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Investigating the Effect of Nanoclay Additives on the Geotechnical Properties of Clay and Silt Soil

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ABSTRACT

With the rapid development of nanotechnology multi-disciplinary cross applications as well as the limitations of traditional materials, nanomaterials have been introduced to improve the soil. This paper investigates the potential advantages of nanotechnology for innovative solutions in the area of soil improvement. Studies on applied nanomaterials in geotechnical engineering show the way these nanoparticles are applied to improve soil engineering parameters. In the present Study, we aimed to investigate the effect of adding Nano clay on the geotechnical properties of clay and silt soil and improve their engineering properties. For this purpose, a series of tests were conducted including granulation, uniaxial, direct shear, Atterberg limits, compaction and triaxial tests on clay and silty soils. The results show that the liquid and plastic limits of soil will increase with increase in nanoparticles in soil composition. Also according to the results of compaction test, with increase in Nano clay the unit weight of clay soil will increase and optimum moisture content will decrease. According to the results from direct shear tests, by increase in nanoparticles, the adhesion of clay and silt soils also increase, however the internal friction angle of both clay and silt soil is reduced.

Keywords: Geotechnical, Nano clay, optimum moisture content, adhesion, internal friction angle.

1. INTRODUCTION

Nanomaterials are defined as microstructures having at least one dimension at a nanometer scale. At the nanoscale, all the properties electronic, magnetic, optical and chemical change, where as it is not the case at the macroscale. The main characteristic of nanoparticles includes small size, granulation distribution with a low level of agglomeration and high dispersion. These unique properties of nanoparticles have led nanotechnology to be incorporated into science and solve many of the relevant problems [1-4]. Fortunately, geotechnical engineering science has not been exempt from this rule and in recent years many efforts have been made to use this new technology in various geotechnical branches. Most nanomaterials used for changing the geotechnical properties of soils are clay nanoparticles that affect soil resistance parameters. One of the suitable practices in dealing with inappropriate soils in geotechnical engineering is the change in the soil properties of the site [5], which is referred to as soil improvement or modification. Soil modification refers to a set of operations that eliminates some inappropriate soil behaviors or imposes appropriate behaviors on it [6,7]. One of these methods is adding cement or auxiliary chemicals to the soil composition, such as cement, bitumen, limestone, volcanic ash, etc. which were used in the past and are also used today [8-11]. Adding these materials to the soil reduces plasticity, improves compaction, reduces shrinkage-swelling, and improves the resistance and stability of the soil after stabilization. Most of these materials are used to stabilize fine-grained clay soils and, in case of application to granular soils, reduce permeability and erosion and increase durability [12]. One of the problems with the use of such additives in the soil is environmental pollution, whereas the use of nanoparticles will reduce the biodegradability. It can also be used to improve soil, control the strength properties, and reduce cement consumption and thus increase economic efficiency [13]. Due to previous studies and unresolved problems available, in this study, the effect of adding Nano clay on engineering properties of clay soil with low plasticity (CL) and silty soil (ML) investigated.

2. MATERIALS AND METHODS

In this laboratory study, the engineering properties of clayey soil was investigated under the influence of Nano clay (kaolinite); the properties of materials used in the research are presented below.

Clayey soil

The granulation diagram from the hydrometric test on this soil is shown in Fig. 1. Also the physical properties of clay soil are given in Table 1. In unified soil classification system, this soil falls into the CL classification.

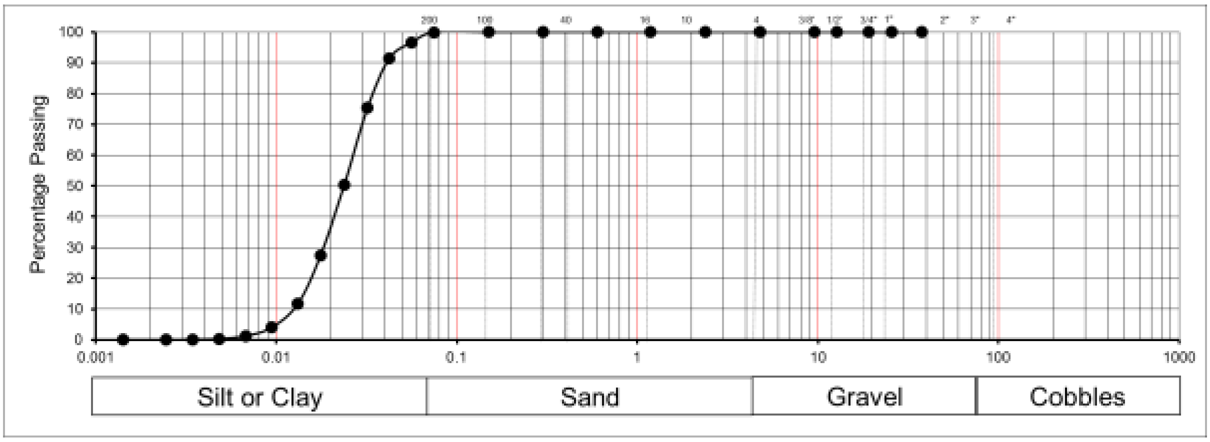

Fig. 1: The granulation diagram from the hydrometric test on clay soil

Table 1: Physical characteristics of used clay soil

Used material	Liquid limit LL (%)	Plastic limit PL (%)	Plasticity index PI (%)	Dry density Gs	Grain size limit (mm)
(A)Clayey soil	40.70	21.70	18.76	2/63	0/001-0/075

As shown in Table 1, the soil has low plasticity. However, in many geotechnical projects, a high plasticity range are required, which can reduce the ability to create gap and increase resistance to the phenomenon of piping [14]. Therefore, it is necessary to check the plasticity of the sample containing various percentages of Nano clay to determine the effect of this additive on the Atterberg limits and the plasticity properties of the clay.

Silty soil

Silty soil is another soil used. In this study, two silt samples with low plasticity were investigated. The granulation diagram from the hydrometric test on the silty soil and the silty soil (B) in are shown in Fig. 2 (A) and Fig. 3, respectively, and the physical properties of these soils are given in Table 2.Both types of silty soil are classified as ML soil.

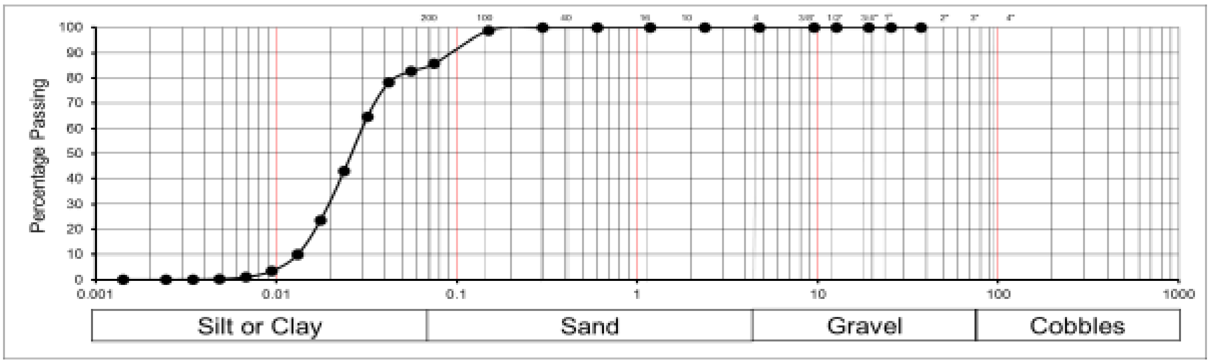

Fig. 2: The granulation diagram for silty soil (B) using hydrometric test

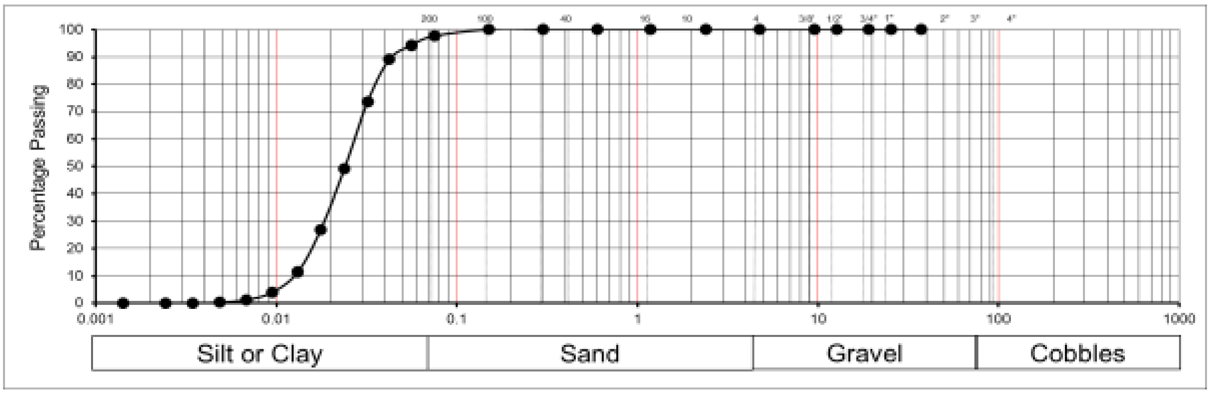

Fig. 3: The granulation diagram for silty soil (A) using hydrometric test

Table 2: Physical characteristics of used silty soil

Used material	Liquid limit LL (%)	Plastic limit PL (%)	Plasticity index PI (%)	Dry density Gs	Grain size limit (mm)
Silty soil (B)	20	18	2	2/7	0/001-0/075
Silty soil (A)	24	20	4	2/68	0/001-0/075

Nano-clay as an additive

The used nanoclay is of kaolinite type that is expressed in Tables 3 to 6. Chemical features, mineralogy, granulation and its plasticity is presented, with Fig. 4 showing the granulation curve of kaolinite.

Table 3: Chemical analysis of kaolinite

Chemical analysis(%)								
L.o.I	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	cao	Mgo	Na_2O	K_2O
9±1	63±1	24±1	0.55±0.1	0.04±0.01	1.2±0.2	0.55±0.06	0.4±0.2	0.3±0.1

Table 4: Mineralogy analysis of kaolinite

Mineralogy analysis(%)	
kaolinite	0/2±64
Quartz	2±27
Calcite	0/5±2/1
Feldspar	0
Others	1±6

Table 5: Kaolinite granulation distribution

Particle size distribution(%)	
Larger than 150 μm	0
Larger than 40 μm	0-0/5
Larger than 20 μm	99
Larger than 2 μm	3±47

Table 6: Plasticity characteristics of kaolinite

Plasticity characteristics		
Liquid limit	Plastic limit	Plasticity index
60/45	15/75	44/70

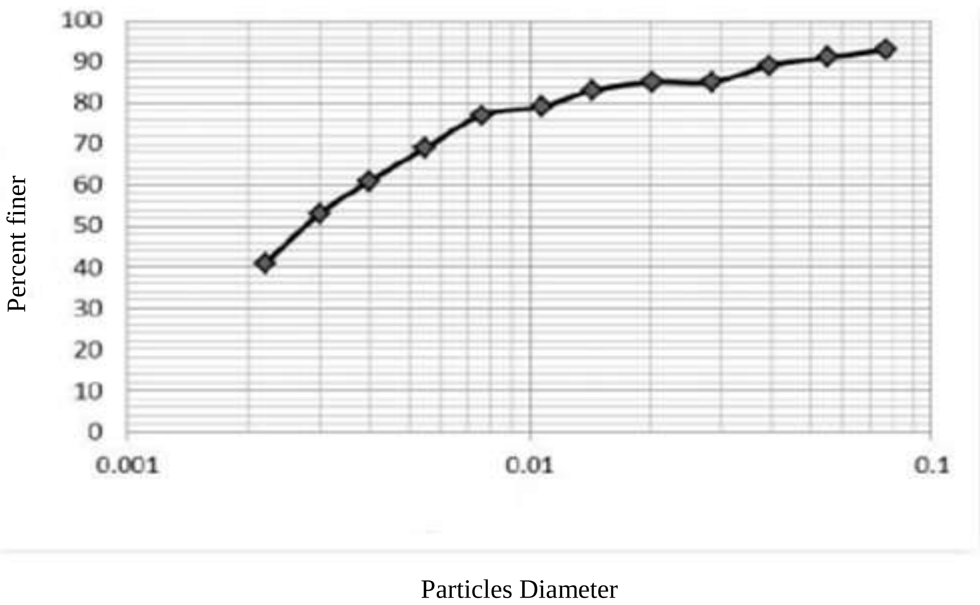

Fig. 4: kaolinite granulation curve

3. Results and Discussion

Several experiments were carried out on soil samples with different percentages of Nano clay, which a brief description will be presented on it below. The steps of performing and presenting the results of the direct shear test are in accordance with the ASTM D 3080-90 standard [15], at first from the soil sample the dry weight of the samples in a normal and non-additive manner, then with addition of 0.5, 1, 1.5 and 2 percent of the Kaolinite Nano clay. And at the following the experiments, direct shear test, Atterberg limit test, Compaction test and uniaxial test were carried out.

4. Results and Discussion:

DIRECT SHEAR TEST

The first Test was direct Shear test and the results of the direct shear test are shown in Table 7 and Fig. 5 and 6.

Table 7: Results obtained from the direct shear test on silt a clay soils

Additive type	Percentage	(kg/cm2)Adhesion			Friction angle		
		c	A	B	c	A	B
Kaolinite nanoclay	0	0/56	0/51	0/69	22	26/1	28/7
Kaolinite nanoclay	0/5	0/7	0/57	0/69	20/9	24/4	27/3
Kaolinite nanoclay	1	0/85	0/74	1/12	20	23/6	26/5
Kaolinite nanoclay	1/5	1/09	1/01	1/42	19/4	22/6	25/6
Kaolinite nanoclay	2	2/12	1/26	2/12	18/80	22	24/3

The results of the direct shear test indicate that the clay and silty soil adhesion increases with the increase in Nano kaolinite content, but the internal friction angle of both clay and silty soil decreases with increase in the Nano kaolinite content.

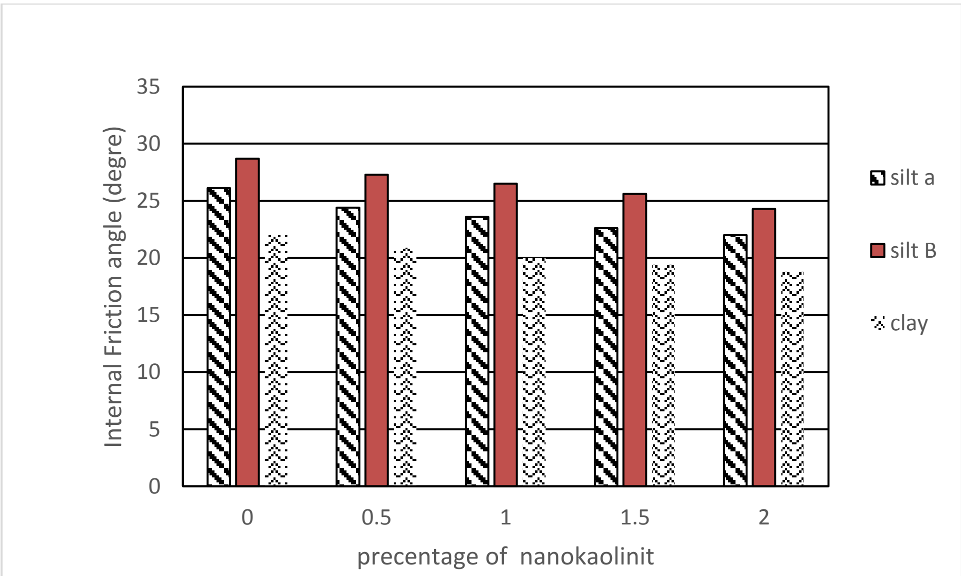

Figure 5: The diagram of variations in clay and silage internal friction angle by adding Nano kaolinite

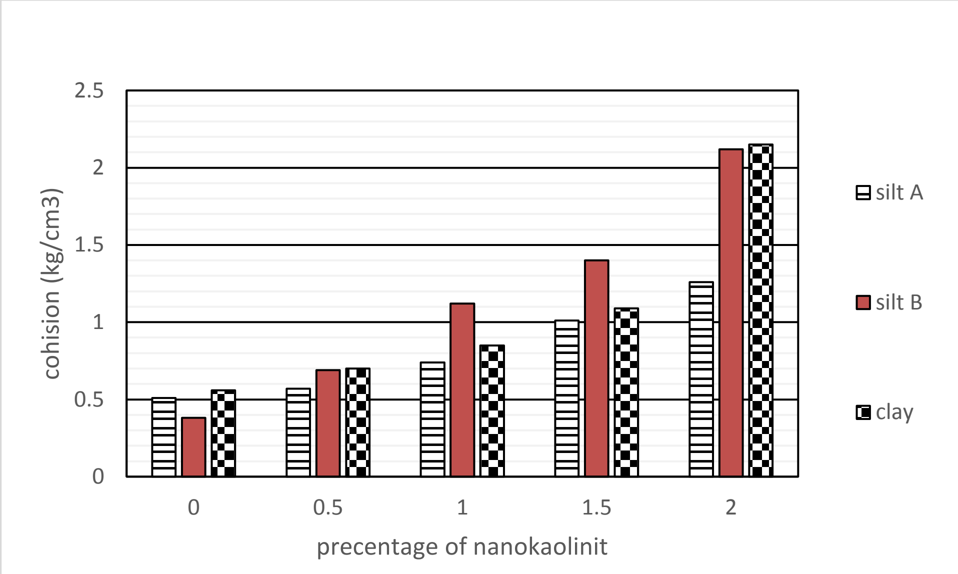

Figure 6: The diagram of variations in clay and silage cohesion by adding Nano kaolinite

The Mohr–coulomb failure criterion is defined by two parameters: friction and adhesion. Generally, soils enriched with nanoparticles have greater friction angle and greater adhesion. This is due to the fact that the fastening and bonding between nanoparticles and other particles of soil increases and ultimately causes relatively thicker and denser masses in the soil. In other words, soil nanoparticles increase the shear strength of soil due to the effect of interlocking in soil mass.

The Atterberg limit test

A general report of the results of the Atterburg limits for various percentages of Nano clay kaolinite addition is given as in Table 8 and Figures 7, 8 and 9.

Table 8: The results obtained from the Atterberg test on clay and silty clay soils with Nano clay

Additive type	Percentage	Liquid limit			Plastic limit			Plasticity range		
		A	B	C	A	B	C	A	B	C
Kaolinite Nano clay	0	20	24/2	40/7	18	21/6	21/7	2	2/6	19
Kaolinite Nano clay	0/5	23	28	43	19/5	22	23	3/5	6	20
Kaolinite Nano clay	1	27	30	47	21	23	24/2	6	7	22/8
Kaolinite Nano clay	1/5	32.5	32	49	23/7	23/7	25	8/8	8/3	24
Kaolinite Nano clay	2	34	33/5	51	25	24/5	25/5	9	9	25/5

It is seen that the liquid limit has increased significantly after adding Nano clay but there is not much change in the amount of plastic limit. However, adding Nano clay has increased the amount of plasticity range. By increasing the plasticity of clay, it can be expected that the permeability coefficient of the sample decreases. This increase in plasticity can be due to an increase in the specific surface area of the samples due to the presence of Nano clay in them, thus increase in electrical charge, which makes the water more absorbed into the sample.

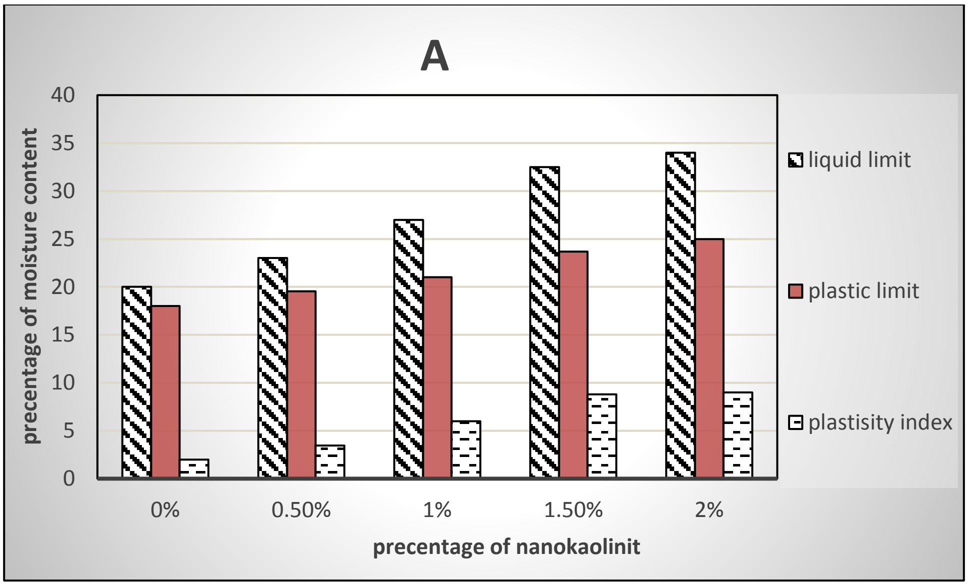

Fig. 7: The diagram for Atterberg limit in silt soil (A) by adding Kaolinite Nano clay

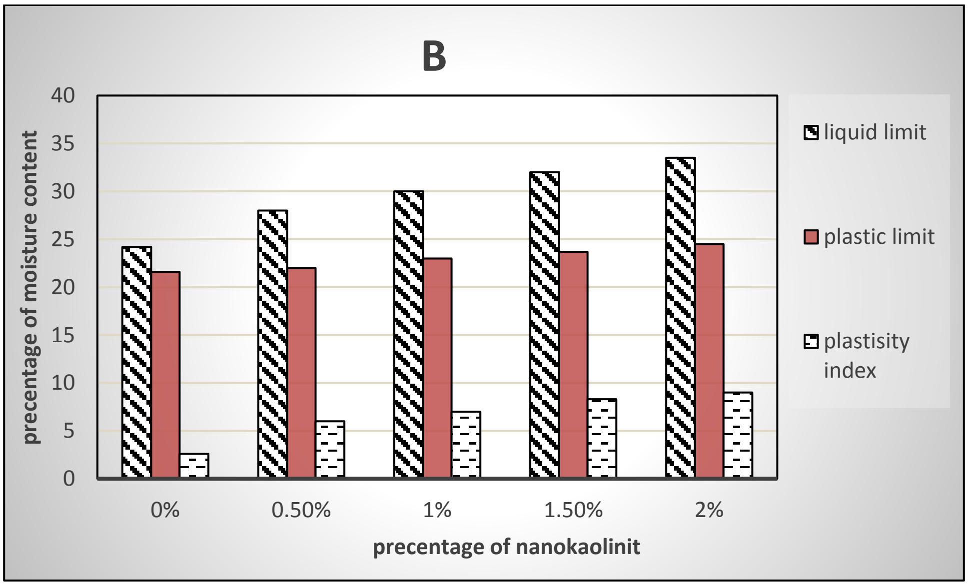

Fig. 8: The diagram for Atterberg limit in silt soil (B) by adding Kaolinite Nano clay

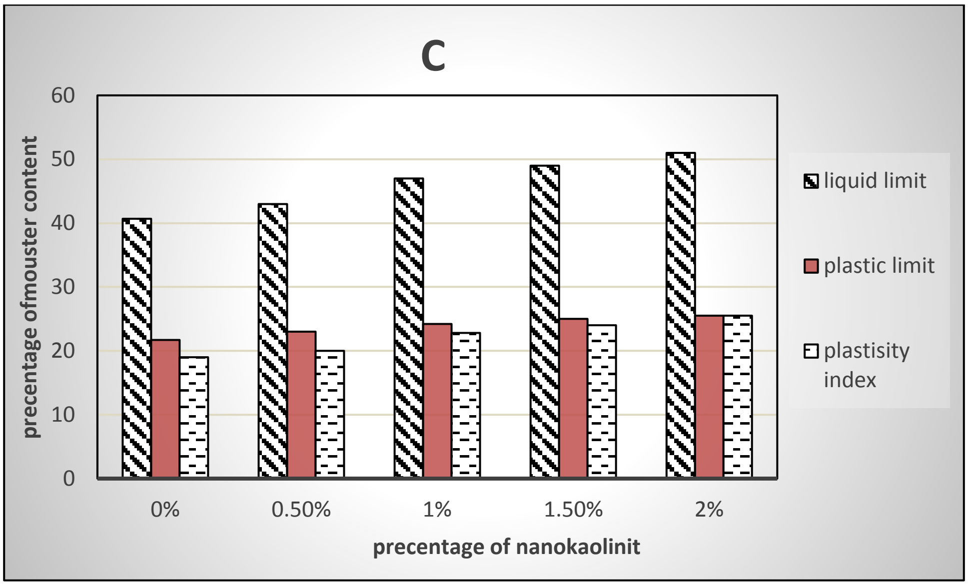

Fig. 9: The diagram for Atterberg limit in silt soil (C) by adding Kaolinite Nano clay

Compaction test

Compaction test was conducted with the aim of obtaining optimum moisture content and maximum dry weight. The results of the compaction experiment on soil composition with different percentages of Nano clay and its effect on soil compaction (optimum moisture content and unit weight) are presented in Table 9 and Figures 10, 11 and 12.

Table 9: Results of compaction experiment on clay and silty soils with different percentages of Nano clay

Percentage of Kaolinite nanoparticles	A		B		C	
	Optimum moisture content **(%)**	)gr/cm3(Density	Optimum moisture content**(%)**	Density) gr/cm3(	Optimum moisture content**(%)**	Density) gr/cm3(
0	15/2	1/8	15	1/82	20	1/75
0/5	14/5	1/85	14	1/9	17/5	1/85
1	13/7	1/9	13	1/95	16	1/95
1/5	13	1/92	12	2	13	2/05
2	12	2/05	11	2/07	12	2/13

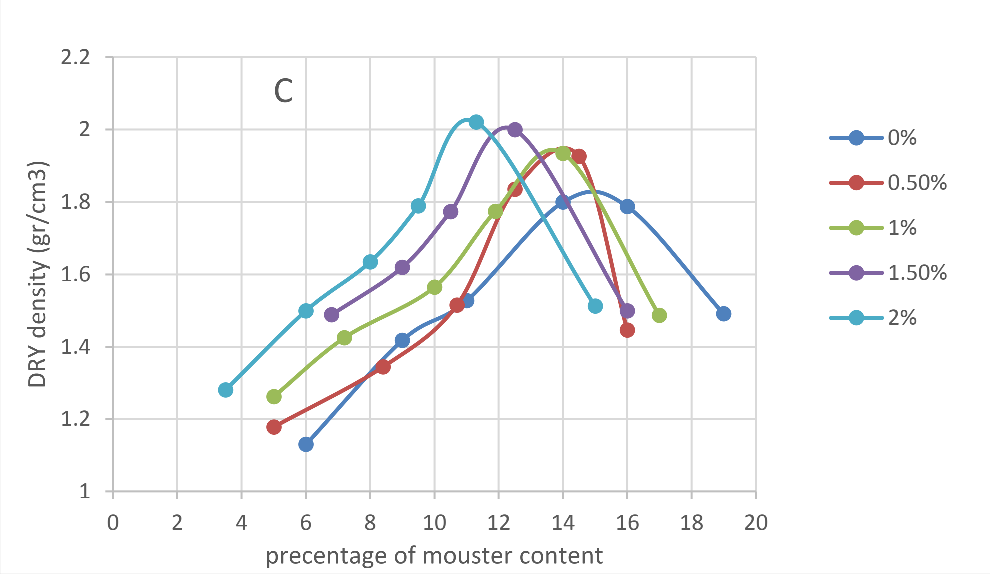

Fig. 10: The diagram of compaction test in clay soil by adding Nano kaolinite

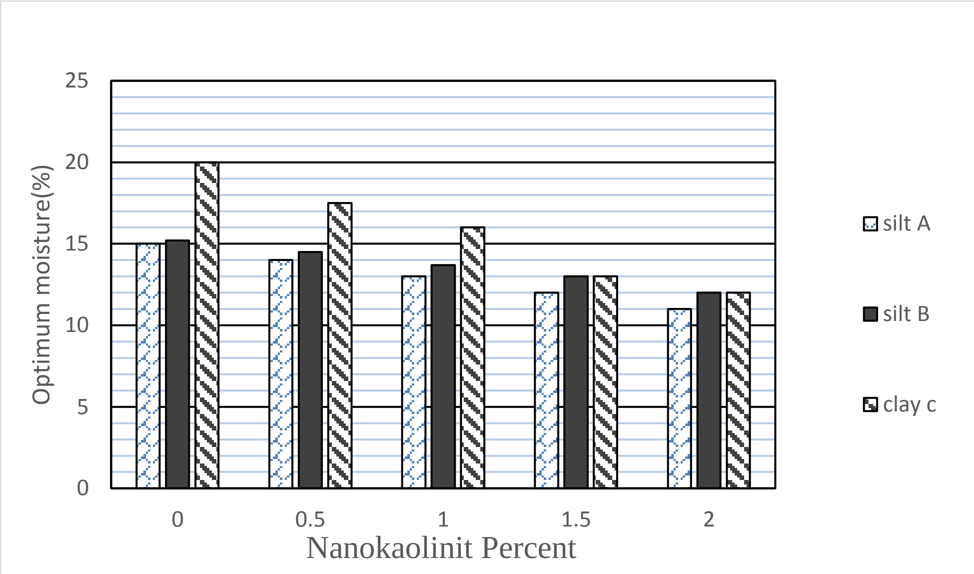

Fig. 11: The diagram of the variation in optimum moisture content by different percentages of Nano kaolinite

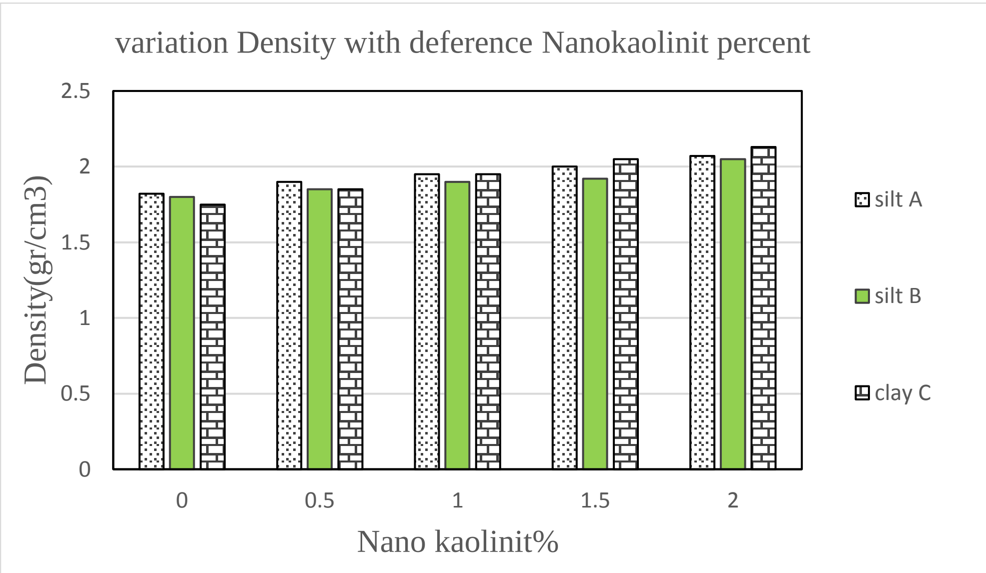

Fig. 12: The diagram of variations in density by different percentages of Nano kaolinite

As seen in the figure, adding Nano clay decreases the optimum moisture content and increases the dry soil specific gravity.

Uniaxial tests

The compressive strength and elasticity modulus with different percentages of Nano kaolinite with a treatment time of seven days in clay and silty soils obtained from the uniaxial test are presented in Table 10 and the diagrams for uniaxial compressive strength and elasticity modulus with different percentages of Nano kaolinite in Figures 13 and 14.

Table 10: Results of uniaxial compression on clay and silty soils with different percentages of Nano clay

Different percentages of Nano kaolinite	A		B		C	
	Compressive (Kpa)strength	Elasticity (Mpa)modulus	Compressive (Kpa)strength	Elasticity (Mpa)modulus	Compressive (Kpa)strength	Elasticity (Mpa)modulus
0	8/62	22	3/73	3	10	3/8
0/5	11/97	30	4/89	4/2	17/2	9/43
1	14/65	40	8/91	15	28	15/61
1/5	16/86	53	10/9	20	43	18/22
2	18/21	56	12/44	27	45	23/14

The compressive strength and elasticity modulus have increased with increase in Nano kaolinite content, which this increase is high in silty (A) and (B) soils and in clayey soil (C). Increasing the amount of Nano kaolinite in clay soils causes a sudden increase in compressive strength and elasticity modulus.

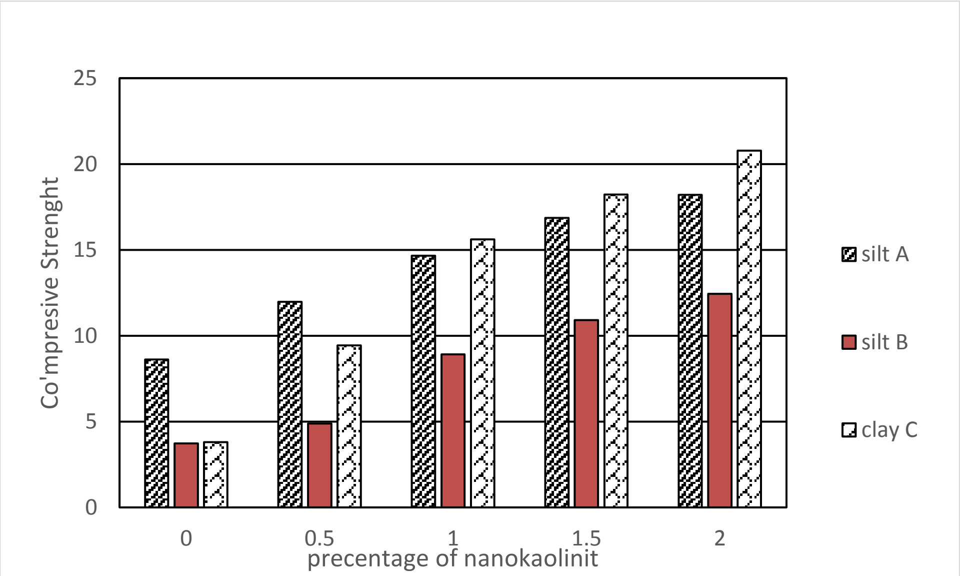

Figure 13: Uniaxial compressive resistance diagram with different percentages of Nano kaolinite

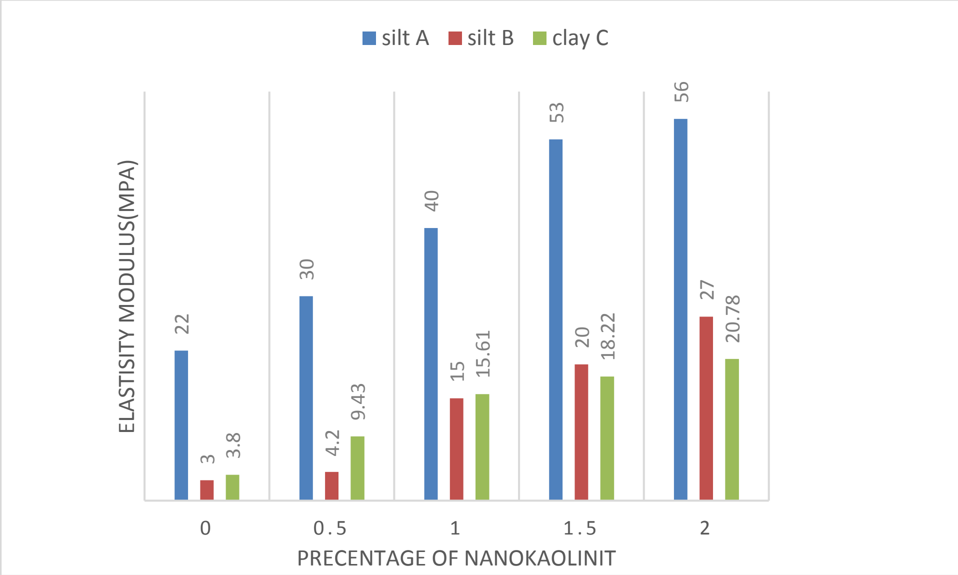

Figure 14: Diagram of elastic modulus variations with different percentages of Nano kaolinite

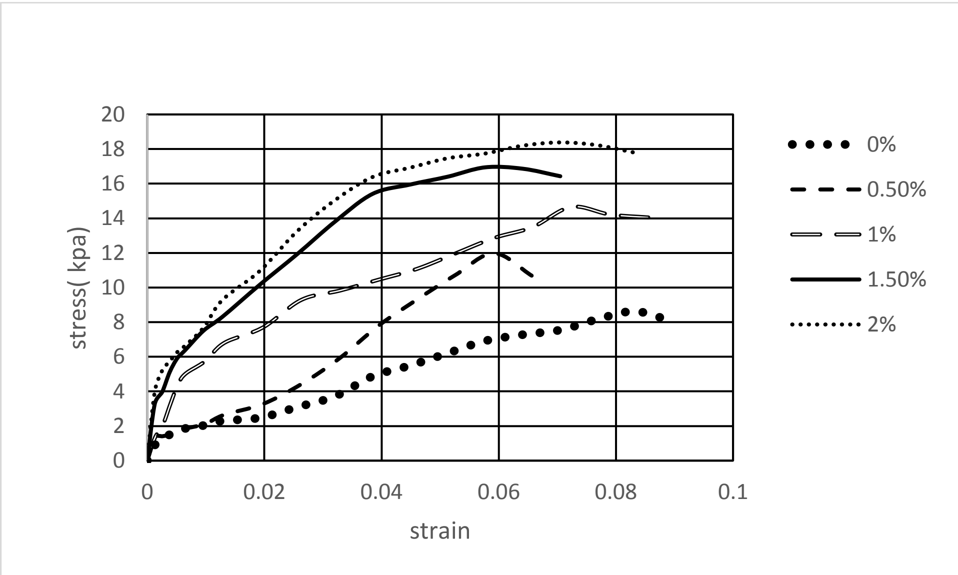

Figure 15: Diagram of stress- strain with different percentages of Nano kaolinite

4. CONCLUSION

While in Atterberg limits test the liquid limit after adding Nano clay increased significantly, there was not much change in the amount of plastic limit. However, adding Nano clay has increased the amount of plasticity range of the soil, and with increase in the plasticity of clay, it can be expected that the permeability coefficient of the sample decreases. The compressive strength and elasticity modulus in uniaxial test have increased with the increase in Nano kaolinite content, which is high and low in silty and clay soils, respectively. Increasing the amount of Nano kaolinite in clay soils causes a sudden increase in compressive strength and elasticity modulus. The results of the direct shear test indicate that the clay and silty soil adhesion increases with the increase in Nano kaolinite content, but the internal friction angle of both clay and silty soil decreases with increase of Nano kaolinite content. The results from the compression test to determine the optimum moisture content and maximum dry weight for each of the clay and silt compositions showed that by increasing the Nano clay content (up to 2% by weight), the optimum moisture content was decreased and the dry weight was maximized.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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