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Laboratory Evaluation of the Improvement of Geotechnical Properties of Fine-grained Soil Stabilized with Plastic Bottle Ash

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ABSTRACT

The first principle in construction works is to have resistant land to build a building. Soil improvement is one of the common methods of improving geotechnical properties and increasing the usability of soil materials. One of the ways to improve the properties of the soil and transform the land into a place where construction is possible is to modify the soil by using additives to it. The use of waste as a material to improve the physical properties of the soil has attracted the attention of researchers. Among these wastes, we can mention rubber wastes, which, in addition to the large volume they occupy, will also cause environmental pollution. In this article, the effect of adding plastic bottle ash on the Zetterberg range and paste properties, the California bearing ratio, and the resistance properties of clay mixed with sand has been investigated. The results of the laboratory tests obtained from this research show the improvement of soil properties by adding plastic bottle ash.

Keywords: Clay, Fine-grained soil, Sand, Ash, Plastic bottles, Geotechnical properties, and CBR.

INTRODUCTION:

Having resistant land is one of the most fundamental principles in civil works. From the point of view of engineering, the role of soil as a support that must resist the forces and stresses caused by the construction of buildings and roads is important. Clay soils usually have low resistance and bearing capacity and swelling problems. Soil stabilization includes activities that improve the engineering characteristics of the soil and bring it closer to the desired characteristics. These measures increase resistance, reduce swelling, reduce permeability, increase efficiency and other very beneficial effects. The use of lime and cement are common methods of stabilizing clay soils (Zhu and Liu, 2008; Muntohar *et al.*, 2012). On the other hand, with the rapid progress of the industry and the increase in the production of waste materials, we are witnessing the large dispersion of waste materials in nature and the emergence of many environmental problems, Especially since plastics are one of the wastes that generally have high mechanical and tensile strength and usually hardly react with acids, bases and other chemical substances, they are also completely resistant to microorganisms and therefore last for years in nature remain unchanged. In this regard, many researches have been carried out to determine the appropriate solution to remove waste or to reuse them, to reduce and control this problem, various methods have been presented. One of these methods is recycling these materials and using them in the industry. In the reinforced soil method, due to the fact that the soil does not have enough tensile strength to withstand the incoming loads, a series of tensile elements including: metal strips, geosynthetics, plastic waste, etc. are used inside the soil (Munfakh, 1997; Babu and Chouksey, 2011). It is worth mentioning that the use of plastic waste in soil improvement does not cost much, and therefore, this type of reinforcement is important from an economic point of view (Consoli *et al*., 2002; Fauzi *et al*., 2016). A large amount of these waste materials cannot be used in the previous industry and cannot be used in the production of the same materials, so they are used in other industries. The use of waste materials and their ash in soil stabilization is a solution that helps to control environmental problems and pollution caused by waste materials, and also improves properties of stabilized soils if appropriate materials are selected (Tingle & Santoni, 2003; Choudhary *et al*., 2010; Kar *et al*., 2021).

Another of its advantages is reducing the destruction of natural resources for the Extraction of common road stabilization materials. It is also very suitable for increasing soil resistance, soil strength, soil permeability, as well as for limiting water absorption, soil erosion control, water loss and soil settlement from an economic point of view. During the last few years, environmental and economic issues have caused attention to the use of waste from worn tires, bottles, glasses, etc. To modify and improve soil properties. Soil stabilization and strengthening methods are often done using geo-synthetics, cementing agents (lime, cement, etc.), synthetic and non-synthetic fibers, or rubber scraps. By adding these materials, it is possible to increase resistance, reduce deformation/settlement, volume stability (swelling and shrinkage control), reduce corrosion, increase durability and reduce soil permeability. Stabilized or rein-forced soils are often composite materials that result from combining and optimizing the proper-ties of individual ingredients. One of the most recent methods in the field of improving soil properties is the use of plastic materials obtained from bottles (Kalumba & Chebet, 2013; Yarbaşı & Kalkan, 2019a).

In recent years, many studies have been conducted on the use of clay soil to increase the bearing capacity of granular soils. Almost in most cases, it has been seen that the studies are limited to embankment reinforced with geosynthetics and metal belts and strips, and the use of plastic waste in embankments is not considered (Dutaa and Sarda, 2007). Among the recent researches in this field, we can refer to the researches of Yarbassi and colleagues. In their research, they investigated the stabilization of sandy soils using plastic bottle waste, stabilization using the combination of stone soil and polyethylene terephthalate fibers, and the mechanical performance of soils reinforced with polyethylene terephthalate fibers and the results proved the better resistance of soils reinforced with these materials (Poor noori & Hajisotode, 2014). In this study, the effect of adding ash from plastic bottles on the geotechnical properties of clay soils mixed with sand has been investigated. After conducting various geotechnical tests on the desired soil with different percentages of plastic bottle ash, the desired goals are:

1) Investigating the effect of plastic bottle ash on Zetterberg limits and the pasty properties of clay mixed with sand
2) Investigating the effect of plastic bottle ash on the bearing ratio of California clay mixed with sand
3) Investigating the effect of plastic bottle ash on the resistance properties of sandy clay.

In the rest of the article, we have described the working method & tests performed and the analysis of the obtained results, & finally we have drawn conclusions.

MATERIALS AND METHODS:

In this article, we will examine the materials used and their various laboratory parameters, the method of making and preparing the tested samples, and explain the basics of the Etterberg limit test, uniaxial test and CBR, the method and steps of the test and the work method in the soil mechanics laboratory.

Sand

The sand soil used in this study is from the sand mines around the city of Sanandaj. After it was transported to the laboratory and washed on a 200 sieve, it was placed in a greenhouse at a temperature of 110 degrees Celsius for 24 hours to dry. Then, in order to determine the size distribution of the particles, it was subjected to a granulation test. Sampling for grading should be done according to the standard method (AASHTO T74-248). According to the percentage of soil passing through each sieve, the granulation diagram of this soil was obtained according to **Fig. 1**.

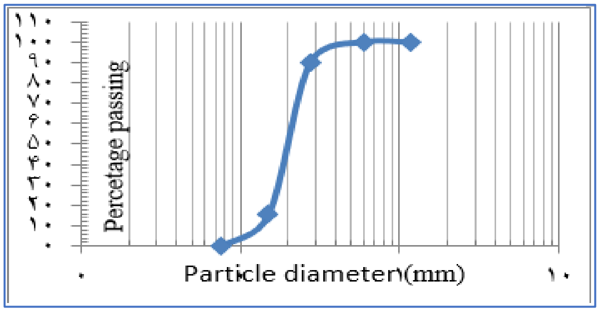

Fig. 1: Sandy soil gradation curve.

According to the obtained values for the coefficients of uniformity and curvature from the granulation diagram, this soil is placed in the SP group (poorly granulated sand) (Halder *et al*., 2022).

Clay

The clay used in this study is kaolin industrial soil with more than 60% pure kaolin, which was obtained from Iran Chinese Soil Company. The soil prepared in order to granulate the soil was tested by the hydrometric method according to the ASTM D 422 standard. 152H type hydrometer was used in this experiment. According to the results obtained from this experiment, the grain size diagram of clay soil is given in **Fig. 2**. After grading the soil, the Zetterberg test was performed to determine the type of soil. This test was done according to ASTM D 4318 standard. The results of the Zetterberg limit test are given in **Table 3**.

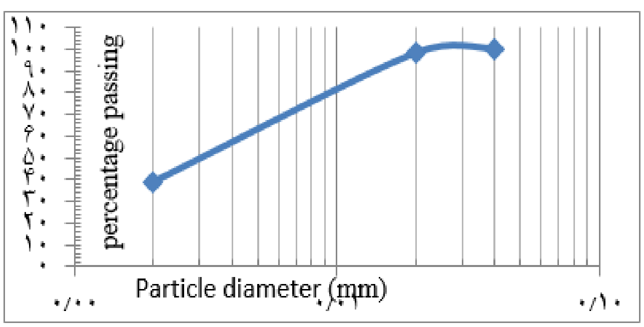

Fig. 2: Clay gradation curve.

Table 1: Chemical composition of plastic bottle ash.

Plasticity (PI) ‘index (LL – PL)	Liquid limit (LL)	Plastic limit (PL)	Soil
23.57	**51.45**	**27.87**	Clay

Therefore, the nomenclature of the clay used is based on the unified CH system (clay with a high paste limit) and based on the Ashto A-7-6 standard.

Ashes of plastic bottles

The obtained plastic bottle ash has a specific density of 2.01 and its chemical characteristics are listed in **Table 2**. The chemical composition of plastic bottle ash meets the requirements of ASTM C618-03 standard for fly ash for use in concrete because the total weight percentage of SiO_2, Al_2O_3 and Fe_2O_3 is more than 70% and its combustion loss is less than 6%.

Table 2: Chemical composition of plastic bottle ash.

Wt%	Composition
63.04	SiO_2
5.72	Al_2O_3
4.17	Fe_2O_3
5.23	CaO
0.13	MgO
5.03	ignition loss

Laboratory program and how to prepare samples

In this research, by adding different percentages of plastic bottle ash to clay soil, which is made by mixing 70% clay and 30% sand, the effect of this material on the soil was investigated in the experiments described below. After naming the soil, in order to better understand the characteristics of the soil, a standard compaction test was performed on it based on the ASTM D 698 standard, the results of which are given below.

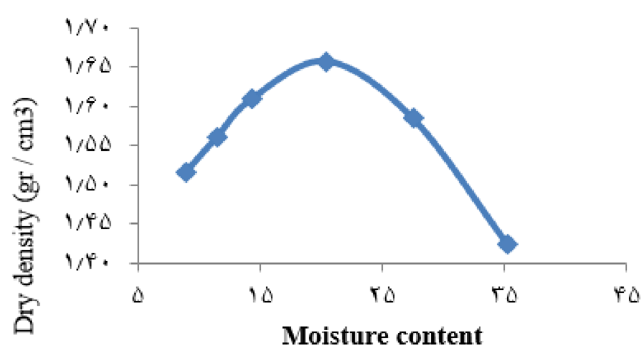

Fig. 3: Clay density curve.

According to the density curve shown in **Fig. 3**, the clay used has a maximum dry specific gravity 1.66 ($\gamma_{d\ max}$) grams per cubic centimeter and an optimal moisture content 20.5%. (ω_{opt}). Also, Gs (density) of the desired clay were obtained as 2.60. Finally, the specifications of the soil used in the experiments are given in below **Table 3**. The percentages of plastic bottle ash added to the soil include 3, 6, and 9 percent of the dry weight of the soil. The granulation tests including granulation by sieve & hydrometric were performed, and the main goal was to know the size of the soil particles and their characteristics. An experiment to determine soil Gs was performed for different combinations of soil and plastic bottle ash.

Table 3: Properties of studied soil (30% s and + 70% clay).

70	The percentage passing sieve No. 200
33.969	Liquid limit (%)
22.07	Plastic limit (%)
11.90	Plasticity index (%)
CL	Unified classification
A-6	AASHO classification
1.656	Maximum dry density (Mg / m3)
20.5	Optimal moisture content(%)
2.65	Specific gravity
White	Color

Analysis of the results

In this section, the results of the tests performed on the samples prepared with different percentages of plastic bottle ash will be presented, which include Etterberg limits, uniaxial resistance and CBR test charts.

Around Etterberg

The effect of plastic bottle ash on liquid limit (LL), pasting limit (PL) and pasting index (PI) for different percentages of plastic bottle ash is summarized in **Table (1-4)** and **(2-4)**. The graph related to the changes of different percentages of plastic bottle ash is shown in **Fig.** (**1-4**). According to **Table 6** and **Fig. 4**, it can be seen that the liquid limit (LL) and the paste limit (PI) both increase with the increase in the percentage of plastic bottles. The increase in flow rate can be due to the cation exchange that takes place due to the presence of plastic bottle ash in the soil, which causes the soil to need more water to become liquid. Increasing the amount of plastic bottle ash causes the accumulation and accumulation of clay particles and increases the effective grain size and the formation of silt-like particles, which as a result increases the pasty limit. The soil paste index decreases & its lowest value is observed in 6% of plastic bottle ash. Reducing the paste index causes a significant reduction in the swelling potential of the soil. These changes with the addition of plastic bottle ash are due to the physic-chemical reaction (cation exchange) which is dependent on the ion hydration of the particle surface and the attraction force between the particles. Plastic bottle ash has the potential to provide polybasic cations (Ca_2+, Al_3+, Fe_3+, Mg_2+), which increase the aggregation of clay particles by cation exchange.

Table 4: Atterberg limits.

Plasticity index (PI)	Plastic limit (PL)	Liquid limit (%)	Plastic bottle ash(%)
11.90	22.07	33.97	0
10.04	24.34	34.37	3
9.97	25.60	35.57	6
10.65	26.37	37.02	9

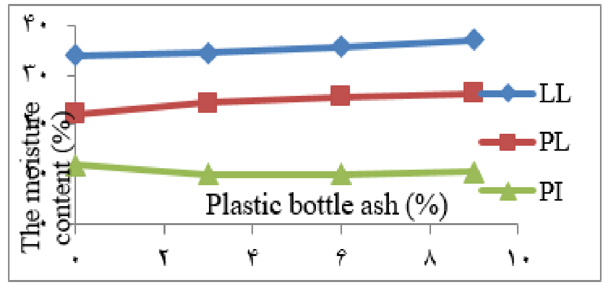

Fig. 4: Variation of Atterberg limits with different percentages of plastic bottle ash.

This reduces the repulsive force and also increases the effective size of the grains due to the accumulation of clay and silt particles and as a result increases the shear resistance. Also, this can be attributed to the increase of plastic bottle ash, which increases the internal friction angle of the clay-ash matrix and also reduces the internal adhesion of the matrix, resulting in the production of siltier materials; Attributed. The decrease in PI with the increase of plastic bottle indicates that the performances of the material as well as the engineering properties are improved.

California CBR bearing ratio test

In order to calculate the California bearing ratio of each soil composition, it is first calculated by dividing the read force values by the corresponding stress penetration piston area. Then the stress diagram is drawn according to the penetration of the piston. Then according to the diagram, the values of the stress related to penetration of 2.5 and 5 mm are read and by dividing these values by the standard stress corresponding to the same amount of penetration, the CBR value is calculated. But if the CBR number for 5 mm penetration is greater than the CBR number for 2.5 mm penetration, the test must be repeated, and if it happens again, the number related to 5 mm penetration is selected as the CBR number. Otherwise, the CBR number is the value corresponding to 2.5 mm penetration. According to the diagram, the CBR of the soil can be calculated:

$$\frac{2.478}{70} = 100CBR = 3.54$$

$$\frac{3.01}{70} = 100CBR = 2.86$$

As a result, the CBR of this soil arrangement is 3.54. After calculating the CBR of the soil related to three different compaction energies, the CBR diagram is drawn in relation to the dry specific gravity of the soil & according to this diagram, the CBR corresponding maximum dry specific gravity of the soil is read. **Fig. 5** shows the CBR diagram in relation to the dry specific gravity of the base soil. The CBR corresponding to the maximum dry specific gravity of the soil is shown in **Fig**. In this way, the CBR of stabilized soil with different percentages of plastic bottle ash is calculated.

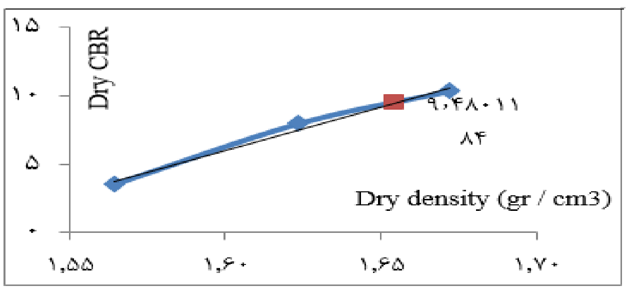

Fig. 5: CBR graph of soil dry density.

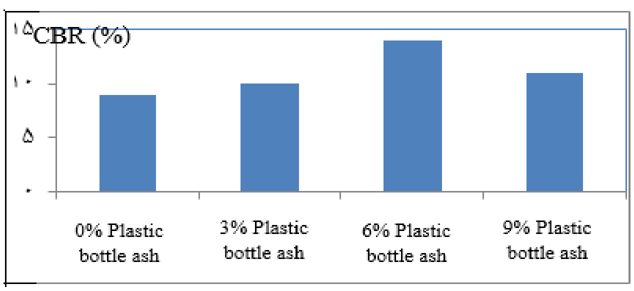

Fig. 6: CBR changes with the percentage of plastic bottle ash.

According to **Fig. 6**, it can be seen that the CBR values increased with the addition of plastic bottle ash. The reason for this is the increase in soil resistance due to the pozzolanic reaction between the bottle ash grains.

Uniaxial test

The uniaxial test is generally used to quickly determine the compressive strength of cohesive soils. Uniaxial resistance is defined by the following relationship:

$$C_u = \frac{q_u}{2}$$

q_u = Simple compressive strength (uniaxial)
C_u = Undrained adhesion (or undrained shear strength)

In this section, the graph of compressive strength in terms of corresponding strain is presented for base soil and soil stabilized with plastic bottle ash. Three tests with three different omnidirectional pressures of 80 kPa, 120 kPa and 200 kPa have been performed on the base soil and nine experiments with the mentioned omnidirectional pressures have been performed for the stabilized soil with 3, 6 and 9% ash. **Fig. 7** to **10** show the changes of compressive strength in terms of corresponding strain for different percentages of plastic bottle ash, and each **Fig.** contains three graphs related to three different all-round pressures.

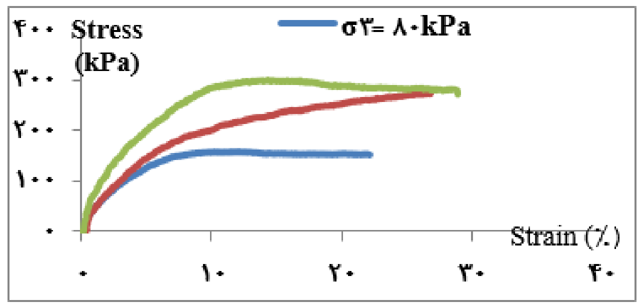

Fig. 7: Stress-strain curve of uniaxial test for 0% plastic bottle ash.

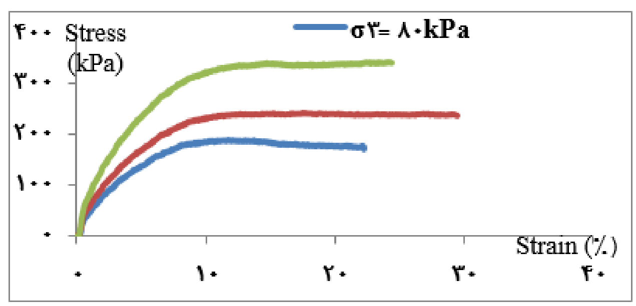

Fig. 8: Stress-strain curve of uniaxial test for 3% plastic bottle ash.

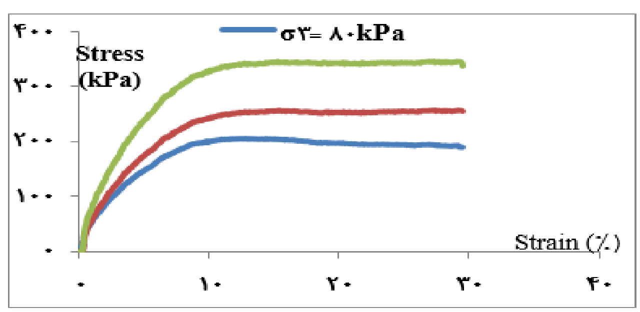

Fig. 9: Stress-strain curve of uniaxial test for 6% plastic bottle as.

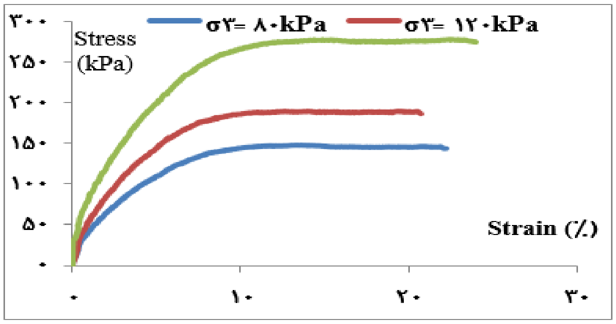

Fig. 10: Stress-strain curve of uniaxial test for 9% plastic bottle ash.

CONCLUSION AND RECOMMENDATIONS:

According to the results obtained from the Etterberg limit test, the amount of the mental limit in the samples increases from 33.97 in the virgin soil sample to 37.02 in the sample with 9% plastic bottle ash. Increasing the amount of plastic bottle ash causes the accumulation and accumulation of clay particles and increases the effective grain size and the formation of silt-like particles, which, as a result, increases the dough limit of the soil from 22.07 in virgin soil to 26.37 in the sample with 9% plastic bottle ash. The soil paste index decreases and its lowest value are equal to 9.97 in 6% plastic bottle ashes. Reducing the paste index causes a significant reduction in the swelling potential of the soil.

1) In this research, dry CBR tests were performed on clay stabilized with plastic bottle ash at 0, 3, 6, and 9% of dry soil weight. CBR values of stabilized soil increased with increasing percentage of plastic bottle ash. The highest increase was observed in 6% plastic bottle ash, which increased the CBR value from 9% to 14%.
2) By increasing the weight percentage of plastic bottle ash from 0 to 6%, the compressive stress increases. Increasing plastic bottle ash from 6% to 9% reduces soil tension and actually reduces soil resistance.

Suggestions

1) The combination of plastic bottles with other additives such as fly ash, rice husk ash, Nano silica, micro silica, etc. should be investigated.
2) To evaluate the effect of time on the performance of the combination of plastic bottle and the desired soil.

Reviewing the theory and using geotechnical software to evaluate the properties of the tested soil stabilized with plastic bottle ash and cement.

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CONFLICTS OF INTEREST:

The authors of this manuscript declare their agreement with the statements and have no conflict of interest.

REFERENCES:

1) Babu, G.S. and Chouksey, S.K (2011). Stress-strain response of plastic waste mixed soil. *Waste management*, **3**(31), p: 481-488. https://doi.org/10.1016/j.wasman.2010.09.018
2) Choudhary, A.K., J.N. Jha & K.S. Gill, (2010). A study on CBR behavior of waste plastic strip reinforced soil. *Emirates j. for engineering research*, **15**(1), p: 51-57.
3) Consoli, N.C. J.P. Montardo, P.D.M. Prietto & Pasa, G. S. (2002). Engineering behavior of a sand reinforced with plastic waste. *J. of Geotechnical & Geoenvironmental Engineering*, **128** (6), p: 462-472. https://doi.org/10.1061/(ASCE)1090-0241(2002)128:6(462)
4) Dutaa R.K., and Sarda, V.K. (2007). CBR behavior of waste plastic strip-reinforced stone dust/fly ash overlying saturated clay. *Turkish J. of Engineering & Environmental Sciences*, **31**(3), p: 171-182.
5) Fauzi, A., Z. Djauhari, U.J. Fauzi, (2016). Soil Engineering Properties Improvement by Utilization of Cut Waste Plastic and Crushed Waste Glass as Additive. *Inter J. of Engineering & Technology*, **8**(1), 15. https://doi.org/10.7763/IJET.2016.V8.851
6) Halder D, Islam MN, Hossain MM, Rahman MA, Samadder R, and Rahman MM. (2022). Synthesis a clay based photocatalyst for the removal of eosin yellow in aqueous solution, *Int. J. Mat. Math. Sci*., **4**(4), 83-93. https://doi.org/10.34104/ijmms.022.083093
7) Kalumba, D., and Chebet, F.C. (2013). Utilization of polyethylene plastic shopping bags waste for soil improvement in sandy soils. *Proc. 18th ICSMGE.*

8) Kar K, Hossain MA, and Roshni A. (2021). Recovery and recycling of valuable metals from low-grade ores using microorganisms: a brief review. *Am. J. Pure Appl. Sci*., **3**(1), 1-16. https://doi.org/10.34104/ajpab.021.01016
9) Munfakh, G.A. (1997). Ground Improvement Engineering - the state of the US practice: Part 1. *Methods, J.* https://doi.org/10.1680/gi.1997.010402
10) Muntohar, A.S., A. Widianti, E. Hartono & W. Diana, (2012). Engineering properties of silty soil stabilized with lime and rice husk ash and reinforced with waste plastic fiber. *J. of Materials in Civil Engineering*, **25**(9), p: 1260-1270. http://repository.umy.ac.id/handle/123456789/1340
11) Poor noori, P. and Hajisotode, M. (2014). Improve soil resistance behavior using waste material, 1 conference of soil mechanics and foundation engineering, *Shahid Rejaei University, Theran, Iran*.
12) Tingle, J. S. and Santoni, R. L. (2003). Stabilization of Clay Soils with Nontraditional Additives, *Transportation Research Board*, **1819** (2003), p: 72-84. https://journals.sagepub.com/doi/10.3141/1819b-10
13) Yarbaşı, N., and Kalkan, E., (2019a). Strength performance of stabilized clayey soils with quartzite material. *Inter J. of Earth Sciences Knowledge & Applications*, **1**(1) 1-5. https://dergipark.org.tr/en/pub/ijeska/issue/55458/760012
14) Zhu, Z.D. and Liu S.Y., (2008). Utilization of a new soil stabilizer for silt subgrade. *Engineering Geology*, **97**(4), 192-198. https://doi.org/10.1016/j.enggeo.2008.01.003

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