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Influence of Plastic Fiber on the Geotechnical Properties of Gypseous Soil

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ABSTRACT

In the last five decades, the rise of the plastic industry led to increase in the waste of plastic in the environment, therefore the scientists were thinking to reduce plastic waste by recycling the plastic. On the other hand, there is a problem of collapse of gypseous collapsible soil upon wetting. In this paper, one of the methods to recycling plastic is adopted to improve the gypseous soil by mixing with 1% plastic fiber to increase the shear strength and improve collapsibility of soil at the state of saturation or soil wetting. The soil used is classified as SW-SM, the gypsum content is 39% and the relative density is equal to 73%. Fiber plastic is made from plastic waste in the environment of investigation. Several tests were conducted on the soil such as collapse test, direct shear test, also model loading test on the soil before and after mixing with fiber plastic. The worst case of gypsum soil is at saturation by rain or groundwater rise which was simulated during the loading test. It was concluded that the value of soil cohesion gradually increases from 2 MPa at the state of the natural soil to 11 MPa after mixing with 1% of plastic fibers. From the three model loading tests, the load carrying capacity of a model footing on submerged gypseous soil increased from 2.66 MPa for untreated soil to 4.8 MPa when the soil is mixed with 1% plastic fiber and extended to a depth of 0.5 B. The earing capacity also increased to 6.8 MPa when the soil is mixed with 1% plastic fiber and extended to a depth of B.

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NOMENCLATURE

USCS	Unified Soil Classification System	CP	Collapse potential %
Cu	Coefficient of uniformity	$D_{15(B)}$	The particle diameter through which (15% of soil) will pass
Cc	Coefficient of curvature	$D_{15(F)}$	The particle diameter through which (15% of filter material) will pass
Gs	Specific gravity	$D_{85(B)}$	The particle diameter through which (85% of the soil) will pass
E	Void ratio	ϕ	Internal friction angle
Δe	Change in void ratio	c	Cohesion, (kPa)
ΔH	Change in the cell height	**Greek Symbols**	
H_o	Cell height	$\frac{D15(F)}{D85(F)} \leq 4-5$	Filter equalization, The first part
τ	Maximum shear stress,(kPa)	$\frac{D15(F)}{D85(F)} \geq 4-5$	Filter equalization, The second part
B	Width of model bace	$Cp = \frac{\Delta H}{H_o} \times 100 = \frac{\Delta e}{1+e_o} \times 100$	(Collapse potential %) equalization

1. INTRODUCTION

Scientists pointed out to estimate in the year 2012 alone, that about 280 million tonnes of plastic have been used worldwide. But about 130 million tonnes of plastics were waste on earth. Therefore, 150 million tonnes of plastic are remaining due to use in the daily lives of human beings.

The growing use resulted in a massive upsurge in the quantity of plastic waste. These wastes have highlights impacts on the environment such as maculation and sapping of resources. Restoring plastic dumps and reusing it helps in alleviating environmental degradation. The recycled plastic waste in U.S.A get

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was 5.7% of the total plastics waste, while Europe recycled 39% of the total plastics waste [1].

Studies have shown that gypseous soil is improved using waste materials such as fiber plastic that is content is available at low cost. Polypropylene that is one of the kinds of plastic waste is used to improve the soil shear strength. When the plastic fiber is added to the soil, this leads to help in mitigating the volume change behaviour [2].

Collapse or unstable soil structure can produce vital problems for construction. Because the super layer of plastic fiber is tensile strength, its price is cheap, and it is widely available as waste material. Some scientists have suggested using it as improved soil mechanical properties [3]. For many causes such as home appearance, durability, ease of installation and energy efficiency, lead to vinyl siding to use in the building and construction industry besides using plastics have a variety of benefits, but the effects are noxious to the environment.

Tang et al. [4] used plastic fiber to improve soil such as clay, life of fibers depends on the percentage temperature as (5, 10, 20) years at a temperature of (121, 110, 99)° C. The temperature of 120°C is stable and approved in the laboratory [5]. The method the fibers interact with soil particles was investigated using sensitive devices such as an optical microscope and a scanning electron microscope, of their studies it appears that the fiber feature that occurs during shearing does not rupture, but the defects of the fibbers are expanded, and some damage may occur in Figure 1. The damage is the beginning of the distance of the plastic fiber with any cutting style.

Researchers pointed out that damage occurs most often when fiber is pressed by a high energy effect. The fibers lose their straightness become many bends (angles) at the end. Figure 1 shows what it interaction steps between the fiber and the particles of soil as hereunder: (a) Particles of soil being curb by fiber from packing tightly. (b) Also, particles of soil are triggering fiber stretch and imprints on the fiber allowing adhesion to develop [4].

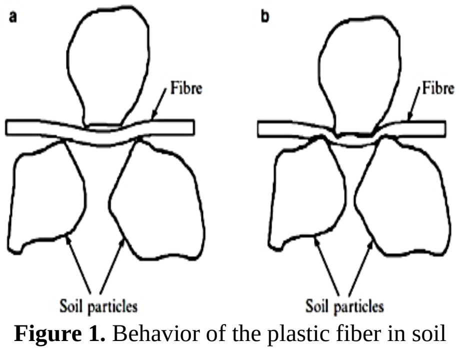

Figure 1. Behavior of the plastic fiber in soil

Previous research that studied the problems of gypseous soil showed that the behavior of this soil refers to strong soil in its dry state, but it collapses when exposed to groundwater or rain due to the dissolution of gypsum in the water. Therefore, some researchers have undertaken studies to solve this problem, as follows:

Injection of gypseous soil with acrylate liquid reduces collapse by more than 50-60% [6].

Improving the properties of gypseous soil by using materials that increase the cohesion property between gypsum soil particles, for example (cement, kaolin, lime, calcium chloride, [7].

Using silicon oil was found to increase the parameters of shear strength of the soil by increasing the cohesion between the grains of soil [8].

Long-term soaking and leaching effects on the strength and stability properties of the gypseous soils stabilized by lime were studied by Aldaood et al., [9]. The stabilized soaked soil specimens showed that the collapsibility properties were decreased as compared to un-soaked specimens.

Hydro-mechanical behavior of unsaturated collapsible soils can be drastically affected by saline infiltrations. Garakani et al. [10], investigated hydro-mechanical characteristics of an unsaturated collapsible loessial soil diluted with saturated solutions of three different salts that are frequently involved in transportation infrastructure (namely NaCl, CaCl2 and KCl) by conducting scanning electron microscopy (SEM), filter paper, uniaxial compression and oedometer tests. Results implied that there is a critical saline degree of saturation (corresponded to each loading path and each mixing salt type), at which the magnitude and modality of the osmotic and matric suctions within the soil fabric are changed. In addition to experimental studies, empirical constitutive models are presented in this paper to predict the changes in strength, stiffness and yield stress of the tested collapsible soil subjected to different road salts. Comparisons show very good agreement between the laboratory test results and the model predictions.

Collapse problem treatment of gypseous soil by nanomaterials was also studied. Hayal et al. [11] added Nano-silica to the soil. the collapse potential (CP) decreased whenever the Nano-silica increases until 1%, the percent of decrease in CP is about 91%.

Zakaria [12] tried to improve soil strength properties and intrusion of reinforcing sorces into soil. The footing was modeled by a square steel plate 0.1 by 0.1 m. The footing is loaded as to have a stress of 40 kPa and settlement was receded in dry and in soaking conditions. Two depths of the geo-mesh reinforcement are used, one B (B is width of footing) and 0.5B. Results revealed that the best improvement obtained is the case of a square geo-mesh width of 7.5B and located at depth of B/2 under footing, with an improvement in terms of collapse settlement of 35%, and a settlement reduction in dry condition of 50%. The least improvement is the case of square geo-mesh with a width of 4B and depth of one B, and it was really negligible, about 4% decrease in collapse settlement.

The objective of the present study is improving the collapsible soil characteristics through reducing the phenomenon of collapse of soaked gypseous soil by mixing the soil with plastic fiber. The study methodology includes tracing the changes in collapse potential investigated in the soaked gypseous soil before and after treatment by carrying out laboratory experiments including collapse test and direct shear strength test.

2. MATERIALS AND MODEL PART TEST

2. 1. Soil The soil sample used is incurred from Iraq with a gypsum content of 39%. The soil used can be categorized as (SW-SM) according to the Unified Soil Classification System (USCS). Figure 2 explains the grain size distribution of the soil used and Table 1 explains the properties of soil that include percent of soil constituents, specific gravity, maximum and minimum dry unit weights and relative density.

2. 2. Plastic Fibers Additives The plastic fiber used is cheap and available in the market and is known as polypropylene (fiber plastic). The specifications of the polypropylene fiber are listed in Table 2 including the physical properties. Figure 3 shows the fiber plastic used.

2. 3. Model Loading Tests

2. 3. 1. Model Parts The model consists of the following parts as shown in Figure 4.

1. A steel container containing saturated gypsum soil prepared with dimensions (350 x 500 x 300) mm.

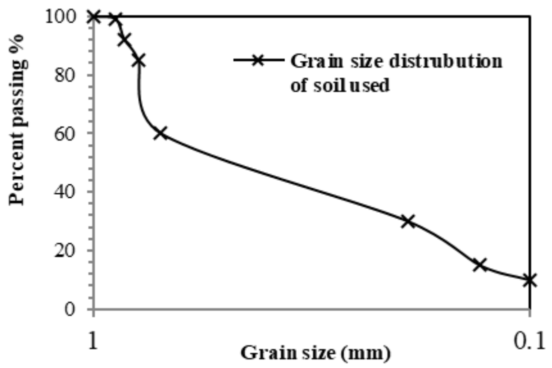

Figure 2. Soil grain size distribution

TABLE 1. The Soil of physicals properties

Index property s	Index value	Specification
Gypsum content (%)	39	
Sand %	94	
Silt & clay %	4	
D_{10}	0.1	
D_{30}	0.19	
D_{60}	0.7	ASTM D422-2001 [13]
Coefficient of uniformity, Cu	7	
Coefficient of curvature, Cc	1.39	
Soil classification, (USCS)	SW-SM	
Specific gravity, (Gs)	2.6	ASTM D854-2005 [14]
Optimum moisture content (%)	11.0	ASTM D-698 [15]
Maximum dry weight, (kN/m^3)	16.8	ASTM D4253-2000 [16]
Minimum dry weight, (kN/m^3)	11.5	ASTM D4254-2000 [17]
Angle of internal friction, θ°	36	ASTM D3080-1998 [18]
Dry unit weight, (kN/m^3)	15.2	
Void ratio, e	0.625	
Relative density (%)	73 %	

Figure 3. Fiber plastic

2. Frame element structure used to carry the exenrual static load to the footing as increments.
3. Dead weights used were (7.5 , 12.5 , 17.5 , 22.5, 27.5 , 32.5) N.
4. Dial gauges to read the settlement of the footing under external load.
5. Square steel footing with dimensions (60 x 60) mm.

TABLE 2. Specification for polypropylene fibers (fiber plastic) [19]

Fiber properties	Values
Fiber type	Single fiber
Length, (mm)	6
Diameter, (mm)	0.034
Density, (g/cm^3)	0.91
Tensile strength, (MPa)	350
Young's modulus, (MPa)	3500
Fusion point , °C	165
Burning point, °C	590° C
Surface area, (m^2/kg)	250
Elongation, %	24.4
Water absorption	Nil
Dispensability	Excellent
Acid & alkali resistance	Very good

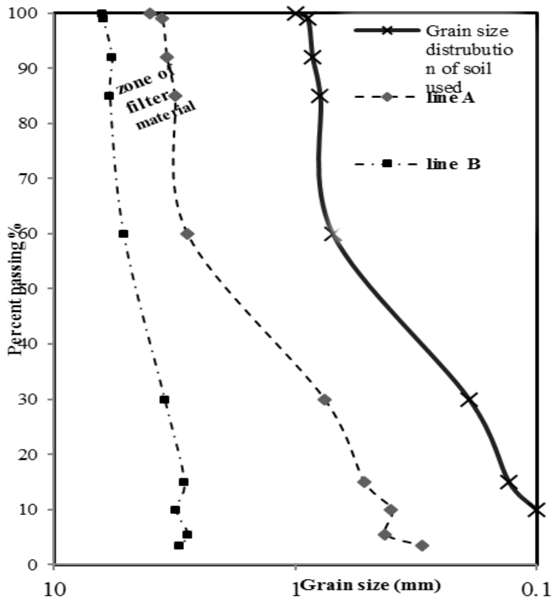

Figure 5. The grain-size distribution of the filter material

Figure 4. Model loading test.

A filter material was placed at the bed of the model to block the soil flow. The filter material was selected based on the following criteria in Equations (1) and (2) [20]:

$$\frac{D15(F)}{D85(F)} \leq 4-5 \quad (1)$$

$$\frac{D15(F)}{D85(F)} \geq 4-5 \quad (2)$$

Figure 5, explains the grain-size distribution of the filter material.

2. 4. Soil Bed Preparation for the Model A water drainage network has been established at the bottom of the container to represent the reality of groundwater. This network is connected to a water tank at a height of 15 m. Through its faucets water is drained from the tank to the water drainage network to feed the container with a water until the water reaches the surface of the model to ensure the representation of the reality of gypsum soil exposure. For groundwater rise saturation with rain together, a new system to make as a soil filter bed preparation is adopted to ensure that all specimens will be equally extremely wetted. The procedure consists of the following steps:

1. A gravel layer was placed at the bed of the container to make the water able to dissipate as shown in Figure (6-a).
2. The hollow plastic tubes have holes to allow the water to rise and pass through a uniform flow, Figures (6-b), (6-c).
3. Fly mesh layer was put at the upper of the hollow plastic tubes to prevent and avert soil drop through the holes to the gravel layer and make an empty space within the filter layer, Figure (6-d).
4. A soil filter was constructed from two layers 50 mm each compacted at relative density of (73%).
5. A double layer of fly-mesh was put over the layers mentioned above to prevent mixing between the filter and soil. Figure (6-e) illustrates the filter material installation.

2. 5. Soil Saturation in the Model The actual state of soil subjected to groundwater or rain is idealized by thoroughly soaking the sample with water. Soaking the soil with water was made for a period of one day to simulate the situation under the footing. The tested soil is supplied with water through the. The flow of water was through a plastic mesh below the filtered soil layer, the tank was closed off and the water flow to the model was stopped.

Figure 6. Steps of preparation of soil model loading test

2. 6. Model Tests Three model tests were established: In the first model, a model foundation was tested on gypseous soil before treatment. The second and third models were tested for the foundation on gypseous soil after treatment by mixing with 1% of the plastic fibers. The mixed soil was extended to depths of (0.5B and 1B), respectively where B is the footing width. The testing procedure is illustrated in Figure 7.

3. DATA ANALYSIS AND TESTING RESULTS

3. 1. Shear Strength Test Results To investigate the effect of mixing the soil with fiber on the parameters of shear strength of the gypseous soil, direct shear test was carried out on the soil in its natural state and after treatment with plastic fiber. In this test, the time of sample soaking in water was 24 hours. Figure 8 explains the relationship between shear stress and normal stress for the soil at its natural soil state and also the soil after treatment by mixing with 1% fiber plastic material. It is observed that both the cohesion and angle of internal friction increase. Table 3 summarizes the increase in the shear strength parameters (c and ϕ) after mixing the soil with 0.1% fiber plastic. From the direct shear test, it is found that the soaked gypseous soil exhibits very high shear strength after treatment by mixing with 1% fiber plastic percent to be more than 5.5 times from soil without treatment. Therefore, fiber plastic is considered a substance that contributes to improve the engineering properties, as it works as a reinforcement to bond the soaked gypseous soil particles and protect it from degradation.

Figure 7. Performing loading on gypseous soil pressure

Nareeman and Fattah (2012) [21] found that the shear stress increased for soil reinforced by horizontal geonet layer, while the vertical displacement decreased. This is because the geonet layer works as a reinforcement layer that strengthens the soil and tends to increase shear strength of the soil. It can be seen that both compression and dilation of the soil are decreased by adding reinforcement layers.

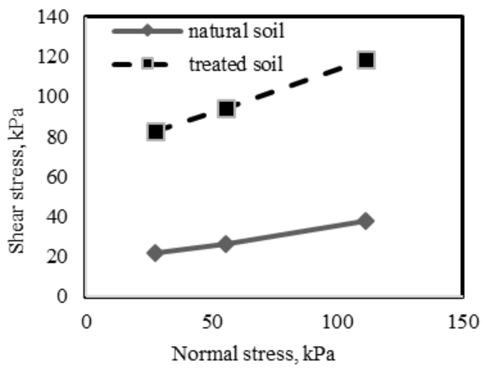

Figure 8. Relationship between shear stress and normal stress in the direct shear test

TABLE 3. Results of direct shear test

Percentage of fiber		0	1
Cohesion, c (kPa)		2	11
Internal friction angle, ϕ°		36	44
Maximum shear stress (kPa)	τ_1	22.1	82.7
	τ_2	26.5	93.9
	τ_3	37.8	118.3

3. 2. Collapse Test Results The results of the odometer test are described for the gypseous soil after mixing with polypropylene fiber (plastic fiber). The collapse potential is calculated as in Equation (3) [22]:

$$Cp = \frac{\Delta H}{H_o} \times 100 = \frac{\Delta e}{1+e_o} \times 100 \quad (3)$$

Figure 9 shows that linear decrease of settlement and the void ratio for the soil can occur under 0.21 to 0.006 MPa pressure. The figure shows a comparison of the results between the gypseous soil tested without treatment, and the gypseous soil after mixing with 1% plastic fibers. Moreover, Table 4 explains the decrease in the collapse of gypseous soil from 12.9 to 0.96 at 1% percentage of fiber plastic where the collapse potential is presented for each case.

Fattah et al. (2013) [23] concluded that the gypseous soil exhibited similar behavior for all unsoaked specimens. The soil showed a clear peak value of shear stress at each normal stress. All soils have a cohesion component; this may be due to the cementing action of gypsum for untreated soil and the cementing action of gypsum and acrylate liquid for the treated soil. In addition, the soil samples exhibited dilation under all normal stresses. The results of specimens sheared after soaking show that the behavior of the stress-strain relationship is changed from dense state to lose state. The curves do not show a clear peak, so the tests were continued until the sample reached a 20% strain. All the samples revealed compression when sheared under all normal stresses.

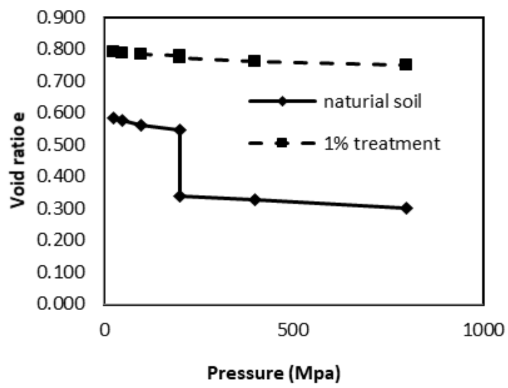

Figure 9. Pressure – void ratio relation for gypseous soil before and after mixing with plastic fiber

TABLE 4. Collapse potential and problem severity type

Severity of the problem	Collapse potential, Cp (%)	Condition
Severely trouble	12.9	Before treatment
No problem	0.96	After treatment

3. 3. Model Loading Test Results In the present study, the failure load is considered the load causing a settlement that represents 10% of the footing width. Figure 10 illustrates the model loading test results on saturated gypseous soils until failure occurs. At 10% of the footing width, the footing failure pressure is (2.66 MPa). Figure 11 shows the result of the pressure – settlement relation for the gypseous soil mixed with 1% plastic fibers extended to a depth equal to half the width of the footing.

At 10% of the footing width, the value of failure pressure is (4.8 MPa). Figure 12 illustrates the pressure – settlement relation for a footing model on gypseous soil mixed with 1% of plastic fibers and extended to a depth equalize to the width of the footing, failure occurs at a settlement of 10% of the footing width, the value of failure pressure is (6.8 MPa). After full inundation of collapsible soil, the bonds of cementing between particles get broken, and the remaining shear strength is derived from the inter-granular frictional forces. Consequently, the angle of internal friction can be utilized as an adequate parameters measure [24].

In addition, fiber plastics provide another type of bond that resists inundation of collapsible soil, it is added to cohesion of soil particles. This treatment is considered economical, as it is used in a very small percentage, and it is an available material that can be obtained from the waste of plastic factories or consumed plastic water bottles or as polypropylene fibers material.

The present action of fiber mixed gypseous soil can be compared with the results of Zakaria (2020) [12] who found that all reinforcement cases for the depth of 0.5B show higher improvement ratios than the similar cases for depth one B, indicating that the majority of collapse potential is taking place in the zone of soil almost directly beneath footing. In addition that the sizes of the geo-mesh in the first case are smaller than that for the latters.

After full inundation of collapsible soil, the cementing bonds between particles get broken, and the

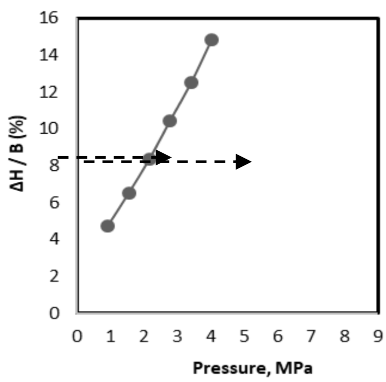

Figure 10. Relation between pressure and settlement for gypseous without treatment

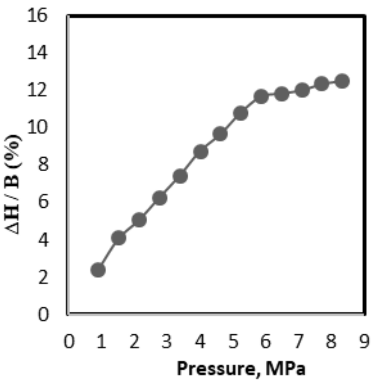

Figure 11. Relation between pressure and settlement for gypseous with mixing with 1% plastic fiber extended to a depth of 0.5 B

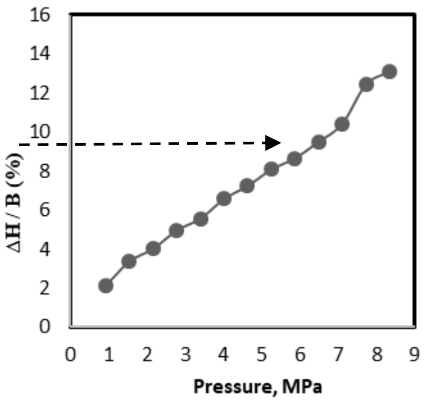

Figure 12. Relation between pressure and settlement for gypseous with mixing with 1% plastic fiber extended to a depth of B

remaining shear strength is derived from the intergranular frictional forces. Consequently, the angle of internal friction can be utilized as an adequate measure of shear strength [25].

4. CONCLUSION

It was noted through previous studies that no study had ever been done regarding the addition of plastic fibers to gypseous soil. Through this paper, the possibility of adding this material as an attempt to improve the soil has been made. In the light of experimental model tests and tests resultant, and also the following conclusions can be drawn:

1. From the direct shear test, the soaked gypseous soil exhibits very high shear strength after treatment by mixing with 1% fiber plastic percent to be more than 5.5 times from soil without treatment.
2. From collapse test results, the collapse potential of gypseous soil with gypsum content was 39% was 12.9% and classified as (severely trouble). After treatment using 1% of fiber plastic, the collapse potential decreased to 0.96% only with a classification of (no problem) which indicates the interesting role of fibers in treatment of collapse problem.
3. From the three model loading tests, the load carrying capacity of a model footing on submerged gypseous soil increased from 2.66 MPa for untreated soil to 4.8 MPa when the soil is mixed with 1% plastic fiber and extended to a depth of 0.5 B. The earing capacity also increased to 6.8 MPa when the soil is mixed with 1% plastic fiber and extended to a depth of B. This means that mixing the soil to a limited depth below the footing with fiber could reveal a beneficial effect in decreasing the soil collapse.

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Persian Abstract

در پنج دهه گذشته ، ظهور صنعت پلاستیک منجر به افزایش ضایعات پلاستیک در محیط شد ، بنابراین دانشمندان در فکر کاهش ضایعات پلاستیک با بازیافت پلاستیک بودند. در این مقاله ، یکی از روشهای بازیافت پلاستیک برای بهبود خاک گچی با مخلوط شدن با ۱٪ الیاف پلاستیک جهت افزایش مقاومت برشی و بهبود قابلیت جمع شدن در حالت اشباع یا خیس شدن خاک در نظر گرفته شده است. خاک مورد استفاده به عنوان SW-SM طبقه بندی می شود ، محتوای گچ ۳۹٪ و چگالی نسبی برابر با ۷۳٪ است. پلاستیک الیافی در محیط تحقیق از ضایعات پلاستیکی ساخته می شود. چندین آزمایش روی خاک انجام شد مانند آزمایش ریزش ، آزمون برش مستقیم ، همچنین آزمون بارگذاری مدل روی خاک قبل و بعد از اختلاط با پلاستیک الیاف. بدترین حالت خاک گچ در اشباع شدن باران یا بالا آمدن آب زیرزمینی است که در هنگام آزمایش بارگیری شبیه سازی شده است. نتیجه گیری شد که مقدار انسجام خاک پس از مخلوط شدن با ۱٪ الیاف پلاستیک به تدریج از ۲ MPa در حالت خاک طبیعی به ۱۱ MPa افزایش می یابد.