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Physio-mechanical evaluation of Nano-soil as an additive to the sand-bentonite mixture for Tabriz city landfill liner

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ABSTRACT: The purpose of this paper is to introduce a suitable material for Tabriz city landfill liner by using local materials. For this reason, the soil was collected from the Tabriz landfill bottom, a new under-construction site (Iran). As an additive, the nano-soil was produced from landfill local soil using the pulverization of soil samples through a high-energy milling process. Chemical and physical tests including Atomic Force Microscopy (AFM) were conducted to determine the nano-soil features and topography. To obtain the minimum requirement for landfill liner soil application, 90% of Tabriz landfill soil was mixed with 10% of Bentonite. The resulting soil was identified as clayey sand with a plasticity index of 13%. Then, the effect of nano-soil on a sand-bentonite mixture as an economical and modern additive for Tabriz city landfill liner application was investigated. This investigation was based on laboratory experiments including compaction, direct shear, and hydraulic conductivity tests. The nano-soil was used as an additive in six different contents including 0.5, 1, 1.5, 2, 2.5, and 3% of soil dry weight. According to the results, with increasing nano-soil content, the maximum dry unit weight increased and the optimum moisture content of the mixture decreased. Moreover, by increasing nano-soil content by 2%, the shear strength and hydraulic conductivity experienced the desired positive effect for a landfill bottom liner, while the excess addition of nano-soil resulted in neglectable or even negative effects.

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1- Introduction

One of the most critical environmental issues is municipal solid waste disposal. Consequently, the leachate generated from the disposal process can influence the performance of the soil as a barrier against contamination. Synthetic materials are alternatives for the utilization in the design and construction of landfill liners but the merit of using them is their long decomposition time and sensitivity to sunlight that has made this method less appropriate. As an alternative, compacted soil with other additives such as bentonite and nano-soil could be used to achieve a low hydraulic conductivity and high shear strength suitable for landfill liners. In these mixtures, the coarse grain fraction controls the soil shear strength behavior, and hydraulic conductivity is expected to be governed by the fine-grained proportion [1-2].

Nanosized particles are described as the smallest particles of 1 to 100 nm. They usually exhibit special enhanced surface features and hence more activity. Due to the high specific surface area, even a small quantity of nanomaterials may affect the Physico-chemical and engineering properties of soils [3-6]. For instance, Nano-Aluminum, as a proportion of cement, increased the uniaxial strength and California Bearing Ratio (CBR) of clayey soil [7]. The effect of clay nanoparticles on the mechanical properties of soil was investigated by many researchers and the positive effects such as strength enhancement and hydraulic conductivity reduction are evident [8-10]. The presence of the silica fume and nano-silica as a stabilizer in the kaolinite clay increased the optimum water content and decreased the maximum dry density of the soil. The addition of 15% silica fume and 3% nano-silica to kaolinite clay improved the unconfined compressive strength up to 70% and 55%, respectively [11]. The presence of recycled polyester fiber and nano-SiO_2 increased both shear and unconfined compression strengths. The increase in the nano-SiO_2 content led to a reduction in failure strain, but the failure strain increased by rising the content of recycled polyester fiber [12]. According to the results of adding nano clay to clay and silt soil, by increasing in nano clay the unit weight of clay soil was increased, and optimum moisture content was decreased. In the direct shear test, by increasing nanoparticles, the cohesion of clay and silt soils also increased. However, the internal friction angle of both clay and silt is reduced [13]. The use of nano soil to stabilize soft clayey soil increased the compressive and effective shear strengths by about 20% [14].

The unconfined compressive strength of soft soil treated with SiO2 nanoparticles increased significantly with an increasing percentage of nano-silica. Moreover, a decrease in maximum dry density and an increase in optimum moisture content of treated soil was observed. The addition of nanoparticles increased the sample's reactivity even at an early age

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Fig.1. Tabriz landfill location on Google map (38º11' 31.3639", 46º15'28.3326").

Fig. 2. Soil sampling at Tabriz Landfill.

and subsequently strength was increased. Therefore, this method to stabilize soft soil deposits for utilization of various geotechnical applications has sustainable environmental features [15].

As the result of conducted research on bentonite-amended sand and slag with nano clay particles (i.e., 1–3%), nano clay increases the plasticity index of both mixes. Further, the addition of 2% nano clay has shown promising results in terms of an increase in maximum dry density and hydraulic conductivity of both mixes. However, it is revealed that minimal nano clay content can reduce the bulk amount of bentonite content to be utilized for various geotechnical construction activities [16].

Tabriz municipality has encountered a leakage problem in their old compacted clay liner (CCL) landfills and the new landfill site in that area is under construction, which the improvement of the liner features is of great importance. The new Tabriz landfill liner has been located in Eastern Azarbayjan, Iran (Figure 1). This study has been performed to introduce a new soil liner design that meets the required criteria by using the nanomaterial produced from local materials. To reach this goal, several laboratory experiments including Producing nano-soil, Compaction, Direct shear, and Hydraulic conductivity tests were carried out.

2- Material and Methods

2- 1- Materials

2- 1- 1- Soil

The soil material was taken from the bottom of the Tabriz landfill and was transferred to the laboratory. Figure 2 shows images of soil sampling from the site. The soil was sieved with sieve #4, and the remained soil on sieve #4 was removed from all the tests. The grain size distribution of untreated soil used in tests is presented in Fig. 3. Since the natural soil did not obtain the minimum requirement of 10% plasticity index for the compacted soil to be used as a landfill liner [17], hence, it was mixed with 10 percent of bentonite soil in dry weight and the resulted soil was identified as clayey sand with a plasticity index of 13% [17, 18]. This combination of soil and bentonite was obtained considering previous studies and the Atterberg test. Initial tests were performed on mixed soil, which resulted in specific gravity of 2.65, the plastic index, liquid limit, and plastic limit of samples were 13%, 29%, and 16% respectively. Some properties of plain powdered bentonite used to increase the plasticity index of the liner soil in this study are listed in Table 1.

2- 1- 2- Nano-soil

The nano soil was produced from pulverized technique

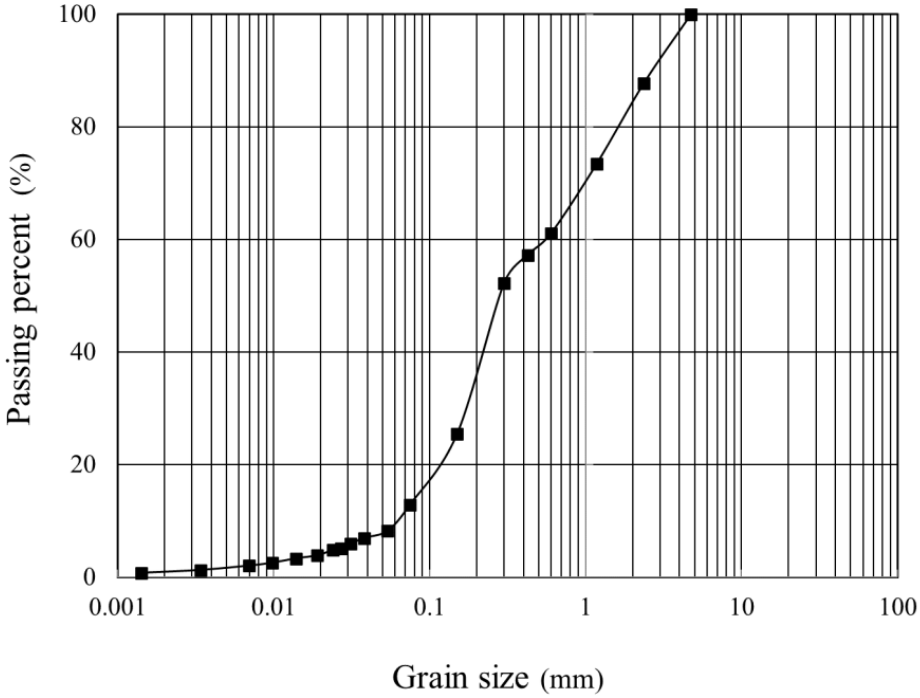

Fig. 3. Grain size distribution of untreated soil of Tabriz landfill.

Table 1. Physical properties of bentonite used in this study.

Material	Plastic limit (%)	Liquid limit (%)	Unified classification
Sodium bentonite	45	196	CH

Table 2. Chemical analysis of nano soil.

Component	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	others
Content (%)	52.6	13	11.2	4.4	3.0	15.8

process using high energy ball milling from the original soft soil passed the number 100 sieve. This milling technique is considered the low cost to produce nanomaterial in the laboratory [14]. Meanwhile, the nano-soil sample was analyzed using atomic force microscopy (AFM) after the milling process to determine the potential sizes of nanoparticles. The AFM is a type of scanning probe microscopy (SPM), with demonstrated resolution on the order of fractions of a nanometer, more than 1000 times better than the optical diffraction limit. The information is gathered by "feeling" or "touching" the surface with a mechanical probe. For imaging, the reaction of the probe to the forces that the sample imposes on it can be used to form an image of the three-dimensional shape (topography) of a sample surface at a high resolution. The topography of powder nano-soil on a 10 square micron area is presented in Fig. 4a, and according to software analysis, the range of 50 to 315 nano-meter for particles size was observed. Moreover, chemical analysis has been conducted to identify the major nano-components of nano soil which is presented in Table 2.

2- 2- Methods

For the preparation of soil mixtures, the dry soil was first mixed with bentonite, and then nanomaterial was added. The mixing procedure was carried out in two stages. The quantity of soil initially premixed (hand-mixed) was divided into five portions in bowels and was mixed by a mixer at 120 rpm for 30 minutes [19]. The direct shear test specimens were prepared by compacting the soil mixture into 10×10 cm molds with a height of 2 cm. The experiment was performed at different loads of 0.5, 1, and 1.5 kg/cm^2 [20].

The Flexible-wall triaxial permeability apparatus was used with the constant-head method in this study [21]. A pair

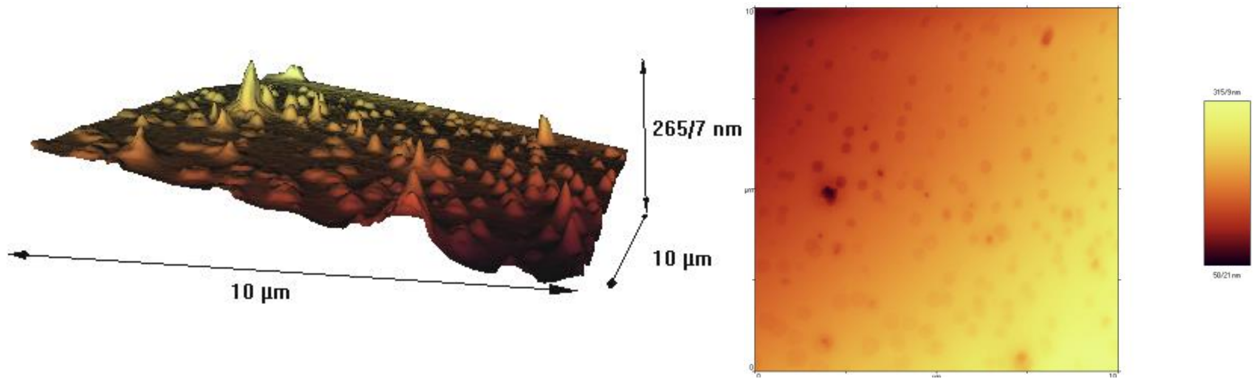

Fig.4. Topography image of nano-soil powder: (a) Three dimensional, (b) Two dimensional.

Fig. 5. A flexible-wall triaxial permeability apparatus.

of bladder accumulators and burettes were prepared to facilitate and monitor water permeation in the apparatus (Fig. 5). After the sample preparation, it was mounted in the permeability cell, then, the cell was filled with water. The specimen was saturated by passing distilled water through the soil for about an average of 3 days and the saturation process was completed by applying incremental cell pressure and back-pressure up to 200 kPa for two days until reached a degree of saturation of more than 98%. The cell, inflow, and outflow pressures were set to be 280, 220, and 200 kPa which resulted in a hydraulic gradient of 30 and effective stress of 70 kPa. These values were used to simulate the in-situ condition of a compacted soil layer inside an engineering landfill. The water flow was controlled by pressure controllers and monitored using the burettes until the measured hydraulic conductivity reached a relatively steady-state condition. By recording volumes of inflow and outflow and Darcy's law equations, the total quantity of flow was calculated.

$$Q = qt = kiAt \tag{1}$$

where A is the area of the cross-section of the specimen. But $i = h/L$, where L is the length of the specimen, and so $Q = k(h/L)At$. Rearranging this gives

$$k = \frac{QL}{hAt} \tag{2}$$

Once all the quantities on the right-hand side of Eq. (2) have been determined from the test, the coefficient of perme-

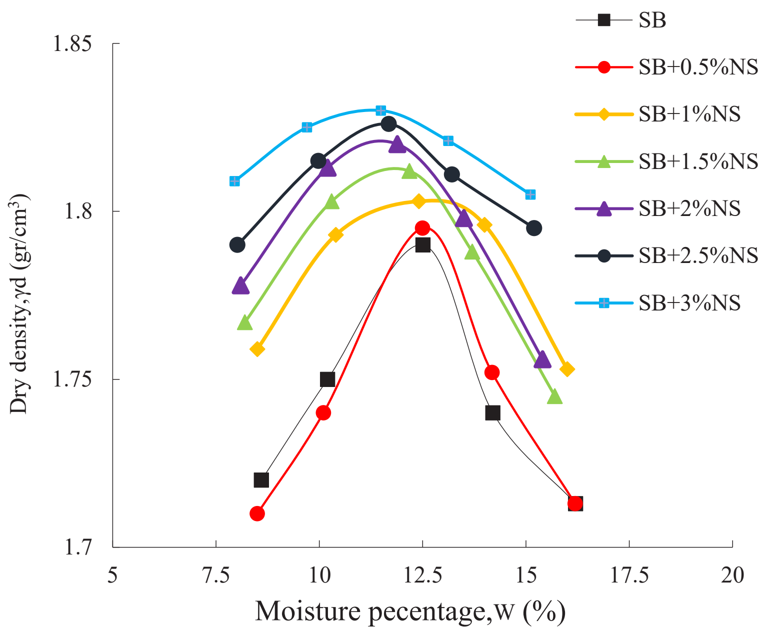

Fig. 6. Variation of dry unit weight versus moisture content for sand-bentonite-nano soil mixtures.

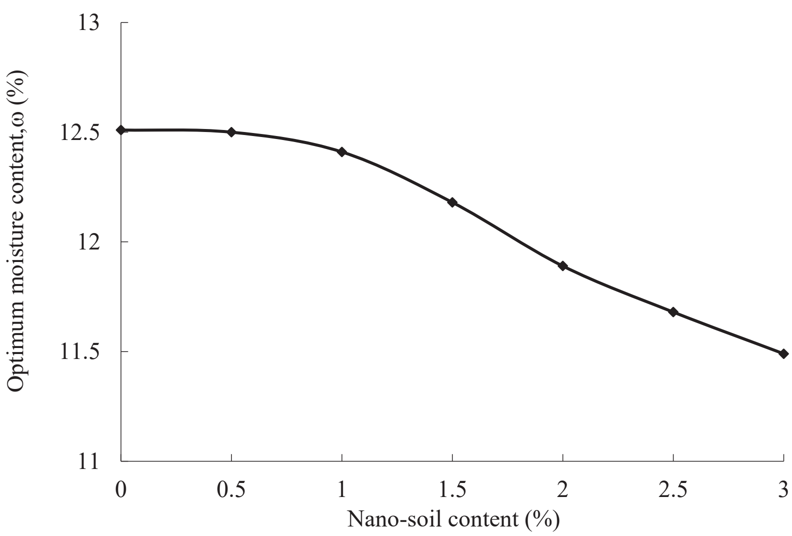

Fig. 7. Variation of Optimum moisture content of soil-bentonite with various amounts of nano-soil content.

ability of the soil can be calculated [17, 21].

3- Results and discussions

3- 1- Compaction parameters

Standard compaction tests were performed for all samples treated with 0, 0.5, 1, 1.5, 2, 2.5, and 3% nano-soil according to ASTM D 698. The effect of nano-soil on soil-bentonite compaction features has been shown in Figs. 6, 7, and 8. With an increase in nano-soil content, the dry unit weight increases, and the optimum moisture content of the mixture decreases. The soil sample admixed with 2% nano-soil turns out to be the optimum content. The maximum dry density varies in the range of 1.78 gr/cm^3 to 1.83 gr/cm^3. Similarly, the OMC decreased from 12.51 to 11.49%. This may be attributed since nano-materials possessing higher unit weight compared to untreated soils and these materials conquer the pore spaces in between the soil grains, which decreases soil porosity and increases shear strength [6].

3- 2- Direct shear test

The direct shear tests were conducted on soil-bentonite

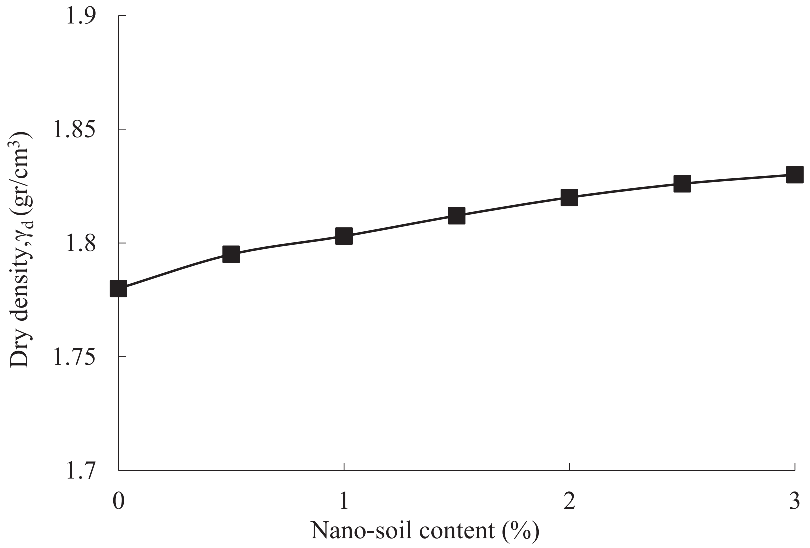

Fig. 8. Variation of maximum dry density with various amounts of nano-soil content.

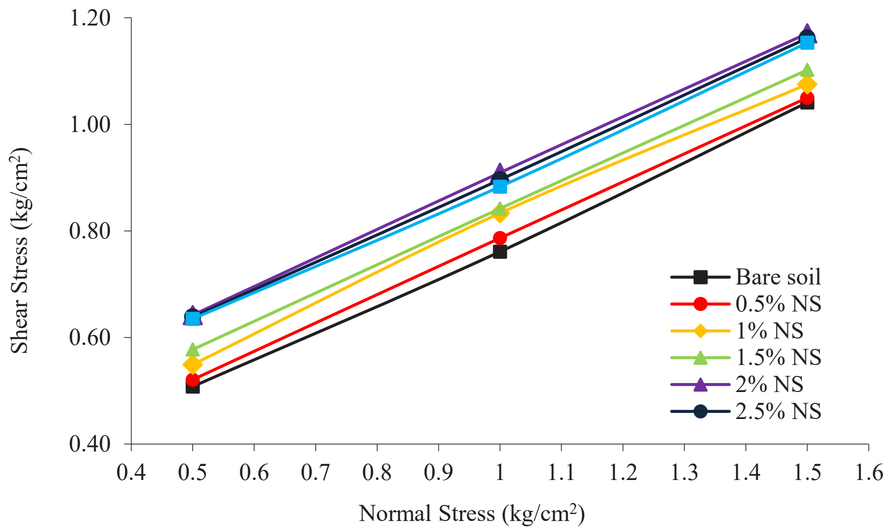

Fig. 9. Change in shear strength of soil with different nano-soil content

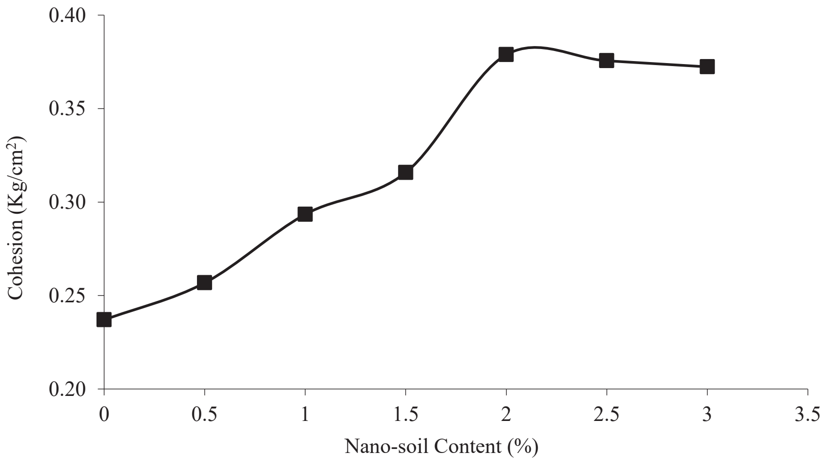

Fig. 10. Cohesion of the soil with different nano-soil content.

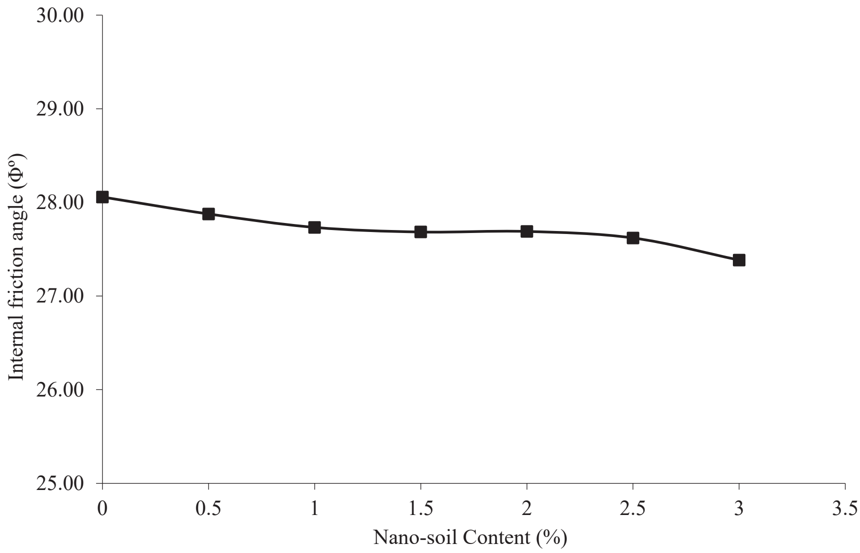

Fig. 11. Change in internal friction of soil with different nano-soil content.

samples consisting of different amounts of nano-soil including 0.5, 1, 1.5, 2, 2.5, and 3% of dry soil weight. Fig. 9 indicates that by increasing the nano-soil content to a specific amount, shear strength increases, which is the result of decreasing void ratio due to nanoparticles incorporation and cohesion due to the chemical reaction of nanoparticles. Nano-soil content of more than 2% does not have a positive effect on the shear strength of the soil compared to soil containing 2% nano-soil. According to the results, the optimum amount of nano-soil is 2% content, which resulted in 19.7% improvement in the shear strength.

Fig. 10 shows the soil cohesion change with nano-soil, which has a major role in increasing the shear resistance of the soil. The optimum content of nano additive enhances the cohesion parameter by 26.39%, while this is not true for friction angle since it has a gradual decrease (Fig. 11). The shear strength gain was mostly due to the increase in cohesion and change in internal friction angle is on the opposite side, which can be caused by a reaction between soil-bentonite and nano soil particles.

3- 3- Hydraulic conductivity test

The change in the hydraulic conductivity of each sample versus nano-soil content is depicted in Fig. 12. Results show that the initial hydraulic conductivity of the soil-bentonite (1.43×10^{-8} m/s) decreases with an increasing amount of nanomaterial. The permeability coefficient of the sample composed of 2% nano-soil was about 1.04×10^{-9} m/s which is a 13.75 times reduction compared to the hydraulic conductivity of bentonite-sandy soil (5.43×10^{-7} m/s). According to previous studies, the reduction of hydraulic conductivity is due to the pores of clay being clogged by the nanomaterial [21, 3].

4- Conclusions

To introduce a new method for Tabriz's New landfill and prevent previous leakage problems, the nanomaterial was

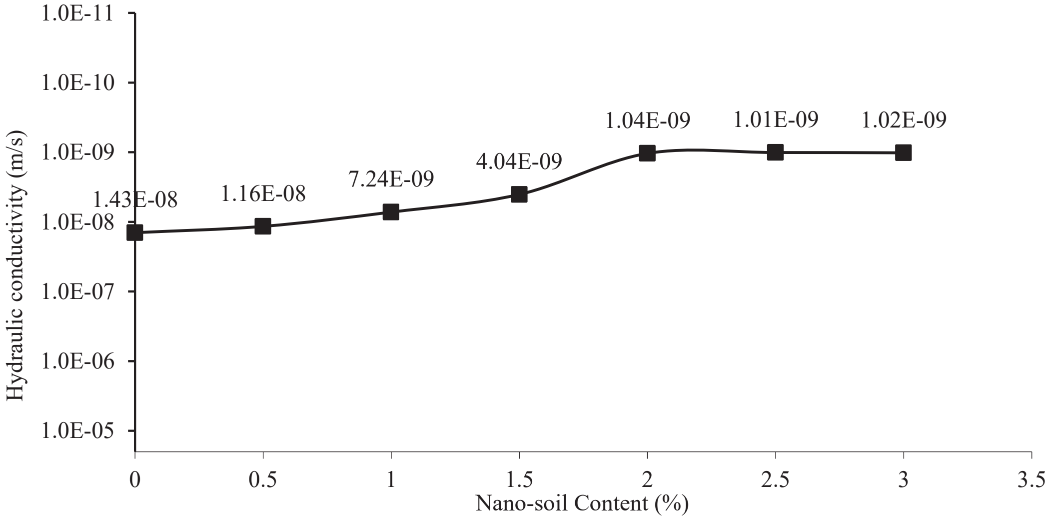

Fig. 12. Change in hydraulic conductivity of soil with different nano-soil content.

produced from local materials. To reach this goal, several laboratory experiments including Producing nano-soil, Compaction, Direct shear, and Hydraulic conductivity tests were carried out. The results illustrated that the addition of nano-soil into a bentonite-sandy soil mixture could enhance the soil geotechnical behavior to use as a landfill liner.

The nano-soil caused the maximum dry density to vary in the range of 1.78 gr/cm^3 to 1.83 gr/cm^3. Similarly, the OMC decreased from 12.51 to 11.49%.

The presence of 2% nano-soil as an optimum content, increased the shear strength by about 19.7%. Soil cohesion has a major role in increasing the shear resistance of the soil. The optimum content of nano additive, enhanced the cohesion parameter by 26.39%, however, this is not applicable for friction angle since it experiences a gradual decrease.

Another important result shows that the addition of nano soil up to about 2% reduces the permeability of the liner soil by 11 times and the excessive amount of nano additive had a .neglectable effect

The final result that can be presented from the recent research is that the combination of nano-soil powder and bentonite is suitable for the sandy soil of Tabriz landfill liner To achieve a specific shear strength and hydraulic conductivity.

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