Improvement of Swelling Soil Properties Using Crushed Glass Wastes and Lime

Shehab Nasr Abdelmoneim Mohamed [1], Mostafa Abdou Abdel Naiem Mahmoud [2], Ahmed Rushdy Towfeek [3]

[1] M.Sc. Student, Civil Engineering Department, Faculty of Engineering, Assiut University, Assiut 71516, Egypt
[2] Professor, Civil Engineering Department, Faculty of Engineering, Assiut University, Assiut 71516, Egypt
[3] Associate professor, Civil Engineering Department, Faculty of Engineering, Al-Azhar University, Qena, Egypt
eng_shehab2017@yahoo.com, mostafaabdo@yahoo.com, ahmed_78_eng@yahoo.com

Abstract: Expansive soil is a soil that has large changes in volume when there is a change in its water content, and it is found in many areas in Egyptian valleys. This research aims to study the effect of using locally low-cost materials such as crushed glass wastes and lime to improve the engineering properties of expansive soil. The expansive soil that has been studied is taken from Al-Kawamil city (New Sohag city); the Sohag region 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. The percentage of soft materials passing through sieve No. 200 (0.075 mm) was more than 90%. This soil was treated only with different ratios of crushed glass wastes (0%, 5%, 10%, 15%, and 20%) by the expansive soil weight, as well as the soil was treated only with different ratios of lime (0%, 2%, 4%, 6%, and 8%) by the expansive soil weight. Atterberg limits (liquid limit, plastic limit, and plasticity index), standard proctor test (optimum moisture content and maximum dry density), and swelling test were carried out. The results have shown an improvement in the engineering properties of the expansive soil, such as Atterberg limits and swelling pressure, by increasing added percentage of crushed glass waste and lime separately. This helps to make use of the local materials available at low cost, make the environment clean from glass wastes and recycle these wastes so they can be utilized at the environmental, economic, and engineering levels. This matches the sustainable development strategy of Egypt's vision 2030 in both the environmental and economic dimensions.

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1. Introduction

The improvement of the properties of the soil is the change of some physical, chemical, or mechanical properties, or all of them to a specific geometric application. Expansive soil is the soil with large changes in volume when there is a change in its water content. It was found in many areas in the Egyptian valleys, which 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].

When an increase in the moisture content of this expansive soil, its granule size increases, 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].

In the sites of expansive soil, it is often required to construct engineering projects. In this case, we need to improve its properties before constructing. This is because the replacement of the expansive soil with other suitable soil for construction will be non-economic (expensive). Thus, it is necessary to find economical ways to improve the properties of expansive soil [2], [7], [8], [9].

There are many ways to improve the engineering properties of the expansive soil, such as thermal, mechanical, 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], [7], [8], [10].

Some previous research has shown that it is possible to use glass wastes easily in the fields of geotechnical engineering. When lime is added to the expansive soil in the presence of water, many reactions are occurred to improve its geometrical properties. Due to the local availability and cheapness of glass wastes and lime, we try in this paper to study the effect of adding separately crushed glass wastes and lime to the expansive soil to improve their engineering properties [1], [2], [4], [7], [11],[12],[13].

2. Objectives and Importance of the Study

The main objectives of this study:

1. This research studies if it is possible to use local and available materials which is cost-effective such as crushed glass wastes and lime, to improve the

engineering properties of the expansive soil in a way that makes it geometrically fit for the construction of buildings without the need to replace it.

2. This study aims to compare the effect of adding only crushed glass wastes to the expansive soil and the effect of adding only lime to the expansive soil in order to improve the engineering properties of the expansive soil.
3. This study also aims to recycle glass waste, which is randomly disposed of, because the recycling of crushed glass wastes in improving the expansive soil engineering properties has a great economic, environmental, and engineering value.

3. Methodology

The research mainly depends on laboratory tests to reach an acceptable amount of only crushed glass wastes by adding only these percentages of crushed glass wastes (0%, 5%, 10%, 15%, and 20%) by the expansive soil weight to the expansive soil as well as to reach an acceptable amount of only lime by adding only these percentages of lime (0%, 2%, 4%, 6%, and 8%) by the expansive soil weight to expansive soil. Experiments of Atterberg limits, standard Procter test, and swelling pressure were carried out on expansive soil taken from Al-Kawamil city, Sohag region before being treated as well, as those tests were performed on expansive soil after being treated only with crushed glass wastes and on expansive soil after being treated only with lime, aims at studying the effects of adding only the crushed glass wastes to the expansive soil and the effect of adding only lime to the expansive soil on consistency properties (Atterberg limits), compaction characteristics and the swelling pressure of the studied expansive soil.

4. Previous Investigations

The research and studies carried out to investigate the effect of the crushed glass wastes additions on the engineering properties of the expansive soil, or the possibility of using these wastes in stabilizing and improving the engineering properties of expansive soil are very scarce. We present some research carried out to investigate the effect of adding only the crushed glass wastes to the expansive soil and the effect of adding only lime to the expansive soil on the engineering properties of expansive soil.

In 2020 Javed and Chakraborty studied the effects of waste glass powder on subgrade soil improvement. They investigate that by adding glass powder to the natural soil, the liquid limit, plastic limit, and plasticity index continuously decreased. Maximum dry density was increasing, and optimum moisture content was decreasing when added glass powder. Both unsoaked and soaked California bearing ratio was increasing with the addition of glass powder. Unconfined compressive strength was increasing and then decreased. The shear strength parameter also increases with the increase of glass powder [13].

In 2018 Attom studied the use of waste glass material to control soil's swelling pressure. He 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 the larger sizes of the glass are more effective than smaller sizes in reducing the swelling pressure of the soil and reduce both the swelling pressure and the swell potential significantly [11].

In 2018 Lingwanda studied the use of waste glass in improving subgrade soil properties. He investigates that adding crushed glass to the natural soil has resulted in an increase in California bearing ratio and a decrease in plasticity index [12].

In 2020 Farghaly et al.; have studied the effect of lime on expansive soil in Al-Kawamil city, Sohag region. They investigate that the liquid limit, plasticity index, and maximum dry density decreased while the plastic limit and optimum moisture content increased [2].

In 2018 Emarah and Seleem; have studied the effect of lime mixed with seawater on treating the swelling properties for road projects. They investigate that the liquid limit, plasticity index, and maximum dry density decreased while the plastic limit and optimum moisture content increased [4].

In 2013 Afaf et al. were studied the effect of adding lime on improving the expansive soil properties of the subgrade at the Qena - Sfaga road. They investigate that the California bearing ratio and optimum moisture content were increased while the maximum dry density, plasticity index, and swelling pressure were reduced [1].

5. Materials

5.1. Soil

Sieve analysis test and hydrometer test were performed to identify some of the properties of the expansive soil. The grain size distribution for expansive soil is shown in Figure 1and the results of laboratory experiments on expansive soil without addition are shown in Table 1.

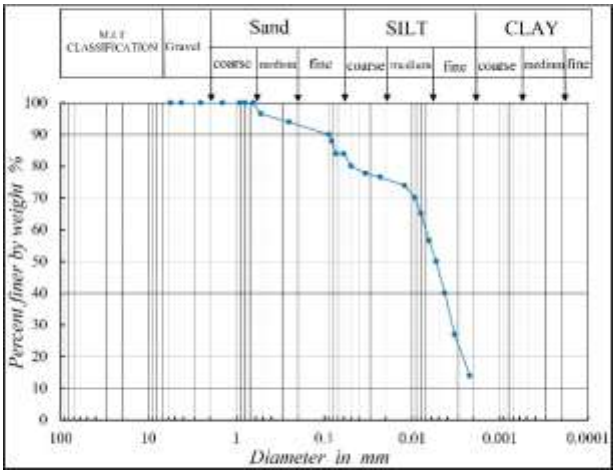

Figure 1. Grain size distribution for expansive soil.

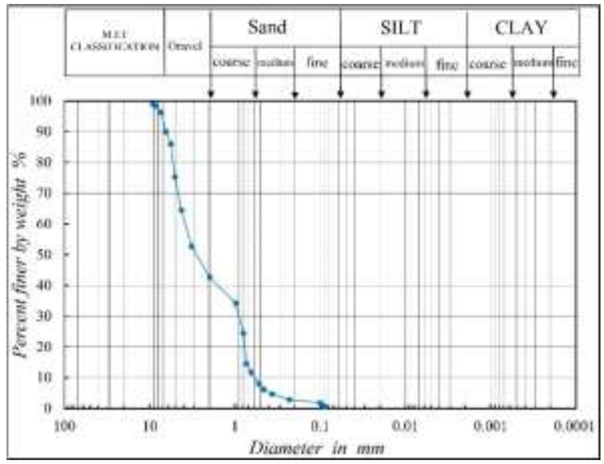

Figure 2. Grain size distribution for crushed glass wastes

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 /cm3)	2.06
Specific gravity	2.69
L.L (%)	70.75
P.L (%)	30.70
P.I (%)	40.05
M.D.D (g /cm3)	1.53
O.M.C (%)	15.75
Swelling pressure (kg/cm2)	3.92
Soil classification according to the AASHTO classification	A-7-6

5.2. Glass Wastes

To identify some of the properties of the glass wastes, the sieve analysis test was performed. The grain size distribution for crushed glass wastes is shown in Figure 2, and the chemical analysis of glass wastes is shown in Table 2.

The glass wastes were brought, ground, and then put in sieve No. 4 (4.75 mm) to do the test of standard compaction and sieve No. 40 (0.425 mm) to do the tests of liquidity limit and plasticity.

Table 2. Shows the chemical analysis of glass wastes

Chemical oxides	Percent (%)
SiO2	74
Na2O	13
CaO	10.5
SO3	0.2
Al2O3	1.3
K2O	0.3
MgO	0.2
Fe2O3	0.04

5.3. Lime

The chemical analysis of lime is shown in Table3.

Table 3. Shows 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
L.O.I	32

6. Result

6.1. Consistency Properties (Atterberg Limits)

The consistency properties (Atterberg limits) of expansive soil without any addition and expansive soil with the addition of crushed glass wastes are shown in Table 4 and Figure 3. In comparison, the consistency properties (Atterberg limits) of expansive soil without any addition and expansive soil with the addition of lime are shown in Table 5 and Figure 4.

Table 4. The effect of adding crushed glass wastes on the consistency properties (Atterberg limits)

Added percentage (%)	L.L (%)	P.L (%)	P.I (%)
0	70.75	30.7	40.05
5	69.25	29.66	39.59
10	64.1	24.75	39.35
15	53.33	23.78	29.55
20	52.51	21.87	30.64

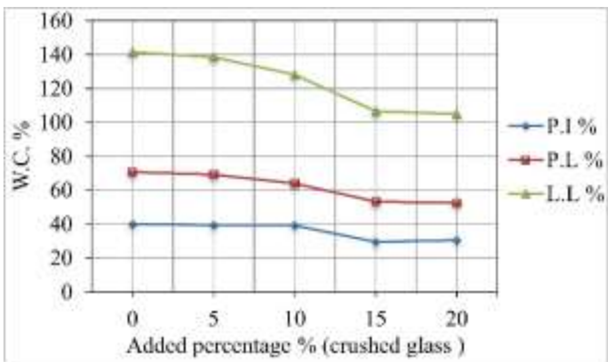

Figure 3. Graph of Atterberg limits against the percentage of crushed glass wastes

Table 5. The effect of adding lime on the consistency properties (Atterberg limits)

Added percentage (%)	L.L (%)	P.L (%)	P.I (%)
0	70.75	30.7	40.05
2	62.95	42.55	20.4
4	60.75	43.55	17.2
6	58.65	45.45	13.2
8	43.65	----	N.P.

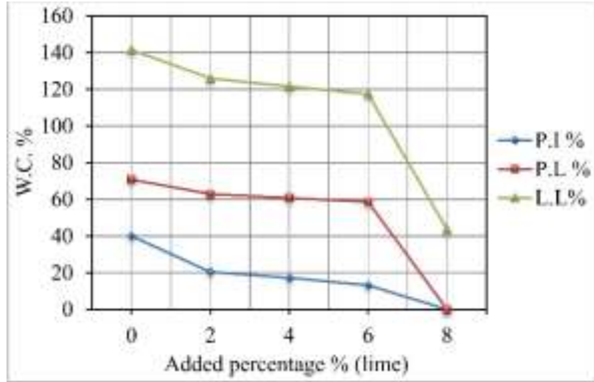

Figure 4. Graph of Atterberg limits against the percentage of lime

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.

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 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.

6.2. Compaction Characteristics (Standard Proctor Test)

The compaction characteristics of expansive soil without any addition and expansive soil with the addition of crushed glass wastes are shown in Table 6 and Figure 5. In comparison, the compaction characteristics of expansive soil without any addition and expansive soil with the addition of lime are shown in Table 7 and Figure 6.

Table 6. The effect of adding crushed glass wastes on compaction characteristics of expansive soil

Added percentage (%)	M.D.D (g/cm3)	O.M.C (%)
0	1.53	15.75
5	1.55	12.95
10	1.59	11.55
15	1.63	9.15
20	1.64	8.25

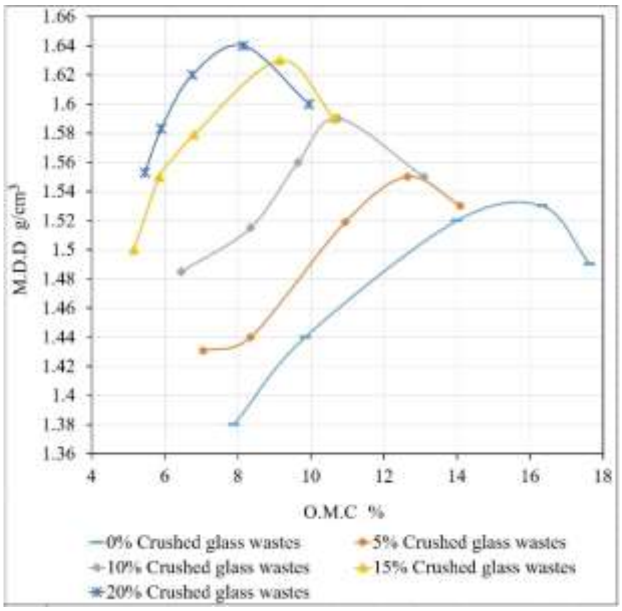

Figure 5. Compaction tests curves of the expansive soil-crushed glass mixtures

Table 7. The effect of adding lime on compaction characteristics of expansive soil

Added percentage (%)	M.D.D (g/cm3)	O.M.C (%)
0	1.53	15.75
2	1.49	16.7
4	1.46	17.6
6	1.43	18.55
8	1.4	19.4

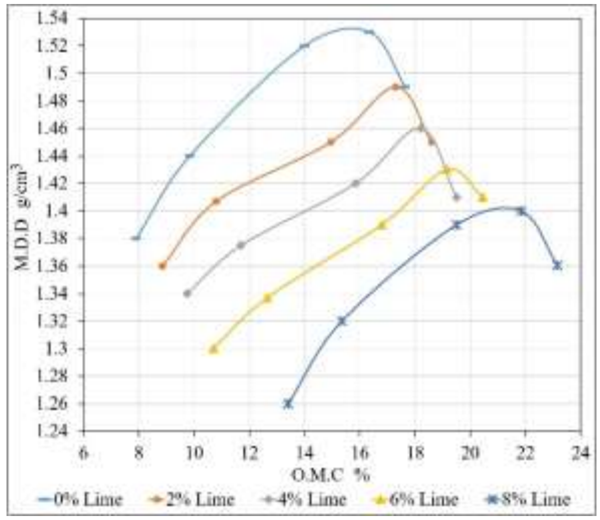

Figure 6. Compaction tests curves of the expansive soil-lime mixtures

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. We can attribute the decrease in optimum moisture content of the expansive soil to which the crushed glass wastes were added to the fact that glass is an inert material that does not absorb water. We can attribute the increase in the maximum dry density of the expansive soil to which the crushed glass wastes were added to the fact that the specific weight of the glass is higher than the specific weight of the expansive soil.

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 was 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. We can attribute the decrease in the maximum dry density of the expansive soil to which lime is added to the occurrence of clumping and accumulation of soil particles, which leads to the difficulty of compaction.

6.3. The Swelling Pressure of the Expansive Soil

The swelling pressure of expansive soil without any addition and expansive soil with the addition of crushed glass wastes are shown in Table 8 and Figure 7. The decrease in swelling pressure (%) of expansive soil without any addition and expansive soil with the addition of crushed glass wastes are shown in Table 8 and Figure8. In comparison, the swelling pressure of expansive soil without any addition and expansive soil with the addition of lime is shown in Table 9 and Figure

9. The decrease in swelling pressure (%) of expansive soil without any addition and expansive soil with the addition of lime is shown in Table 9 and Figure 10.

Table 8. The effect of adding crushed glass wastes on the swelling pressure of the expansive soil

Added percentage (%)	Swelling pressure (kg/cm2)	The decrease in swelling pressure (%)
0	3.92	0
5	3.45	12
10	2.96	24.5
15	2.48	36.73
20	2	49

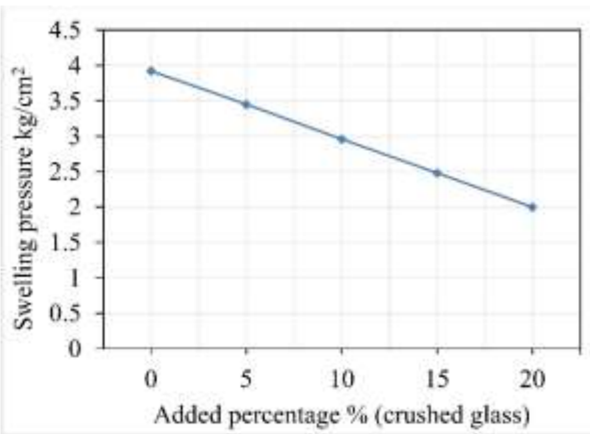

Figure 7. Graph of swelling pressure against the percentage of crushed glass wastes

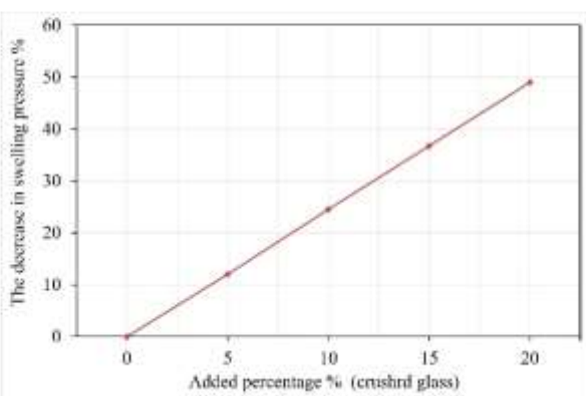

Figure 8. The percentage of decrease in swelling pressure against the percentage of crushed glass wastes

Table 9. The effect of adding lime on the swelling properties of expansive soil

Added percentage (%)	Swelling pressure (kg/ cm2)	The decrease in swelling pressure (%)
0	3.92	0
2	2.93	25.25
4	1.9	51.53
6	0.79	79.85
8	0	100

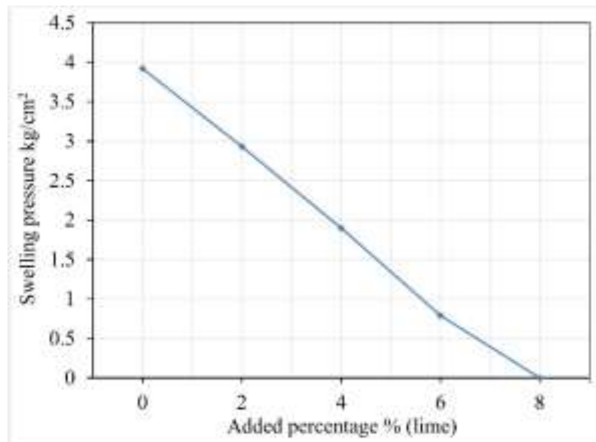

Figure 9. Graph of swelling pressure against the percentage of lime

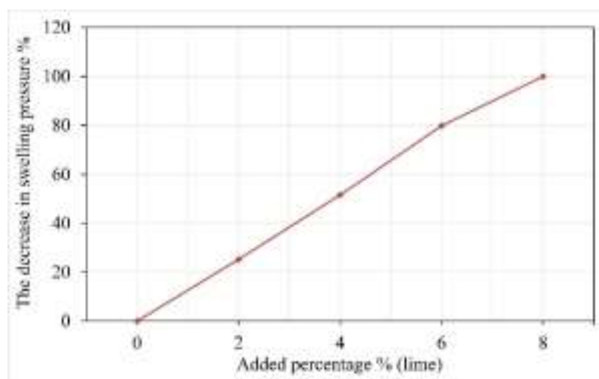

Figure 10. The percentage of decrease in swelling pressure against the percentage of lime

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. We can attribute the decrease in the swelling pressure of the expansive soil to which the crushed glass wastes were added to a decrease in the thickness of the expansive soil due to the interaction between crushed glass wastes and expansive soil.

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, and this, in turn, leads to the reduction of the swelling pressure of the expansive soil.

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

The comparison between the effect of adding separately crushed glass waste and lime on the geotechnical properties of the expansive soil are shown in Table 10.

Table 10. Comparison between the effect of adding separately crushed glass waste 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)	By adding the crushed glass wastes to the expansive soil, the liquid limit and the plastic limit decreased; the decrease in the liquid limit was greater than the decrease in the plastic limit, which led to a decrease in the plasticity index.	By adding lime to the expansive soil, the liquid limit decreased, 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 that makes it none plastic.
Compaction characteristics (standard proctor test)	By adding crushed glass wastes to the expansive soil, the optimum moisture content was reduced, and the maximum dry density increased by increasing the percentage of addition.	By adding lime to the expansive soil, the optimum moisture content was increased, and the maximum dry density of the soil was decreased.
The swelling pressure of the expansive soil	By adding crushed glass wastes to the expansive soil, the swelling pressure of the expansive soil was reduced by increasing the percentage of addition.	By adding lime to the expansive soil, the swelling pressure of the expansive soil was reduced to zero by increasing the percentage of addition.

8. Abbreviations

L.L=liquid limit; P.L=plastic limit; P.I=plastic limit; W.C= water content; M.M.D=maximum dry density; O.M.C=optimum moisture content

9. Conclusions

The Consistency properties (Atterburg limits) of the expansive soil, improved by adding only the crushed glass wastes to the expansive soil and by adding only lime to the expansive soil. By adding only crushed glass wastes to the expansive soil, it led to a decrease in the liquid limit and the plastic limit, the decrease in the liquid limit was much greater than the plastic limit decrease, which led to a decrease in the plasticity index while by adding only lime to the expansive soil, the liquid limit decreased, 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 that makes it none plastic.

The compaction characteristics of the expansive soil were affected by adding only crushed glass wastes to it through a decrease in the optimum moisture content and an increase in the maximum dry density by an increase in the percentage of addition, but by adding only lime to the expansive soil, led to an increase in the optimum moisture content and a decrease in the maximum dry density of the expansive soil.

The swelling pressure of the expansive soil improved by adding only the crushed glass wastes to the expansive soil and by adding only lime to the expansive soil; by adding separately crushed glass waste and lime to the expansive soil causing the swelling pressure of the expansive soil to be reduced by the increase in the percentage of this addition.

Corresponding Author:
Shehab Nasr Abdelmoneim Mohamed
M.Sc. Student, Civil Engineering Department, Faculty of Engineering, Assiut University, Egypt
E-mail: eng_shehab2017@yahoo.com

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