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Using Sea Shell, Lime and Zeolite as Additives in the Stabilization of Expansive Soils

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ABSTRACT

Swelling soils are increasingly recognized as a critical issue in geotechnical engineering, as their presence can lead to substantial damage to built structures. When structures are built on such soils and free swelling is prevented, stresses can develop that may lead to significant damage to the structure. Soil stabilization through the use of additive materials has garnered considerable attention as an effective method for mitigating this problem. The objective of this study was to stabilize the clay soil (CH) with high swelling potential by using sea shell, lime and zeolite additives in two stages. In the initial phase, consistency limits were tested by mixing high plasticity clay soil mixed with 8-10-12-14-16% sea shell 0-3-5-6-8% lime (one of the most used soil stabilizer) and 0-5-10-15-20% zeolite by weight. The three mixtures and the two best percentages determined for each mixture were then combined. Upon completing these steps, five experimental sets were prepared by combining the percentages that yielded the best results. Compaction test, percent swelling test and swelling pressure tests were performed with these datas. According to the test results, adding 14% sea shell, 6% lime and 5% zeolite by weight (SS14L6Z5) gave the smallest swelling value as 1,07% and highes swelling pressure as 23 kPa. This study concludes that the combined use of these additives led to a substantial 96% increase in swelling pressure, along with a marked reduction in swelling potential.

Keywords: Swelling soils, soil stabilization, swelling pressure, swelling percentage, seashell, lime, zeolite.

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1. INTRODUCTION

Expansive soils pose a significant challenge in numerous regions, particularly in countries characterized by arid and semi-arid climates. Inyang et al. argue that the shrink-swell performance of soils with wide moisture ranges, especially at low ground pressures and on large surface areas such as airports, accounts for more than half of the soil-related damage to structure [1].

The swelling mechanism in soils is typically categorized into two zones: interparticle or intercrystalline. In the interparticle zone, when clay is wetted, capillary tensions decrease causing the clay to swell. Intercrystalline swelling occurs in clays with weak bonds such as montmorillonite [2]. The study by El-Sohby and Mazen [3] claimed that mineralogical properties of clay also have a significant effect on swelling. Studies have shown (e.g., [4]) that the swelling percentage and capacity increase with added bentonite, while the swelling decreases as the water content of the mixture increases. During the swelling process, the soils volume expands, exerting high pressures on surrounding structures [4].

Various methods have been introduced to improve the geotechnical properties of such soils, [3] including mechanical and chemical stabilization. The purpose of mechanical stabilization is to convert two or more soils into a soil that meets the desired conditions by mixing them in appropriate proportions. This technique typically involves mixing coarse-grained soils with fine-grained soils. The earliest examples of this method can be seen on the roads of ancient Babylon and Rome [6, 7]. Stabilization of soil with additives is one of the oldest processes in geotechnical engineering. Type of chemical soil stabilization is a process by which several materials are added to soil to make better its engineering properties [10]. These materials enter between the grains of the soil, altering their chemical properties and resulting in the formation of a new soil with a different structure.

The effects of different materials, such as lime, fly ash, cement, which are known to be primarily effective in stabilizing expansive soils, have been the subject of investigation for a long time (e.g., [8, 9, 10, 11, 12]). Additionally, the use of eco-friendly additives is sensible approach for stabilizing expansive soils, as it conduce a sustainable and economic solution [13, 14] taken to safeguard the interest of natural environment [8].

Lime is the oldest traditional stabilizer used for soil stabilization [15, 5] and is employed to increase the bearing capacity of soil in various structures, such as airports, railway, and foundation bases [16, 17, 14]. The cations present in lime facilitate the agglomeration of clay particles by reducing the surface area and water absorption capacity of the soil sample [8]. Chandran and Soman [18] conducted a series of parametric studies on stabilizing swelling clays with lime and demonstrated that this method is a cost-effective method that can be used effectively to reduce the swelling problem. To stabilize a highly plastic clay soil, Özkan and Yenginar [32] used filter sludge, a waste material from the sugar industry. They observed that as the amount of filter sludge added to the soil increased, the plastic limit and optimum water content increased, while the liquid limit, plasticity index and maximum dry density decreased. Notably, when 15% sludge was incorporated into the samples, swelling decreased by 52,5%. Furthermore, this improvement was found to be positively correlated with curing time.

However, despite the important advantages of lime, certain disadvantages exist. Lime may lead to increased infiltration and swelling of untreated layers due to its higher hydraulic conductivity [1]. For this reason, alternative solutions have been sought alongside lime. Taşçı [19] aimed to improve the engineering properties of a dispersive clay with high swelling potential by incorporating silica fume in addition to lime additive. By adding 3% lime and 10% silica fume to the sample, the swelling pressure was reduced by 95%. This study achieved significant improvement and contributed to the introduction of low-cost, optimal additives to the literature. Indiramma, Sudharani, and Needhidasan [8] used fly ash and lime, which are frequently preferred additives for stabilization, in their experimental studies. The free swelling index was initially 142%, but it decreased to 72% with 8% lime additives and to 70% with a combination of 10% fly ash and 8% lime additives.

To improve a soil sample with high dispersibility, Öztürk and Türköz [28] employed silica fume (SF) as an admixture. The standard Proctor test was conducted to determine the compressive properties of soil samples mixed with varying ratios of SF (0, 5, 10, 15, 20, 25, and 30 percent). In addition, the strength parameters of the samples were measured using unconsolidated undrained triaxial (UU) tests. The results of this experimental study indicated that silica fume is effective in stabilizing dispersive soils. Furthermore, significant increases in strength were observed as a function of curing time, attributed to the high silica content of silica fume.

Although there has been tremendous research such as lime and cement stabilization globally, the investigation of the effect of local materials, such as seashells, on soil stabilization should be expanded. Seashells, which are biomaterials containing approximately 90% calcium carbonate by weight, exhibit properties similar to those of lime. Mounika, Narayana, Manohar and Vardhan [20] aimed to stabilize the clay with high swelling potential by using varying percentages of seashell in their experimental study. The best results were obtained with 16% seashell additive. Similarly, Patel and Mishra [21] sought to enhance the properties of infrastructure soil by incorporating seashell powder, adding 12%, 15%, and 18% seashell by weight to the soil. They determined that a 15% seashell contribution to the infrastructure soil gave positive results.

One of the additives used for stabilization is zeolite. Components such as silicon oxides, particularly aluminum, make zeolite an effective type of pozzolanic material due to its high cation exchange capacity [22, 23]. Turkoz and Vural [24] claimed that the addition of clinoptilolite zeolite that is the type of zeolite used in most of the aforementioned research, increased the unconfined compressive strength of cement- stabilized clayey soil. Sharo, Shaqour, and Ayyad [23] observed a reduction in swell potential from 6,9% to 4,9% with the addition of 15% zeolite and 10% cement kiln dust.

Recent studies have increasingly focused on the application of chemical additives for soil stabilization, extending beyond traditional natural additives. GuhaRay, Syed, and Kar [14] demonstrated in their work that the addition of 10% and 15% alkali-activated binder (AAB) resulted in a reduction of swell percentage by 62% and 70%, respectively. AAB has been found to behave like a helpful cement binder with higher functionality performance with low ecological damage [25]. Lu, She, Duan, Yao, and Liu [26], in his article, transformed the soil into an almost non-swelling soil by using the Al/soil ratio above 0,10 mmol/g. They noted that this transformation was attributed to increased flocculation of soil particles, facilitated by the exchangeable cations between Al_{13} and the swelling soil. The treatment of expansive soil with the addition of Al_{13} shows greater potential durability than traditional stabilizers.

However, it is important to note that the presence of aluminum in PHA solutions may lead to aluminum toxicity, posing risks to living organisms.

Özkan and Çokça [29] reported that lime diffuses slowly into clay soil due to its low porosity. Thus, their study incorporated sodium lignosulphonate, a plasticiser commonly used in the concrete industry, into lime columns to enhance the diffusion of lime particles. These columns were filled with two different mixtures: water-lime and water-lime-sodium lignosulphonate, to investigate the effect of the addition of sodium lignosulphonate. Free swelling and compressive strength tests were carried out on undisturbed expansive clay samples obtained from the space between the columns. The experimental study revealed that the treated expansive clay samples placed between the lime columns containing sodium lignosulphonate had higher compressive strength than the untreated expansive clay samples. Consequently, it was found that adding sodium into lime columns yielded improved performance for the treatment of expansive clays compared to lime columns alone. Ertuğrul and Canoğulları [30] systematically reviewed the results of previous mechanical tests on fibre-cohesive soil mixtures. The results showed that the shear strength of the reinforced soil increased with the fibre content and that the consolidation settlement of clay soil mixed with polypropylene fibres decreased significantly.

In recent years, researchers have increasingly focused on the use of technology in soil improvement practices Narmandakh, Butscher, Ardejani, Yang, Nagel, and Taherdangkoo [31] to determine the swell potential of natural and artificial clay soils, it has developed advanced feed- and step-based neural network models trained using Levenberg-Marquardt and Bayesian optimization algorithms. The swelling potential experimental datasets collected from literature to develop network models were compared with empirical and semi-empirical correlations. The analysis revealed that the predictive performance of the Levenberg-Marquardt-trained feedforward neural network was satisfactory, demonstrating an acceptable fit to the experimental data.

Most studies on soil stabilization have not adequately addressed the effects of using seashells in combination with other additives (e.g., [20, 21, 27]).

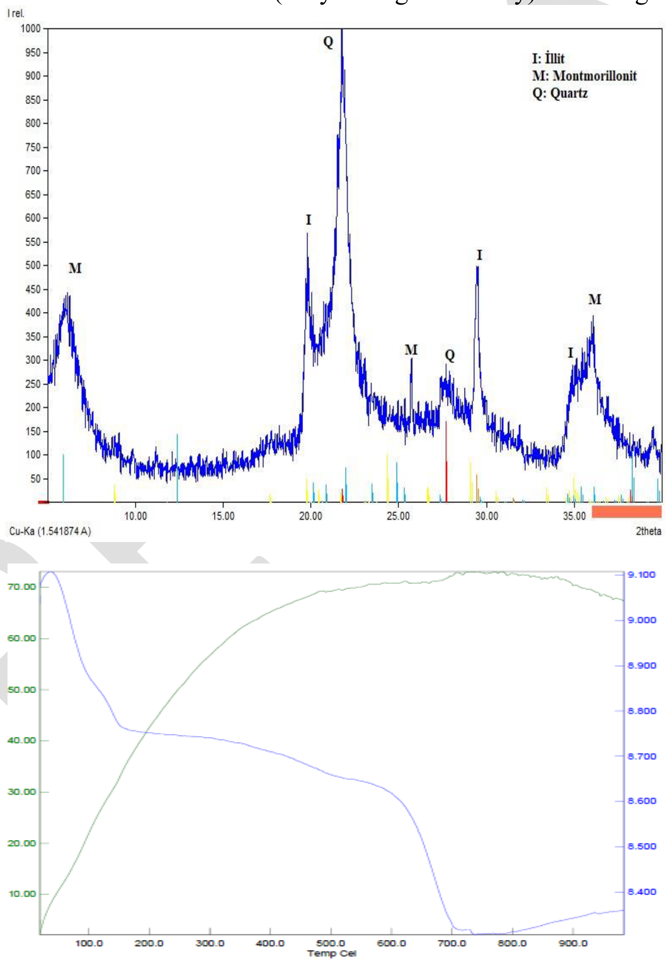
The present study aims to determine the optimal additive ratios that result in the best performance by examining changes in geotechnical properties such as consistency limits, compaction, and swelling potential. This will be achieved using lime, seashell, and zeolite as source materials, sourced from the Denizbükü District of Ünye in Ordu province. The study introduces an innovative approach to utilizing seashells, a waste material, in combination with naturally available lime and zeolite. This strategy not only aids in preventing environmental pollution but also contributes economic value by strengthening the country's economy. Seashells, which form the exoskeleton of molluscs and are collected near the coast, contain up to 90% calcium carbonate, making them similar to lime in composition. Cause of seashells have properties akin to lime, they were chosen as an additive material and used in higher proportions than lime by weight to avoid the need for large amounts of lime. This decision was made in light of evidence indicating that lime can be detrimental to human health and may not be compatible with all types of clay [33]. The aim is to use shells as an alternative to lime and the use of zeolite will be a replacement for the cement additive.

Furthermore, this study combines widely recognized materials such as zeolite and lime, which have previously yielded positive results in research, with seashells, which have also demonstrated efficacy when used independently. The chemical reactions that take place when these materials are used together have almost the same results as lime and cement additives; however, the damage to human health in comparison to lime and cement has not yet been clarified. This research examines the combined use of these materials on swelling soil as a new approach.

2. MATERIALS AND METHODS

2.1. Soil

The soil sample used in the study was collected as a disturbed sample from a depth of 1,5 meters from the Yazlak locality area of Denizbükü Neighborhood, within the Ünye district of Ordu. The soil is classified as CH (Clay of High Plasticity) according to the Unified Soil



(a)

(b)

Figure 1 - Mineralogy properties of the soil: (a) X-ray diffraction result (b) Differential thermal analysis result

Classification System (USCS) and as A-7-5 based on the American Association of State Highway and Transportation Officials (AASHTO) classification system, based on consistency limits and particle size distribution results. Soil samples brought to the laboratory were first left to dry in air and then dried in an oven according to the conditions of the experiments to be applied. The index geotechnical characteristics of the soil are shown in Table 1. Differential thermal analysis (DTA) and X-ray diffraction (XRD) analysis were performed to make the mineralogical description of clays. The results of XRD analysis indicated that the main clay mineral of the soil sample is “montmorillonite” and the other contents are illite and mixed clay mineral as shown in Figure 1(a). The DTA technique was used to identify peaks in the curve drawn by the temperature differences resulting from phase changes and chemical reactions. This analysis confirmed that the primary mineral is "montmorillonite," while illite and mixed clay minerals also identified, as illustrated in Figure 1(b).

Table 1 - Physical and Index Properties of the Soil Sample

Properties	Quantity	Standart
Grain Size Distribution		
(a) Sand (%)	32	ASTM D422 (2007)
(b) Silt (%)	39	ASTM D422 (2007)
(c) Clay (%)	29	ASTM D422 (2007)
Specific gravity (g/cm^3)	2,625	ASTM D857 (2014)
Liquid Limit (%)	143,6	ASTM D4318 (2017)
Plastic Limit (%)	38,8	ASTM D4318 (2017)
Plasticity Index (%)	104,8	ASTM D4318 (2017)
USCS	CH	ASTM D2487 (2017)
Maximum Dry Density (g/cm3)	1,23	ASTM D698 (2012)
Optimum Moisture Content (%)	37,4	ASTM D698 (2012)
Unconfined Compressive Streght (kPa)	327,17	ASTM D2166 (2016)
Swelling Percentage (%)	62,17	ASTM D4546 (2021)
Swelling Pressure (kPa)	580	ASTM D4546 (2021)

Table 2 - Physical properties of zeolite

Parameters	Value
Powder Density	1,42 g/cm^2
Solid Density	2,143 g/cm^2
Spill Density	0,54 g/cm^2
Hardness	3,5 – 4,0 mohs
Specific Surface	14,500 cm/g
Colour	Ivory
Fluidization Temperature	1506 C°

2.2. Stabilizers

Within the scope of this study, seashells obtained from the Black Sea coasts in Trabzon were brought to the laboratory. Following collection, the seashells were washed and allowed to dry for 24 hours at 105°C in a furnace. Subsequently, they were ground using a mill to achieve a final weight of 1209,7 g, rendering them suitable for use in the experiments.

The zeolite used in this work is provided from Leonardit Bio Market, and the properties taken from the laboratory testing are furnished in Tables 2 and 3. CL 80 S slaked powder calcium lime was purchased from Barkisan Lime Factory. The particle size distribution of all materials is illustrated in Figure 2.

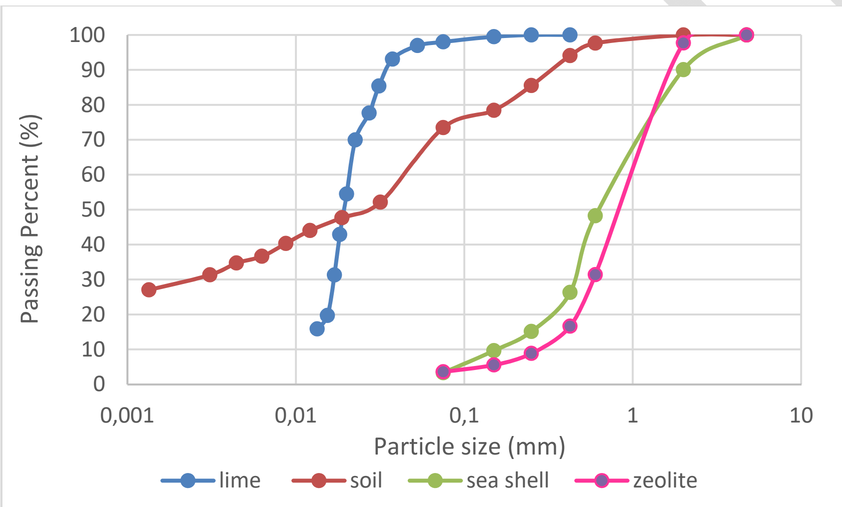


Figure 2 - Particle size distribution of the studied materials

Table 3 - Chemical Properties of zeolite

Parameters	**% by Mass**
SiO_2	69,2
Al_2O_3	10,81
TiO_2	0,08
Fe_2O_3	1,18
Na_2O	0,367
K_2O	2,78
CaO	2,98
MgO	1,48
P_2O_3	0,021
SO_2	0,036
Dry Matter (1500 C°)	10,21
Ph	7,0

2.3. Method

The laboratory experiments were carried out in two stages. In the first stage, liquid limit and plastic limit tests, which provide important information in the evaluation of the swelling potential of the soil, were carried out in relevance with the ASTM D4318 (2017) standard. In the stabilization of the high plasticity natural material, mixtures containing by weight 8, 10, 12, 14, 16% sea shell, 0, 3, 5, 6, 8% percent lime and 0, 5, 10, 15 and 20% percent zeolite were prepared (Table 5). The experimental studies conducted as part of this research were executed in two stages utilizing the optimization technique known as the Taguchi method. This method involves creating an orthogonal matrix based on the selected factors and levels, with the resulting experimental sets serving as a reference. The primary objective is to predict a greater number of experimental outcomes from a reduced set of experiments. The experimental sets employed in the Taguchi design were generated using an orthogonal array. The optimal five additive percentages, identified from the literature review, were designated as levels, while the three additive materials selected for use were defined as factors.

Following the soil mechanics experiments conducted to ascertain the mechanical and physical properties of the natural material, consistency limit experiments were performed to assess the swelling behavior of the soil. These experiments were carried out separately for 16 combination ratios using the Taguchi method, as outlined by the orthogonal matrix (L16). The data obtained from these experiments were subsequently analyzed using the Taguchi method, leading to the selection of the two percentages that yielded the best results for each additive based on the program's output. Thus, the first stage was completed. In the second stage of the study, these percentages were reassessed as five experimental sets according to the Taguchi analysis program. Compaction tests, swelling percentage assessments, and swelling pressure experiments were conducted for the five determined combination ratios. The plastic limit (PL) tests were performed using the material prepared for the liquid limit (LL) tests, with all experiments conducted at room temperature. The results indicated that the optimal seashell content ranged from 12% to 14% by weight, while the optimal lime content ranged from 5% to 6% by weight. For zeolite, the best results were obtained with an additive ratio of 5% to 10% by weight. Furthermore, the three mixtures, along with the two best percentages identified for each mixture, were combined. According to the combination result, 5 experimental sets were determined and mixture combinations were made to determine the behavior of these mixtures when used together (Table 4).

Table 4 - Mixtures used for stabilized soil.

Soil mixture	**Symbol**	**Percentage**			
		Seashell	**Lime**	**Zeolite**	**Soil**
12% Seashell + 6% Lime + 10% Zeolite	SS12L6Z10	12	6	10	72
14% Seashell + 6% Lime + 5% Zeolite	SS14L6Z5	14	6	5	75
12% Seashell + 5% Lime + 5% Zeolite	SS12L5Z5	12	5	5	78
14% Seashell + 5% Lime + 10% Zeolite	SS14L5Z10	14	5	10	71
14% Seashell + 6% Lime + 10% Zeolite	SS14L6Z10	14	6	10	70

When these abbreviations are classified;

In the expression that SS (1) L (2) Z (3)

S: soil, S; shell, L; lime, Z; zeolite and

(1); Percentage of seashell by dry weight in the total sample.

(2); Percentage of lime by dry weight in the total sample

(3); The percentage of zeolite by dry weight in the total sample are symbolized.

Table 5 - Only mixtures used for stabilized soil.

Soil mixture	**Symbol**	**Additive percentace**	**Soil percentace**
100% soil	S	0	100
8% seashell	SS8	8	92
10% seashell	SS10	10	90
12% seashell	SS12	12	88
14% seashell	SS14	14	86
16% seashell	SS16	16	82
3% lime	SL3	3	97
5% lime	SL5	5	95
6% lime	SL6	6	94
8% lime	SL8	8	92
5% zeolite	SZ5	5	95
10% zeolite	SZ10	10	90
15% zeolite	SZ15	15	85
20% zeolite	SZ20	20	80

In the second stage of the study, five experimental sets were prepared by combining the percentages that gave the best results. Compaction, swelling percentace and swelling pressure tests were performed for these five determined combination ratios. The Standard Proctor Test was carried out in accordance with ASTM D698 (2012).

To determine the swelling parameters of the mixture samples, experiments were carried out in accordance with the ASTM D4546 (2021) Standard. After a curing period of one day, the samples were placed in a conventional oedometer and subjected to swelling under a surcharge load of 1 kPa. Test data were taken and recorded during the experiment. Upon completion of the swelling process, vertical pressures were applied until the samples returned to their initial height. The pressure necessary for the samples to revert to their original height was recorded as the swelling pressure.

3. RESULTS AND DISCUSSION

3.1. Atterberg's Limits

Liquid limit (LL) and plastic limit (PL) tests were performed on different percentages of seashell (8%, 10%, 12%, 14%, 16% by dry weight of the soil), lime (3%, 5%, 6%, 8%) and zeolite (5%, 10%, 15%, 20%). The effects of additive ratios on consistency limits are shown in Figure 3, 4, and 5. In addition, LL and PL experiments results shown in Table 6 for the combination of additive percentages.

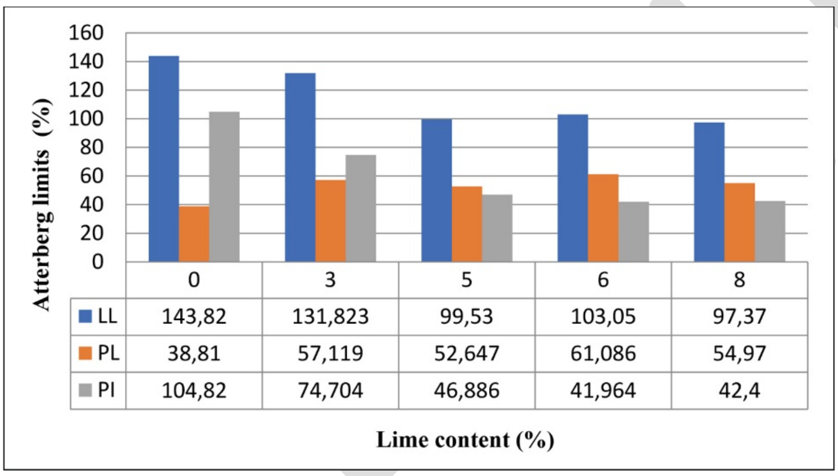


Figure 3 - Atterberg limits of natural soil-lime mixture

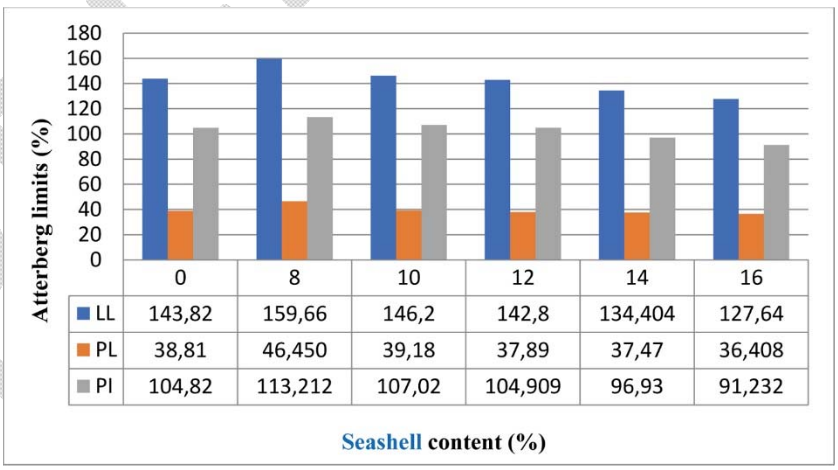


Figure 4 - Atterberg limits of natural soil-seashell mixture

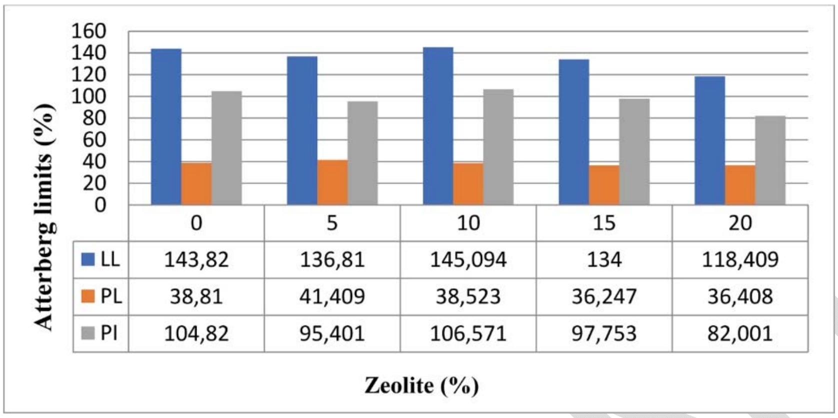


Figure 5 - Atterberg limits of natural soil-zeolite mixture

Table 6 - Results of Atterberg limits of mixtures

Soil mixture	LL	PL	PI
SS12L6Z10	82,32	57,56	24,73
SS14L6Z5	88,34	58,69	29,65
SS12L5Z5	83,74	36,25	47,49
SS14L5Z10	79,59	52,37	27,22
SS14L6Z10	74,45	49,21	25,24

3.2. Compaction Test

The compaction test was used to determine the impact of stabilizers on optimum water content and maximum dry density of the expansive soil. Mixtures were prepared according to five test sets and Standard Proctor test was performed in accordance with ASTM D698 (2012). Before starting the experiment, the water content of the soil and additives that were left to dry in the air was calculated. The water content calculated on the material mixture percentages was added and mixed by weight at the determined ratios. The compaction test commenced with the addition of approximately 20% water content to the air-dried soil sample, followed by incremental increases of approximately 3% in water content during subsequent stages. The compaction curves obtained at the end of the experiments are given in Figure 6. The minimum increase in maximum dry density and the minimum decrease in optimum water content were observed in SS12L5Z5 mixture. For all other mixtures, decreases in optimum water content (w_{opt}) and increases in maximum dry density were observed. The optimum water content for all mixtures was between 32%- 37% and the maximum dry density ranged between 1,27-1,31 kN / m^3. All additives reduced the optimum water content of the soil. Additionally, the results of the LL and PL experiments for the combinations of additive percentages are presented in Table 6.

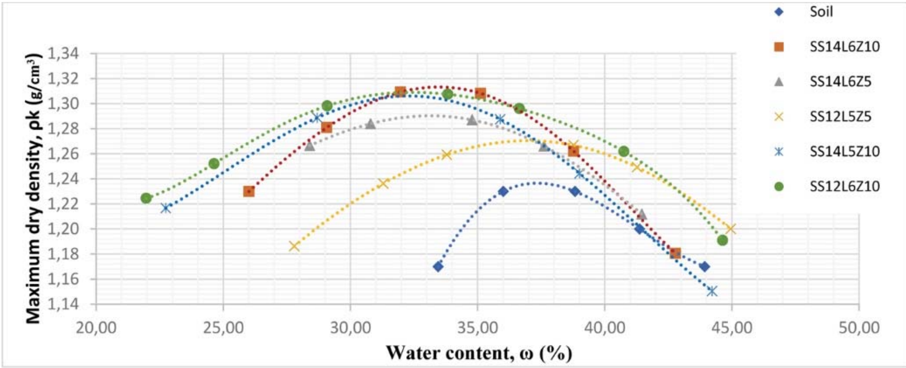


Figure 6 - Compaction curves of mixtures

3.3. Swelling Percent and Swelling Pressure Test

Accurately determining the swelling behavior of soils is crucial in geotechnical engineering, as damage is often inevitable in light structures built on expansive soils without proper precautions. Swelling behavior can sometimes occur not only with the change of water contens in the environment, but also with the decrease of the current load exposed to the ground over time. Therefore, to assess the swelling potential of a construction site, it is essential to carefully evaluate parameters such as the swelling percentage and swelling pressure during the project's planning phase.

In this study, swelling properties were determined in accordance with ASTM D4546 (2021) Standard. Samples prepared at the rates indicated in Table 5, were compressed with optimum water content and maximum dry unit weight. After a one-day curing period, the samples were allowed to swell under an surcharge load of 1 kPa in a conventional oedometer.

Measurements were taken and recorded during the experiment. After the swelling was completed, vertical pressures of 5, 10, 15, 20, 40, 80, kPa etc. were applied until the samples reached the initial height value. The pressure that allowed the samples to return to their initial height was recorded as the swelling pressure. The results obtained from the swelling pressure and swelling percentage experiments are given in Figure 7 and 8. As the amount of additive increased, a prominent reduce in swelling percentage and swelling pressure values was observed. This indicates that the combined application of seashell, zeolite, and lime effectively mitigates the swelling potential of clay soils.

The addition of 12% seashell, 6% lime, and 10% zeolite to the natural soil sample resulted in an 87% reduction in the swelling percentage, while the swelling pressure remained relatively stable. This is likely because the specified proportions of additives increased the strength of the treated soil, preventing vertical displacement. In a mixture with 12% seashell, 5% lime, and 5% zeolite, the swelling pressure was reduced by 88%, while the swelling percentage decreased by 98% compared to the untreated soil. Thus, the combination of 12% seashell, 5% lime, and 5% zeolite is sufficient to improve the swelling potential of the soil.

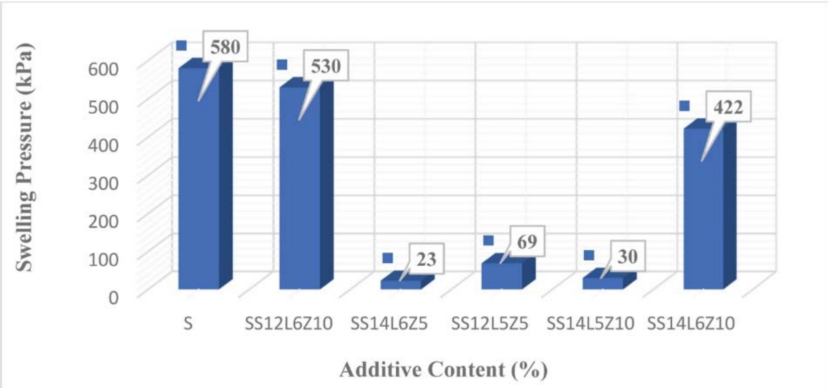


Figure 7 - Variation of swelling pressure with seashell, lime, and zeolite contents

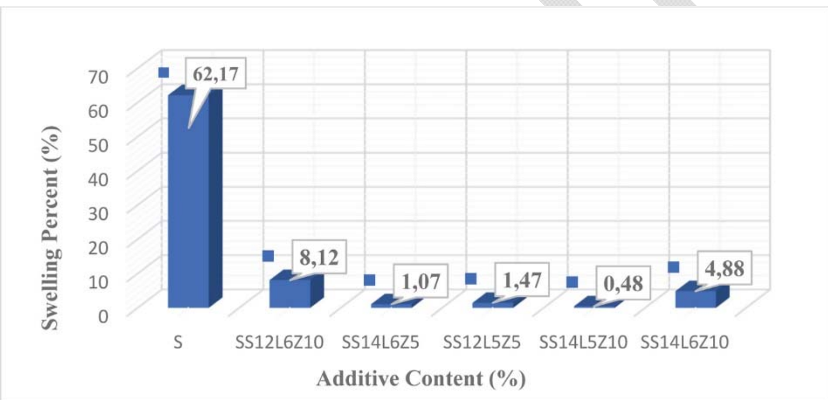


Figure 8 - Variation of swelling percent with seashell, lime, and zeolite contents

4. CONCULUSION

Soil swelling is a common problem in many regions of the world. Much research has been carried out in geotechnical engineering to solve this problem. Previous studies have evaluated the effect of additives such as sand, cement and lime on the swelling potential and the results obtained showed that the swelling properties were improved. In recent years the effect of new additives designed to replace these has been investigated. Specifically, the use of waste materials such as shells has increased in stabilising studies. In this study, the use of shells and alternative materials such as lime and zeolite in superficial soil stabilisation and the effects of these materials on the swelling problem of the soil were investigated. Experimental data from many previous studies in the literature were reviewed and the mix ratios used in this study were determined. To investigate the effect of alternative materials such as lime, shell and zeolite on soil stabilisation, mixtures were prepared by adding 8, 10, 12, 14 and 16 wt% shell, 0, 3, 5, 6, 8% lime and 0, 5, 10, 15, 20 wt% zeolite to natural soil. According to the results of the Atterberg Limits, the best results were calculated for shells between 12 and 14 wt%, for lime between 5 and 6 wt% and for zeolite with an addition of 5 to 10 wt%.

The findings of this study may have significant implications for addressing soil stabilization issues by utilizing alternative materials such as lime, seashell, and zeolite. Based on the results of a series of Tests carried out the following conclusions can be drawn:

- While the liquid limit and plasticity index values of all mixtures in which additives are used together have decreased to a great extent, an increase has occurred in the plastic limit value. Since lime causes significant changes in the effective grain diameter and microstructure of the soil, it has been seems that the natural soil sample with lime added has started to show silty behavior.
- All additives added to the ground reduced the optimum water content of the soil. While the optimum water content of the natural soil was 37,4% and the maximum dry density weight was 1,23 g/cm^3, the optimum water content for all mixtures was between 32%-37% and the maximum dry density varied between 1,27- 1,31 g/ cm^3. The addition of materials with high unit volume weight such as seashell and zeolite also increased the maximum dry density of the soil.
- According to the swelling percentage tests performed on the samples prepared by adding additives to the natural soil, the mixture with 14% sea shell, 6% lime and 5% zeolite added by weight (SS14L6Z5) gave the smallest swelling value. The swelling percentage of the mixture added by weight was determined as 1,07%. The swelling percentage for this mixture was determined to be 1.07%, representing a 98% reduction compared to the natural soil sample. This helps in reducing the water retention abilities in the treated these rates.
- According to the swelling pressure tests performed on the samples prepared by mixing natural soil and additives, the minimum swelling pressure value was calculated as 23 kPa in the mixture with 14% sea shell, 6% lime and 5% zeolite (SS14L6Z5) by weight. The swelling pressure value of the mixture (SS14L6Z5) decreased by 986% compared to the swelling pressure value of the natural soil. However, unexpected high results of swell pressure were obtained for some mixtures which could be referred to their high strengths. The reason is probably the very high compressive strength of this compound.

  This study proposes an environmentally friendly solution that improves the geotechnical properties of the swelling soil by making use of available waste materials.

We hope that future studies, which consider the effectiveness of commercially available additives for the stabilization of expansive soils, will further validate our findings.

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