Study on the Changes in Characteristics of Highly Expansive Soil in Cirebon Due to Addition of Eggshell Powder

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ABSTRACT

Expansive soils, which swell with increased moisture and lose strength compared to their dry state, can cause landslides, structural cracks, and other shrink–swell related issues. Lime treatment is commonly used to mitigate these problems but is unsustainable and leaves a large carbon footprint. As an alternative, eggshell powder (ESP), rich in calcium, is proposed as a stabilizing agent. Soil properties were tested in accordance with ASTM standards. Consistent with Lee and Suedkamp, high-plasticity soil shows no distinct optimum dry density, making it difficult to establish a clear pattern of changes in this property. ESP addition reduces the Atterberg limits and Methylene Blue Value, lowers the swelling potential, and increases the unconfined compressive strength (UCS). The calcium content in ESP decreases the soil's capacity to swell, although the effect appears limited due to remaining organic components. A significant improvement in UCS was observed with 5% ESP at 14 days of curing, increasing strength from 181.87 kPa to 327.49 kPa, while the most notable reduction in swelling potential occurred with 15% ESP at 7 days of curing. However, both UCS and swelling potential showed no consistent trend, likely due to complex interactions of organic materials in ESP that reduce its effectiveness in soil stabilization.

Keywords: Eggshell Powder, Highly Expansive Soil, High Plasticity Soil, Swelling

1. INTRODUCTION

Expansive soil undergoes significant volume changes due to variations in moisture content. Another characteristic of this soil is its high strength in dry conditions, but as the moisture content increases, its shear strength decreases. Expansive soil is highly plastic, shiny when cut with a knife, and has deep shrinkage cracks [5]. The significant volume change due to moisture variations in expansive soil can cause nearby buildings to shift and potentially result in damage. The decrease in shear strength can trigger landslides or collapses, leading to potential losses.

Lime and cement have been used to improve the properties of expansive soil [6]. Although, the total process leaves a significant carbon footprint and therefore is not preferable as sustainable materials [3]. Alternative stabilizator is required, where it should be environmentally friendly while not increasing the cost.

Eggshells are high in calcium content and might be a potential substitute for lime. The use of eggshell powder (ESP) had been previously applied to improve soil properties. Various studies conducted on clay show improvement in its properties [10][11]. Soil stabilized with ESP shows decrease in Liquid Limit value and has increased optimum dry density and shear strength parameter [8].

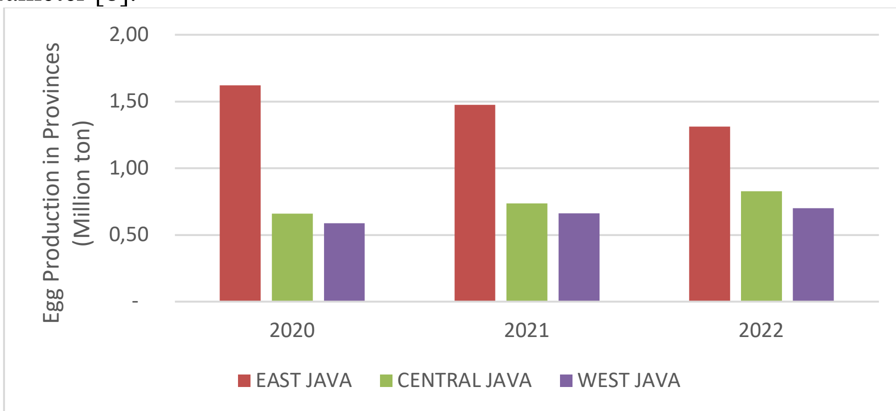


Figure 1. Production of Eggs in Several Province in Indonesia (*bps.go.id*)

In several European countries, eggshell waste has been collected and utilized for various purposes, such as animal feed and industrial applications [4]. In Indonesia, it is observed that eggshells have been collected for limited application, such as fertilizer. As shown in Figure 1, according to data from the Indonesian Central Statistics Agency (*Badan Pusat Statistik*), several provinces show high production rates of eggs, indicating significant potential for collection particularly in regions with a high concentration of food industries, such as East Java. With the implementation of an organized collection system, eggshell waste can be efficiently gathered and utilized across various sectors, including as an alternative material for soil improvement.

2. THEORY AND METHODS

2.1 Expansive Soil

The expansive nature of soil occurs due to the strong attraction between water particles and clay surface, although this attraction decreases with increasing distance. This happens because, first, water is electrostatically attracted to the clay crystals due to its polar nature (having one negative and one positive side). Second, water is bound to the clay crystals by hydrogen bonds (the hydrogen in water is attracted to oxygen or hydroxyl atoms on the surface of the clay crystals). Third, the surface of the clay crystals is negatively charged, which attracts cations in the water [5].

Smectite (including montmorillonite), the most expansive mineral within the clay group, features a 2:1 alumino-silicate layer structure. This structural configuration promotes its formation in silica-rich environments, where silica can flocculate with alumina. The development of smectite is favored under conditions of high pH, elevated electrolyte concentrations, and a predominance of divalent cations (Mg^{2+} and Ca^{2+}) over monovalent cations (Na^{+} and K^{+}) [5]. Furthermore, climatic conditions in which evaporation exceeds precipitation—combined with poor drainage, as commonly found in arid and semi-arid regions—also contribute significantly to smectite development.

2.2 Expansive Soil Properties

The Atterberg limits provide a relationship between soil behavior at specific moisture contents. This allows for the establishment of correlations with the expansive properties of soil, which are also influenced by moisture content. [1], provides the following correlation:

Table 1. Correlation Between Plasticity Index and Expansive Properties [1]

Swelling Potential	Plasticity Index
Low	0 - 15
Medium	10 - 35
High	20 - 55

The Atterberg limits are influenced by the composition and the clay minerals that form the soil. This can be differentiated through the soil's activity, A, which is defined as the ratio of the Plasticity Index to the percentage of clay content. The correlation between activity and types of minerals is shown in the table below.

$$Activity = \frac{Plasticity\ Index}{\% < 2\mu m} \qquad (1)$$

Table 2. Activity of some soil minerals [5]

Mineral	Activity
Na-montmorillonite	4 - 7
Ca-montmorillonite	1.5
Illite	0.5 - 1.3
Kaolinite	0.3 - 0.5
Mica (muscovite)	0.2

2.3 Methylene Blue Test

The Methylene Blue (MB) test utilizes the negative surface charge characteristic of clay minerals, which is also responsible for the attraction of water molecules in expansive soils. In this test, a methylene blue solution is gradually added to a soil suspension, allowing the dye to be adsorbed onto the negatively charged clay particle surfaces. The point of saturation is determined by periodically placing drops of the mixture onto filter paper and observing the formation of blue halos around the central spot. This visual indication reflects the presence of un-adsorbed MB, indicating that the Cation Exchange Capacity (CEC) of the clay has been exceeded. The presence of a light blue halo around the spot indicates that the methylene blue is no longer being absorbed by the soil. Research shows that the methylene blue value correlates with the swelling properties of a soil [12]. The values proposed are as follows

Table 3. Correlation Between Methylene Blue Value and Degree of Expansion [12]

Methylene Blue Value	Degree of Expansion
0-4	Low
4-8	Medium
8-15	High
>15	Very High

2.4 Compaction of High Plasticity Soil

Research by Lee and Suedkamp in 1972 [2][7] demonstrated the existence of four types of compaction curves. These compaction curve patterns are related to the soil's liquid limit. Type A: Bell Shaped (30 < LL < 70); Type B: One and one-half peaks (LL < 30 or LL > 70); Type C: Double peak (LL < 30); Type D: Odd shaped (LL > 70). Generally, expansive soils have high plasticity values, so the resulting compaction curve tends to be odd-shaped. In such graphs, determining the optimum dry weight of compacted soil is challenging.

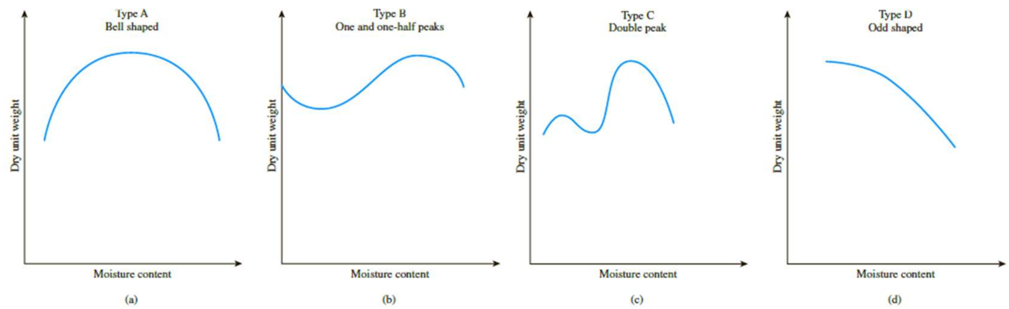


Figure 2. Four types of Compaction Graph [2][7]

2.5 Eggshell

Eggs are commonly consumed worldwide. Eggs are used in both small-scale and large-scale food industries as a basic ingredient for final products, such as packaged foods. However, only the contents of the egg are consumed, while the leftover material, the shell, is generally discarded. In addition to consumption waste, eggshells are also a byproduct of poultry farming. Eggshells contain a high amount of calcium, which may be utilized as an alternative calcium source in various fields.

Approximately 10% of an egg's mass is the eggshell, making the waste generated from egg consumption quite significant. Eggshell waste has already been utilized for various purposes, such as animal feed or industrial applications in Europe [4].

2.6 Standards and Method

This research was conducted in the laboratory to obtain parameters relevant to the behavior of expansive soil. The samples reviewed were from Cirebon, West Java, which indicated high plasticity values and were thus used in this study. Soil samples were acquired as disturbed samples and mobilized to laboratory for test preparation. The following in Figure 3 presents an overview of the research methodology for this research.

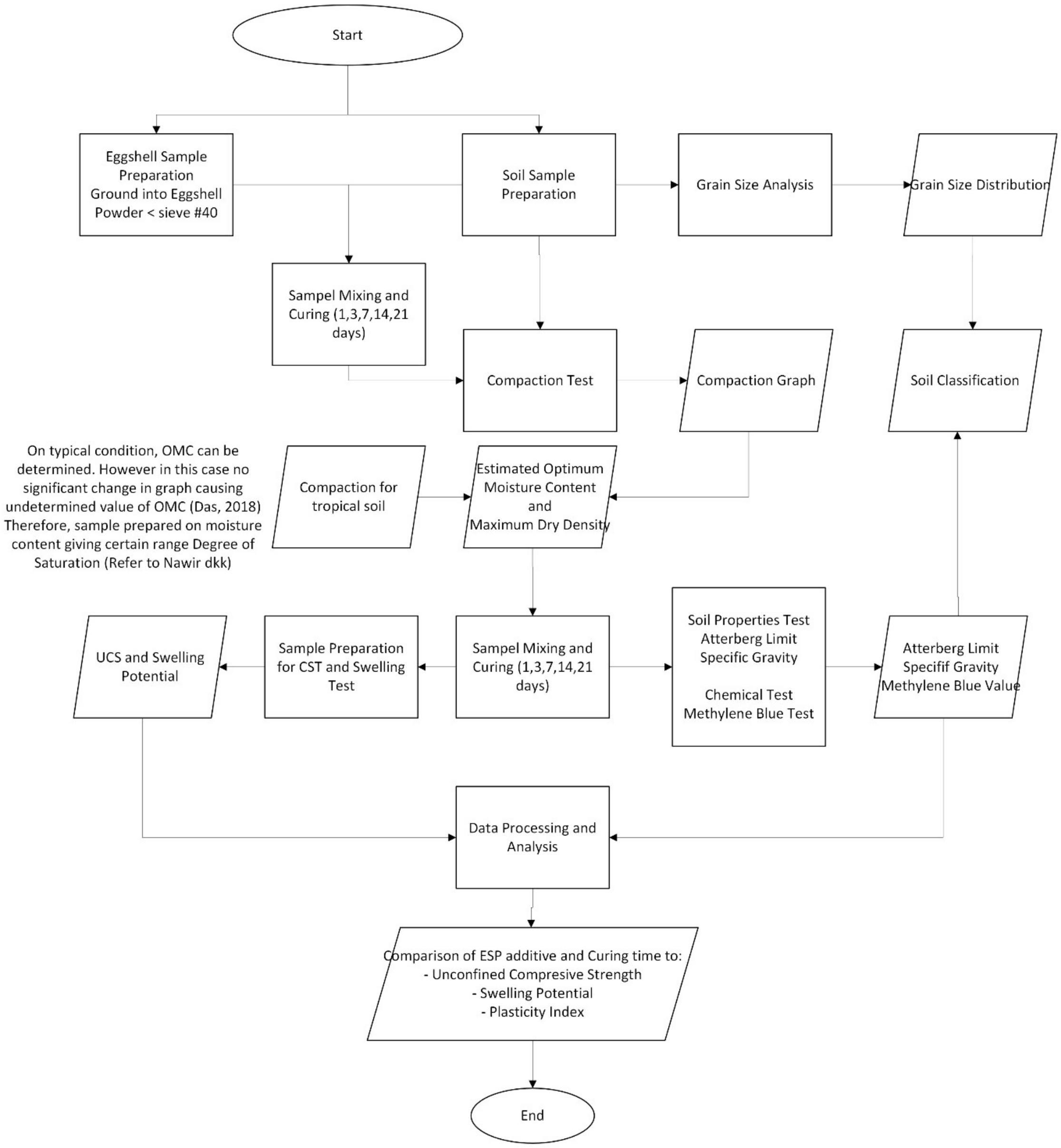


Figure 3. Flow Chart of The Research Methodology

The eggshells were first washed and sun-dried for approximately 7 days. They were then ground into eggshell powder with a size of less than 0.425 mm, equivalent to fine sand. The eggshell powder was mixed with the soil samples for further testing. The soil and eggshell powder mixture was then left to sit for 1, 3, 7, 14, and 21 days in airtight plastic containers to examine the effect of curing time.

The research process adhered to international ASTM standards as follows: Atterberg Limits (ASTM D 4318), Standard Proctor Compaction (ASTM D 689), Unconfined Compression Strength (ASTM D 2166), and 1-Dimensional Swelling Test (ASTM D-4546). For the Methylene Blue test, the standard refers to JBAS-107-91.

Method A of one-dimensional (1D) swelling test was applied in this study to evaluate the swelling potential of the soil. In this method, the soil specimen is submerged in water and permitted to swell vertically under a controlled seating pressure ranging from 1 to 2 kPa. The test continues until primary swelling is completed, allowing for the measurement of the soil's full swelling capacity under minimal confining stress.

3. RESULTS AND DISCUSSION

3.1 The Properties of Highly Expansive Soil

The test results for the samples from Cirebon showed that the soil has very high plasticity. Based on Figure 2, the soil activity value is close to 1, indicating that the dominant mineral component in the soil is probably Illite or montmorillonite. Consistent with the high liquid limit value, the resulting compaction curve is of an odd shape as shown in Figure 4. The swelling potential, determined using Method A in ASTM D4546, indicates very high swelling characteristics.

Table 4. Properties of Cirebon Soil Sample

Grain Size Distribution (%)			**Spesific Gravity (%)**	**Liquid Limit (%)**	**Plastic Limit (%)**	**Plasticity Index (%)**	**Activity (%)**	**MB Value (%)**
Sand	Silt	Clay						
2.51	24.71	72.78	2.77	110.77	31.30	79.47	0.984	26.11

Table 5. Swelling and strength parameter of the soil sample

Swelling Parameters	
Swelling Potential (%)	25.43
Degree of Expansion	Very High
Unconfined Compressive Strength	
Undrained Cohesion (kPa)	181.87

3.2 Changes in Atterberg Limit

The Atterberg limits show a decreasing value, particularly in the liquid limit value. As the amount of eggshell powder in the soil mixture increases, the liquid limit value decreases as well as shown in Figure 5. The pattern of increase over curing time may occur due to the presence of organic content, which makes the soil more acidic and thus reduces the effectiveness of the soil stabilization.

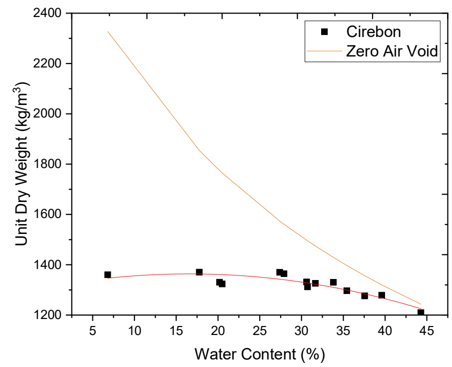
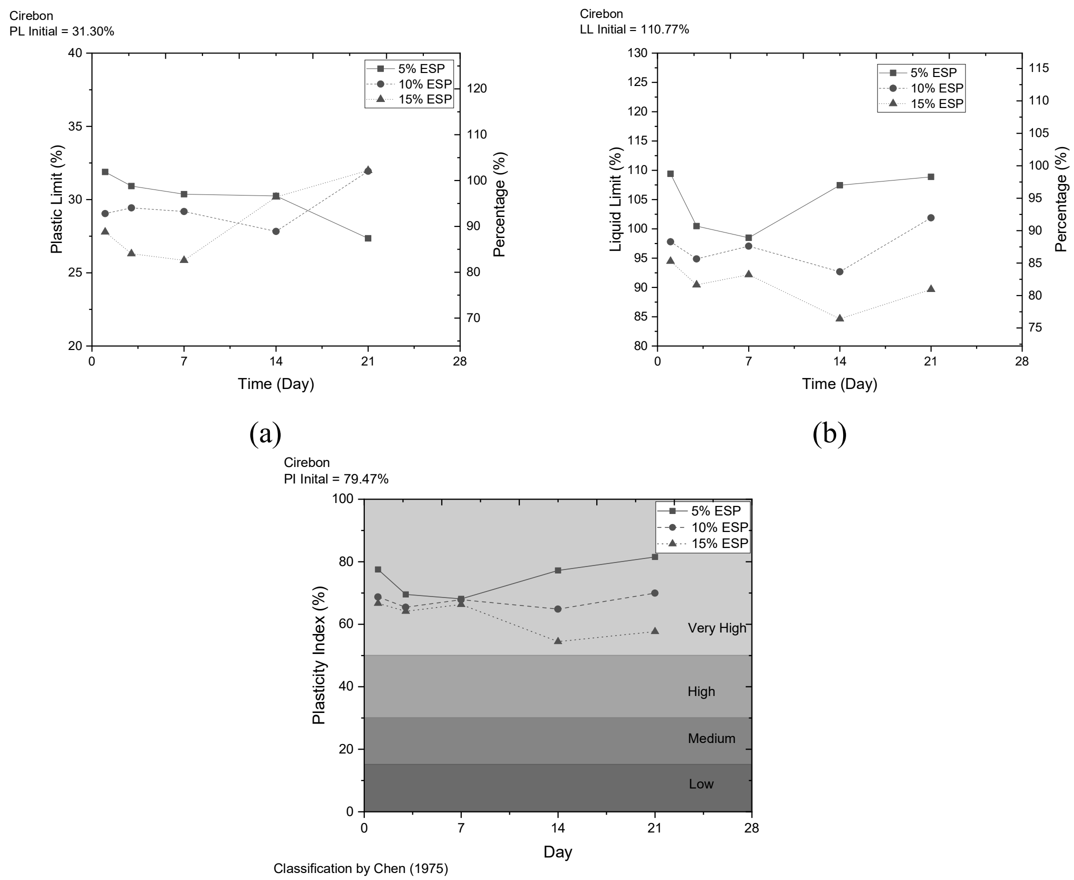


Figure 4. Compaction curve of Cirebon soil sample



(c)

Figure 5. Atterberg limits value after ESP stabilization. (a) Plastic limit, (b) Liquid Limit, and (c) Plasticity Index

3.3 Changes in Methylene Blue Value

The methylene blue value decreases with increasing ESP. This is relevant to the reduction of expansive components in the test samples. No significant changes are observed due to the curing time as shown in Figure 6.

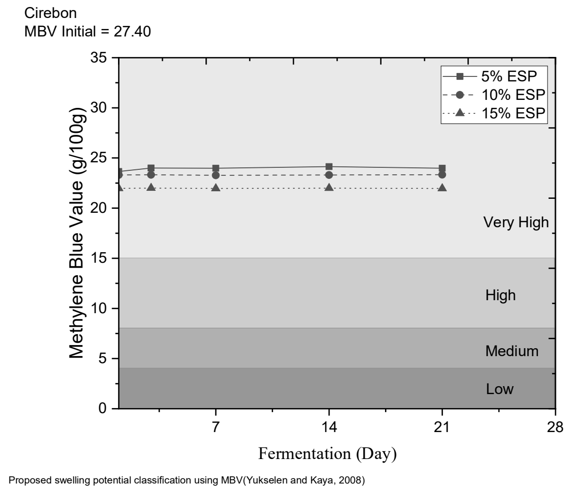


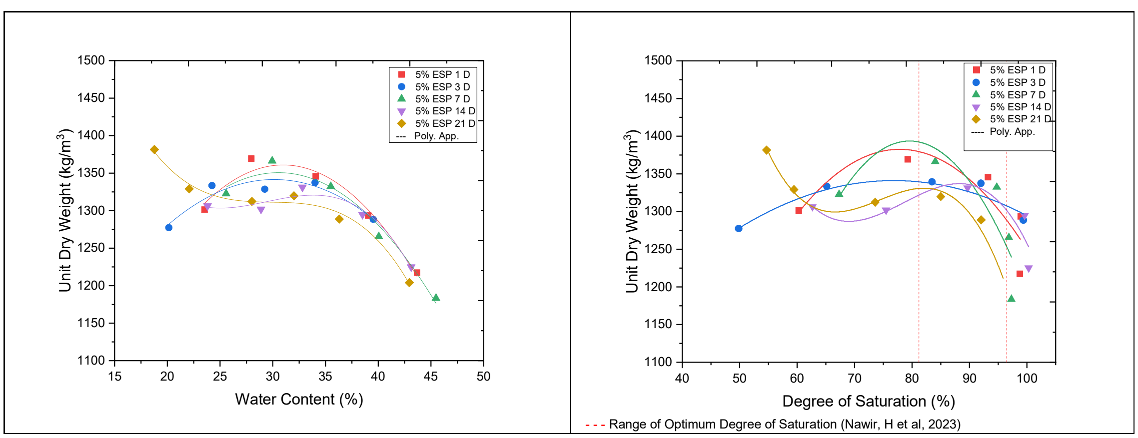
Figure 6. Methylene Blue Value after ESP stabilization

3.4 Compaction Curve of Compacted Expansive Soil Mixed with ESP

According to the trend in Figure 7, the compaction curves of the test samples exhibit an odd shape pattern. This pattern does not show changes with the addition of eggshell powder. Due to this odd shape pattern, the optimum moisture content (OMC) of the compacted soil cannot be determined. A set of experiments [9] on soils in tropical regions indicates a range of saturation degrees that would provide the optimum dry density. In this study, swelling potential and unconfined compressive strength tests were conducted within this range.

3.5 Unconfined Compression Strength and Swelling Potential of Compacted Expansive soil mixed with ESP

The UCS values show a less regular pattern at short curing times, but over longer curing periods, higher ESP levels result in poorer strength quality as shown in Figure 8. As the proportion of organic components from ESP increases with higher mass addition, the long-term effectiveness of soil stabilization tends to decline.



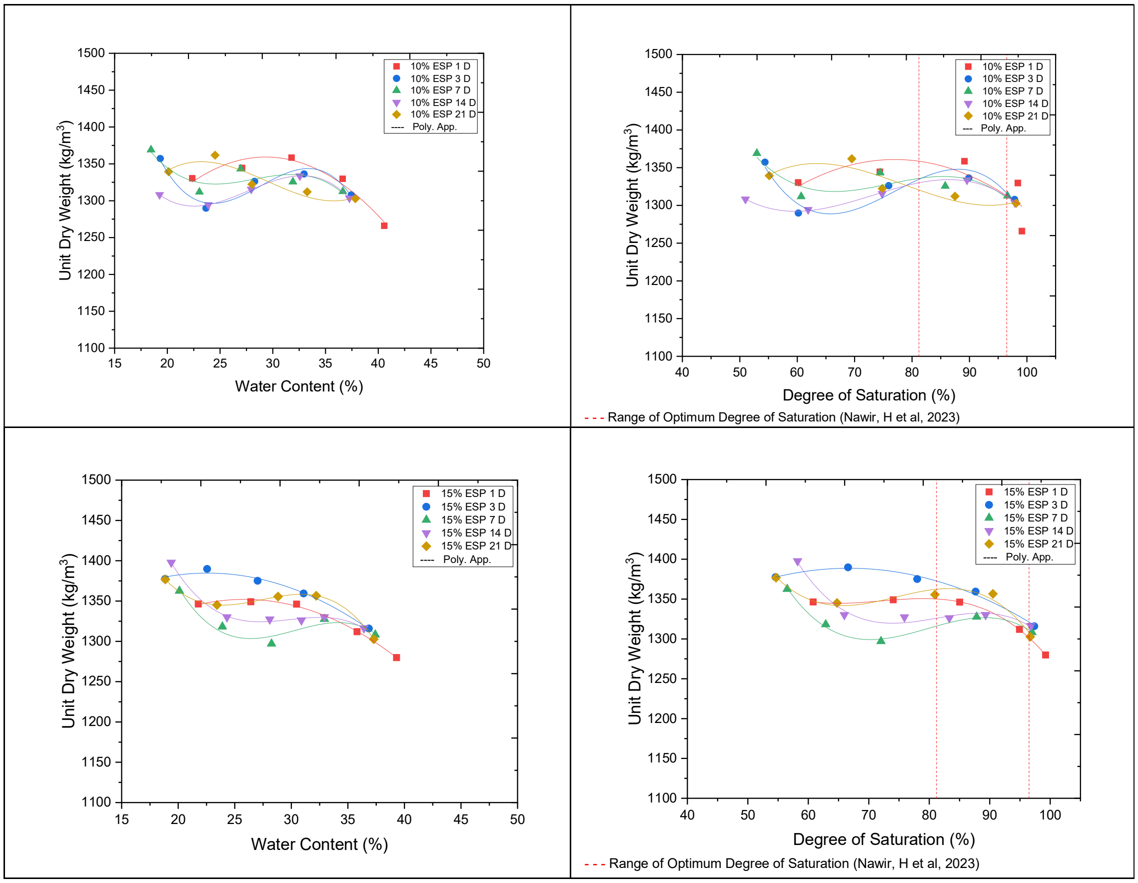


Figure 7. Compaction curve after ESP stabilization

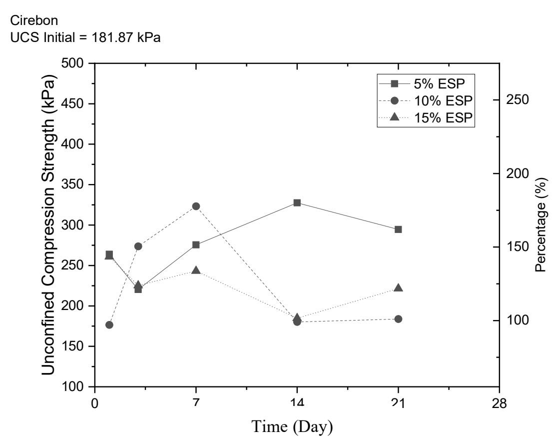


Figure 8. UCS value after ESP stabilization

The swelling potential tends to decrease with increasing amounts of ESP, and longer curing times also improve stabilization quality. Over the long term, the bonds between ESP and the soil samples appear to strengthen, thereby reducing swelling potential. Unlike the improvement in compressive strength, organic components do not have a detrimental impact on swelling behavior in the long term.

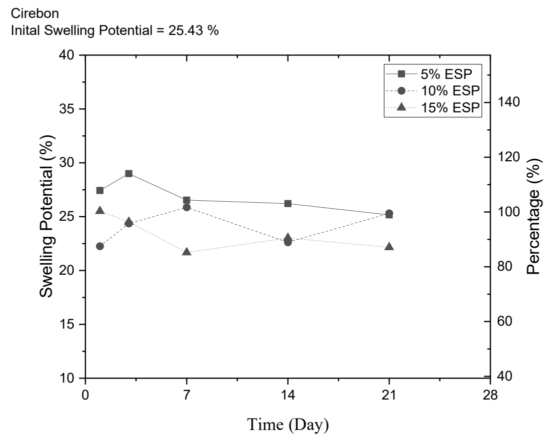


Figure 9. Swelling Potential after ESP stabilization

4. CONCLUSIONS

The tests conducted indicate that a decrease in Atterberg limits corresponds to a potential reduction in the expansive properties of the soil with increasing ESP levels. Similarly, a decrease in the methylene blue value shows that the water absorption capacity of expansive soil has been reduced, corresponding to the increased addition of the stabilizing agent. Expansive soils exhibit an irregular-shaped compaction curve, complicating the determination of the optimum moisture content; however, the addition of eggshell powder does not significantly alter the shape of this curve. The unconfined compressive strength (UCS) results do not exhibit a consistent trend, which may be attributed to complex interactions involved in the stabilization process, including soil expansion behavior, changes in soil pH due to the presence of organic matter, and irregular variations in test moisture content. The most significant UCS result shows an increase in strength from 181.87 kPa to 327.49 kPa with the addition of 5% ESP at 14 days of curing. Expansivity of the soil generally decreases with increasing ESP content, although the measured changes are relatively minor, with the most significant reduction occurring with the addition of 15% ESP at 7 days of curing; the complexity of the relationship with organic material may have reduced the effectiveness of ESP. Overall, the use of eggshell powder as a stabilizer for highly expansive soils appears to be ineffective, and future research should consider evaluating its performance on soils with lower expansivity and/or in combination with other stabilizing materials to enhance its effectiveness.

5. ACKNOWLEDGEMENTS

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