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Effect of Engineering Properties of Soft Clay Soil Stabilized with Limestone, Eggshells Powder and Eggshells Ash

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ABSTRACT

Soft clay soil is one of the problematic soil which is widespread in Iraq especially in middle and south of Iraq and has a low bearing capacity. This study investigates some of the mechanical properties of soft clay soil after adding the environmental waste material, egg shells. This study compares eggshell ash (ESA), eggshell powder (ESP), and limestone (L), which can be used as a stabilizer for soft clay while preserving natural limestone from consumption. ESP can be used as a replacement for limestone due to some similarities in chemical composition between it and limestone components. Soft clay soil brought from southern Iraq, which is used for this study and mixed with different percentages of ESA (2 - 6%), ESP (4 - 20%), and L (4 - 24%) by dry weight of soil. Lab tests such as specific gravity, Atterberg limits, compaction, and triaxial tests were used to evaluate the amendment samples and compare them with the reference one. The experimental results indicated that ESA increased the qualities of consistency, strength, and plasticity. It was found that the activity of the natural soil without any additives was decreased from 0.60 to 0.20 at 6% of ESA, while the activity dropped to 0.23 at 20% of ESP and 0.25 at 30% of L. Thus, it can be concluded that ESA was an effective stabilizer for improving the mechanical properties of soft soil samples.

Introduction

Civil engineering projects are always built into the ground. As a result, any structure requires a foundation with suitable bearing capability. Soil improvement is still a concept from antiquity and the Renaissance in expanding present methods and inventing new ones for this purpose, especially in developing countries with rising population and economic concerns (Nicholson, 2015). Moisture acts as an adversary to these soils, making them particularly detrimental to structures erected atop them, such as foundations and light structures. Soft clay is one of these difficult soils. Soft clay covered huge sections of Iraq's geographic geography, particularly in the country's central and southern regions. Soft clay is one of those difficult soils that needs improvement (Abbas, Ibrahim, & Shihab, 2020). There is a lot of soft clay soil in many places of the planet. This soil is classified as a poor construction soil (Arulrajah, Piratheepan, Disfani, & Bo, 2013; Bhavsar & Joshi, 2014). When soil is subjected to a given amount of load, it tends to deform along the direction of the load application. The type and magnitude of deformation vary depending on the soil. Such soils require either replacement with suitable soil or treatment with a suitable mechanism to achieve sufficient bearing capacity and strength to support the load exerted on them. Soft clay soils, such as silty and clayey soils with high moisture content, peat foundations, and loose sand deposits near or beneath the water table, contain considerable proportions of tiny particles (Indraratna, Chu, & Cholachat, 2015). Soft clays are common and have low strength, high sensitivity, and high compressibility (Huang et al., 2020; Indraratna et al., 2015). Soft to very soft clay soils are generally connected with significant challenges. Because these soils are prone to deformation and have low shear strength, they may cause structural damage during construction and during the life of the project. Such soils require either replacement with suitable soil or treatment with a suitable method to achieve sufficient bearing capacity and strength to handle the load exerted. These percentages were used to reduce the Atterberg limits correspondingly. Because of the heavyweight nature of this substance and its capacity to absorb water (Ibrahim, Çabalar, & Abdulnafaa, 2018), the maximum dry density was enhanced but the optimal moisture content was decreased (Karkush & Yassin, 2019). Plasticity in the processing of clay-based materials is a fundamental property since it defines the technical parameters to convert a ceramic mass into a given shape by application of pressure (Astbury, Moore, & Lockett, 1966; Moore, 1965; Norton, 1983; Singer & Singer, 1979). Plasticity, in this case, and particularly in clay mineral systems, is defined as "the property of a material which allows it to be repeatedly deformed without rupture when acted upon by a force sufficient to cause deformation and which allows it to retain its shape after the applied force has been removed (Perkins, 1995). A high plasticity clay-water system requires more force to deform and deforms to a greater extent without cracking than a low plasticity clay-water system, which deforms more easily and ruptures sooner (Brownell & W.E., 1977).

The shape of the plate-like clay mineral particles that glide over each other when water, which works as a lubricant, is related to the flexibility of clays. Plasticity increases with increasing water content in clay, up to a maximum dependent on the type of the clay. Clay professionals are used to referring of "fat" or highly plastic clays like ball clay or "lean" generally non-plastic clays like kaolin, but expressing these concepts in measurable quantities is problematic. Plasticity is also used in the industry (Ibrahim et al., 2018). Several research on the application of recent findings or the usage of recycled materials as essential substitute components in soil alteration development have been conducted (Karkush & Yassin, 2019). Furthermore, using waste materials as geotechnical alternatives has been identified as a significant strategy to improve environmental health (Ahmed & Issa, 2014; Norton, 1983). Waste materials are currently being used for a variety of planning and geotechnical purposes, reducing their environmental impact. Furthermore, waste materials possess unique qualities that make them suitable for specific geotechnical and planning applications. Before a design and infrastructure upgrade can be executed, the durability, strength, and deterrent features of waste materials must be established (Blayi, Sherwani, Ibrahim, Faraj, & Daraei, 2020). Global egg production is increasing somewhat, necessitating the delivery of more than 8 million tons of eggshell waste each year (Sathiparan, 2021). Egg usage in families and bistros is very comparable to egg usage in large-scale manufacture of liquid eggs for food and non-food uses in egg breaking plants (Pliya & Cree, 2015). The total quantity of eggs delivered from breaking facilities in Canada and France is around 2.3 billion (Sathiparan, 2021). In 2011, 8979.8 million eggs were consumed; by 2017, this number had risen to 12,235.3 million eggs, and it will need to rise more in the next years (Tiong, Lim, Lee, Ong, & Yew, 2020). In landfills, around 150,000 tons of eggshell (ES) waste is disposed away. As a result, it is clear that as the population grows, so do eggshell wastes (Tiong et al., 2020; Wei, Xu, & Li, 2009). When limestone powder is applied to clayey soil, the experimental results of reveal a relatively good effect on the geotechnical qualities (Pastor, Tomás, Cano, Riquelme, & Gutiérrez, 2019). When 25% of the additive is applied, the Liquid Limit and Plasticity Index are reduced by up to 17 and 32%, respectively (Pastor et al., 2019). By mixing the gypsum soil with 16% eggshell powder, it improves and increases the cohesion of the soil and also the type collapse for this percentage is to be (no problem) (Abdulrahman & Ihsan, 2020). The addition of eggshell ash to the soil-cement eggshell ash stabilized lateritic soil enhanced the optimum moisture content but lowered the maximum dry density (Okonkwo, Odiong, & Akpabio, 2012). However, just a few attempts at working with eggshell ash have been made. Because of the increased calcium oxide offered by the inclusion of eggshell ash, eggshell ash has been established as a good accelerator in cement with a focus on the setting time (Islam, Dwivedi, & Dwivedi, 2021; Mtallib & Rabiu, 2009). They assessed the effectiveness of sawdust ash and ESA mixtures in the stabilization of lateritic blocks. They found that the combination of sawdust ash and ESA can be employed as a feasible alternative to cement in the stabilization of blocks (Yie, 2019). investigated the stabilization of soft clay using mixtures of silica fume and ESA. An experiment discovered that combining 6% silica fume with 6% ESA increased unconfined compression strength by 69% (J. O. Afolayan, F. O. P. Oriola, G. Moses, & Sani, 2017). They noticed that increasing the amount of ESA in the mix resulted in greater longevity of the stabilized soil. According to the existing literature, ESA is a waste material with high success for soil stabilization.

The main objective of this research is to investigate the properties of the soft clay soil stabilized with different percentages of additives. The additives are limestone (L), Eggshells powder and Eggshells ash.

METHODOLOGY (Materials, Sample preparation, and Procedures)

Materials

soft clay

In order to understand and fully appreciate the stabilized effects if limestone, Eggshells Powder or Egg shells Ash treatment, it is important to understand the basic of clay mineralogy or, more specifically, clay chemistry and its interaction with water. Table (1) illustrates the physical properties of the soil.

Table 1. Physical properties of the soil

The physical properties of soil.	The value
Optimum Moisture Content (OMC)	14.8
Dry unit weight	18.54
Clay fraction (F)	60%
Specific gravity (Gs)	2.75
Water content	45
Liquid Limit (L.L)	70
Plastic Limit (P.L)	28
Plasticity Index (P.I)	42
Activity (A)	0.6

Limestone powder

Limestones are rocks predominantly made by minerals of calcite (calcium carbonate with trigonal structure, $CaCO_3$). They are solid and grained sedimentary rocks of organic or chemical origin. The calcium carbonate content is often above 95%.

Eggshells powder

Eggshells are agricultural waste materials generated from chick hatcheries, bakeries; fast food restaurants among others which can litter the environment. ESP primarily contains CaO_3 (95%) and the remaining consists of Al_2O_3, SiO_2, Cl, Cr_2O_3, MnO and CuO. Specific Gravity of ESP used= 1.32. Chemical composition of a typical egg shell (Calcium oxide) CaO = 50.70 (Islam et al., 2021).

Egg shells Ash

Egg shell is calcium carbonate, during incineration to ash the calcium carbonate will decompose into calcium oxide and carbon dioxide as shown in Equation 1. Specific Gravity of ESA used= 2.14.

$$CaCO_3 \xrightarrow{(Heat)} CaO + CO_2 \quad (1)$$

Sample preparation

In this research used in this study were ordinary limestone, Eggshells Powder, or Eggshells Ash to treatment soft clay.

Limestone powder

Limestone was obtained by crushing locally collected limestones using a jaw crusher and then, grounding the material using a ball mill. Both limestone powder and cement were sieved through #200 sieve (75 μm) and used as stabilizers at different contents (Norton, 1983).

The eggshells Powder (ESP)

The experimental program consisted eggshells were offtake from market-place and laundered with double dribbled water followed by drying in air oven at 110°C for 12 hours.and crushed the egg shells by to be powder as illustrated in figure (1).

Figure 1. Steps producing egg shells powder

EggShells Ash (ESA)

Egg Shell Ash (ESA) was obtained by incinerating fowls' eggshells to ash. Egg shells powder were burned at a temperature of 550°C for 4 hours by using incineration to became ash and the steps of preparing eggshells ash illustrate in Figure (2).

Figure 2. Steps of producing egg shells ash

Procedure

Tests performed are: modified proctor, test atterberg limits test, and triaxial test for soil before and after mixing with the percentage below.

- The percentage of limestone powder ranges from 4%, 8%, 12%, 16%, 20%, and 24%.
- The percentage of egg shell powder ranges from 4%, 8%, 12%, 16%, and 20%.
- The percentages of egg shell ash range from 2% to 6%.

Test results and discussions

Test Atterberg Limits

The liquid limit, plastic limit, plasticity index and activity results are tested according to ASTM D4318-10. Figures 3- 6 illustrated the relationship between liquid limit, plastic limit, plasticity index and activity with the percentage of the additives, respectively. From Figure (3), the addition percent of treatment (up to 24% of L, 20% of ESP, and 6% of ESA) is observed to increase, and the liquid limit of clay tested is reduced.

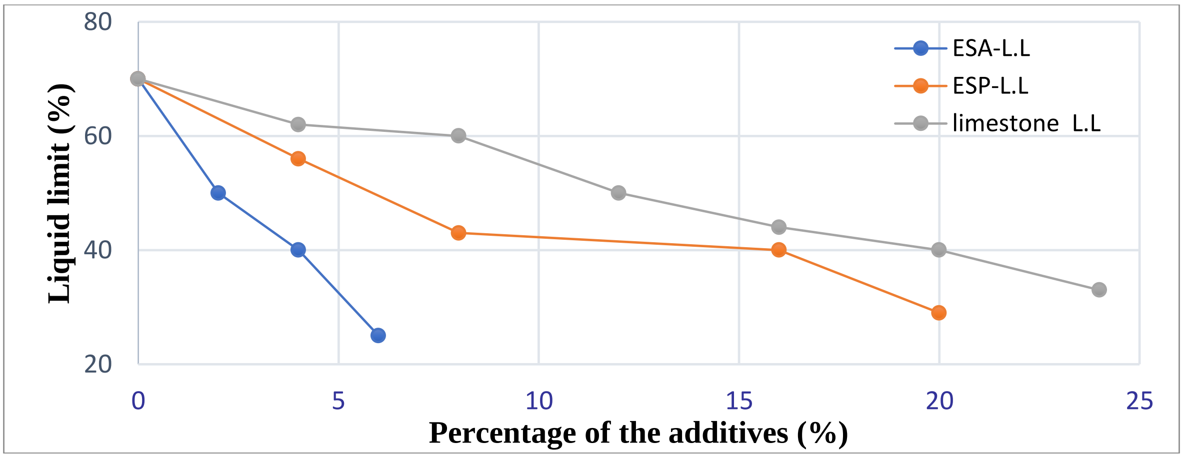

Figure 3. Relation between liquid limit with percentage for soil with mixing L, ESP or ESA

According to Figure 4, which shows that the soil is treated with L, ESP, , and ESA. It can be deduced that the plastic characteristics of the soil sample are gradually decreasing with an increase in the percentage of the addition percent of treatment up to 2٤% of L ,20% of ESP, and 6% of ESA.

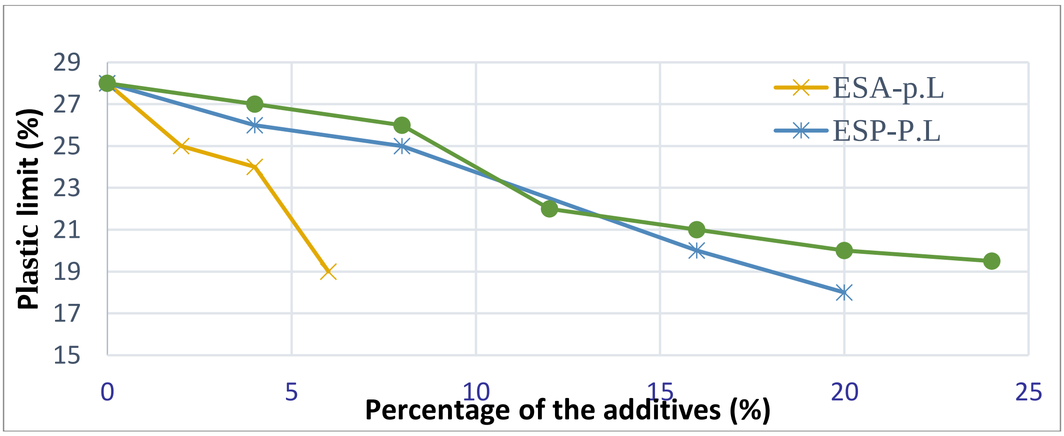

Figure 4. Relation between plastic limit with percentage for soil with mixing L, ESP or ESA

Figure 5 shows that, up to 24% L, 20% of ESP, and 6% ESA) is added, there is a considerable decrease in PI, and after that the value seems to be almost constant. That means the soil was treated from type very high plasticity to be at mixing (medium plasticity, medium plasticity, low plasticity) (24% L, 20% ESP, 6% ESA) respectively.

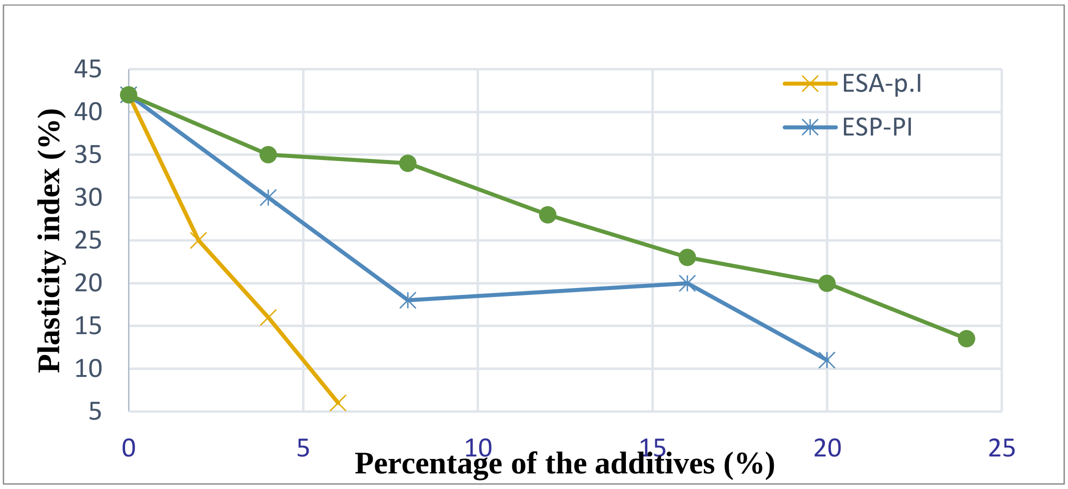

Figure 5. Relation between plastic index with percentage for soil with mixing L, ESP or ESA

Figure 6 explains that the activity of the soil was 0.8ɛ decreased to be (0.27, 0.22 and 0.21) at 24% L, 20% ESP, and 6%ESA) respecified. That means the soil was treated from type normal active to be inactive at mixing (24% L, 20% ESP, 6% ESA) respectively.

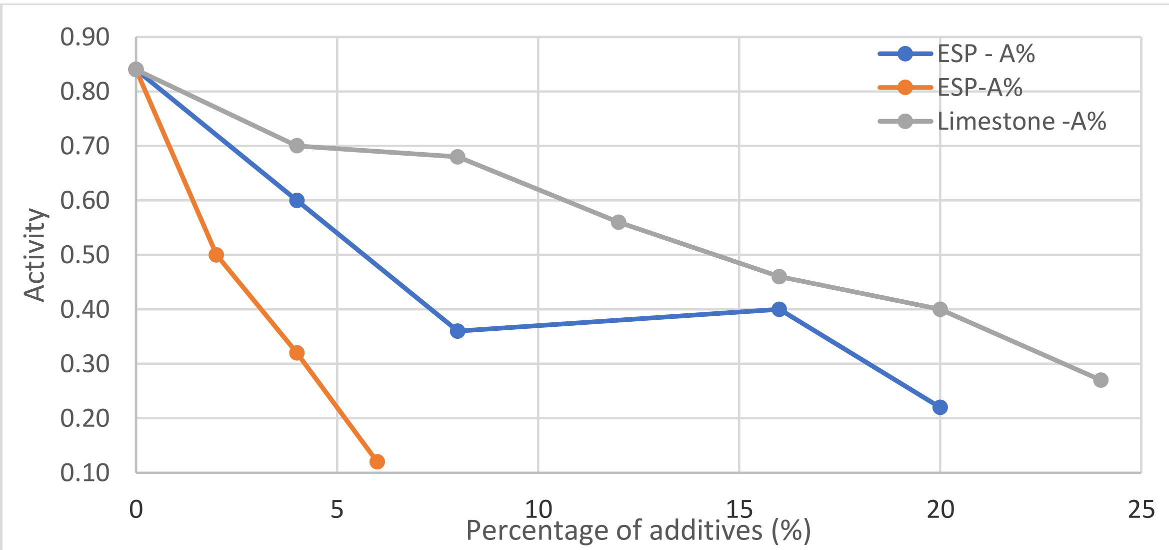

Figure 6. Relation between at addition eggshells ash for soft clay

Modified Proctor test

In this part, a modified proctor test has been performed on the untreated and treated soft clay The maximum dry density increased as L, ESP and ESA additions increased till reaching 24% L addition, 20% ESP and 6%ESA addition, then decreased. This increase in the maximum dry density is due to the replacement of the clay particles with L, ESP and ESA particles that occupied spaces within the soil to form weak bonds between the soil and the cementitious compounds formed by reaction.

Figure 7 explains and shows the relationship between maximum dry density and eggshell ash content. The maximum dry density for soil without addition is 18.54. increased progressively to 15.4% at 6% ESA content, to 15.8 % at 20 % ESP content, and to 16.6 % at 24% L. Figure 8, explains, shows the relationship between Optimum Moisture Content of the soil before and after mixing with L, ESP, and ESA. With addition, the optimum moisture content for soil is to be gradually increased to 18% at 6% ESA content, 17.2% at 20 % ESP content, and 16.6% at 24% L content.

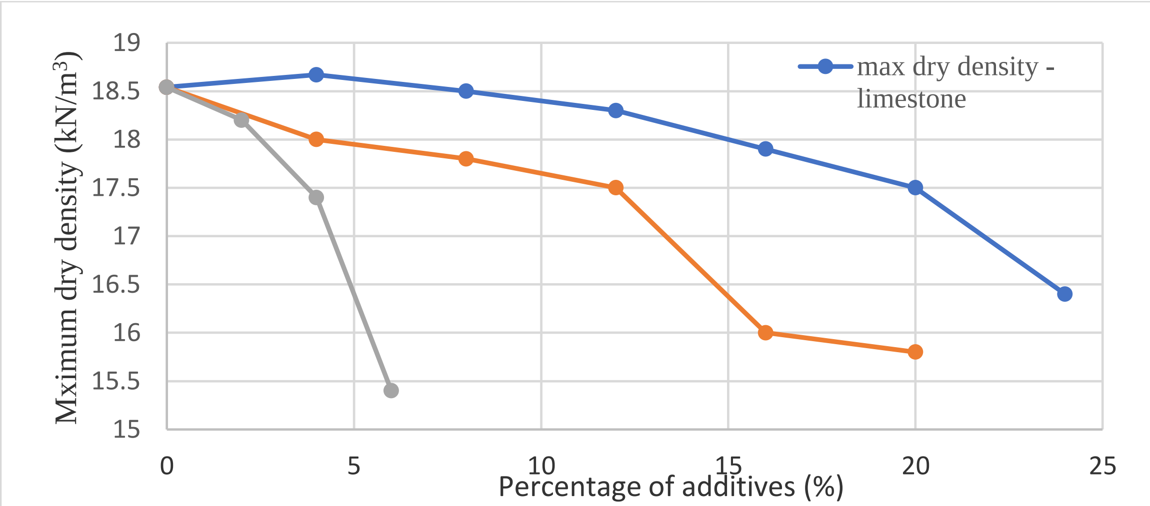

Figure 7. Relation between maximum dry density with percentage for soil with mixing L,ESP or ESA

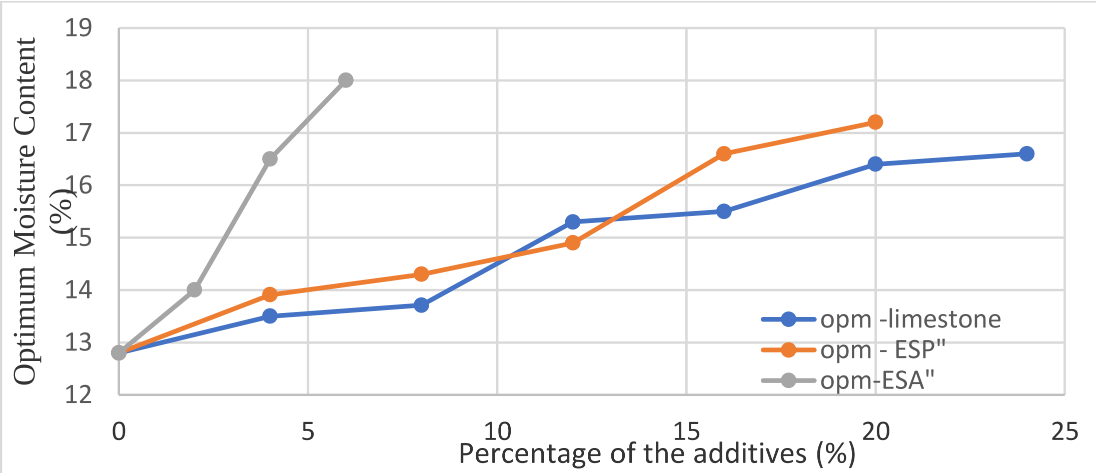

Figure 8. Relation between Optimum Moisture Content with percentage for soil with mixing L, ESP or ESA

Unconfined Compression Test

For testing of unconfined compression test, the triaxal assembly is used as aprocess to calculate the compression pressure. The steps of preparing and testing the samples are similar to unconfined compression test just using for more accuracy. Figure (9) represented the sample in triaxial device. Figure (10) explained the testing triaxial apparatus as a process to determine the unconfined compression pressure. It was noticed an increase in shear strength of about once at 24% L mixing with soil, about twice at 20% ESP with soil, and about four times at 6% ESA mixing with the soil. That means the soil was treated from type normal active to be inactive at mixing (24% L, 20% ESP, 6% ESA) respectively.

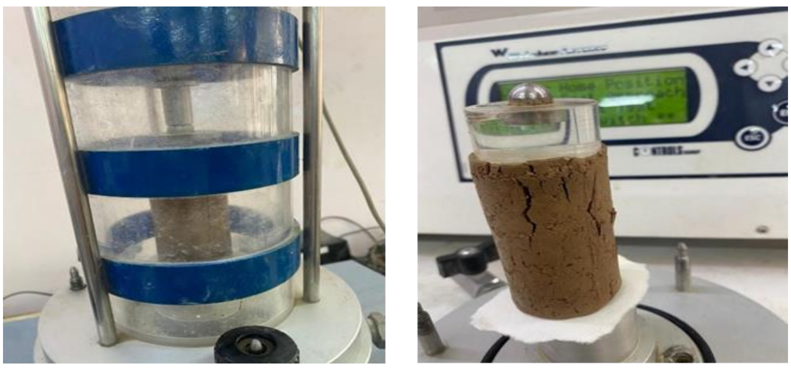

Figure 9. Samples in the triaxail apparatus.

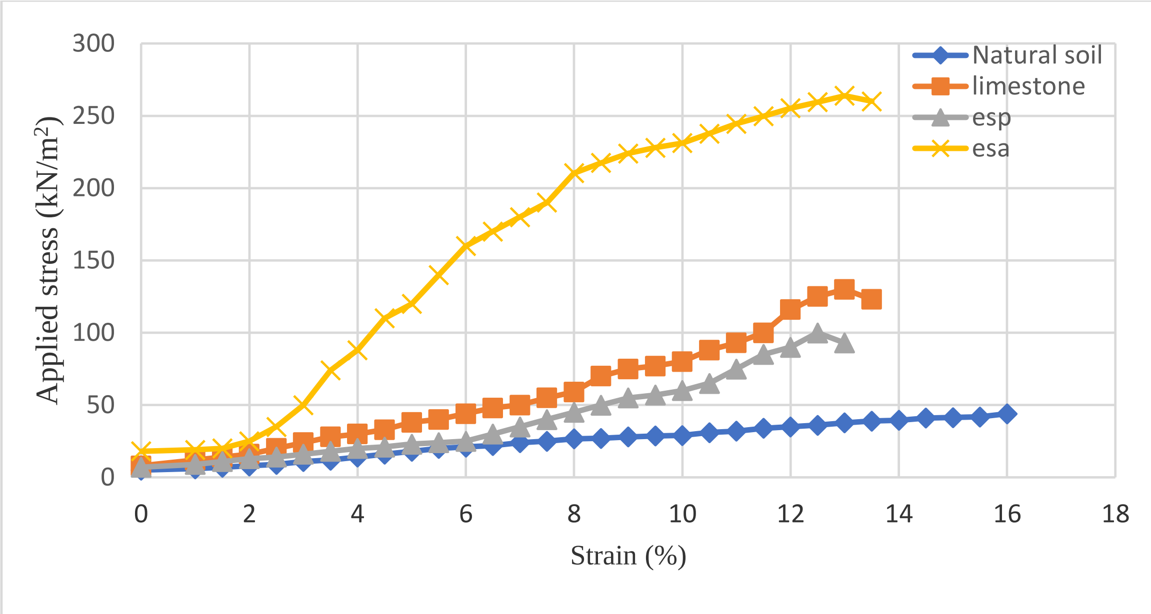

Figure 10. Relation between stress and strain with percentage for soil with mixing L,ESP or ESA

Conclusion

From all results can be concluded that:

The results of tests carried out through this research could indicate that the ideal proportion is 6% eggshell ash. Therefore, the proportions can be reduced by limestone with an increase in eggshell ash proportions in order to reduce the economic cost of a certain project that requires improved soft clay soil by lime, especially in Iraq, where our country is a producer of limestone.

With the addition of L, ESP, and ESA, there is a considerable decrease in Atterberg's Limits, and after 24%, 20%, and 6%, respectively.

With an increase in the percentage of (L, ESP, ESA), OMC rises and maximum dry density falls.

Conflict of interest

The author declare there is no conflict of interest.

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