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Treatment of Swelling Soil Using Crushed Glass Wastes and Lime

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Keywords
Expansive soil; Crushed glass wastes; Lime; Atterberg limits; Compaction characteristics; Shear strength parameters; Free swell; Swelling pressure; California Bearing Ratio; Engineering properties; Soil treatment.

Abstract

This research aims to improve the engineering properties of expansive soil by using locally low-cost materials such as crushed glass wastes and lime. The studied expansive soil is considered unsuitable soil for civil engineering projects such as roads and buildings, as it was classified according to the AASHTO classification A-7-6. This soil was treated only with different ratios of crushed glass wastes (0%, 5%, 10%, 15%, and 20% by weight of dry soil), as well as the soil was treated only with different ratios of lime (0%, 2%, 4%, 6%, and 8% by weight of dry soil). Experiments of Atterberg limits, standard Procter, direct shear, free swell, swelling pressure, and both un-soaked and soaked California Bearing Ratio tests were carried out on the untreated and treated soil. The results showed that by increasing added percentage of crushed glass wastes and lime separately, the consistency properties (Atterberg limits), the shear strength parameters (direct shear test), free swell, swelling pressure, and both un-soaked and soaked California Bearing Ratio of the studied expansive soil were improved; except for compaction characteristics, by adding crushed glass wastes the M.D.D was increased and O.M.C was decreased while by adding lime, the M.D.D was decreased and O.M.C was increased. This helps to make use of low-cost local materials, clean the environment of glass wastes, and recycle these wastes so that they can be used on an environmental, economic, and engineering level. This aligns with Egypt's Vision 2030 sustainable development approach in both the environmental and economic dimensions.

1. Introduction

Expansive soil is the soil that is prone to large volume of changes that are directly related to changes in water content. Expansive soils are widely distributed in Egyptian valleys, which

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were chosen for their expansive areas for the construction of new cities and roads, for example, New Sohag city and New Akhmeem city. [1], [2], [3], [4], [5], [6]. The fundamental problem associated with expansive soil is notable volume change of the soil mass, which leads to the subsidence effect and an increase in their susceptibility to swelling. These properties are undesirable geometrically. When expansive soil dries, it shrinks due to loss of water. The presence of this type of expansive soil causes serious consequences for the planning of civil engineering projects such as roads and buildings. [1], [2], [3], [4], [5], [6], [7].

In the sites of expansive soil, it is often required to construct engineering projects. In this scenario, we must first improve its qualities before construction. This is because it will be uneconomical to replace the expansive soil with other suitable soil for construction (expensive). As a result, finding cost-effective solutions to improve the qualities of expansive soil is critical. [2], [6], [8], [9], [10]. There are many ways for improving the engineering properties of expansive soil. Examples include thermal, mechanical, and chemical methods, and improvement with additions such as cement, lime, and metal additives, or adding inert materials to increase soil density, cohesion, and friction resistance. [2], [4], [6], [8], [9], [11]. Some previous studies have demonstrated that glass wastes can be used in geotechnical engineering applications. There has been very little research and study done to look at the influence of crushed glass wastes additions on the engineering properties of expansive soil, or the possibility of employing these wastes to stabilize and improve the engineering properties of expansive soil. Here, some studies are presented on the effect of adding only crushed glass wastes to expansive soil and the effect of adding only lime to expansive soil on the engineering properties of expansive soil.

In 2020, researchers studied the effects of waste glass powder on subgrade soil improvement. that was investigated by adding glass powder to the soil, the additive had a positive impact on soil and had improved the soil properties; as the Liquid limit, Plastic limit, and Plasticity index continuously decreased with the increase of the glass powder. The maximum dry density value had a clear increase with the addition of glass powder up to 8% of the dry weight of soil while for the percentage of 10% the increase was not remarkable. On the other hand, optimum moisture content decreased with the increment of glass powder. Both unsoaked and soaked California Bearing Ratio increased with the addition of glass powder. The unconfined compressive strength increased when adding 8% glass powder and then decreased when adding 10% glass powder of the dry weight of soil. The shear strength parameters also increase with the increase of the glass powder but the rate of increment was decreasing after the addition of 8% glass powder. Therefore, the optimum percentage of waste glass powder for soil improvement is found to be 8% [14]. In 2018, a researcher studied the use of waste glass material to control soil's swelling pressure. It was concluded that increasing the percentage of cement and the glass in the mix will reduce both the swelling pressure and the swell potential of the soil. Additionally, it was found that larger sizes of the glass are more effective than smaller sizes in reducing the swelling pressure and the swell potential of the soil [12].

In 2018, a researcher studied the use of waste glass in improving subgrade soil properties. It was investigated that adding crushed glass to the natural soil increased the California bearing ratio and a decrease in plasticity index [13]. In 2018, researchers studied the assessment of subgrade soil improvement by waste glass powder. It was investigated that by adding glass powder to the soil, the additive had a positive impact on the soil and had improved the soil properties, liquid limit, plastic limit, and plasticity index was decreased with the increase of glass powder [15].

In 2020, researchers studied the effect of lime on expansive soil in Al-Kawamil city, Sohag region. It was observed that the liquid limit, plasticity index, and maximum dry density decreased while the plastic limit and optimum moisture content increased [2]. In 2018, researchers studied the effect of lime mixed with seawater on treating the swelling properties for road projects. It was observed that the liquid limit, plasticity index, and maximum dry density decreased while the plastic limit and optimum moisture content increased per the increase of the added percentage of lime mixed with seawater [4]. In 2013, researchers studied the effect of adding lime on improving the expansive soil properties of the subgrade at the Qena - Sfaga road. It was investigated that the California bearing ratio and optimum moisture content were increased while the maximum dry density, plasticity index, and swelling pressure were reduced [1].

In 2016, a researcher studied the improvement of swelling soil properties by mixing it with lime for road projects. It was found that adding lime to the natural expansive soil leads to the liquid limit and the dry density decreased, whereas, at the same time, the California bearing ratio increased [7]. We try to explore the effect of adding separately crushed glass wastes (particles size less than 0.075 mm) and lime to the same type/sample of the expansive soil in order to provide a detailed comparison between the effect of adding separately crushed glass waste and lime on the geotechnical properties of the expansive soil.

2. Objectives and Importance of the Study

The main objectives of this study:

- This study aims to improve the engineering properties of expansive soil in a way that makes it geometrically fit for the construction of buildings without the need to replace it by using local, available and cost-effective materials such as crushed glass wastes and lime.
- This research compares between the effect of adding separately crushed glass wastes and lime on the geotechnical properties of the expansive soil.
- This study aims to make use of the local materials available at low cost, make the environment clean from glass wastes, and recycle these wastes, which are randomly disposed of, because the recycling of crushed glass wastes has a great economic, environmental, and engineering value.

3. Methodology

Index properties tests such as natural moisture content, specific gravity, and grain size analysis tests for the natural soil were carried out.

The research mainly depends on laboratory tests to reach an acceptable amount of crushed glass wastes (particles size less than 0.075 mm) and lime separately for the expansive soil treatment. Expansive soil samples were oven-dried for 24 hours at (105 c° ~ 110 c°). Crushed glass wastes were added with different percentages of 5%, 10%, 15%, and 20% by weight of dry soil; while lime was added with different percentages of 2%, 4%, 6%, and 8% by weight of dry soil. After the mixing process, the specimens were compacted at the optimum moisture content (O.M.C) and maximum dry density (M.D.D) in order to get the geotechnical properties such as the California Bearing Ratio test. Experiments of Atterberg limits, standard Procter, direct shear, free swell, swelling pressure, and both un-soaked and soaked California Bearing Ratio tests were carried out on the untreated and treated soil.

The California Bearing Ratio (CBR) test was carried out on the untreated and treated soil with crushed glass wastes and lime separately. The CBR test was performed as unsoaked and soaked for 7 days. The soil samples were compacted at the optimum moisture content (O.M.C) and maximum dry density (M.D.D). The soil samples were directly subjected to the CBR penetration test (unsoaked CBR) as well as the soaking condition before being transferred to the CBR penetration machine to measure the soaked CBR.
The swelling pressure test was conducted on the untreated and treated soil with crushed glass wastes and lime separately. The swelling pressure was measured in the conventional oedometer cell performed on compacted soil samples at optimum moisture content (O.M.C) and maximum dry density (M.D.D). The soil was initially allowed to swell under a seating pressure and after reaching a peak swelling value it was then compressed by adding weights. The weights were added each day to retain back the expanded sample to the started dial gauge reading. The compressed pressure of the expanded sample to its original volume was considered to be the swelling pressure.
The quick direct shear test on untreated and treated soil is used to find out the cohesion (c) and the angle of internal friction (ϕ) of the soil. These are the soil shear strength parameters. The soil samples were compacted at the optimum moisture content (O.M.C) and maximum dry density (M.D.D). The test is conducted by putting the soil specimens inside the shear box which is made up of two independent parts. A constant normal load is applied to obtain one value of c and ϕ. Shearing load is increased at a constant rate and is applied till the failure point is reached.

3. Materials Used

4.1. Natural Soil

Expansive soil was obtained from Al-Kawamil region in New Sohag city (Egypt) at a depth of 5 meters. Natural soil was greenish grey, very hard, laminated clayey silt-some sand. The groundwater table was not being found. A test pit was excavated to obtain samples. Soil samples were prepared and tested. The laboratory experiments' results for expansive soil without addition are shown in Table 1. The geotechnical tests were performed based on the Egyptian Code of Soil Mechanics and Foundation Design and Construction (ECP 202/2-2001, 2009). The soil was classified as A-7-6 according to the AASHTO classification. Sieve analysis and hydrometer tests were performed to identify some of the properties of expansive soil. The grain size distribution for expansive soil is shown in Figure 1.

Table 1. Shows the results of laboratory experiments on expansive soil without the addition

Experiments	Results
Passing from the sieve No. 200 (0.075 mm) (%)	more than 90
Natural moisture content (%)	3.35
Field dry unit weight (g /cm^3)	2.06
Specific gravity	2.69
L.L (%)	70.75
P.L (%)	30.70
P.I (%)	40.05
M.D.D (g /cm^3)	1.53
O.M.C (%)	15.75
Cohesion (c) (kg/cm^2)	0.60
Angle of internal friction (ϕ)	25.63

Experiments	Results
Free swell (%)	183
Swelling pressure (kg/cm^2)	3.92
Un-Soaked California Bearing Ratio (CBR) (%)	2.56
Soaked California Bearing Ratio (CBR) (%)	1.35
Soil classification according to the AASHTO classification	A-7-6

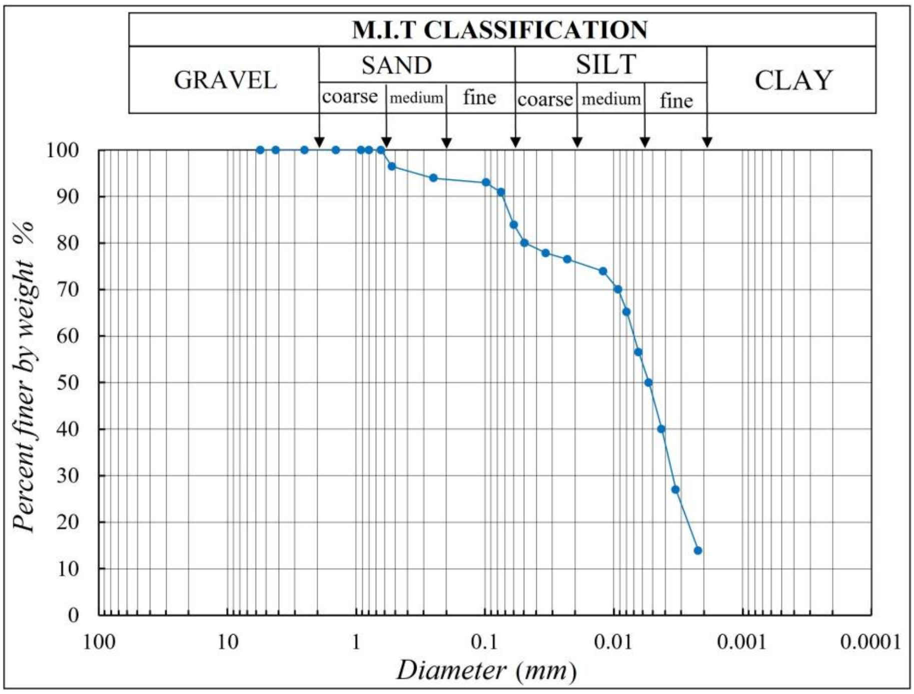

Figure 1. Grain size distribution for the expansive soil

4.2. Crushed Glass Wastes

The materials used in carrying out this study are crushed glass wastes with particles size less than 0.075 mm. Crushed glass wastes have been used to prepare the additive material, cleaned from the dust and other material then broken cautiously into small pieces by using a hammer and covering the glass with a piece of cloth to avoid raveling the glass. After crushing the glass into suitable pieces, it was put in a grinding machine to transform it into powder and screened by using sieve No. 200 (0.075 mm) to obtain the powder. The passing glass particles through this sieve (No. 200) had been taken as proposed materials for expensive soil treatment. The chemical composition of the used crushed glass wastes is shown in Table 2.

Table 2. The chemical analysis of glass waste

Chemical oxides	Percent (%)	Action in soil
SiO_2	74	Sand, cohesionless improve consistency
Na_2O	13	
CaO	10.5	Given strength
SO_3	0.2	
Al_2O_3	1.3	
K_2O	0.3	
MgO	0.2	
Fe_2O_3	0.04	

4.3. Lime

The lime used in this study is a high-quality hydrated lime, produced locally and satisfies the general requirements for construction purposes. As a commercial product, lime often also contains magnesium oxide, silicon oxide, and smaller amounts of aluminum oxide and iron oxide. The chemical composition of the used lime is shown in Table 3.

Table 3. The chemical analysis of Lime

Chemical elements	Percent (%)
Mg	1.9
Al	0.1
Si	1.1
Cl	---
K	0.27
Ta	62.6
Ti	0.01
Mn	---
Fe	1.4
P	0.01
Na	0.55
Loss of ignition (L.O.I)	32

5. Result

5.1. Consistency Properties (Atterberg Limits)

Atterberg limits (Plastic limit “P.L”, Liquid limit “L.L”, and Plasticity index “P.I” = L.L-P.L) play an important role in soil identification and classification. These parameters indicate some of the geotechnical problems such as workability. One of the important and principal aims of this study was to evaluate the changes in liquid, plastic limits, and plasticity index by adding separately crushed glass wastes and lime to the expansive soil.

To achieve this objective, the Atterberg limits test (including P.L, L.L, and P.I) was conducted on natural soils, different crushed glass wastes-soil mixtures, and different lime-soil mixtures. P.L and L.L of both different soil- crushed glass wastes mixtures and different lime -soil mixtures were determined after 1-day curing. In general, the addition of crushed glass wastes and lime separately for the case of studied soil led to a decrease in the plasticity index. The decrease in plasticity index indicates an improvement in the swelling properties of the expansive soil.

The consistency properties (Atterberg limits) of expansive soil without any addition and expansive soil with the addition of crushed glass wastes are shown in Figure 2. In comparison, the consistency properties (Atterberg limits) of expansive soil without any addition and expansive soil with the addition of lime are shown in Figure 3.

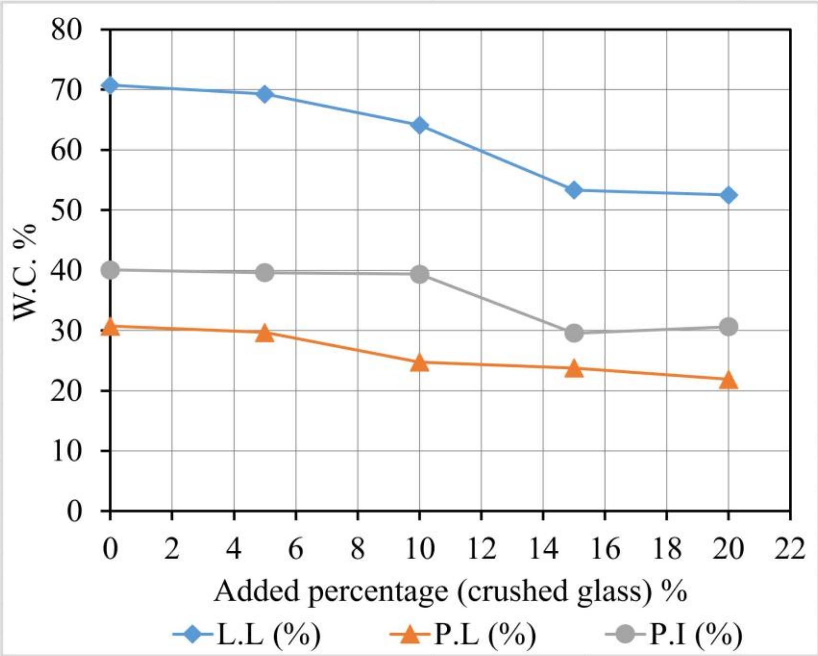

Figure 2. Graph of Atterberg limits against the percentage of crushed glass wastes

As clarified in Figure 2, by adding the crushed glass wastes to the expansive soil, the liquid limit and the plastic limit decreased from 70.75% to 52.51%, and from 30.7% to 21.87%, respectively. The decrease in the liquid limit was greater than the decrease in the plastic limit, which led to a decrease in the plasticity index from 40.05% to 30.64%. The decrease in the liquid limit can be attributed to the fact that the ability of the crushed glass wastes to retain water is much less than the ability of the expansive soil to retain it. The decrease in plastic limit can be attributed to the fact that the crushed glass wastes are a non-plastic or low plastic material, which led to a decrease in the plastic limit of the expansive soil to which the crushed glass wastes were added.

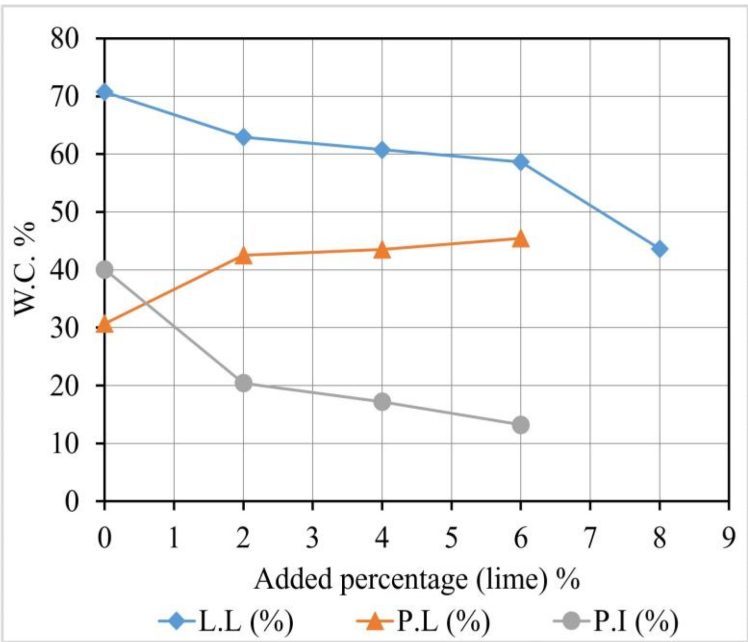

Figure 3. Graph of Atterberg limits against the percentage of lime

As clarified in Figure 3, by adding lime to the expansive soil, the liquid limit decreased from 70.75% to 43.65%, but the plastic limit increased slightly. The decrease in the liquid limit was much greater than the increase in plastic limit, which led to a decrease in the plasticity index, making it none plastic. The decrease in the liquid limit can be attributed to the interaction of the lime with the expansive soil, which leads to the merging and agglomeration of expansive soil particles. This results in the thickness of the water layer known as the double electrode layer, and, consequently, the swelling ability of the expansive soil is decreased by the addition of water. The slight increase in the plastic limit can be attributed to the fact that lime is a plastic material, which led to a slight increase in the plastic limit of the expansive soil to which the lime was added.

5.2. Compaction Characteristics (Standard Proctor Test)

The geotechnical properties of soil (such as CBR, permeability, compressibility, etc.) are dependent on the moisture and density at which the soil is compacted. Generally, a high level of compaction of soil enhances the geotechnical parameters of the soil, so achieving the desired degree of relative compaction necessary to meet specified or desired properties of soil is very important. The aim of the proctor test (moisture-density test) was to determine the optimum moisture contents of both untreated compacted and the soil treated with crushed glass wastes and lime separately. In general, the addition of crushed glass wastes for the studied soils led to a decrease in the optimum moisture content and an increase in the maximum dry density. In comparison, the addition of lime to the studied soils led to an increase in the optimum moisture content and a decrease in the maximum dry density. The compaction characteristics of expansive soil without any addition and expansive soil with the addition of crushed glass wastes are shown in Figure 4. In comparison, the compaction characteristics of expansive soil without any addition and expansive soil with the addition of lime are shown in Figure 5.

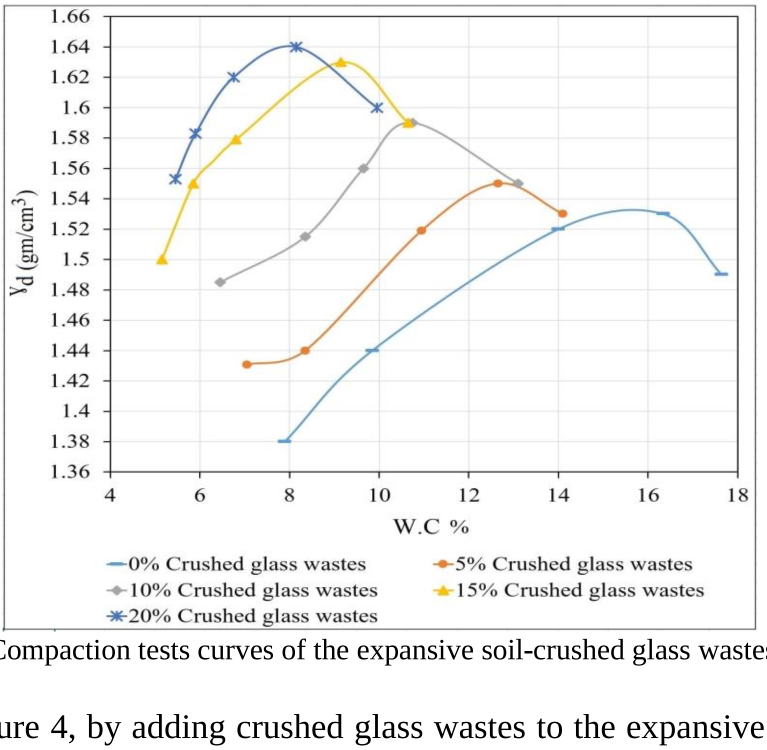

Figure 4. Compaction tests curves of the expansive soil-crushed glass wastes mixtures

As clarified in Figure 4, by adding crushed glass wastes to the expansive soil, the optimum moisture content was reduced from 15.75% to 8.25%, and the maximum dry density increased by increasing the percentage of addition from 1.53 g/cm^3 to 1.64 g/cm^3. The decrease in optimum moisture content of the expansive soil to which the crushed glass wastes were added can be attributed to the fact that glass is an inert material that does not absorb water. The increase in the maximum dry density of the expansive soil to which the crushed glass wastes were added can be attributed to the fact that the specific weight of the glass is higher than the specific weight of the expansive soil.

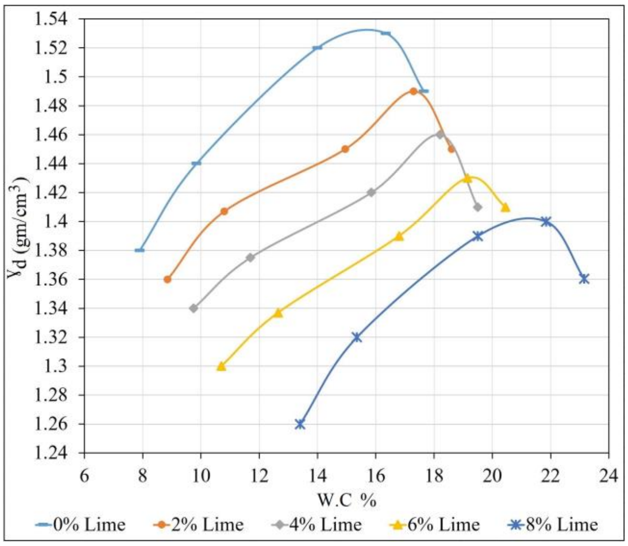

Figure 5. Compaction tests curves of the expansive soil-lime mixtures

As clarified in Figure 5, by adding lime to the expansive soil, the optimum moisture content increased from 15.75% to 19.4%, and the maximum dry density of the soil decreased from 1.53 g/cm^3 to 1.4 g/cm^3. The increase in the optimum moisture content of the expansive soil to which lime was added can be attributed to the fact that the lime requires additional water for the hydrolysis process. The decrease in the maximum dry density of the expansive soil to which lime is added can be attributed to the occurrence of clumping and accumulation of soil particles, which leads to the difficulty of compaction.

5.3. Direct Shear Test

The effect of crushed glass wastes on shear strength parameters of different samples that were tested is shown in Figure 6. In comparison, the effect of lime on shear strength parameters of different tested samples is shown in Figure 7. Increasing crushed glass wastes and lime separately also provides a positive influence on the development of cohesion and angle of internal friction. The cohesion of the natural soil was 0.60 kg/cm^2 and increased to 1.03 kg/cm^2 when 20% of crushed glass wastes was added. The angle of internal friction was also increasing with the increase of the percentage of crushed glass wastes. The angle of internal friction was found to be 25.63 and increased to 31.3 when 20% of crushed glass wastes was added. In comparison, the cohesion of the soil was increased to 1.757 kg/cm^2 when 8% of lime was added. The angle of internal friction was also increased with the increase of the percentage of lime. The angle of internal friction increases from 25.63 to 43.63 when 6% of lime was added and then decreases to 41.93 when the percentage 8% of lime was added.

As clarified in Figure 6, by adding crushed glass wastes to the expansive soil caused the shear strength parameters to be improved. The increase in the shear strength parameters (i.e., cohesion and angle of internal friction) of the soil treated with crushed glass wastes is due to an increase in the resistance of the expansive soil to which the crushed glass wastes was added.

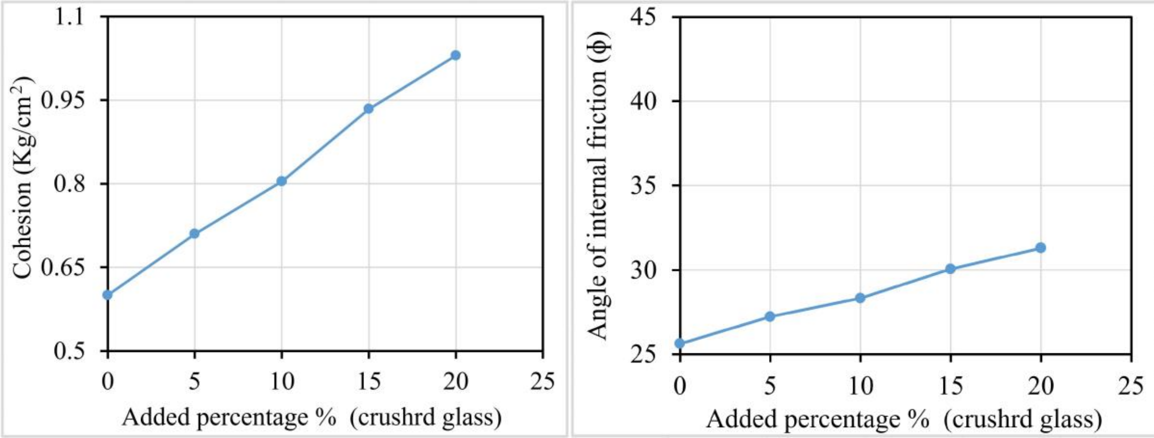

Figure 6. Variation of the shear parameters values against the percentage of added crushed glass

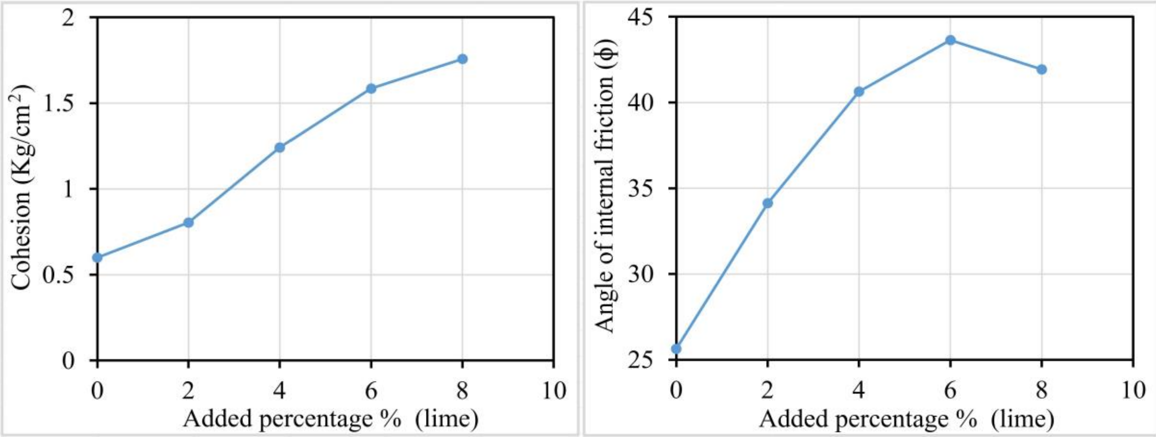

Figure 7. Variation of the shear parameters values against the percentage of added lime

As clarified in Figure 7, by adding lime to the expansive soil caused the shear strength parameters to be improved. The increase in the shear strength parameters (i.e., cohesion and angle of internal friction) of the soil treated with lime is due to the interaction that occurs between the lime and the expensive soil particles in the soil over a long period, which results in cementation materials that bind the soil particles together. This interaction gives resistance to the treated soil. It is noticed that for the case of adding lime with the percentage of 8%, the increase of the angle of internal friction was lower than the case of adding lime with the percentage of 6%. This is because after adding too much lime, a lot of free lime particles exist in the soil play a lubricating effect, so the angle of internal friction decrease quickly.

5.4. Free Swell

The free swell is expressed as a percentage increase in the volume to the original volume of the soil. The free swell of the natural soil was found to be 183%. The free swell of expansive soil without any addition and expansive soil with the addition of crushed glass wastes are shown in Figure 8. In comparison, the free swell of expansive soil without any addition and expansive soil with the addition of lime is shown in Figure 9. It is seen that with the increasing percentage of separately crushed glass wastes and lime, the FS decreases non-linearly. As clarified in Figure 8, by adding crushed glass wastes to the expansive soil, the free swell was reduced from 183% to 165% by increasing the percentage of addition. The decrease in the free swell of the expansive soil to which the crushed glass wastes were added can be attributed to a decrease in the percentage of void ratio in the expansive soil, and this, in turn, reduces the free swell values of the expansive soil to which the crushed glass wastes was added.

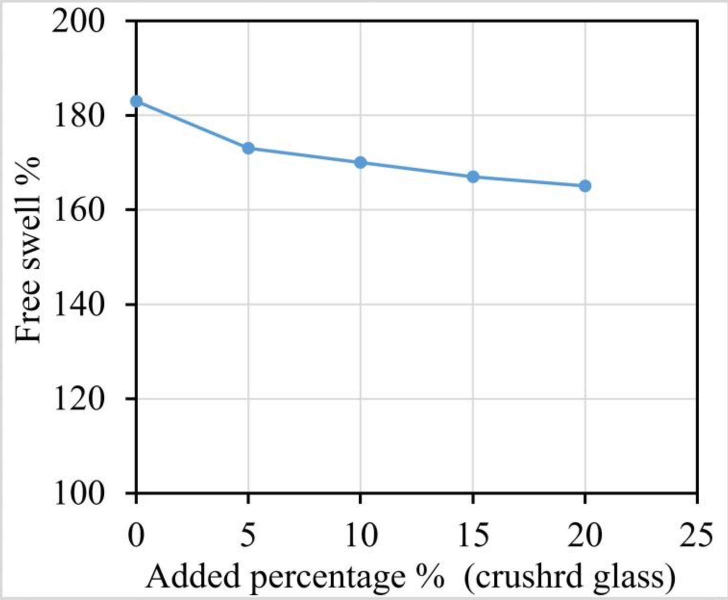

Figure 8. Variation of free swell values for different crushed glass wastes content

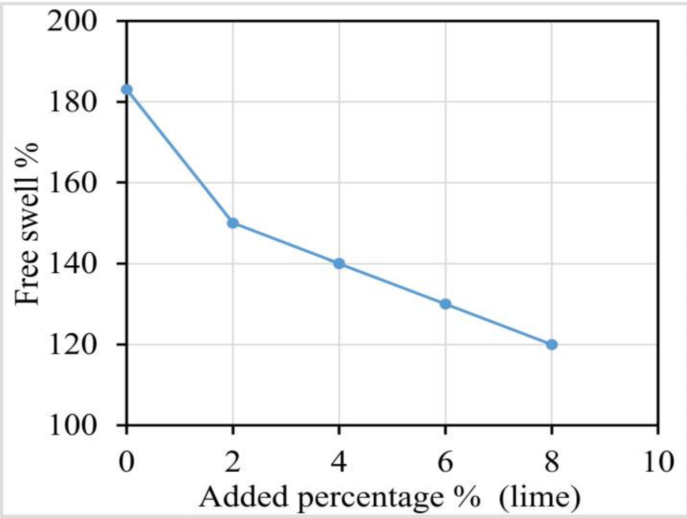

Figure 9. Variation of free swell values for different lime content

As clarified in Figure 9, by adding lime to the expansive soil, the free swell was reduced from 183% to 120% by increasing the percentage of addition. The decrease in the free swell of the expansive soil to which lime is added can be attributed to a decrease in the thickness of the double ionic layer due to the decrease in the capacity of the ion exchange (hydrolysis of ions), as a result of the solidification and agglomeration of the expansive soil particles; this, in turn, leads to the reduction of the free swell of the expansive soil to which the lime was added. Similar trends were reported in pervious investigation [16].

5.5. The Swelling Pressure of the Expansive Soil

An Oedometer instrument was used to investigate the volume change characteristics of the studied sample (in case of untreated and treated soil samples). The test specimen is in the form of a disc, held inside a metal ring and lying between two porous stones. The upper porous stone, which can move inside the ring with a small clearance, is fixed below a metal loading cap through which pressure can be applied to the specimen. The whole assembly sits in an open cell of water to which the pore water in the specimen has free access. The ring confining the specimen is floating (being to move vertically). The inside of the ring has a smooth polished surface to reduce side friction. The compression or swell of the specimen under pressure is measured by the means of a dial gauge operating on the load cap. A series of Oedometer tests on studied specimens were carried out to observe their swelling behavior. The required pressure to return the sample to its original volume is designated as swelling pressure.

Figure 10 shows the swelling pressure of expansive soil without any addition and expansive soil with the addition of crushed glass wastes, as well as, the decrease in swelling pressure (%) of expansive soil without any addition and expansive soil with the addition of crushed glass wastes. In comparison, figure 11 shows the swelling pressure of expansive soil without any addition and expansive soil with the addition of lime, as well as, the decrease in swelling pressure (%) of expansive soil without any addition and expansive soil with the addition of lime. The swelling pressure for the natural soil is 3.92 kg/cm^2.

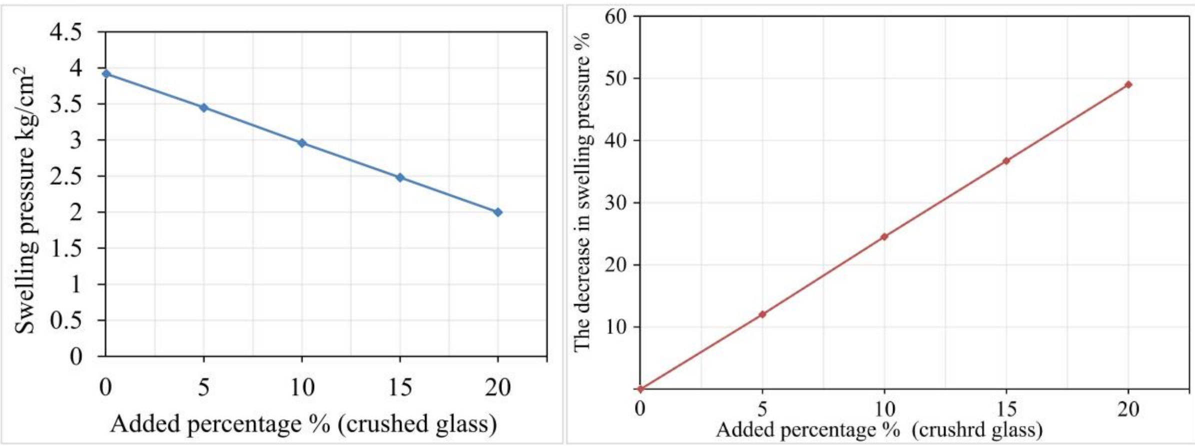

Figure 10. The effect of adding crushed glass wastes on the swelling pressure

As clarified in Figure 10, by adding crushed glass wastes to the expansive soil, the swelling pressure was reduced from 3.92 kg/cm^2 to 2 kg/cm^2 by increasing the percentage of addition. The decrease in the swelling pressure of the expansive soil to which the crushed glass wastes were added can be attributed to a decrease in the percentage of void ratio in the expansive soil, and this, in turn, reduces the swelling pressure values of the expansive soil to which the crushed glass wastes was added. Similar trends were reported in pervious investigation [12].

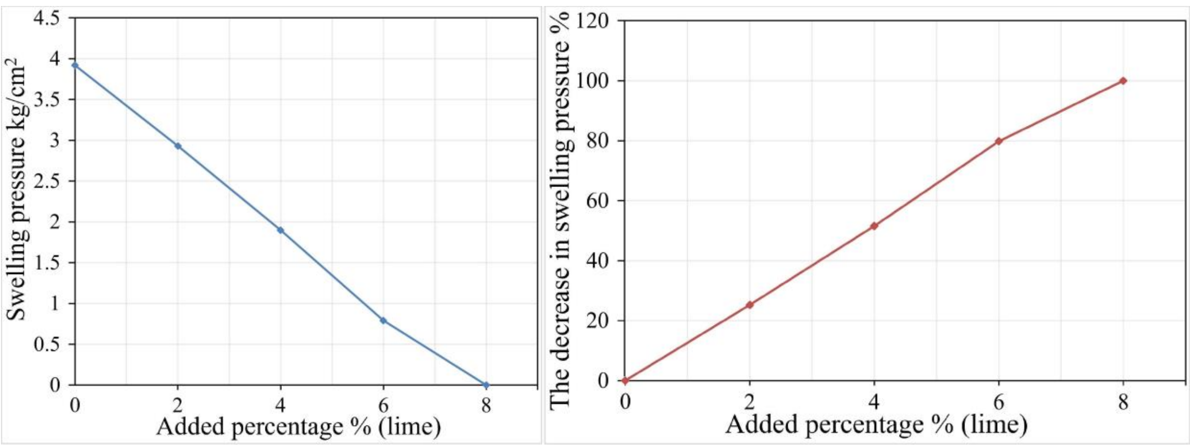

Figure 11. The effect of adding lime on the swelling pressure

As clarified in Figure 11, by adding lime to the expansive soil, the swelling pressure was reduced from 3.92 kg⁄cm^2 to zero by increasing the percentage of addition. The decrease in the swelling pressure of the expansive soil to which lime is added can be attributed to a decrease in the thickness of the double ionic layer due to the decrease in the capacity of the ion exchange (hydrolysis of ions), as a result of the solidification and agglomeration of the expansive soil particles; this, in turn, leads to the reduction of the swelling pressure of the expansive soil to which the lime was added. Similar trends were reported in pervious investigation [1].

5.6. The California Bearing Ratio

The California Bearing Ratio test is one of the most common tests used to assess the quality of the base and subgrade materials for highway and road construction. Figure 12 shows the graph of both un-soaked and soaked CBR against the percentage of crushed glass wastes; Figure 13 shows the penetration-load curves of the expansive soil-crushed glass wastes mixtures based on the un-soaked/soaked CBR tests. In comparison, Figure 14 shows the graph of both un-soaked and soaked CBR against percentage lime; Figure 15 shows the penetration-load curves of the expansive soil-lime mixtures based on the un-soaked/soaked CBR tests. In general, this Figures depicts an improvement in both un-soaked and soaked CBR values with an increase in crushed glass wastes and lime separately.

By adding crushed glass wastes with percentages varying from 5% to 20% to the expansive soil, the un-soaked and soaked California Bearing Ratio was increased from 2.56% to 24.5% and from 1.35% to 9.26% respectively by increasing the percentage of addition. In comparison, By adding lime with percentages varying from 2% to 8% to the expansive soil, the un-soaked and soaked California Bearing Ratio was increased from 2.56% to 71.27% and from 1.35% to 120.7% respectively by increasing the percentage of addition. The increase in un-soaked/soaked CBR of the expansive soil treated with crushed glass wastes and lime separately can be attributed to an increase in friction between expansive soil granules. Similar trends were reported in pervious investigations [1], [7], [13], [14].

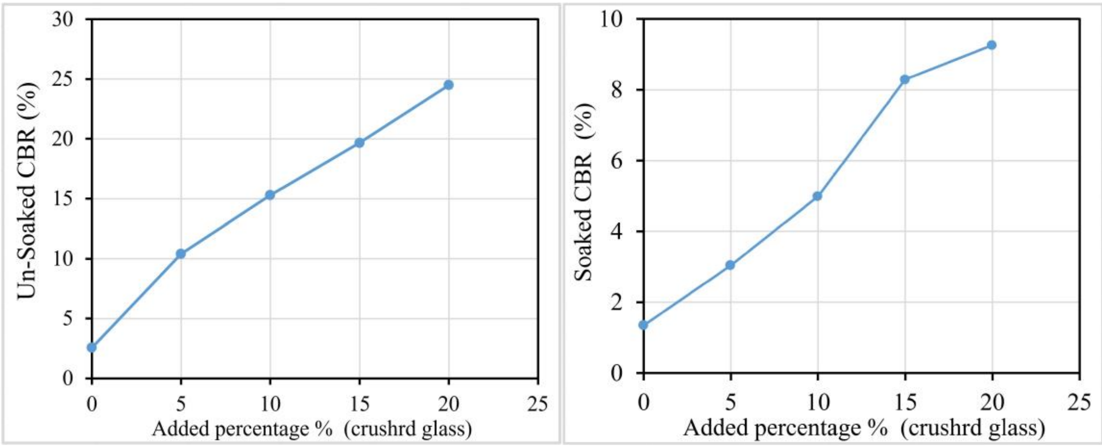

Figure 12. Graph of un-soaked/soaked CBR against added percentages of crushed glass wastes

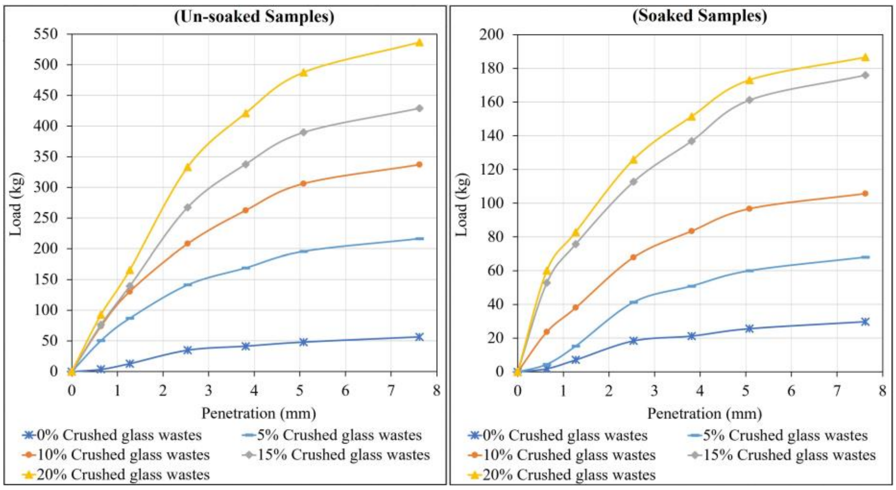

Figure 13. The penetration-load curves of the expansive soil-crushed glass wastes mixtures based on un-soaked/ soaked CBR tests

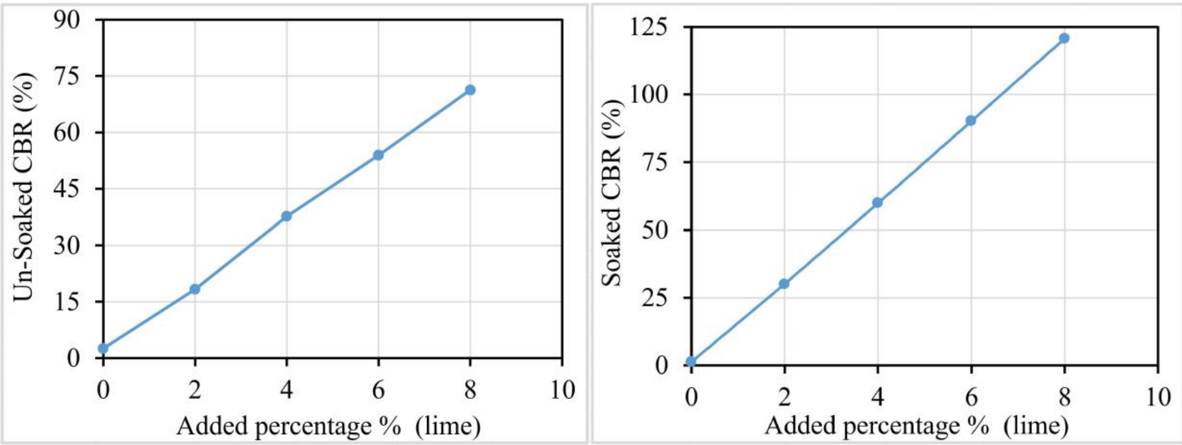

Figure 14. Graph of un-soaked/soaked CBR against added percentages of lime

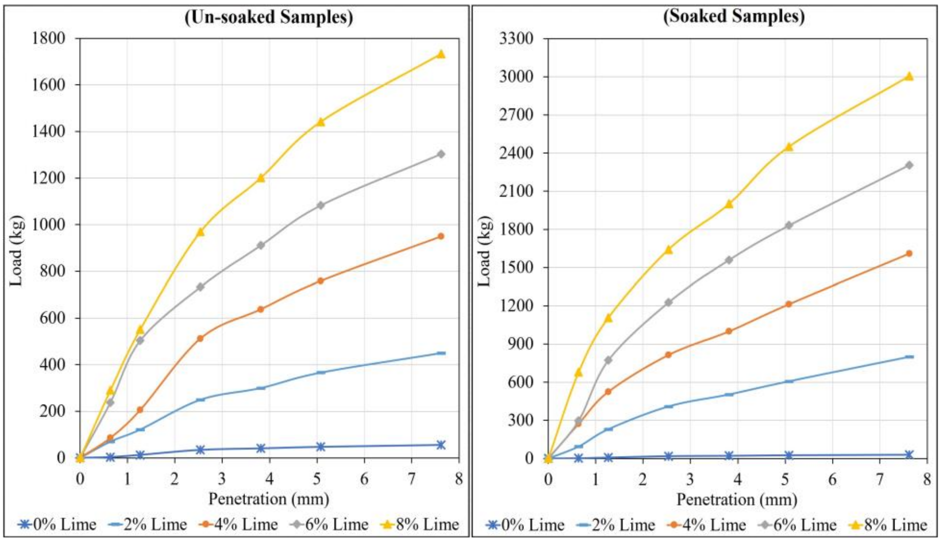

Figure 15. The penetration-load curves of the expansive soil-lime mixtures based on un-soaked/ soaked CBR tests

Table 4. Comparison between the effect of adding separately crushed glass wastes and lime on the geotechnical properties of the expansive soil

Geotechnical properties of expansive soil	Using crushed glass wastes	Using lime
Consistency properties (Atterburg limits)	The consistency properties (Atterburg limits) of the expansive soil improved by adding crushed glass wastes to it due to the decrease in the plasticity index through increasing the percentage of this addition.	The consistency properties (Atterburg limits) of the expansive soil improved by adding lime to it due to the decrease in the plasticity index that makes it none plastic through increasing the percentage of this addition.
Compaction characteristics (standard proctor test)	The compaction characteristics of the expansive soil were affected by adding crushed glass wastes to it due to the decrease in the optimum moisture content and an increase in the maximum dry density through increasing the percentage of this addition.	The compaction characteristics of the expansive soil were affected by adding lime to it due to the increase in the optimum moisture content and a decrease in the maximum dry density through increasing the percentage of this addition.
The shear strength parameters	By adding crushed glass waste to the expansive soil causes the cohesion and the angle of internal friction of the expansive soil were increased through increasing the percentage of this addition.	By adding lime to the expansive soil, which led to an increase in both cohesion (c) and angle of internal friction (ϕ); It is noticed that for the case of adding lime with the percentage of 8%, the increase of the angle of internal friction was lower than the case of adding lime with the percentage of 6%.
The free swell and the swelling pressure	Both free swell and swelling pressure of the expansive soil were improved by adding crushed glass wastes to it due to the decrease in the free swell and the swelling pressure through increasing the percentage of this addition.	Both free swell and swelling pressure of the expansive soil were improved by adding lime to it due to the decrease in the free swell and the swelling pressure through increasing the percentage of this addition.
The California Bearing Ratio	Both the un-soaked and soaked California Bearing Ratio of the expansive soil were improved by adding crushed glass wastes to it due to the increase in un-soaked and soaked California Bearing Ratio through increasing the percentage of this addition.	Both the un-soaked and soaked California Bearing Ratio of the expansive soil were improved by adding lime to it due to the increase in un-soaked and soaked California Bearing Ratio through increasing the percentage of this addition.

6. Comparison Between the Effect of Adding Separately Crushed Glass Wastes and Lime on the Geotechnical Properties of the Expansive Soil

The comparison between the effect of adding separately crushed glass wastes and lime on the geotechnical properties of the expansive soil is shown in Table 4. Figure 16 shows the comparison between the effect of adding crushed glass wastes and lime separately on soil's shear parameters. Figure 17 shows the comparison between the effect of adding crushed glass wastes and lime separately on soil's swelling properties (free swell and the swelling pressure).

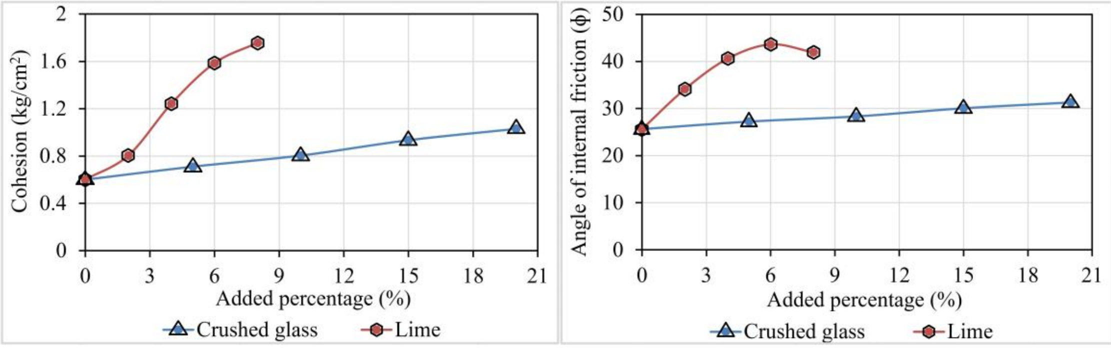

Figure 16. The comparison between the effect of adding crushed glass wastes and lime separately on soil's shear parameters

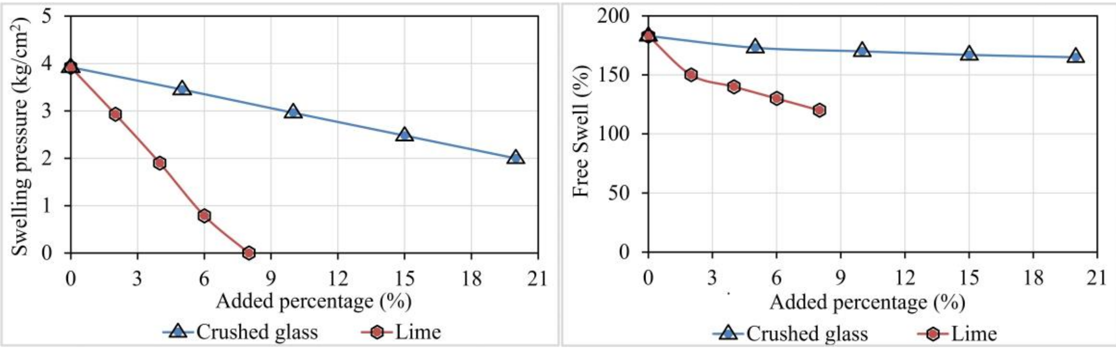

Figure 17. The comparison between the effect of adding crushed glass wastes and lime separately on soil's swelling properties

7. Conclusions

1. Adding crushed glass wastes by 20% to the expansive soil led to a decrease in both liquid limit and the plastic limit, which led to a decrease in the plasticity index. In comparison, by adding lime by 8% to the expansive soil, the liquid limit decreased, but the plastic limit increased slightly, which led to a decrease in the plasticity index that makes it none plastic.
2. Adding crushed glass wastes by 20% to the expansive soil led to a decrease in the optimum moisture content from 15.75% to 8.25% and an increase in the maximum dry density from 1.53 g/cm^3 to 1.64 g/cm^3. In comparison, adding lime by 8% to the expansive soil led to an increase in the optimum moisture content from 15.75% to 19.4% and a decrease in the maximum dry density from 1.53 g/cm^3 to 1.4 g/cm^3.
3. Adding crushed glass wastes by 20% to the expansive soil led to an increase in both cohesion (c) and angle of internal friction (ϕ). In comparison, adding lime by 8% to the expansive soil, which led to an increase in both cohesion (c) and angle of internal friction (ϕ); It is noticed that for the case of adding lime with the percentage of 8%, the increase of the angle of internal friction was lower than the case of adding lime with the percentage of 6%.
4. Adding crushed glass wastes by 20% to the expansive soil causes the free swell of the expansive soil to be reduced from 183% to 165%. In comparison, adding lime by 8% to

the expansive soil causes the free swell of the expansive soil to be reduced from 183% to 120%.

5. Adding crushed glass wastes by 20% to the expansive soil caused the swelling pressure of the expansive soil to be reduced from 3.92 kg/cm^2 to 2 kg/cm^2. In comparison, adding lime by 8% to the expansive soil caused the swelling pressure of the expansive soil to be reduced from 3.92 kg/cm^2 to zero.
6. Adding crushed glass wastes by 20% to the expansive soil caused the un-soaked California Bearing Ratio of the expansive soil to be increased from 2.56% to 24.5%. In comparison, adding lime by 8% to the expansive soil caused the un-soaked California Bearing Ratio of the expansive soil to be increased from 2.56% to 71.27%.
7. Adding crushed glass wastes by 20% to the expansive soil caused the soaked California Bearing Ratio of the expansive soil to be increased from 1.35% to 9.26%. In comparison, adding lime by 8% to the expansive soil caused the soaked California Bearing Ratio of the expansive soil to be increased from 1.35% to 120.7%.

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معالجة التربة ذات الخواص الأنتفاشية باستخدام مطحون النفايات الزجاجية والجير

ملخص البحث

التربة الانتفاشية عبارة عن تربة يحدث بها تغيرات كبيرة في الحجم عند حدوث تغير في المحتوي المائي لها وتوجد بمناطق عديدة بوديان مصر. تعتبر التربة الانتفاشية التي تم دراستها والمأخوذة من منطقة الكوامل (سوهاج الجديدة) بمصر بانها غير صالحة كطبقة أساس او تحت الاساس في الطرق والابنية بسبب ضعف قوة تحملها حيث صنفت طبقا لنظام أشتوA-7-6 وكانت نسبة المواد الناعمة المارة من المهزة رقم (٢٠٠) أكثر من ٩٠٪.

نحاول في هذا البحث دراسة تأثير إضافة مطحون النفايات الزجاجية (ذات حجم حبيبي أقل من ٠.٠٧٥ مم) والجير منفصلين للتربة الانتفاشية لتحسين خصائصها الهندسية وتم معالجة التربة الانتفاشية بنسب مختلفة من مخلفات النفايات الزجاجية وهي (٠٪–٥٪–١٠٪–١٥٪–٢٠٪ من وزن التربة الجافة) وكذلك تم معالجة التربة بنسب مختلفة من الجير وهي (٠٪–٢٪–٤٪–٦٪–٨٪ من وزن التربة الجافة)، وتم إجراء اختبارات: حدود أتبرج (حد السيولة وحد اللدونة ومبين اللدونة)، وبروكتور القياسي (محتوى الرطوبة الامثل والكثافة الجافة العظمي)، والقص المباشر، والانتفاش الحر، وضغط الانتفاش، ونسبة تحميل كالفورنيا (غير المغمور والمغمور لمدة سبع يام).

أظهرت النتائج أن إضافة مطحون النفايات الزجاجية والجير منفصلين إلي التربة الأنتفاشية قد حسن مواصفات القوام (حدود أتربرج) ومعاملات القص والانتفاش الحر وضغط الانتفاش ونسبة تحميل كالفورنيا (غير المغمور والمغمور لمدة سبع يام) بينما أظهرت نتائج مواصفات الرص للتربة الانتفاشية (اختبار بروكتور القياسي) أنه بإضافة مطحون النفايات الزجاجية إلي التربة الأنتفاشية ادي الي زيادة نسبة الكثافة الجافة العظمي ونقص نسبة محتوى الرطوبة الأمثل و بإضافة الجير إلي التربة الأنتفاشية ادي الي زيادة نسبة محتوى الرطوبة الامثل ونقص نسبة والكثافة الجافة العظمي.

بصورة عامة يمكن أعتبار مطحون النفايات الزجاجية والجير ذات تاثير ايجابي علي الخواص الهندسية للتربة الانتفاشية ويساعد علي نظافة البيئة من المخلفات الزجاجية وإعادة تدويرها والاستفادة من المواد المحلية المتاحة قليلة التكلفة كمطحون النفايات الزجاجية والجير بيئيا واقتصاديا وهندسيا وهذا يتوافق مع استراتيجية التنمية المستدامة مصر ٢٠٣٠ في كلا المحورين البيئي والاقتصادي.