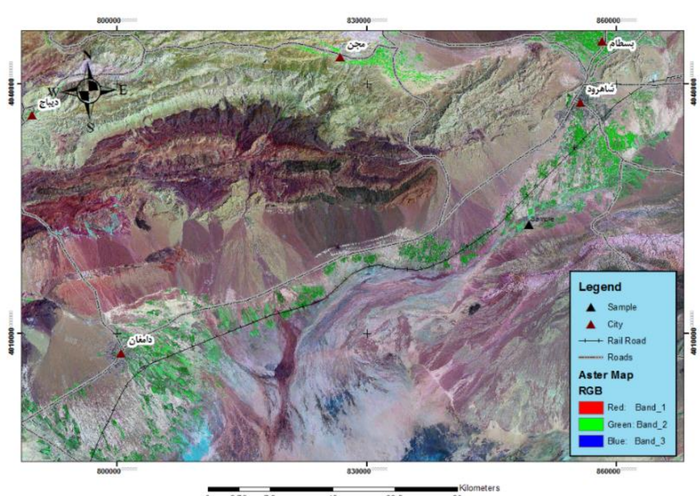

Fig. 2. The location of the study area and sampling location in this research

Fig. 3. Collapsing Soil condition in the study area

Fig. 4. Sampling location and the position of the created channels in relation to the railway

2.3. Laboratory flowchart

Fig. 5 shows the method of sampling along with the method of related tests. The characteristics of the sampling site and soil sampling method are explained in this research and its results. In this research, additive materials with percentages of 5 and 10 percent have been used to improve problematic soil.

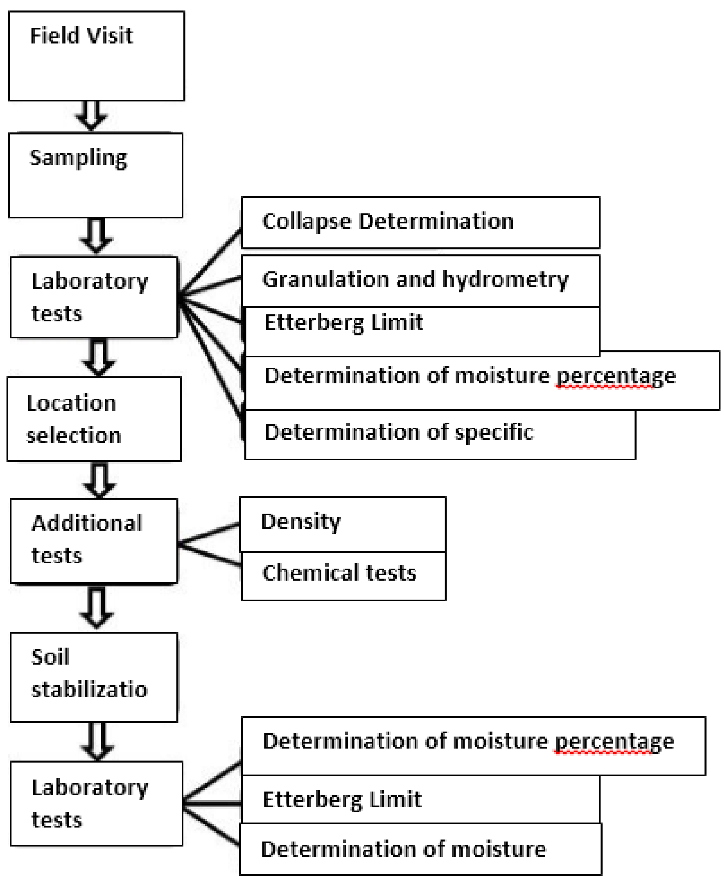

Fig. 5. Flowchart of how to conduct studies in this research

2.4. Additive materials

Additives include lime and cement, whose characteristics are discussed below.

• Lime

The lime used in this research is the type of shale that has been passed through sieve number 100 and its pH is about 12.81. Chemical analysis of lime using XRF test is shown in Table 1.

Table 1. Chemical analysis of lime

SiO2	CaO	Al2O3	Fe2O3	MgO	K2O+Na2O	L.O.I
1.71	72.26	0.7	0.2	0.2	0.1	**23.83**

• Cement

In this research, type II cement from Bukan cement factory in the northwest of Iran was used, and the results of its physical and chemical properties are shown in Table 2.

Table 2. Cement analysis results

Properties	Vale
Physical properties	
Density ^{3})m/g(	3.005
Fineness	1.54
Chemical properties	
SIO_2 (%)	23.13
AL_2O_3 (%)	5.53
Fe_2O_3 (%)	3.51
CaO (%)	58.95
MgO(%)	1.18
Na_2O(%)	0.33
K_2O(%)	0.85
So_3(%)	2.19
Insoluable Residue	6.36
[1]L.O.I	3.41
Free Cao	0.88
Na2o +0.658K2O	

• Water

The water used in this research was distilled water for all the experiments.

[1] Loss on ignition

3. RESULTS

3.1. Base soil test results

After sampling, the samples were transferred to the laboratory for laboratory tests, and according to ASTM and ASSHTO standards, relevant tests were performed to perform physical and mechanical properties. At first, to determine the characteristics of the base soil, relevant tests were conducted on it, and the results are discussed below.

• Granulation characteristics of the base soil

Fig. 6 shows the granulation status of the used materials, based on the granulation done, and the percentage of different sizes of materials is shown in Table 3. In this research, it is considered from the fine-grained soil sample for improvement that this soil sample is of ML type, which is shown in Fig. 6 of the graining curve of the soil sample used in this research. Table 4 shows the characteristics and size of soil particles used in this research. In Fig. 7, the location of the soil sample used in this research is shown in the plasticity diagram. Based on the USDA soil classification system used in this research, it is classified as Silt Loam.

• Consolidation parameters

In addition to the physical parameters, the consolidation parameters were examined, which was done based on the ASTM D5333-03 standard, which is used to measure the subsidence potential of soils.

In this test, it is done by using the consolidation test with the use of an oeometer device, taking into account the vertical pressure until reaching the real pressures of the ground. In this test, the soil is subjected to the influence of water and becomes saturated, and at this stage, the possible shapes due to the subsidence of the soil were recorded per square centimeter loaded in natural humidity and then it is done with weights of 1, 2, 4 and 8 kg/cm2. Fig. 8 and Table 4 show the characteristics and results obtained from double consolidation on natural soil.

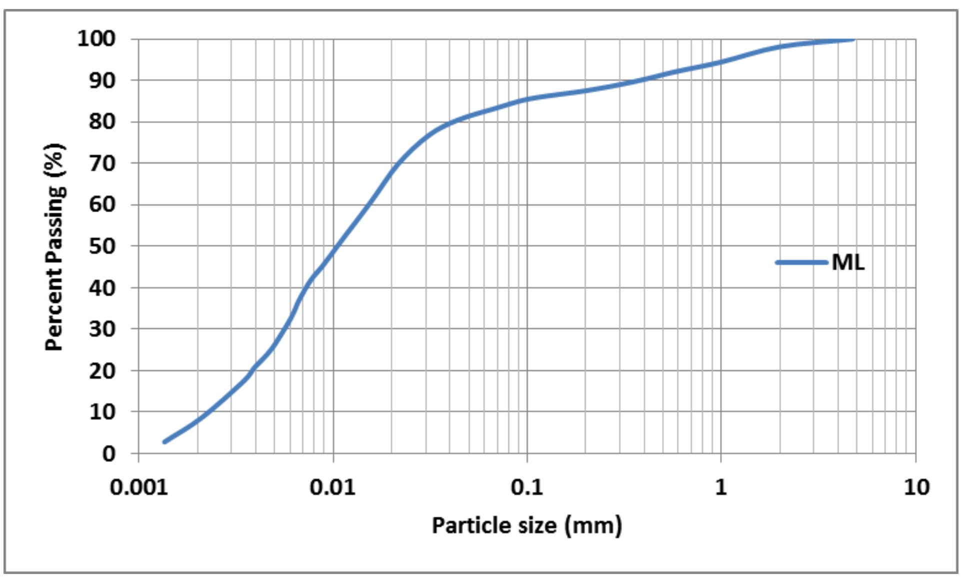

Fig. 6. The situation of the granulation curve of the materials used in this research

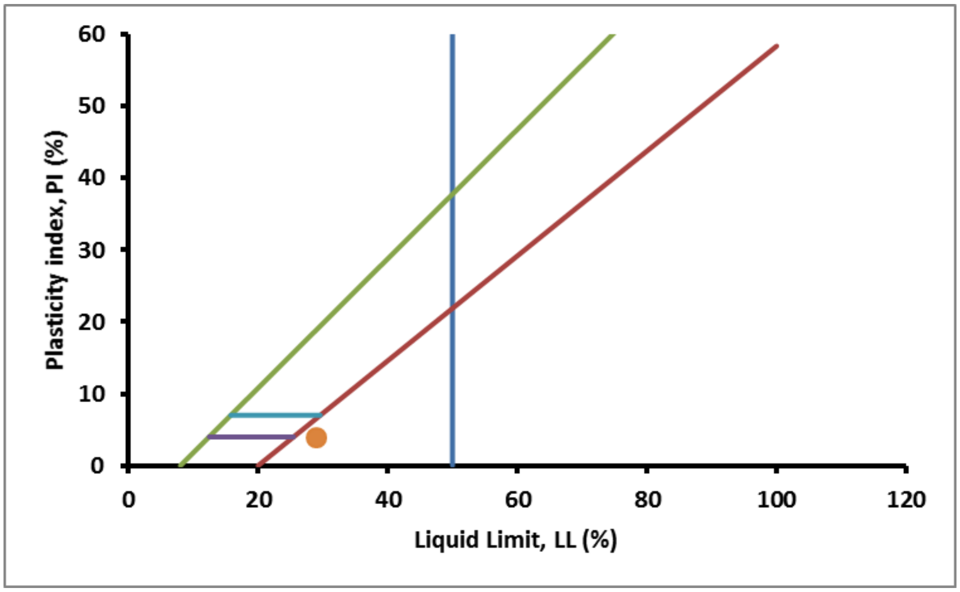

Fig. 7. The position of the sample in the plasticity diagram

Table 3. Characteristics of the soil used in this research

Soil	Specifications
0	Gravel (%)
15	Sand (%)
76,4	Silt (%)
8,6	Clay (%)
29	LL
25	PL
4	PI
16,8	w (%)
1,34	□$_d$(gr/cm^3)
0.0022	D10
0.0055	D30
0.016	D60
2.56	GS
ML	Unified Classified
0.47	Activity(%)

• Consolidation parameters

In addition to the physical parameters, the consolidation parameters were examined, which was done based on the ASTM D5333-03 standard, which is used to measure the subsidence potential of soils.

In this test, it is done by using the consolidation test with the use of an oeometer device, taking into account the vertical pressure until reaching the real pressures of the ground. In this test, the soil is subjected to the influence of water and becomes saturated, and at this stage, the possible shapes due to the subsidence of the soil were recorded per square centimeter loaded in natural humidity and then it is done with weights of 1, 2, 4 and 8 kg/cm2. Fig. 8 and Table 4 show the characteristics and results obtained from double consolidation on natural soil.

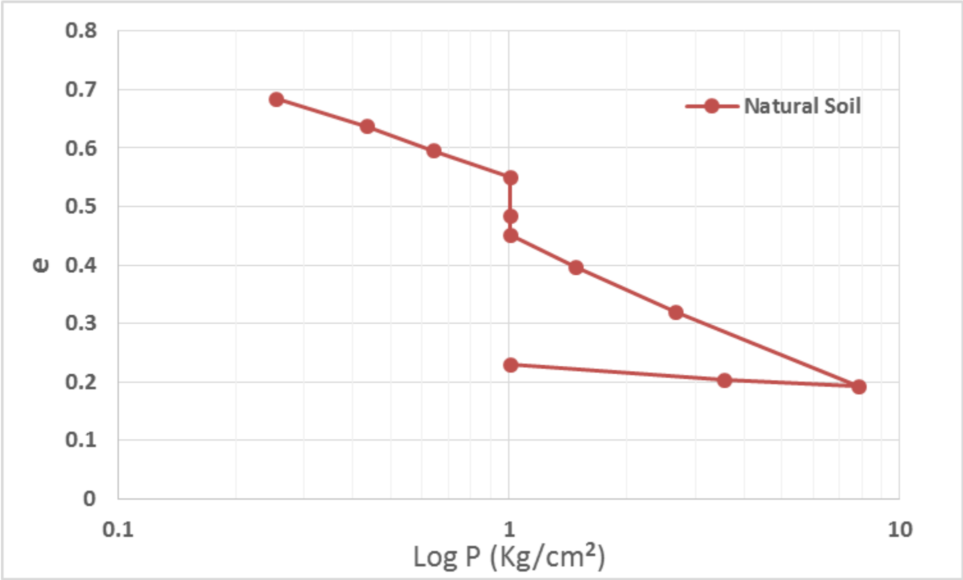

Fig. 8. Double consolidation test curve on the base soil sample

Table 4. Parameters obtained from the consolidation test for the soil used in the study area

No.	e_0 (%)	e_1 (%) Before saturation	e_2 (%) After saturation	W_0 (%)	e_f (%)	Cc Before saturation	Cc After saturation	Cs	Gs
1	0,88	0,55	0,45	6	0,2	0,24	0,31	0,048	2,56

• Triaxial CU test

This test is the parameters of soil shear strength. The triaxial test is a more complex and reliable method than other tests to determine the shear strength of soils. One of the methods for determining the shear parameters of the soil is the triaxial test using the CU method, which is based on the ASTM D2850 standard. In this method, the drained type is under hydrostatic pressure during consolidation, and at the time of the test, drainage is not done by closing the drainage valves until the soil breaks. 5 parameters obtained from the triaxial test are shown. Fig. 9 shows the amount of changes in the stress-strain curve in the triaxial test in the studied soil.

Table 5. Parameters obtained from the triaxial test for the soil used in the study area

No.	Sr_0 (%)	W_0 (%)	γ_d (gr/cm^3)	Cu (Kg/cm^2)	ϕ_u (Deg)	C' (Kg/cm^2)	ϕ' (Deg)
1	23	6	1.31	0.7	5.6	0.55	12.98

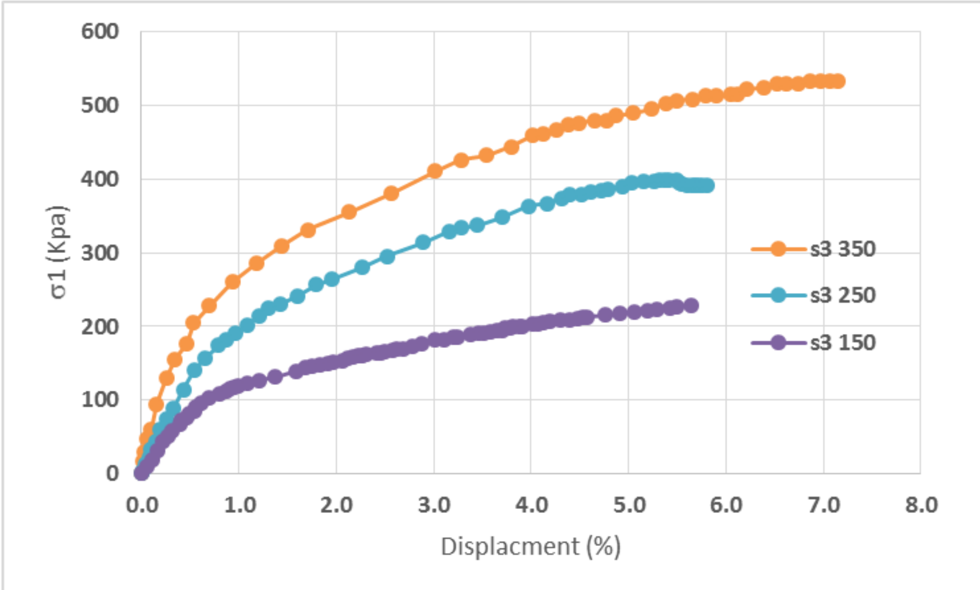

Fig. 9. The stress-strain curve of the triaxial test in the soil of the studied area

3.2. Soil test results with additives

In this research, according to the obtained results, it shows that the soil of the studied area is of collapsing type, which can cause changes in soil parameters due to saturation and cause many problems, so it needs to be improved with Paying attention to the evidence in the region and quick access to traditional additives, traditional lime and cement additives were used. The results of these additions are fully explained below.

3.2.1. Effects of additives on consolidation parameters

• The effect of lime additive percentage on consolidation parameters

In order to improve the consolidation parameters, in this research, 5 and 10% lime percentages were used to improve the parameters. Fig. 10-4 shows the amount of changes made in the consolidation chart at different percentages of lime. Table 7 and Fig.s 10 to 12 show how to improve consolidation parameters in soil added with different percentages of lime.

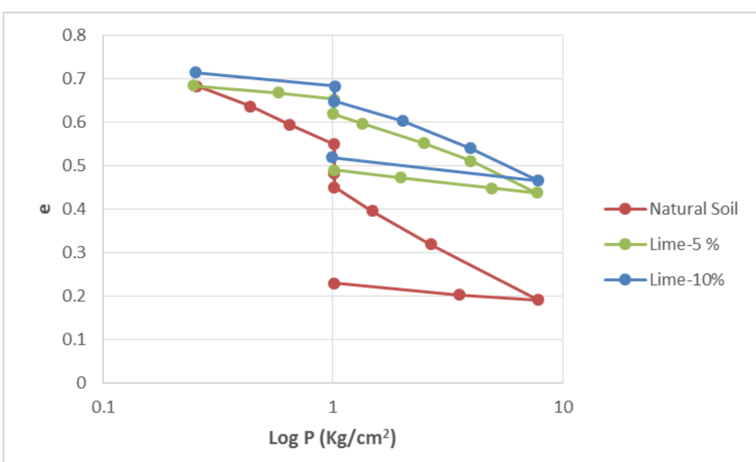

Fig. 10. Change of consolidation curves with lime addition

Table 7. Parameters obtained from the consolidation test for the soil used in the study area

Additive percentage	e_0 (%)	e_1 (%) Before saturation	e_2 (%) After saturation	W_0 (%)	e_f (%)	Cc Before saturation	Cc After saturation	Cs	Gs
5 %	0,79	0,68	0,65	6	0,47	0,06	0,22	0,059	2,59
10 %	0,75	0,64	0,62	6	0,44	0,058	0,21	0,061	2,61

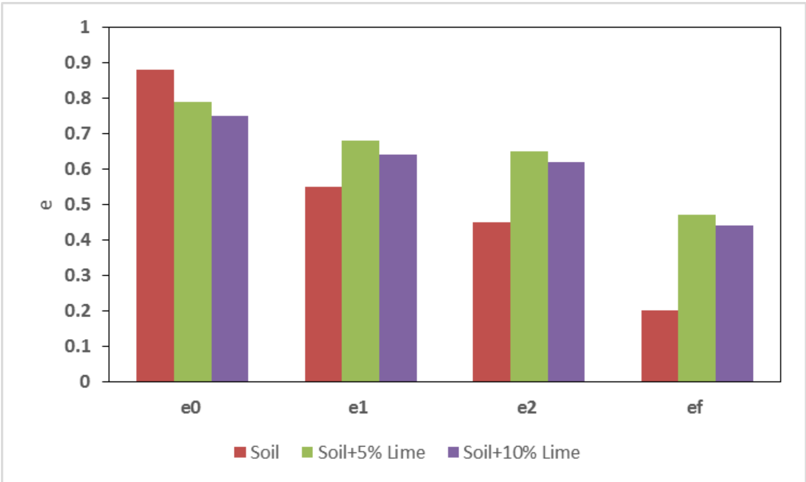

Fig. 11. The state of changes in different porosity ratio parameters in the consolidation test with different percentages of lime addition

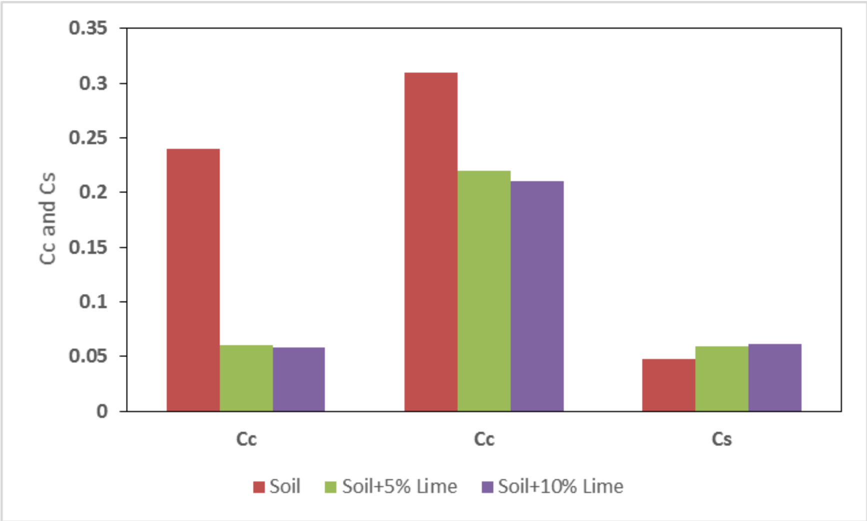

Fig. 12. The state of changes in the parameters of the consolidation indices in the consolidation test with different percentages of lime addition

According to the results, it shows that by adding lime, it is effective in controlling and increasing the parameters of soil compaction. So that at the time of adding 5% additive to the soil, it settled about 0.036 cm, and after adding 10% additive, the amount of soil settlement was about 0.03 cm, which shows the improvement in the amount of soil settlement when the soil is saturated. According to the results, it shows that the collapsing soil with the addition of 5 to 10% of lime controls the Collapse and the collapsing index has changed to a low level according to ASTM.

• Cement additive percentage in improving consolidation parameters

In order to improve the consolidation parameters, in this research, 5 and 10% cement percentages were used to improve the parameters. Fig. 13 shows the amount of changes made in the consolidation chart in different percentages of cement. Table 8 and Fig.s 14 and 15 show how to improve consolidation parameters in soil added with different percentages of cement.

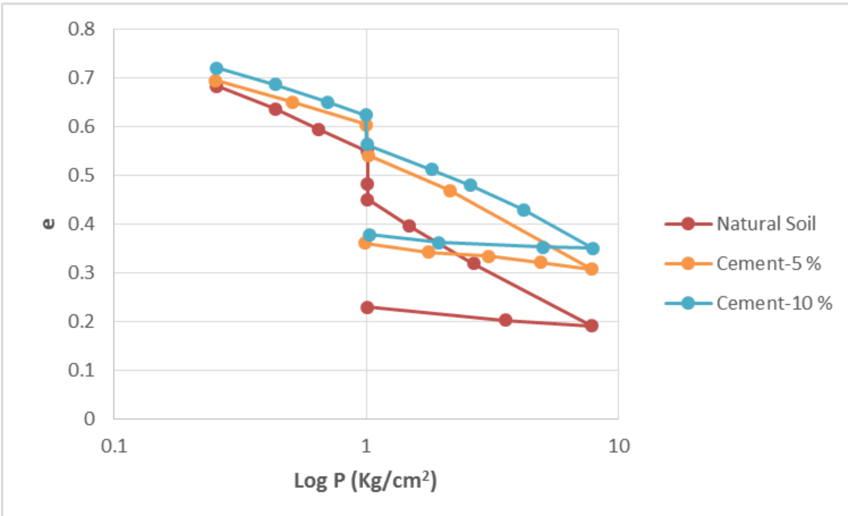

Fig. 13. Change of consolidation curves with cement additive

Table 8. Parameters obtained from the consolidation test for the soil used in the study area

Additive percentage	e_0 (%)	e_1 (%) Before saturation	e_2 (%) After saturation	W_0 (%)	e_f (%)	Cc Before saturation	Cc After saturation	Cs	Gs
5 %	0,85	0,605	0,54	6	0,31	0,22	0,264	0,05	2,65
10 %	0,78	0,62	0,56	6	0,35	0,17	0,33	0,033	2,67

According to the results, it shows that by adding cement, it is effective in controlling and increasing the parameters of collapsing soil, that the more the amount of cement added to the soil increases, the reduction of collapsing index is added, and the amount of soil settlement is also reduced. So that at the time of adding 5% additive to the soil, it settled about 0.062 cm, and after adding 10% additive, the amount of soil settlement was about 0.038 cm, which shows the improvement in the amount of soil settlement when the soil is saturated.

According to the results, it shows that the collapsing soil with the addition of 5 to 10% of cement controls the compaction and the compaction index has changed to the medium category according to ASTM.

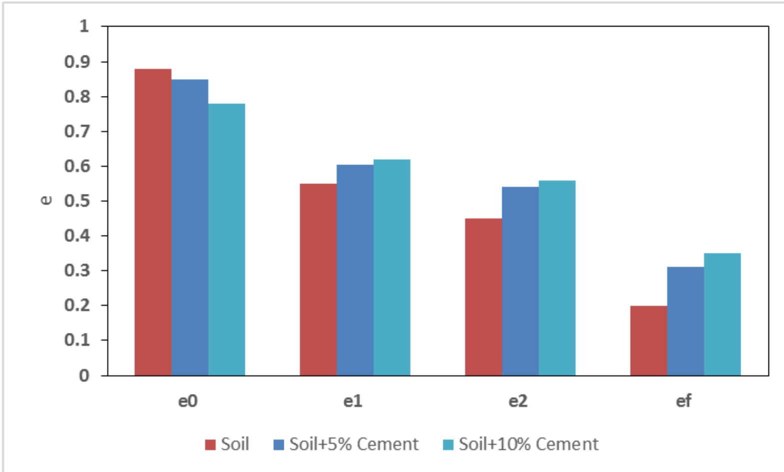

Fig. 14. The state of changes in different porosity ratio parameters in the consolidation test with different cement additive percentages

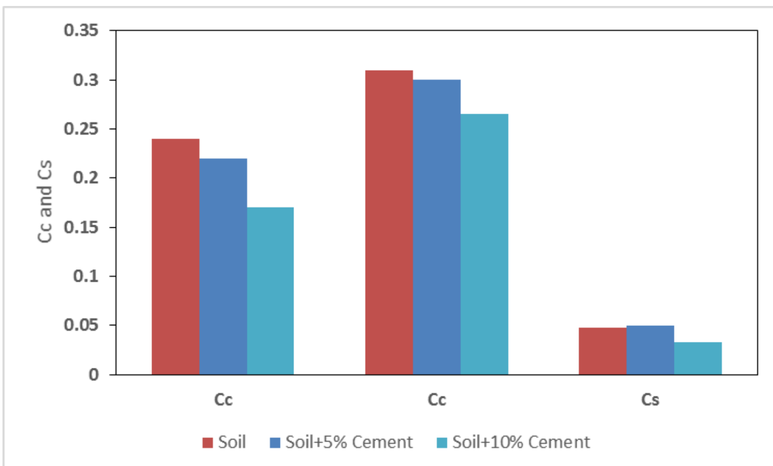

Fig. 15. The state of changes in the parameters of consolidation indices in the consolidation test with different percentages of cement additives

3.2.2. The effect of additives on the triaxial shear parameters of CU

Below, we explain the effects of additives on the shear properties shown in the triaxial CU test.

• The effect of lime additive percentage on shear parameters

In order to improve the shear parameters in this research, at first, 5 and 10% lime percentages were used to improve the parameters. Fig.s 16 and 17 show the changes in adhesion and internal friction angle of the soil in different percentages of lime. According to the obtained results, it shows that the addition of lime increases the shear parameters of the soil so that the friction angle increases in both cases, which indicates the increase of the shear parameter in this type of soil obtained by adding lime. According to the increase in the friction angle, it shows that in this case, there is a decrease in adhesion in the soil, which indicates an improvement in the behavior of the soil after the desired addition to the soil.

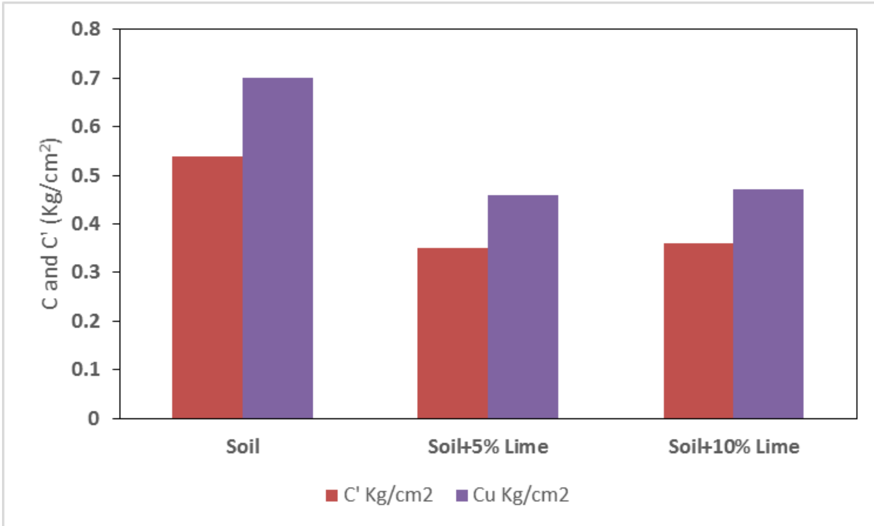

Fig. 16. The state of changes in soil adhesion parameters in the triaxial test with different percentages of lime addition

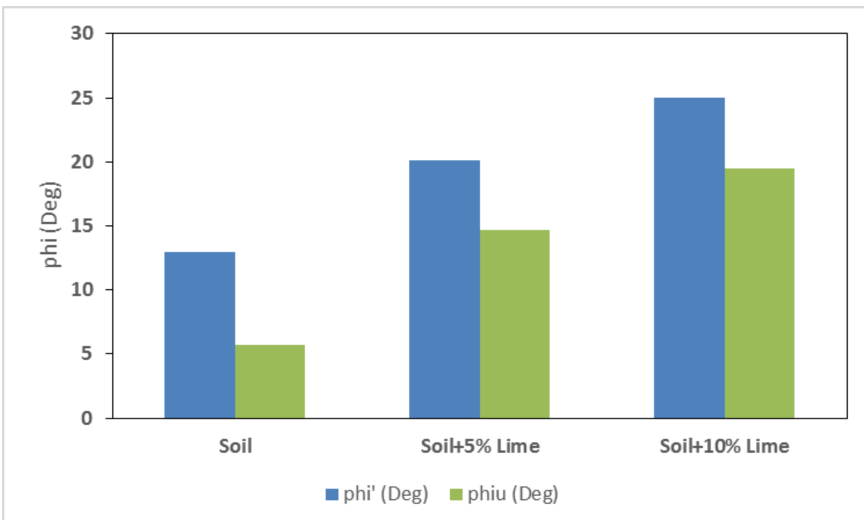

Fig. 17. The state of changes in soil friction angle parameters in the triaxial test with different percentages of lime addition

• The effect of cement additive percentage on shear parameters

In order to improve the shear parameters in this research, 5 and 10% cement percentages were used to improve the parameters. Fig.s 18 and 19 show the changes in the adhesion and internal friction angle of the soil in different percentages of cement. According to the obtained results, it shows that the addition of cement percentage increases the shear parameters of the soil so that the friction angle increases in both cases, which indicates the increase of the shear parameter in this type of soil obtained by adding cement. According to the increase in the friction angle, it shows that in this case, there is a decrease in adhesion in the soil, which indicates an improvement in the behavior of the soil after the desired addition to the soil.

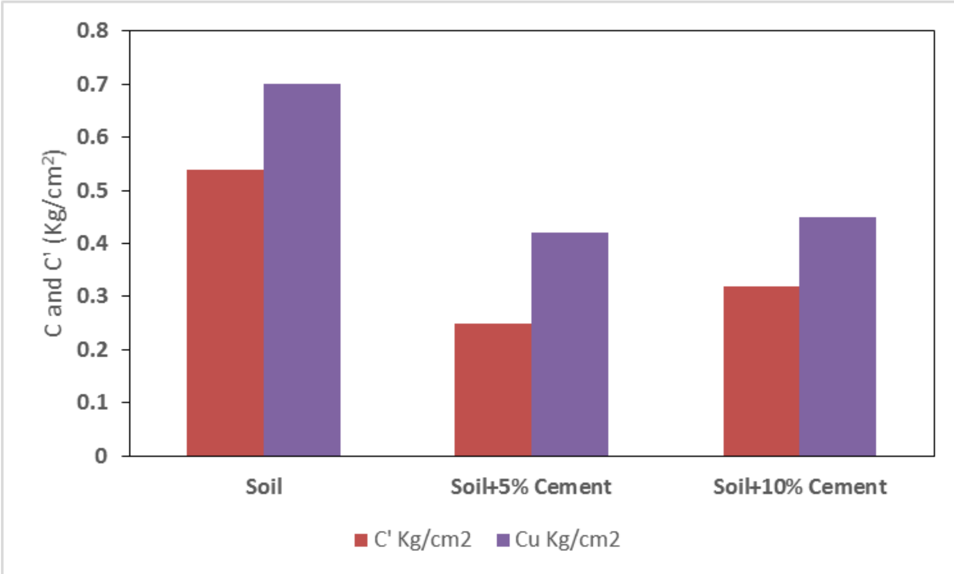

Fig. 18. The state of changes in soil adhesion parameters in the triaxial test with different cement additive percentages

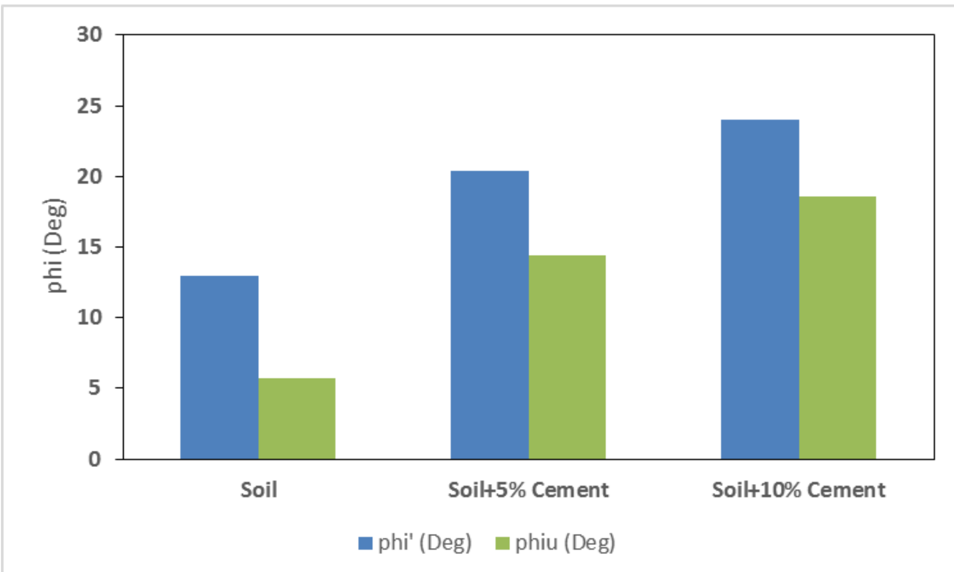

Fig. 19. The state of changes in soil friction angle parameters in the triaxial test with different percentages of cement addition

4. SUMMARY

According to the results obtained, the base soil was evaluated based on different criteria, the results of which are shown in Table 9. Based on these relationships and criteria, it shows that the said soil is in the category of medium to high leveling, so it will need to be improved. According to the obtained results, the desired soil should be evaluated. which was done in this research to improve traditional lime and cement additives.

Table 9. The condition of the soil under study based on the criteria of reclamation

No.	Criterion	Criterion result
1	Cloninger criterion	Medium Collapse
2	Bering et al. criterion	Medium Collapse
3	Schwartz and Bates criterion	Medium Collapse
4	Kasf and Henken criterion	Medium Collapse
5	Holtz and Hilfe criterion	Weak Collapse
6	Indian criterion	High collapse
7	Eyadat and Balvaheri criterion	The possibility of collapse
8	Eyadat and Oli criterion	The soil is susceptible to collapse
9	Eyadat and hana criterion	Collapsing soil
10	Abelf criterion	High collapsing soil
11	Jennings and Knight criterion	Intense collapsing soil
12	ASTM D5333 standard	Relatively intense collapsing soil

The results obtained regarding the addition of cement and lime to the compacted soil show that the compaction index in the addition of lime is better than that of cement, which is shown in Fig. 20. With the increase of lime, the soil has a 68% and 78% decrease in soil compaction index, respectively, but when cement is added to the soil, it causes a 34% and 37% improvement in the compaction index.

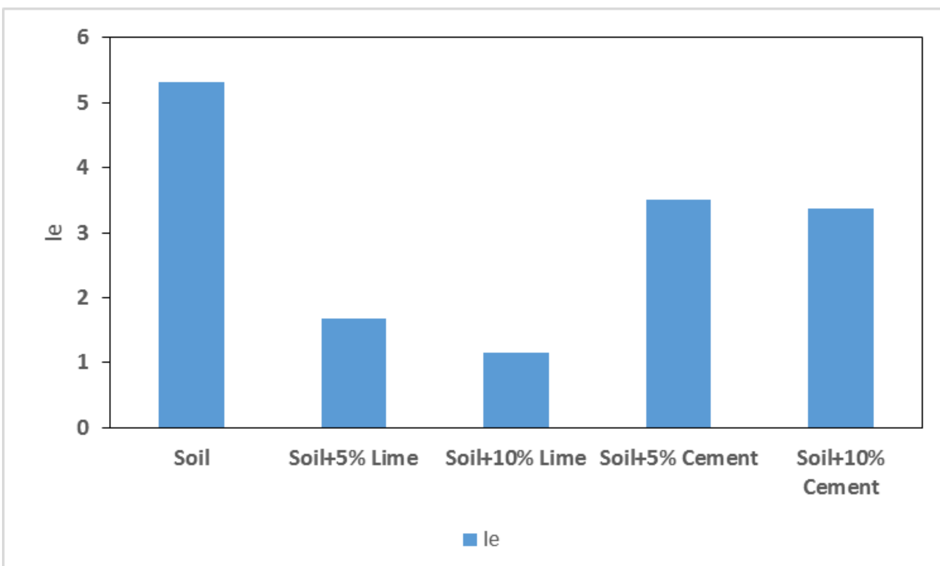

Fig. 20. Changes in soil compaction index in relation to the percentage of different additives

5. RESULTS

The obtained results show that the soil of the studied area is of the type of soil and the indices of the two criteria of Jenning and Kinght (1975) and ASTM (2003) have a more appropriate assessment of the state of the area. Therefore, according to these conditions, other soils of this region can be evaluated from this criterion. According to the obtained results, it shows that with the traditional additions of lime and cement, it is possible to improve the collapse index of these soils. According to the obtained results, it shows that lime can increase the parameters of the soil and especially the index of soil compaction compared to cement due to the greater reaction of this soil. With the addition of lime and cement, the shear properties of the soil have been improved so that the friction angle in the soil has increased, which indicates the improvement in the soil parameters.

REFERENCES

Abbeche K, Bahloul O, Ayadat T, Bahloul A (2010) Treatment of collapsible soils by salts using the double consolidation method. In: Experimental and Applied Modeling of Unsaturated Soils. pp 69–78

Al-Obaidi QAJ, Ibrahim SF, Schanz T (2013) Evaluation of collapse potential investigated from different collapsible soils. In: Multiphysical testing of soils and shales. pp 117–122

Babanejad M, Beheshtian M, Jamshidi F, et al (2022) Genetic etiology of hearing loss in Iran. Hum Genet 141:623–631. https://doi.org/https://doi.org/10.1007/s00439-021-02421-w

Bell FG (2013) Engineering geology and geotechnics. Elsevier

Bell KR, Baka JE, Galagoda M (2007) Installation and instrumented load testing of Deep Soil Mixing columns. In: 7th FMGM 2007: Field Measurements in Geomechanics. pp 1–14

Clevenger WA (1958) Experiences with loess as foundation material. Trans Am Soc Civ Eng 123:151–169

Clevenger WA (1956) Experiences with loess as foundation material. J Soil Mech Found Div 82:1021–1025

Cui S, Xie W, Wang J, Huang S (2019) Engineering Properties of Collapsible Loess Stabilized by Cement Kiln Dust. Soil Mech Found Eng 56:328–335. https://doi.org/10.1007/s11204-019-09610-w

Evstatiev D (1988) Loess improvement methods. Eng Geol 25:341–366

Gibbs H, Bara J (1962) Predicting surface subsidence from basic soil tests. In: Field Testing of Soils. ASTM International

Gibbs HJ, Bara JP (1967) Stability problems of collapsing soil. J Soil Mech Found Div 93:577–594

Handy RL (1973) Collapsible loess in Iowa. Soil Sci Soc Am J 37:281–284

Houston WN, Nelson JD (2012) The state of the practice in foundation engineering on expansive and collapsible soils. In: Geotechnical Engineering State of the Art and Practice: Keynote Lectures from GeoCongress 2012. pp 608–642

Jefferson I, Evstatiev D, Karastanev D (2008a) The treatment of collapsible loess soils using cement materials. In: GeoCongress 2008: Geosustainability and geohazard mitigation. pp 662–669

Jefferson I, Evstatiev D, Karastanev D (2008b) The Treatment of Collapsible Loess Soils Using Cement Materials. Am Soc Civ Eng GeoCongress 2008 - New Orleans, Louisiana, United States (March 9-12, 2008)-GeoCongress 2008 662–669. https://doi.org/10.1061/40971(310)82

Jefferson I, Rogers C, Evstatiev D, Karastanev D (2005) Treatment of metastable loess soils: Lessons from Eastern Europe. In: Elsevier geo-engineering book series. Elsevier, pp 723–762

Johari A, Golkarfard H, Davoudi F, Fazeli A (2022) Experimental investigation of collapsible soils treatment using nano-silica in the Sivand Dam Region, Iran. Iran J Sci Technol Trans Civ Eng 46:1301–1310. https://doi.org/10.1007/s40996-021-00675-y

Karimiazar J, Mahdad M, Teshnizi ES, Karimizad N (2020) Assessing the geotechnical properties of soils treated with cement and nano-Silica additives. JOJ Sci 2:56–59. https://doi.org/10.19080/JOJS.2020.02.555587

Karimiazar J, Sharifi Teshnizi E, Mirzababaei M, et al (2021) California bearing ratio of a reactive clay treated with nano-additives and cement. ASCE J Mater Civ Eng In Press: https://doi.org/10.1061/(ASCE)MT.1943-5533.0004028

Karimizad N, Teshnizi ES, Mahdad M, Karimiazar J (2020) Investigating the design features of CSG dams. JOJ Sci 2:60–66. https://doi.org/10.19080/JOJS.2020.02.555588

Khodabandeh MA, Nagy G, Török Á (2023) Stabilization of collapsible soils with nanomaterials, fibers, polymers, industrial waste, and microbes: Current trends. Constr Build Mater 368:130463. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2023.130463

Mirzababaei M, Karimiazar J, Sharifi Teshnizi E, et al (2021) Effect of nano-additives on the strength and durability characteristics of marl. Minerals 11:1–15. https://doi.org/10.3390/min11101119

Munfakh GA (2003) Ground improvement in transportation projects: from old visions to innovative applications. Proc Inst Civ Eng Improv 7:47–60. https://doi.org/10.1680/grim.2003.7.2.47

Murthy VNS (2007) Advanced foundation engineering. CBS publishers \& distributors New Delhi

Opukumo AW, Davie CT, Glendinning S, Oborie E (2022) A review of the identification methods and types of collapsible soils. J Eng Appl Sci 69:1–21. https://doi.org/https://doi.org/10.1186/s44147-021-00064-2

Pells P, Robertson A, Jennings JE, Knight K (1975) A guide to construction on or with materials exhibiting additional settlement due to" Collapse" of grain structure

Pye K (1995) The nature, origin and accumulation of loess. Quat Sci Rev 14:653–667

Rahimi E, Ebrahim &, Teshnizi S, et al Cement take estimation using neural networks and statistical analysis in Bakhtiari and Karun 4 dam sites, in south west of Iran. https://doi.org/10.1007/s10064-018-1271-0

Rollins KM, Kim J (2010) Dynamic compaction of collapsible soils based on US case histories. J Geotech Geoenvironmental Eng 136:1178–1186. https://doi.org/https://doi.org/10.1061/(ASCE)GT.1943-5606.0000331

Sariosseiri F, Muhunthan B (2008) Geotechnical properties of Palouse loess modified with cement kiln dust and Portland cement. In: GeoCongress 2008: Characterization, Monitoring, and Modeling of GeoSystems. pp 92–99

Seiphoori A, Zamanian M (2022) Improving mechanical behaviour of collapsible soils by grouting clay nanoparticles. Eng Geol 298:106538. https://doi.org/https://doi.org/10.1016/j.enggeo.2022.106538

Sharifi Teshnizi E, O'Kelly BC, Karimiazar J, et al (2022) Effects of cement kiln dust on physicochemical and geomechanical properties of loess soil, Semnan Province, Iran. Arab J Geosci 15:1482. https://doi.org/10.1007/s12517-022-10751-w

Thornton SI (1972) Collapsible silts in Louisiana. Louisiana State University and Agricultural & Mechanical College

Zhang Y, Yao Y, Du W, Zhou H (2021) Experimental study on improvement design of loess curing in engineering environment. Bull Eng Geol Environ 80:3151–3162. https://doi.org/https://doi.org/10.1007/s10064-021-02112-w