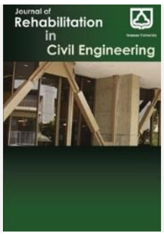

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Experimental Study on Lime-Stabilization of Isfahan Landfill

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ABSTRACT

Utilization of landfills for possible construction projects requires investigation and improvement of geomaterials in these areas. In this research, the effects of lime on improving the behavior of soil materials in Isfahan landfill were investigated through a series of laboratory experiments. Unstabilized and stabilized samples with 3 %, 6 % and 9 % lime were tested. Direct shear tests under different overburden and falling head permeability tests were conducted. X-ray diffraction tests were also performed to check the structure of the samples. Also, the scanning electron microscope images of the tested samples were prepared and compared. The results indicate that the lime-stabilization improves the stress-strain behavior of the treated samples. At the strains greater than 1 %, the positive effect of lime-stabilization of treated soil samples is obvious. Tests results indicate that the optimal amount of lime for Isfahan landfill's soil stabilization is 6 %. Stabilization of samples with 6% lime under vertical overburden stresses of 0.5, 1 and 2 kg/cm^2 increases the maximum shear strength of the samples by 113.95 %, 30.95 % and 9.88 %, respectively. The results show that the permeability coefficient of stabilized samples decreases with the increase of lime content. Stabilization using 3 %, 6 % and 9 % lime has resulted in a decrease of 14.66 %, 84.83 % and 93.62 % of the permeability coefficient of the landfill soil samples compared to the unstabilized samples, respectively. The results also show that the decreasing rate of permeability coefficient is increasing up to 6 % of lime and beyond that has decreased.

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1. Introduction

Soil contamination affects the soil specifications and consequently the soil behavior under applied loads. Therefore, improvement in resistance characteristics of such soils requires the investigation of different improvement and stabilization methods [1]. Areas around landfills are prone to the soil contamination problems, due to the leachates [2–5].

Shear behavior of the materials from the landfills in San Francisco was investigated by Bray et al. [6] using triaxial and simple shear laboratory studies. The composition of landfill materials was the effective parameter on the behavior of the tested samples. Cetin et al. [7] studied the effects of tire-chips, which constitute a significant part of the landfills, on clayey soil behavior. Their results indicate that the mixture of such materials with soil can be used as a filling material. Geotechnical characteristics of one of the largest landfills in China was studied by Feng et al. [8]. Their results had been considered as an effective step in utilization of the studied landfill. Kumar and Kumari [9] investigated the performance of different clay liner around landfills. They compared the geotechnical specifications of liners with various materials. Woods et al. [10] introduced the dynamic compaction as one of the improvement methods for landfills. Effects of various rubber materials on shear behavior of the materials from one of India's landfills was investigated by Singh and Uchimura [11] using direct shear experiments. Their results demonstrated that the landfill contamination, significantly affects shear resistance of geomaterials.

Karimpour-Fard et al. [12] investigated the landfill material behavior using large scale triaxial experiments. The results indicated that the presence of fibers in test samples have led to higher shear resistance. The results of experimental studies on geotechnical characteristics of soil materials around the landfill in Saravan demonstrate a reduction in uni-axial resistance due to the contamination propagation to the adjacent areas [13]. Using laboratory studies, Ouria and Farsijani [14] investigated the effects of leachate on the resistance parameters of clayey soils with low and high plasticity. The results demonstrated the significant effect of the leachate on consolidation and shear behavior of the samples. The seismic response of Tehran's landfill was investigated using shake table experiments [15]. It was concluded that geosynthetic layers would improve the seismic performance of the landfill. Falamaki et al. [16] studied the effects of temperature on shear resistance of the landfill materials. According to this study, the shear resistance decreased by increasing the temperature. Physical and mechanical specifications of Tabriz landfill was analyzed by testing samples with different ages [17]. The results indicate a significant change in material properties with time. The reason was described as the change in the landfill ingredient materials. Experimental studies on stabilized soils indicated that curing condition have an important role on mechanical strength of samples [18,19].

In this study, the behavior of samples from Isfahan landfill was investigated through experimental program. Direct shear and permeability tests were performed on unstabilized and stabilized samples with different lime contents. Effects of the lime on shear resistance and permeability coefficient of the Isfahan landfill's samples were investigated. The optimum lime content required for improvement of the landfill material behavior was evaluated. X-ray diffraction tests were performed in order to study the structure of the samples. Moreover, the scanning electron microscope images of the tested samples were prepared and compared.

Journal Pre-proof

2. Isfahan landfill

The study focuses on the Isfahan landfill which is located at approximately 45 km east of Isfahan city, Isfahan province, Iran. Location of the landfill is shown in Fig. 1. The piping and sloping of Isfahan landfill is in a way that the produced leachate is led to a drain placed at the center of the site and then, is transferred to the leachate lagoon through the implemented canals. The lagoon is sealed with geotextile and geomembrane liners. Since leachate is an extremely dangerous liquid consisting of poisonous contents, its leakage to the water and soil resources will lead to irreparable consequences.

Fig. 1. Location of Isfahan landfill

3. Experimental studies

Bulk samples were collected from bed soils of landfill. Initial characterization of the collected samples was carried out through particle-size analysis and compaction tests according to ASTM C136 and ASTM D698 standards, respectively. The grain size distribution of the samples is shown in Fig. 2. The landfill geomaterials is fine-grained soil. The compaction test results are presented in Fig. 3. As seen in Fig. 3, maximum dry unit weight is 1.85 gr/cm^3 and optimum moisture is resulted as 12.5 %.

Soil specifications, including the average particle size (D_{50}), specific gravity of the soil solid particles (G_s), liquid limit (LL), plastic limit (PL), plasticity index (PI), as well as the optimum moisture content (ω_{opt}) and the maximum dry unit weight ($\gamma_{d,max}$) are indicated in Table 1. The lime utilized was a commercially available lime typically used in construction projects.

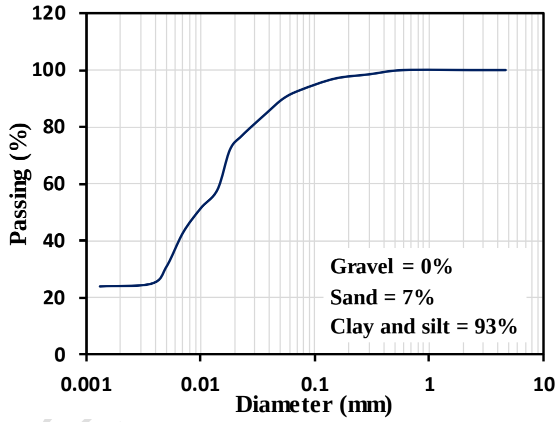

Fig. 2. Grain size distribution of landfill geomaterial

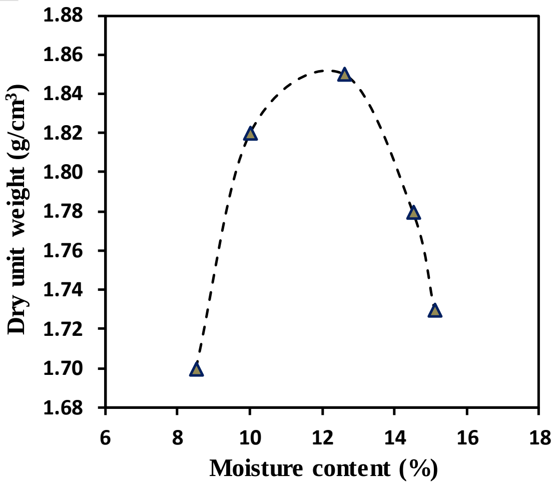

Fig. 3. Compaction curve of landfill geomaterial

Table 1. Characteristics of the tested geomaterials

Parameter	Value
D_{50} (mm)	0.009
G_s	2.62
Sand content (%)	7
Fine content (%)	93
$\gamma_{d,max}$ (gr/cm^3)	1.85
ω_{opt} (%)	12.5
LL (%)	38
PL (%)	21
PI (%)	17

After weighting the mixture components (i.e, landfill geomaterial, lime, and water), the soil and lime as dry portions were mixed until uniformed consistency of blend was attained. Then the water was added and the mixing process continued until a homogeneous sample was achieved. The lime content for each sample was calculated on the basis of the dry soil mass. The behavior of soil samples stabilized with different lime contents were investigated under various conditions. After improvement with 3, 6, and 9 % of lime, samples were tested through direct shear and permeability experiments. The experiments were conducted in the soil mechanics laboratory of Shahrekord University. The effects of soil stabilization on shear resistance and permeability coefficient of treated samples were assessed.

3.1. Direct shear tests

The tested samples have been stabilized with ratios of 3, 6, and 9 % of the dry soil weight with lime. After mixing of the soil and lime, soil moisture was increased up to the optimum value. The samples were then placed within plastic bags to avoid significant variations in moisture content and cured in a humid room temperature of 23° ± 2°C and relative humidity of 90 ± 2 % for 28 days. After preparation and curing, soil-lime mixture was poured into a shear box with the dimensions of 100×100×20 mm and compacted up to 90 % of the maximum dry unit weight. Then, the normal stress was applied as overburden. The direct shear test device used in this study is shown in Fig. 4.

The applied vertical stresses (P_v) to the test samples were 0.5, 1, and 2 kg/cm^2. Strain-controlled experiments were performed according to ASTM D3080 and, with a displacement rate of 2 mm/min [20,21]. During the experiment, horizontal deformations of the soil sample were recorded. Testing program of direct shear experiments are presented in the Table 2.

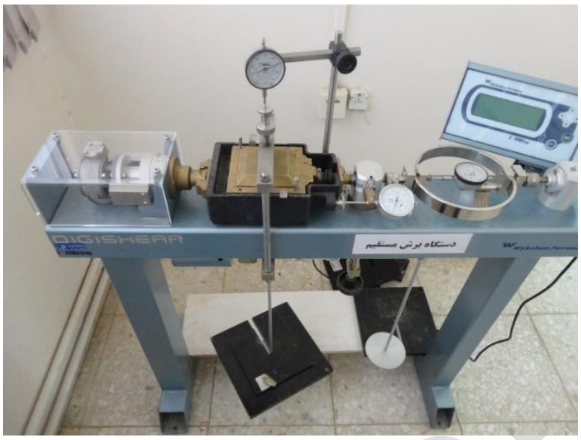

Fig. 4. Direct shear apparatus used in experimental program

Table 2. Testing program of direct shear experiments

Test No.	Lime content (%)	P_v (kg/cm^2)
1	0	0.5
2	3	0.5
3	6	0.5
4	9	0.5
5	0	1
6	3	1
7	6	1
8	9	1
9	0	2
10	3	2
11	6	2
12	9	2

3.2. Permeability tests

Permeability of the unstabilized and stabilized soil samples with different lime contents were evaluated using falling head method according to BS 1377-5:1990. Soil samples were saturated using vacuum pumps and tested in permeability device. The permeability test device used in this study is depicted in Fig. 5.

Permeability coefficient was calculated from Eq. 1:

$$k = 2.303 \frac{al}{At} \log \frac{h_1}{h_2} \quad (1)$$

where k is the permeability factor, h is the hydraulic head at the time t, A is the cross section of the test sample, l is the sample

Journal Pre-proof

length, and a is the internal cross section of the tube attached to the top of the sample.

Fig. 5. Permeability apparatus used in experimental program.

4. Results and discussions

4.1. Shear behavior

The stress-strain behavior of lime-stabilized and unstabilized samples under direct shear tests is shown in Figs. 6 (a-c). Isfahan landfill samples were stabilized using 3, 6, and 9 % of lime. Direct shear tests were conducted under vertical overburden stresses (P_v) of 0.5, 1, and 2 kg/cm^2 (Figs. 6a-c). As shown in these figures, the stress-strain behavior of tested samples has been improved with increasing lime content.

Increasing the amount of lime content up to 6 % improved the stress-strain behavior of the stabilized samples under direct shear test, and beyond that, it resulted in a decrease in the shear strength of the samples (Fig. 6). Thus, the optimum lime content for stabilization of the landfill samples was determined as 6 %. Addition of lime up to 6% provides the amount of bond needed to increase the shear strength. Beyond this value, the lime has led to a decrease in soil shear strength. As the direct shear tests results (Fig. 6) indicate, under lower vertical overburden stresses, lime had a greater effect on improving the stress-strain behavior of the stabilized landfill samples.

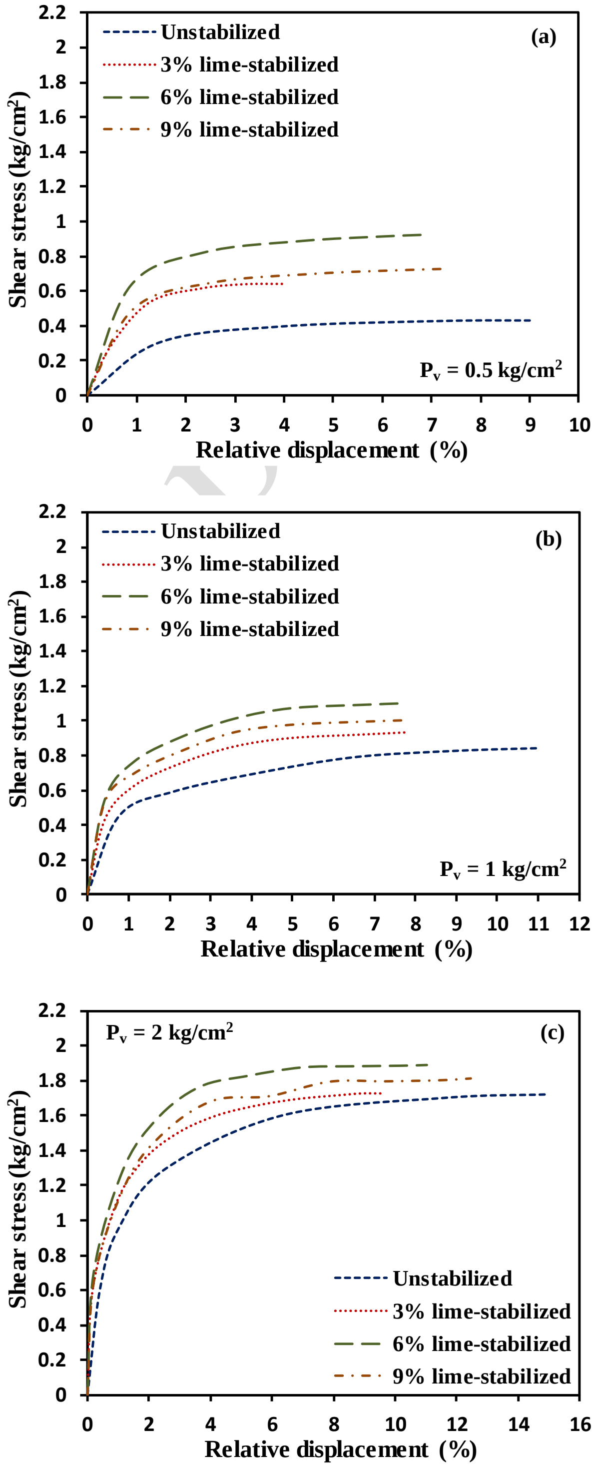

Fig. 6. Stress-strain behavior of unstabilized and lime-stabilized landfill samples under vertical overburden stresses of a) 0.5 kg/cm^2, b) 1 kg/cm^2, c) 2 kg/cm^2.

The test results (Figs. 6a-c) indicate that stabilization of the studied landfill material with lime had no significant effect on shear strength of the samples at strains less than 0.5 %. As can be seen in Fig. 6, at strains larger than 1 %, the effect of lime-stabilization of the landfill soil is considerable.

Variation of the maximum shear strength of the samples with different lime content under various overburden stresses are shown in Fig. 7. As shown in this figure, the maximum shear resistance is achieved at stabilized samples with 6 % lime.

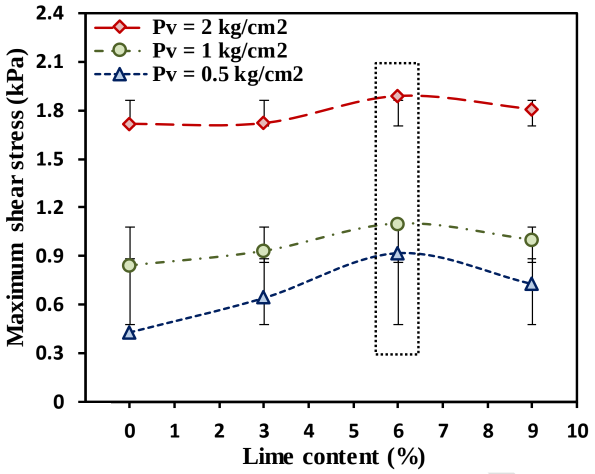

Fig. 7. The effect of lime-stabilization on the maximum shear strength of tested samples.

Under vertical overburden of 0.5 kg/cm^2, adding lime contents of 3 %, 6 %, and 9 % respectively has lead to increased maximum shear strength of the landfill soil samples up to 49.37 %, 113.95 %, and 69.77 % compared to the unstabilized samples (Fig. 7). Also, addition of lime up to 3 %, 6 %, and 9 % to the test samples under vertical overburden stress of 1 kg/cm^2 has led to 10.71 %, 30.95 %, and 19.05 % increase in maximum shear strength of the stabilized samples, respectively, and to 0.29 %, 9.88 %, and 5.23 % under overburden stress of 2 kg/cm^2 (Fig. 7). According to the results, addition of the lime under lower overburden stresses has a better performance in improvement of the shear behavior of the samples.

4.2. Permeability

The results of permeability test with falling head method on unstabilized samples as well as the lime-stabilized samples are shown in Fig. 8. Permeability coefficient of the unstabilized samples and stabilized with 3, 6, and 9 % of lime have been obtained as 5.8×10^{-4} cm/sec, 4.95×10^{-4} cm/sec, 0.88×10^{-4} cm/sec, and 0.37×10^{-4} cm/sec, respectively. As demonstrated in Fig. 8, permeability coefficient of the landfill samples has been decreased with increasing lime content. This is attributed to the increase in cohesion of the stabilized sample due to pozzolanic action of fine particles and lime. The results indicated that addition of 3, 6, and 9 % lime has resulted 14.66 %, 84.83 %, and 93.62 %, respectively, decrease in permeability coefficient compared to the unstabilized sample (Fig. 8). The permeability test results on lime-stabilized samples (Fig. 8) indicate that the decreasing rate of permeability coefficient was ascending up to 6 % of lime and decreased afterwards.

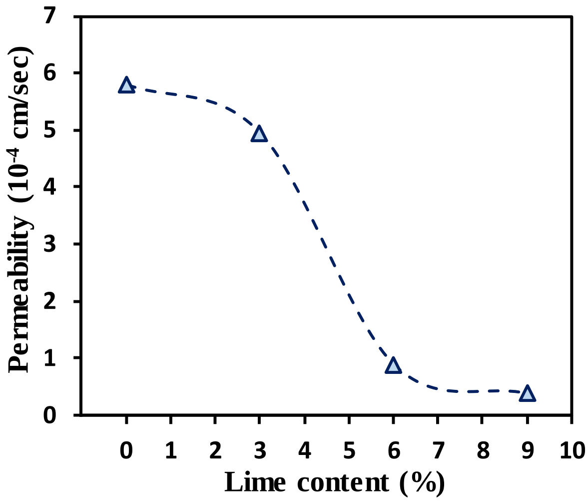

Fig. 8. The effect of lime-stabilization on the permeability of tested samples.

4.3. SEM images and XRD tests

In order to investigate the structure of the unstabilized and stabilized landfill samples, images were taken from the samples by electron microscope. Scanning electron microscope (SEM) images of the unstabilized and stabilized samples with 3, 6, and 9 % lime

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in 5 μm and 10 μm scales are presented in Fig. 9 and Fig. 10, respectively. Development of new bonds due to lime addition is visible in these images.

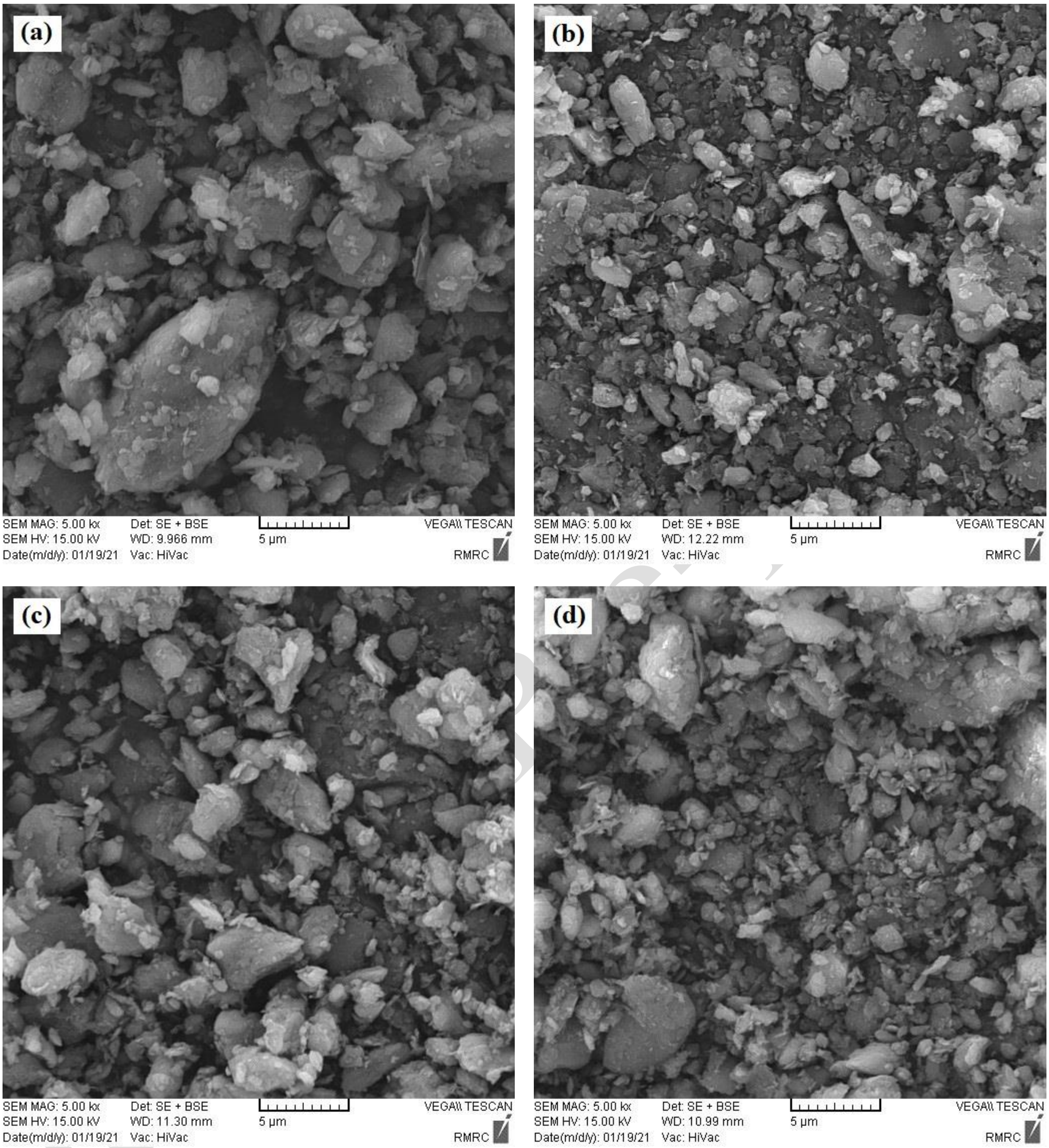

Fig. 9. SEM images with 5 μm scale, a) Landfill material, b) stabilized with 3 % lime, c) stabilized with 6 % lime, d) stabilized with 9 % lime.

X-ray diffraction (XRD) tests were performed for determining the predominant minerals in test samples. This test is a mature X-ray technology widely utilized for identification of minerals [22–24]. In XRD test, a maximum point is indicated for each mineral, which describes its relative amount in the soil. Although this test does not provide a quantitative amount for the subject mineral, but comparing the predominant maximums in a way describes the amounts of the minerals available in the soil. The XRD test on unstabilized and lime-stabilized samples are presented in Fig. 11.

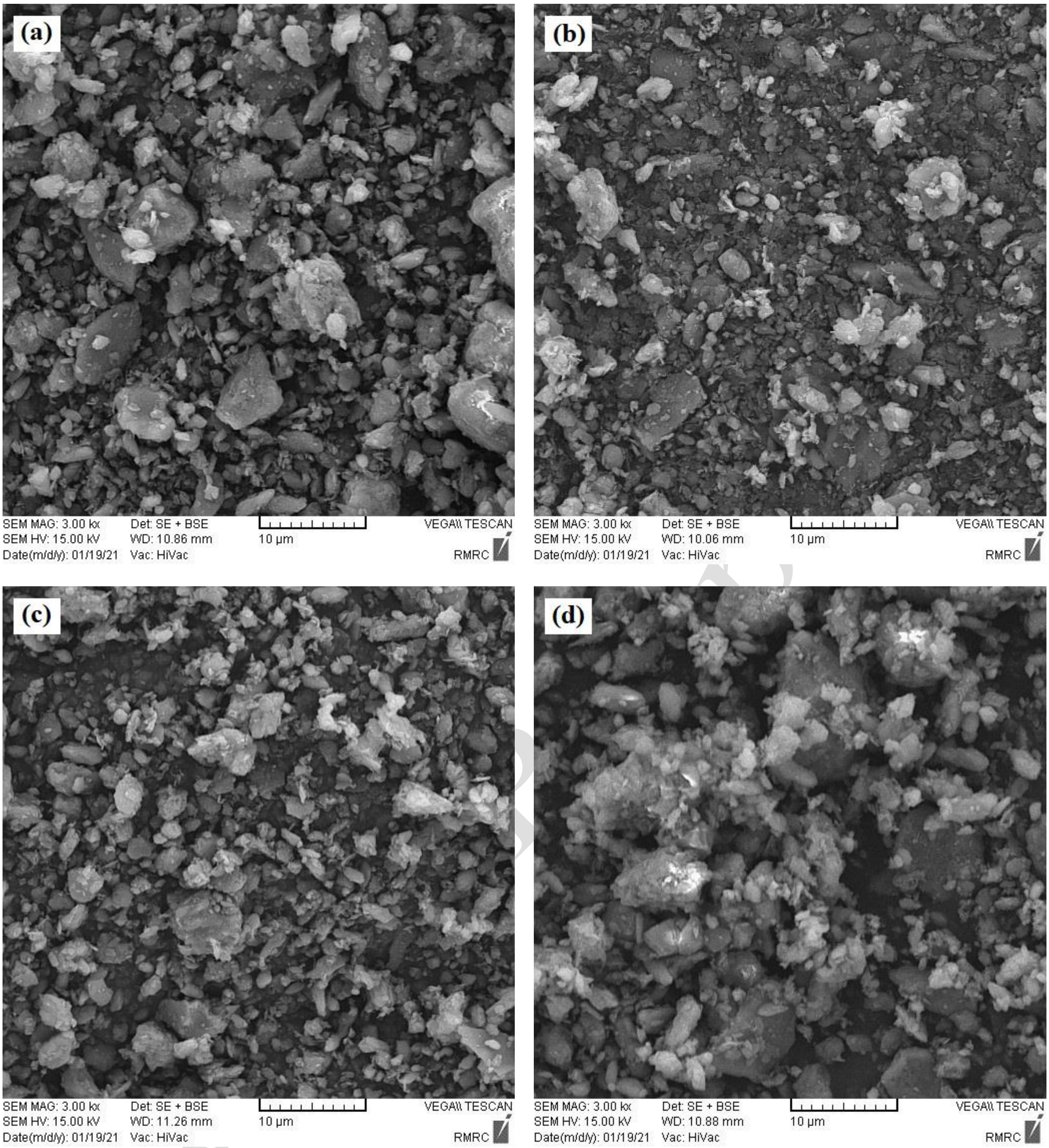

Fig. 10. SEM images with 10 μm scale, a) Landfill material, b) stabilized with 3 % lime, c) stabilized with 6 % lime, d) stabilized with 9 % lime.

The most predominant chemical components in test samples at 2θ = 29.5 ° and 2θ = 27 ° are lime and quartz, respectively (Fig. 11).

5. Summary and conclusions

Due to rapid population growth and increased waste production, construction of a waste dumping area is crucial. Contamination expansion at landfills and the adjacent areas affects the physical and mechanical properties of the soil. Soil improvement is one of the common methods for improving the soil properties. Lime is one of the most widely materials used for improvement and stabilization of soils. This study focuses on the lime-stabilization of Isfahan landfill geomaterial. Unstabilized and lime-stabilized samples were experimentally investigated.

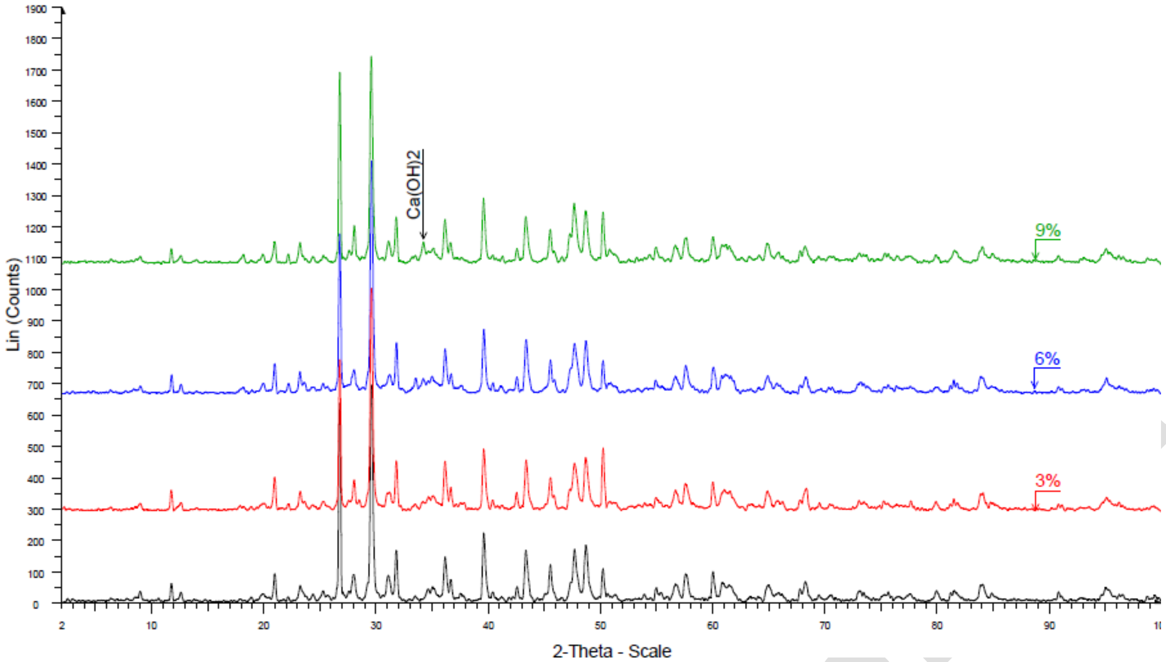

Fig. 11. XRD tests on the unstabilized and stabilized landfill geomaterial.

Stress-strain behavior and permeability coefficient of unstabilized and stabilized samples with 3, 6, and 9 % of lime were studied. Shear strength and permeability coefficient were assessed using direct shear test and falling head method test, respectively. The results indicate that application of lime has improved the behavior of the studied landfill soil samples. The mechanism by which the increment in lime content affects the shear strength is related to the existence of a larger number of grains contacts. The optimum lime content for improvement of the Isfahan landfill materials is determined as 6 %. Addition of 6 % lime under vertical overburden stresses of 0.5, 1, and 2 kg/cm^2 has led to an average increase by 51.6 % in maximum shear strength of stabilized soil samples. The results of permeability tests indicate that addition of lime has resulted in the decreasing of the permeability coefficient of the samples.

Increasing the lime content up to 6 % has led to a significant decrease in permeability coefficient and the decreasing rate was reduced afterwards. Therefore, lime-stabilization the landfill material not only improves the soil stress-strain behavior, but also leads to the decreased permeability of the landfill materials, which can play a significant role in reducing the contamination expansion. The decrease in permeability coefficient is mainly attributed to the reaction between the clay present in the soil material and the lime. The XRD tests results indicate that the predominant minerals in test samples were lime and silica, respectively. Furthermore, comparing the scanning electron microscope (SEM) images of the unstabilized and stabilized samples demonstrate the formation of new bonds due to lime addition.

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