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# Freeze-Thaw Effect on High Plasticity Clayey Soils Reinforced with Waste Glass Bottle Powder

**Necmi Yarbasi[1]*, Ekrem Kalkan[1], Elif Agirman Akturk[1]**

[1] *Atatürk University, Faculty of Engineering Department of Civil Engineering, 25240, Erzurum, Turkey*

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**Contact**
*Necmi Yarbasi
nyarbasi@atauni.edu.tr

**ABSTRACT**

In today's world, climatic changes and waste/residual materials caused by technological developments pose an extreme threat to the environmental system. It is widely used in various engineering applications to reduce the negative effects of such materials and bring them into the economy. This subject has started to be used especially in civil engineering, in applications of improving/strengthening basic soil properties. In this study, the freeze-thaw effect on the strength of highly plastic clayey soils reinforced with waste glass bottle powder was investigated. Clayey soils mixed with waste glass bottle powder at 5%, 10%, and 15% were compacted at optimum water content using the Standard Proctor Test. The effect on freeze-thaw behavior of clayey soil samples stabilized using waste glass bottle powder was determined by unconfined compression tests. For these tests, all samples were cured and subjected to freeze-thaw cycles. According to the experimental results, the highest unconfined confined strength was obtained in a 28-day curing in a clayey soil samples stabilized 10% ratio of waste glass bottle powder. Clay soil samples stabilized with 10% waste glass bottle powder were found to have high unconfined confined strength value and it was determined that waste glass bottle powder can be used in the stabilization of clay soils.

## 1. Introduction

The rapidly growing world population has increased the demand for land and made it necessary to use areas that are not suitable for housing for housing. This situation causes serious problems in both construction and post-construction periods. To eliminate or minimize the structural problems caused by unfavorable soil conditions, it is of great importance to create favorable soil conditions by improving the properties of these weak soils. It is of great importance in preventing earthquake-induced structural damages, especially in active tectonic zones that produce earthquakes and in the immediate vicinity of these zones, to locate the construction areas on solid soils or to improve the properties of weak soils and make them suitable for construction.

In most civil engineering projects, it is very difficult to obtain a construction site that will meet the design requirements without soil modification, especially in areas prone to liquefaction and in areas covered with soft clay and organic soils due to the insufficient bearing capacity of the base soil. Current practice is to improve the engineering properties of poor bearing capacity and problematic soils to meet the design specifications. Various soil improvement methods have been developed and the appropriate soil improvement method is selected and applied according to the soil properties and soil conditions. The purpose of soil stabilization method, which is one of the various soil improvement methods, is to increase the strength of the soil and its resistance to softening with water by binding the soil grains together, making the grains waterproof or a combination of the two (Sherwood, 1993; Şengül and Vitoşoğlu, 2023).

Soil stabilization is carried out by various methods and these methods are grouped under two main groups as mechanical and chemical stabilization. Mechanical stabilization is carried out by changing the physical structure of natural soil grains through vibration or compaction or by incorporating other physical elements such as barriers and nails into the soil structure. Chemical stabilization is carried out to improve the geotechnical properties of natural soils to meet specific engineering objectives.

The geotechnical properties of natural soils can be improved by improving shear strength parameters, increasing tensile strength and increasing stiffness. In this technique, chemically active materials are added to soils to increase or maintain the stability of the soil mass. Chemical soil stabilization is based on the following principles to achieve the desired effect It depends on chemical reactions between the stabilizer, which is a cementitious material, and soil minerals containing pozzolanic substances and can be used to improve a wide variety of types of subgrade soils, from swelling clays to granular materials (Kalkan, 2003; Rogers and Glendinning, 1993; Sherwood, 1993; Şengül and Vitoşoğlu, 2023).

Stabilizing agents, when in contact with water or when pozzolanic minerals reacts with water in the presence of water to form cementitious composite materials binders. Commonly used binders are lime, cement, fly ash, blast furnace slag and bituminous materials. Apart from these, pozzolans, rice husk ash, lime kiln dust, cement kiln dust, silica fume and geopolymers are also used in the stabilization of soils. These additives generally cheap, locally available, biodegradable and as they are environmentally friendly materials, their use provides many advantages.

Using these materials individually or in combination, the base has a significant effect on improving the properties of soils (Şengül and Vitoşoğlu, 2023). Nowadays, many scientific studies are carried out within the scope of strengthening soils with such weak geotechnical properties with these wastes or residues (Prabakar and Sridhar, 2002; Yurtsever Kara, 2002; Asaga et al., 2006; Akbulut et al., 2007; Yarbaşı et al., 2007; Ustunkol and Turabi, 2009; Hejazi et al., 2012; Khmiri et al., 2012; Maliakal and Thiyyakkandi, 2012; Yarbaşı, 2019; Kalkan et al., 2020; Mahmutluoglu and Bagrıacik, 2020; Yarbaşı, 2020; Yarbaşı and Kalkan, 2020; Ahmadi et al., 2021).

In recent years, there has been an increase in the search for alternative materials within the scope of additive stabilization studies. Especially by adding a cohesionless material to cohesive soils, problems such as swelling and consolidation settlement of natural soils can be reduced. In this context, waste glass has taken its place in stabilization studies as an alternative material. With the utilization of these wastes, it is aimed to reduce the amount of waste to be stored and the costs of soil stabilization. The use of waste glass as an additive material in various applications such as soil stabilization has a significant environmental and economic impact (Dadanlar, 2019). There are many studies on the use of waste glass materials in the chemical stabilization of weak soils. In these studies, increasing the strength, reducing the permeability and improving the swelling properties of weak soils have been investigated (Wartman et al., 2004a; Wartman et al., 2004b; Grubb et al., 2006; Malasavage et al., 2007; Ozkan, 2007; Deniz, 2011; Arabani et al., 2012; Kulkarni et al, 2014; Nuruzzaman and Hossain, 2014; Olufowobi et al., 2014; Ikara et al., 2015; Tozsin et al., 2015; Fauzi et al., 2016; Al-Neami et al., 2016; Çanakcı et al., 2016; Bağrıaçık 2017; Benny 2017; Mishra, 2017; Salamatpoor and Salamatpoor, 2017; Parihar et al., 2018a; Bilondi 2018a; Bilondi 2018b; Yarbaşı et al., 2021).

Today, considering economic conditions, sustainability, and environmental impacts, the transition to natural additives has accelerated. Due to technological development and globalization in almost every field in the world, industrialization and urbanization are increasing rapidly and all resources are being consumed unconsciously. As a result of this consumption frenzy, waste occurs. Within the scope of this study, by using waste/residue materials in ground improvement, a contribution will be made to the protection of our environment and the improvement works will be carried out more economically.

The main objective of this experimental research was to evaluate the freeze-thaw effect on high plasticity clayey soils reinforced with waste glass bottle powder. To accomplish this objective, a series of tests were performed on the natural and stabilized samples. The experimental results indicate that waste glass bottle powder additive material is acceptable material to enhance the freeze–thaw properties of clayey soils in geotechnical applications.

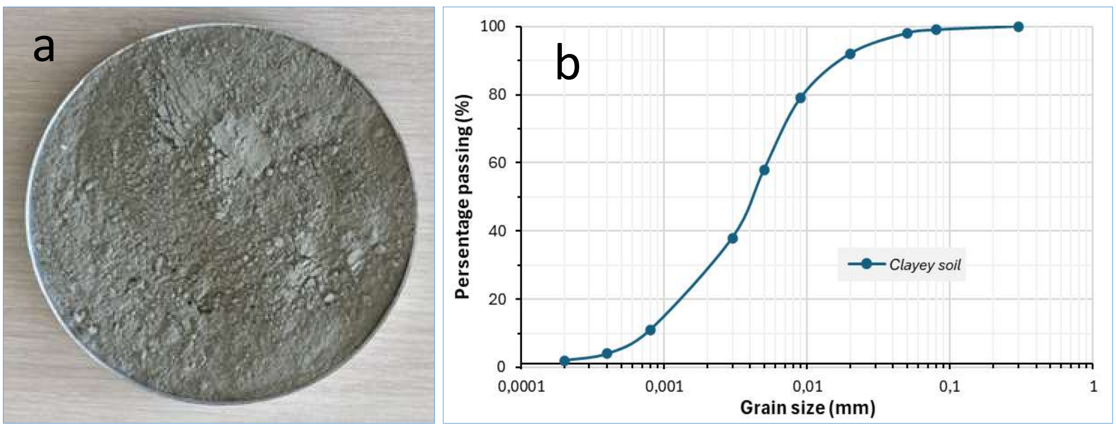


Fig. 1. Photographs, clayey soil material (a) and granulometry curve (b)

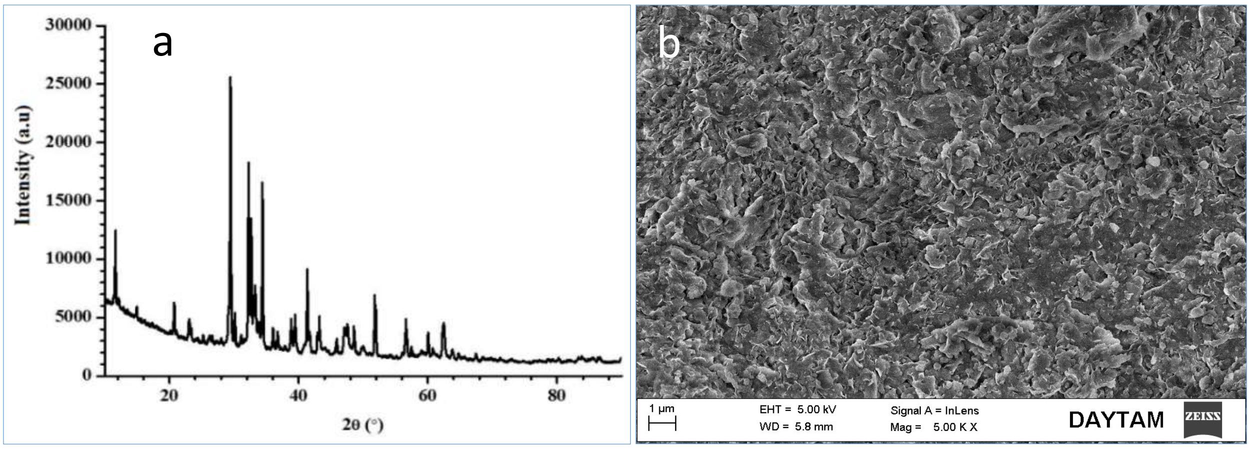


Fig. 2. XRD graph (a) and SEM pattern (b) of clayey soil

## 2. Material and Method

### *2.1. Clayey soil*

The clayey soil samples used in this study were obtained from the deposits of the Oltu Oligocene sedimentary basin, Erzurum, Northeast Turkey. This soil with green color and high plasticity is over-consolidated and it has clayey-rock characteristics in natural conditions (Kalkan, 2003; Kalkan and Bayraktutan, 2008). The photo of clayey soil material (a) and its granulometry curve (b) were shown in Fig. 1. The XRD graph (a) and SEM image (b) of clayey soil material were shown in Fig. 2. Also, its physical and mechanical properties were given in Table 1.

Table 1. Physical and mechanical properties of clayey soil (Kalkan and Bayraktutan, 2008)

| Characteristics | Clayey soil |
|---|---|
| Specific weight, Gs | 2,64 |
| Sand (%) | 10,00 |
| Silty (%) | 58,00 |
| Clay (%) | 32,00 |
| LL (%) | 68,00 |
| PL (%) | 28,00 |
| PI (%) | 40,00 |
| [1]Optimum water amount (%) | 25,80 |
| *Max. dry weight (kN/m$^3$) | 14,10 |
| **Soil category (USCS) | CH |

**Obtained from the Standard Proctor Test*
***It was determined according to the USCS soil classification system*

### *2.2. Waste Glass Bottle Powder*

Waste glass bottles were obtained from waste material collection containers created in Erzurum (Turkey) center and its surroundings. After washing with pressurized water and drying in order to avoid any residual material in the glass bottles, it was ground in the etching device at 6000 revolutions. In the elemental analyzes of the waste glass bottles that were ground into powder, oxygen 44.53%, sodium 9.94%, magnesium 1.61%, aluminum 1.46%, silicon 33.93%, and calcium 8.53%. Analyzes were made at East Anatolia High Technology Application and Research Center (DAYTAM) of Atatürk University. The photo of the waste glass bottle (a), photo of the waste glass bottle powder (b) and its granulometry curve (c) are shown in Fig. 3 and the XRD graph and the SEM image are shown in Fig. 4.

### *2.3. Preparation of Samples*

Firstly, the clay soil and waste glass bottle materials were dried in an oven at approximately 65 °C and then ground . After the grinding process was completed, they were weighed and blended in dry form at the determined ratios to obtain clayey soil-waste glass bottle powder mixtures. The proportions of waste glass bottle powder in the mixtures were selected as 0%, 5%, 10% and 15%. Then, the optimum water content values for each mixture were determined by Standard Proctor Procedure (ASTM D 698, 1995) and mixed by adding water at the optimum water content ratios obtained. The mixtures were compacted in accordance with the Standard Proctor Procedure (ASTM D 698, 1995) and samples were prepared for unconfined compaction and freeze-thaw tests. The samples were 70 mm in length and 35 mm in diameter. When the samples to be used in the experimental study were prepared, they were kept in a desiccator until the beginning of the experiment to maintain their moisture content.

### *2.3. Compaction Test*

The samples used in this study, which investigated the effect of waste glass bottle dust on the freeze-thaw performance of clayey soils, were obtained by compression with a standard proctor tester. Then, clayey soil materials containing natural and waste glass bottle dust (5%, 10%, and 15% of dry weight) were compressed at optimum water content using a Standard Proctor tester and cylindrical samples with a diameter of 35 mm and a height of 70 mm were prepared.

### *2.4. Unconfined Compression Test*

Compressive strength of soils is one of the most important design parameters in road construction and earthworks applications (Yarbaşı et al., 2007). In this study, unconfined compression tests were carried out to investigate the effect of waste glass bottle powder on the freeze-thaw performance of clayey soil samples. The compressive strength tests were measured by breaking stabilized cylindrical samples in a compression-testing machine at 240 kgf/s loading speed. This test was performed in accordance with ASTM D 2166.

### *2.5. Freeze-Thaw Test*

Freeze-thaw tests were conducted to determine the freeze-thaw performance of clayey soil samples stabilized with waste glass bottle powder. Freeze-thaw tests were carried out with a programmable freeze-thaw apparatus. Within the scope of the experimental study, cylindrical samples cured for 1, 7, 14 and 28 days were subjected to freeze-thaw tests according to ASTM C 666. Unsterilized and clayey soil samples stabilized with waste glass bottle powder were placed in the freeze-thaw test setup and kept at -18 °C for 2.30 hours.

Then, all samples removed from the freeze-thaw test setup were transferred to a test environment at +18 °C to allow thawing for 2.30 hours. After the freeze-thaw cycle was repeated 20 times, free compression tests were performed on the samples and unconfined confined strength (UCS) values were obtained. The samples, the freeze-thaw test device and the uniaxial pressure device used in this study are shown in Fig. 5.

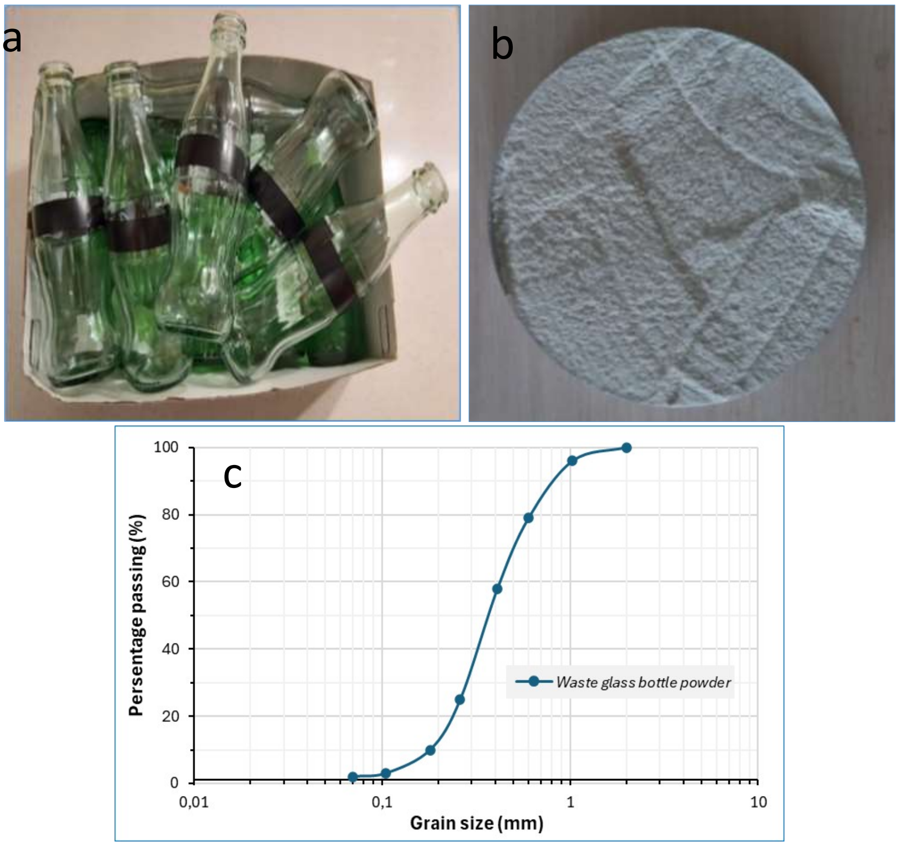


Fig. 3. Photographs, waste glass bottle (a), waste glass bottle powder (b) and granulometry curve (c)

## 3. Results and Discussion

### *3.1. Effects of waste glass bottle powder on UCS*

The effects of waste glass bottle powder on the UCS of clayey soil samples were determined by unconfined compression tests and the obtained results were given in Fig. 6.

As can be seen in the figure, waste glass bottle powder had a positive effect on the UCS of clayey soil samples. When waste glass bottle powder was added to the clayey soil samples at gradually increasing rates, the UCS values of the clayey soil sample first increased and then decreased. The maximum UCS value was obtained in clayey soil samples stabilized with 10% waste glass bottle powder.

The increase in the UCS value was attributed to the changed grain size distribution of the clayey soil samples with the addition of waste glass bottle powder. It was noted in literature that the addition of additive changed the composition, mineralogy and particle size distribution of clayey soil (Gillot, 1968; Ola, 1978; Kalkan and Akbulut, 2004; Kalkan, 2006; Kalkan, 2009a; Kalkan, 2009b, Kalkan, 2011). With the changed grain size distribution, the optimum water content values of the clayey soil samples decreased and the maximum dry unit volume weight values increased. The increase in the maximum dry unit volume weight values of the clayey soil samples resulted in higher UCS values.

In order to determine the effect of curing on clayey soil samples stabilized with waste glass bottle powder, all samples were subjected to curing for 1, 7, 14 and 21 days and the results obtained are presented in Fig. 6. The curing process was repeated for the samples that were not subjected to freeze thaw and for the samples that were subjected to freeze thaw. The UCS increase rate in the samples, satbilized with 10% waste glass bottle powder and cured 28 days was 53.64%. The UCS increasing with curing time can be explained by chemical reactions that take place over a period of time (Thompson, 1968; Okagbue and Onyeobi, 1999). When waste glass bottle powder is added to clayey soil material, hardening behavior occurs in clayey soil samples stabilized with waste glass bottle powder due to aging. As a result, mechanical resistance increases with curing time (Okyay and

Dias, 2010). Among the different variables affecting the UCS values of clayey soil samples stabilized with waste glass bottle powder, curing is of great importance. Its effect on UCS is a function of time, temperature and relative humidity (Mitchell and Hooper, 1961; Bell, 1996).

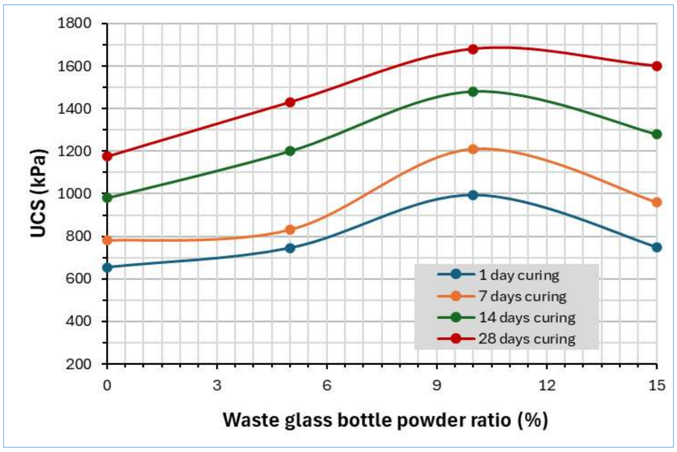


Fig. 6. Effect of waste glass bottle powder on UCS values

### 3.2. Effects of freeze-thaw on the UCS

The freeze-thaw tests were carried out to determine the effects of freeze-thaw on the UCS of stabilized with waste glass bottle powder and obtained test results were illustrated in Fig. 7. The results showed that freeze-thaw had a negative effect on all samples, but the negative effect was less in the samples stabilized with waste glass bottle powder. This can be explained by the changed properties of the material stabilized with waste glass bottle powder. The effect of freeze-thaw on the degree of deterioration varies depending on the properties of the material. Although there are various reasons, freezing-thawing cycles can be detrimental to soft granular and porous brittle materials when exposed to lower temperatures (Hori and Morihiro, 1998; Yarbasi et al., 2007)

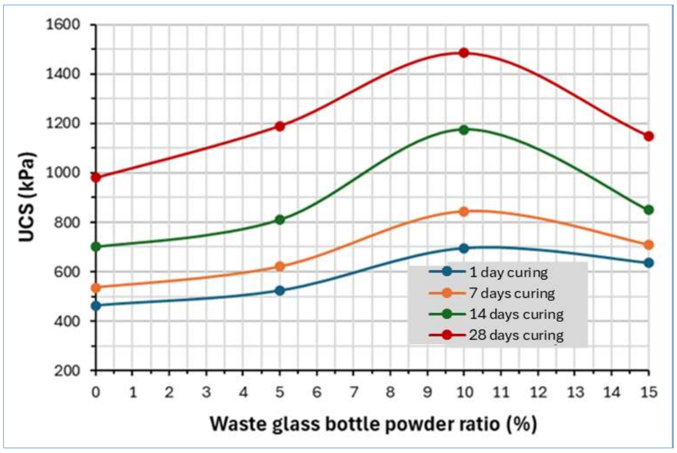


Fig. 7. Effect of curing on UCS values of stabilized with waste glass bottle powder and exposed to freeze-thaw samples

The UCS increase rate in the samples stabilized with 10% waste glass bottle powder, cured 28 days and exposed to freezing thawing cycles was 50.67%. The main mechanism governing the alteration of soil behavior caused by the freezing-thawing cycles appears to be changes in the soil structures. The decrease in the compressive strength of unstabilized samples is attributed to the changes in soil sample structure due to particle rearrangements and the initiation of cracks (Cruzda and Hohmann, 1997; Viklander, 1997; Viklander and Eigenbrod, 2000; Yarbasi et al., 2007).

## 7. Conclusion

In this study, the changes in the strengths of clayey soils reinforced with the addition of waste glass bottle powder at three different rates were investigated before and after freeze-thaw cycles. As a result of the experimental studies, the highest strength increase was observed in clayey soil samples stabilized with the addition of 10% waste glass bottle powder before and after freeze-thaw cycles and at the end of 28 days of cure. In this mixture, the strength increase rate before freeze-thaw cycles was 53.64%, while the strength increase rate after freeze-thaw cycles was 50.67%. In the light of the obtained data, it was concluded that the powder form of glass bottles, which is a waste material, can be used in the stabilization of clayey soils with poor geotechnical properties in terms of durability, low cost, sustainability and positive environmental impact and that it is a waste material that reduces costs.

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## Declaration of Conflict of Interests

There are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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