Građevinski materijali i konstrukcije
Building Materials and Structures
journal homepage: www.dimk.rs

doi: 10.5937/GRMK2202065V UDK: 624.138.23
624.131

Preliminary report

Durability performance of a lime stabilized expansive soil with egg shell ash as a subsidiary admixture

Sivapriya Vijayasimhan*[1)], Jijo James[1)], Yuvaraj Karunanithi[2)], Sushritha Gunipati[2)]

[1)] *Associate Professor, Department of Civil Engineering, Sri Sivasubramaniaya Nadar College of Engineering, Kalavakkam, Chennai, India – 603110*
[2)] *Undergraduate Students, Department of Civil Engineering, Sri Sivasubramaniaya Nadar College of Engineering, Kalavakkam, Chennai, India – 603110*

Article history
Received: 06 April 2022
Received in revised form: 02 June 2022
Accepted: 05 June 2022
Available online: 30 June 2022

Keywords
stabilization;
lime;
egg shell ash;
durability;
sea water;
compressive strength

ABSTRACT

Stabilization is broadly classified as mechanical and chemical stabilization. Lime stabilization is the most commonly adopted method for stabilising expansive soils. In recent years, lime has been combined with other waste materials for improved performance in stabilization. One such waste is egg shell waste, generated by the poultry industry. Calcination of egg shell waste results in the formation of egg shell ash (ESA) which has a chemical composition very similar to that of quick lime. This investigation focuses on the potential of ESA as an auxiliary additive for lime in the stabilization of expansive soils. The initial consumption of lime of the expansive soil was determined using the Eades and Grim pH test. The lime content in the stabilization process was modified with ESA up to 0.5% in increments of 0.1%. Unconfined compression strength test samples of dimensions 38 mm x 76 mm were cast and cured for a period of 21 days and tested for their strength. The durability of the samples was also evaluated by subjecting the samples to 1, 4, 7, and 10 cycles of wetting and drying. The results of the investigation revealed that 0.2% ESA was the optimal dosage of additive to lime stabilization for improved performance.

1 Introduction

High plastic clays are problematic soils that are difficult to work with. They tend to exhibit a good amount of compressibility as well as a swelling nature due to variations in moisture content and applied loading conditions. Stabilization of such soils using chemical admixtures has been found to be effective, especially with the addition of lime. The addition of lime to such soils makes them friable and results in reduced plasticity and improved workability. However, recently, increasing investigations have focused on the effectiveness of lime stabilized soil under conditions of durability like wetting-drying, freeze-thaw, and extreme variations in pH, to name a few. These investigations have brought out the lack of effectiveness of lime stabilized soil under such conditions. Several researchers have attempted to augment the performance of lime stabilization by substitution as well as auxiliary addition of solid wastes [1]. Utilization of wastes is based on the possibility of augmenting the potential of lime by either increasing the supply of calcium ions or providing silica and alumina to enhance the pozzolanic reactions. There are several waste materials that have been adopted in soil stabilization for their effective reuse while also achieving beneficial results in soil improvement [2]. One such waste material that is generated in significant quantities in India is eggshell waste (ESW). India produced as many as 103.32 billion eggs in the year 2018-2019 [3]. Taking 5.5 grams as the average shell weight of an egg [4], the estimated ESW generated in India is as high as 568,260 tonnes. This quantity of waste is definitely a strain on the solid waste management system. Utilization of these wastes in Civil Engineering applications, including concrete, bricks and blocks, and soil stabilization, is therefore desirable. Egg shell waste is basically rich in calcium carbonate. Carbonate lime is not very reactive and is mostly inert [5]. Hence, it is not preferred for stabilization of soil. However, ESW can be activated into a more reactive form by calcining it at a sufficiently high temperature, which converts it into eggshell ash (ESA). ESA is very similar in composition to quick lime [6]. There are quite a few investigations involving the use of ESW. However, the use of ESA in Civil Engineering applications has started to gain traction recently. Its use in soil stabilization is still evolving and has a lot of potential for achieving beneficial modifications in soil engineering. Okonkwo et al. [6] investigated the potential of utilizing ESA in combination with cement in stabilizing lateritic soil. They found that 8% cement with 10% ESA resulted in the maximum strength of the lateritic soil.

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* Corresponding author:
E-mail address: sivapriyavijay@gmail.com

James and Pandian [7] attempted to study the effect of ESA on the development of the early strength of a lime stabilized soil. Their investigation revealed that the addition of 0.5% ESA was capable of enhancing the early strength of 5.5% lime stabilized soil by 10% at 7 days of curing. James et al. [4] investigated the possibility of ESA being utilized in lime stabilization of an expansive soil as an auxiliary additive. Their investigation revealed that addition of 2% ESA along with 4% lime was able to generate a 24.43% increase in the strength of the expansive soil at 28 days of curing and reduce its plasticity by almost 7%. Bensaifi et al. [8] delved into the influence of crushed granulated blast furnace slag and calcined eggshell waste on the mechanical properties of compacted marl. They found that a 15% dosage of a combination of the slag and calcined egg shell waste was capable of developing the maximum strength and bearing. Ayodele et al. [9] evaluated the performance of combinations of sawdust ash and ESA in the stabilization of lateritic blocks. They concluded that the combination of sawdust ash and ESA can be used as a viable alternative to cement in the stabilization of blocks. Yie [10] researched the stabilization of soft clay using combinations of silica fume and ESA. His investigation revealed that 6% silica fume with 6% ESA was able to increase the unconfined compression strength by 69%.

Afolayan et al. [11] looked into the prospects of using ESA as a replacement for cement in the manufacture of sandcrete blocks. They found that ESA could replace up to 30% of cement without much loss in the strength of the block. James et al. [12], in a later investigation, attempted to study the potential of ESA as a potential replacement for lime in the stabilization of lime under conditions of wetting and drying (WD). They found that increasing ESA in the mix resulted in more durability of the stabilized soil. Looking at the available literature, it is clear that ESA is a waste material with good potential for soil stabilization. However, the focus of the majority of the investigations was only on the strength of the stabilized soil or blocks. However, there is a need to study the durability of ESA stabilized soil under varying conditions. This investigation focuses on the durability of lime stabilized soil modified with ESA when it is subjected to alternate cycles of WD in faucet (tap) water as well as seawater.

2 Materials and methodology

The various materials used in this investigation were the virgin soil, hydrated lime for its stabilization, ESA (used as the subsidiary admixture), tap water, and sea water as the weathering agents for durability study.

2.1 Materials

The soil used in conducting the experiments was collected from the banks of the Thaiyur Lake, Kalavakkam near Chennai, India. The soil sample has a large percentage of clay content with 68.7%, silt at 28.4%, and 2.9% of sand. The collected soil is oven dried for characterisation using the relevant Indian standard code; it has a specific gravity of 2.76, a liquid limit of 75.8%, a plastic limit of 23.5% and a shrinkage limit of 11.2%. From the obtained results, the soil is classified as high compressible clay (CH).

High quality industrial grade calcium hydroxide, also called as hydrated lime, procured from M/s. Shiyal Chemicals, India, was used in the experiments.

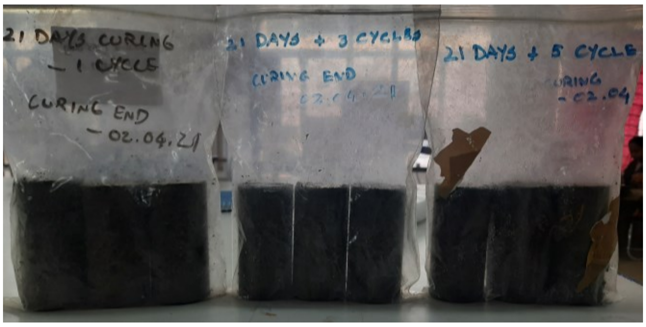
ESA was obtained by calcining egg shells in a muffle furnace. The egg shell waste for manufacture of ESA was obtained from SKM Egg Products, Erode. The obtained egg shell waste was in crushed form, free from proteins and organic content. It was further pulverized and sieved to obtain a fine powder of particle size finer than 75 microns. This powder was calcined in a muffle furnace at a temperature of 500°C for a period of 15 minutes to obtain ESA.

2.2 Experimental methodology

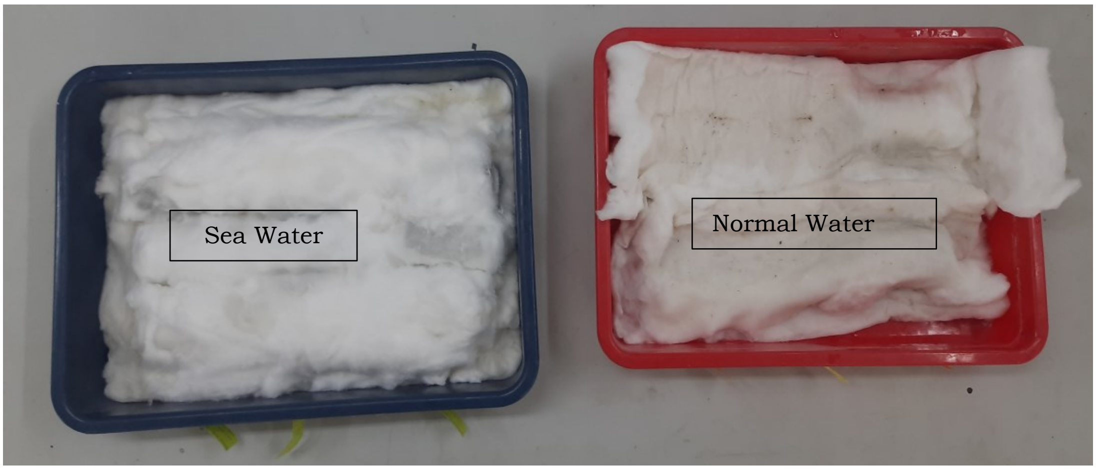
The experimental programme began with the characterization of the soil collected. It was subjected to various geotechnical properties tests, including liquid limit and plastic limit [13], shrinkage limit [14], specific gravity [15], grain size distribution [16], compaction characteristics [17], unconfined compression strength (UCS) [18], and classified based on the BIS code [19]. The soil was then subjected to the Eades and Grim pH test [20] in accordance with ASTM code [21] for the determination of Initial Consumption of Lime (ICL). After the determination of ICL, the compaction characteristics of the soil-lime mix were determined using the mini compaction test method proposed by Sridharan and Sivapullaiah [22], in accordance with the BIS code for stabilized soils [23]. After the determination of compaction characteristics, particles passing 2 mm sieve were used to find the UCS of the soil with a 38 mm diameter and 76 mm height cylindrical split mould, compacted to its maximum dry unit weight at its optimum moisture content. With the known dry unit weight, the quantity of the sample for the test was back calculated. The soil, lime and ESA were initially hand mixed in dry conditions for a minimum duration of 10 minutes until a homogeneous mix was obtained, before adding water. Following this, the computed quantity of water based on the compaction characteristics was sprinkled and a uniform mix was prepared. To maintain uniform preparation of samples, the same duration of mixing was followed for all the combinations. This was then packed into the split mould and compacted using static compaction. The results were obtained from the average of three samples after a curing period of 21 days in sealed polythene covers for various combinations. The quantity of ESA was increased in increments of 0.1% up to 0.5% by weight of dry soil to determine the optimum dosage of ESA for maximum strength. The mix proportions of soil, lime, and ESA are shown in Table 1. To understand the durability behaviour of the soil with admixtures, samples were prepared for the optimum percentage of ESA and cured with faucet, i.e., tap and sea water. The durability of the specimens was determined by wrapping the samples in a bed of cotton and placing them in a tray which was drenched with normal tap and sea water for a period of 24 hours. This was followed by a period of 24 hours wherein the samples were placed in the open air at room temperature. This constituted one cycle of WD. Samples were subjected to 1, 4, 7, and 10 cycles of WD (figure 1) after 21 days of air curing. The tap water used had a pH value of 6.9 while the sea water, collected from Thiruvanmiyur beach, Tamil Nadu, India, had a pH value of 7.9.

Table 1. Mix Proportions

Mix Proportion	Notation	Soil (%)	Lime (%)	ESA (%)
Soil + 4.5%L	SLE0	95.69	4.31	0.00
Soil + 4.5%L + 0.1%ESA	SLE1	95.60	4.30	0.10
Soil + 4.5%L + 0.2%ESA	SLE2	95.52	4.29	0.19
Soil + 4.5%L + 0.3%ESA	SLE3	95.42	4.29	0.29
Soil + 4.5%L + 0.4%ESA	SLE4	95.33	4.29	0.38
Soil + 4.5%L + 0.5%ESA	SLE5	95.24	4.29	0.47



a. Prepared sample



b. Sample under WD process

Figure 1: Sample for testing

3 Results and discussion

The maximum dry unit weight of the virgin soil was 13.34 kN/m^3 with an optimum moisture content of 28.2%. The ICL of the soil found using the Eades and Grim method was 4.5%. The maximum unit weight value of modified clay with ICL was 12.74 kN/m^3 and the optimum moisture content was 32.23%. The samples were prepared at their optimum levels to obtain their strength properties.

3.1 UCS of lime stabilized soil modified with ESA

Figure 2 shows the performance of ESA amended lime stabilized soil. It is seen that the addition of ESA to the mix results in an overall increase in the strength of the stabilized soil, irrespective of the content of ESA. All dosages generated strength higher than the strength of the virgin soil as well as lime stabilized soil. Similar increases in strength due to the addition of ESA to lime in the stabilization of soil have also been reported by other researchers [4], [7]. It is also obvious that an ESA content of 0.2% is the optimum dosage for the development of maximum strength. The strength of the virgin soil increased from 80 kPa to 229.5 kPa for 4.5% lime stabilization at 21 days of curing. With the

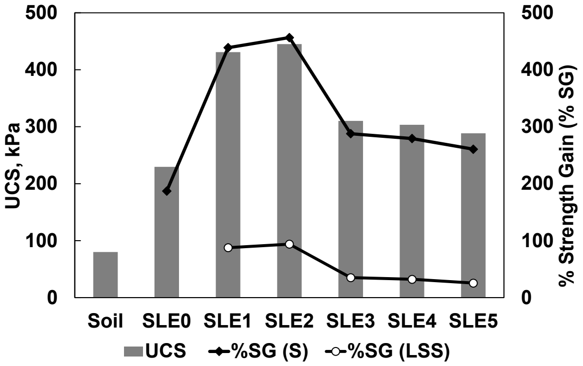


Figure 2. Performance of ESA amended lime stabilized soil

addition of 0.2% dosage of ESA with 4.5% lime, the strength further increases to 445.1 kPa. Earlier, James and Pandian [7] reported an optimum ESA content of 0.5% and an ICL of 5.5% for the soil in their investigation. With a further increase in the ESA content of the stabilized soil, the strength of the soil is reduced. However, the strength was still higher than the strength of the virgin soil as well as the lime stabilized soil. Beyond an ESA content of 0.3%, the reduction in strength of the soil was less and more or less stable as seen from the height of the bars. Thus, it can be concluded that the addition of small quantities of ESA will definitely result in a beneficial effect on the strength of the lime stabilized soil.

Figure 2 also shows the percentage strength gain (%SG) due to the addition of lime and ESA to the mix. The line with solid markers represents the %SG of the stabilized soil, computed based on the strength of the virgin soil, denoted by %SG (S) in the figure. The addition of 4.5% lime results in a %SG of 187% compared to the strength of the virgin soil. It can also be seen that all doses of ESA produce a significant gain in the strength of the stabilized soil. The addition of 0.5% ESA results in a minimum strength gain of 260.5%. The addition of 0.1% and 0.2% ESA results in a strength gain of 438.7% and 456.5%, respectively, when compared to virgin soil. In order to understand the contribution of ESA to the strength development, the %SG was also computed based on the strength of the lime stabilized soil. The line with hollow markers represents the %SG of the stabilized soil computed based on the strength of 4.5% lime stabilized soil, denoted by %SG (LSS) in the figure. The addition of 0.1% ESA increases the strength of the lime stabilized soil by 87.7%, whereas 0.2% ESA increases it by 93.9%. A further increase in ESA content results in a drop in %SG to 25.6% when ESA content is increased to 0.5%. However, all doses of ESA considered in this investigation were capable of further augmenting the strength of the lime stabilized soil. Table 2 shows the strength results of all the combinations tested in this investigation.

It can also be seen from the strength gain figures that the dosages divide the stabilization into two zones at 0.2%. The strength values below 0.2% are comparable, whereas the strength values beyond 0.2% are comparable as well. Nasrizar et al. [24] identified the boundaries of ICL and optimum lime content (OLC), dividing lime stabilization into three phases. However, the boundary seen in the results may be limited only to the present investigation, and more future investigations are essential to identify the presence of such boundaries in ESA modified soil. Thus, ESA being very similar to lime in composition, there are possibilities of boundaries existing in the stabilization process which involves ESA.

Figure 3 shows a comparison between the present study and earlier studies involving ESA. In order to bring in the effect of both the stabilizers into the comparison, the composition of the stabilizers has been reduced to an ESA/Lime ratio as done in some earlier investigations [12], [25], [26]. Most of the work with egg shell waste predominantly deals with egg shell powder. To enhance the effective usage of the egg shell waste, it is further calcined and used as a subsidiary material in the modified soil. Very few researchers have addressed this in their investigations, especially since the combination of lime and eggshell ash is virtually absent in literature. Two earlier studies done by James et al. in the year 2017 [4] and 2020 [12] were considered for comparison due to their similarities with the present study viz. use of combinations of lime and ESA in stabilization of a highly plastic soil. The authors of the present investigation were unable to find any other similar research using the combination of lime and ESA for comparison. Pure lime stabilization results have not been included in the comparison. Before the actual interpretation of the comparison, it is imperative to list out the limitations of the comparison. (i) The soil stabilized using the combinations of ESA and lime in each of these investigations is not the same and, hence, forms the first and foremost impediment in bringing the results to the same plane. (ii) The available data for the previous two studies were for 28-day cured samples, whereas in the present study they were for 21-day cured samples. (iii) The conditions of testing in laboratory-controlled conditions may not be the same for the three studies.

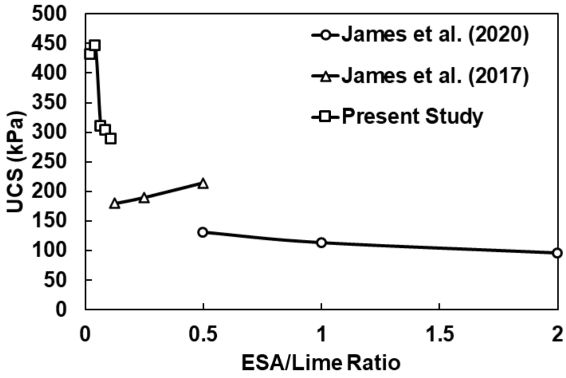


Figure 3. Comparison of present study with previous studies

The figure reveals the fact that the strength test results obtained in the present study are the highest of the three studies compared. A look at the comparison also reveals the fact that the strength values of the stabilized soil are higher when the ESA/lime ratio is lower. On the whole, when the ESA/lime ratio is lower than 0.5, the strength values are higher. This is somewhat in agreement with the conclusion given by James et al. [12], who recommended adopting ESA/lime ratios of less than one. Another important point to be noted is that in the work done by James et al. [12], ESA was used as a replacement for lime, as a result of which the minimum quantity of lime required for stabilization was not maintained. This may have been a reason for the low development of strength in their study. To summarize, lower ratios of ESA/lime can provide greater benefits when compared to higher ratios

Table 2. UCS (kPa) and % SG of all combinations

Parameter	Soil	SLE0	SLE1	SLE2	SLE3	SLE4	SLE5
UCS	79.98	229.54	430.87	445.08	310.14	303.34	288.34
%SG (S)	-	187	438.7	456.5	287.8	279.3	260.5
%SG (LSS)	-	-	87.7	93.9	35.1	32.1	25.6

3.2 Durability of ESA modified lime stabilized soil

The durability of the stabilized soil was determined by studying the strength of the stabilized specimens after they were subjected to 1, 4, 7, and 10 cycles of WD. The samples which were not subjected to any cycles were considered the control specimens. Figure 4 shows the effect of WD on the strength of the ESA modified lime stabilized soil. It is clear that the effect of WD results in a reduction in the strength of the stabilized soil. For the samples immersed in tap water, there is a drastic reduction in strength till 7 cycles of WD, whereas in the case of samples immersed in sea water, there is a significant reduction in strength of the specimens until 4 cycles of WD. The strength of the samples drops from 445.1 kPa to just 105.1 kPa after 7 cycles of WD. At 10 cycles of WD, the strength marginally increases to 110.85 kPa, which is still higher than the strength of pure lime stabilized soil under normal conditions.

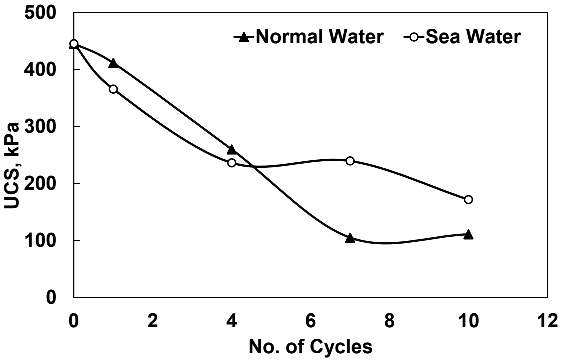


Figure 4. Durability of ESA modified lime stabilized soil subjected to WD

In the case of sea water weathering, the initial strength of the specimens is lower than that of the tap water weathering. However, after 4 cycles of WD, the specimens resist loss in strength much better than specimens subjected to tap water weathering. The strength of the samples reduces from 445.1 kPa to 236.2 kPa at 4 cycles of WD and thereafter drops to 171.8 kPa at 10 cycles of WD. This is significantly higher than the strength of pure lime stabilized soil. Kavak et al. [27] as well as Bilgen et al. [28] report that stabilized soil specimens prepared with sea water developed higher strength when compared to those with tap water. Kavak et al. [27] attributed this to the flocculation effect of salt present in seawater. As a result, the deterioration of the strength of the specimens in sea water is lower than in tap water. Table 3. shows the UCS of the optimally modified soil after different cycles of wetting and drying in normal and sea water.

To better understand the durability of the stabilized specimens in the present study, the strength index (I_{qu}) of the stabilized soil specimens was determined. Muntohar and Khasanah [29] report the strength index to be the ratio of the strength of the stabilized specimen subjected to WD cycles to that of the strength of the specimens not exposed to WD. Figure 5 shows the strength indices of the ESA modified stabilized soil along with the results of the work done by James et al. [12]. They considered only up to 5 cycles of WD in their investigation. The total binder content was 3%, in which the lime/ESA ratio was varied as 2:1, 1:1, and 1:2. For the purpose of comparison, the data from the present study is limited to 7 cycles, as the other study investigated only up to 5 cycles. At the outset, it is clear that the strength index of the specimens tested in the present study steadily decreases. In the case of the samples subjected to seawater weathering, the strength index stabilizes after 4 cycles of WD. Comparing the results of the present study with those of James et al. [12], it can be seen that their strength indices are lower than those of the specimens in the present study, with the exception of LE12. The combination LE12 has an increase in strength index with increase in the number of WD cycles. This may be mainly due to the fact that the proportion of ESA was double that of lime in the mix. ESA is rich in calcium oxide, which is more reactive when compared to hydrated lime. The immersion of the specimen would have supplied additional water content required for hydration of this calcium oxide from ESA, resulting in an increase in strength. Thus, it was found that the durability of the ESA modified lime stabilized soil was much better in saline environments when compared to normal environments. However, more detailed investigations are required to understand the mechanism behind the improved resistance using microstructural studies.

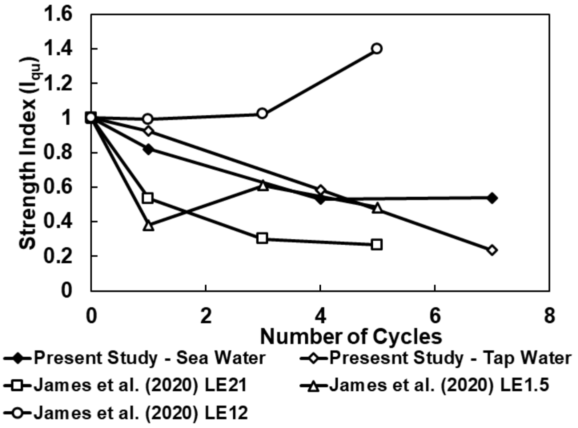


Figure 5: Strength index of stabilized specimens

3.3 Stress-strain characteristics of ESA modified lime stabilized soil

Figure 6 shows the stress-strain characteristics of the lime stabilized soil modified with an optimal dosage of ESA and subjected to cycles of WD. The sample not subjected to WD has been taken as the control specimen. For the sake of clarity, the samples subjected to 1, 4, and 10 cycles alone have been shown along with the control specimen. It is clear that 0.2% ESA modified lime stabilized soil exhibits brittle behaviour, with the failure strain at 1.07%. The first cycle of WD in normal tap water (T) results in an increase in the brittleness of the specimen with the failure strain reduced to 0.7%, However, the peak stress also reduces marginally.

Table 3. UCS (kPa) of optimally modified soil after various cycles of wetting and drying

Agent / Cycles	0	1	4	7	10
Normal Water	445.08	411.32	259.68	105.08	110.85
Sea Water	445.08	365.50	236.21	239.50	171.79

But, on the other hand, WD in seawater (S) results in a slight reduction in brittleness with a lowered peak stress and increased failure strain at 1.45%. The first cycle of WD has different effects on the stabilized soil specimens due to the difference in the fluid to which the specimens were exposed. With an increase in the number of cycles of WD to 4 cycles, the behaviour of the specimens, both in tap water and seawater, exhibits an increased ductile behaviour with a significant reduction in peak stress and an increase in corresponding peak strain. The specimen in seawater had a peak failure strain of 2.37%, whereas the specimen in tap water had a peak strain of 2.89%, both of which are significantly higher than the failure strains in the first cycle. At this stage, both tap water as well as seawater cycled specimens exhibit more or less similar stress-strain characteristics. After 10 cycles of WD, specimens in both tap water as well as seawater seem to have recovered some of their brittle nature, though the peak stress is significantly reduced when compared to the control. The failure strains were 1.05% and 1.18% for seawater and tap water cycled specimens, respectively. At this stage, specimens in seawater seem to have developed more stiffness when compared to tap water cycled specimens. Based on the stress-strain characteristics, it can be inferred that WD cycles significantly influence the stress-strain characteristics of the specimens. Moreover, the type of pore fluid also significantly influences the stress-strain behaviour. Lastly, the extent of exposure to different pore fluids can result in different stress-strain behaviours, as seen from the opposing stiffness behaviours at the start and end of the durability cycles for tap water and seawater cycled specimens. However, the durability of specimens in seawater is not as frequently investigated as in normal tap water. More detailed investigations with various controls can reveal a much better picture of the stress-strain behaviour of such stabilized specimens.

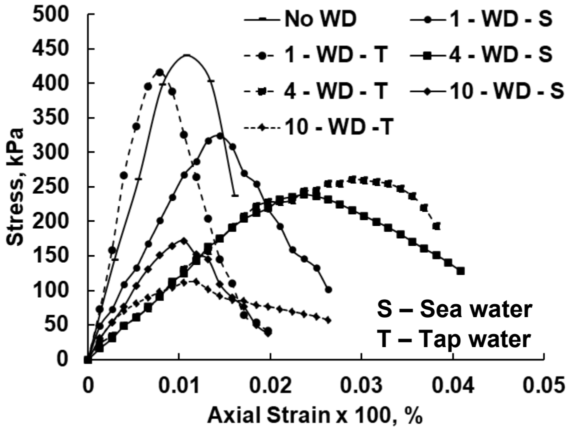


Figure 6: Stress - strain behaviour of ESA modified lime stabilized soil

4 Conclusion

The use of sustainable material to increase the shear strength of the soil has been heavily researched by many researchers in recent times. With advancements in technology, poultry and agricultural by-products are also used after processing or calcinating them to modify the properties of the soil by mixing them in various portions.

In this study, egg shell obtained from poultry is calcined and mixed with ICL content to modify the shear strength of a problematic soil. ESA was added to the soil in concentrations ranging from 0.1% to 0.5%, and experiments were carried out. To understand the durability characteristics of ESA + ICL in soil, the WD process was carried out with tap and sea water for 1, 4, 7, and 10 cycles. The following observations were made from the test results.

1. The ILC of the soil was found to be 4.5%; for this soil, the optimum percentage of ESA was 0.2%. With the addition of 4.5% lime to the soil, the shear strength increases from 79.98 kPa to 229.54 kPa, which is 2.87 times. The addition of 0.2% ESA to 4.5% lime stabilized soil results in the strength further increasing to 445.1 kPa, an increase of 1.93 times. Beyond the addition of 0.2% of ESA with lime to the soil, the role of ESA diminishes in increasing the strength of the soil, but the UCS value at 0.5% ESA is almost 1.26 times that of the pure lime stabilized soil. This indicates that the role of ESA in stabilization is appreciable.
2. The optimal dosage of 0.2% ESA seems to divide the stabilization into different stages. There is a possibility that such boundary values may exist for ESA just like ICL and optimum lime content (OLC) exist for lime stabilization, which needs to be further researched.
3. When the ratio of ESA/lime reduces, the UCS of the soil increases. This is true both for ESA as an additive as well as ESA as a replacement, as seen in a previous study. Thus, it can be concluded that lower ratios of ESA/lime are more beneficial in stabilization. Further research can be carried out to establish this for other types of soils and conditions.
4. The increase in the number of WD cycles with tap and sea water reduces the strength of the soil. With an increase in the number of cycles, the WD process with sea water shows better performance than with tap water, which is due to the speedy reaction of hydrated lime with the cations of ESA and sea water, making the soil flocculated. Thus, it can be stated that ESA modification of lime stabilization can be adopted in the stabilization of soils exposed to seawater.
5. Based on the stress-strain response, it can be stated that the stress-strain behaviour of the soil is influenced by WD conditions, the type of pore fluid, as well as the extent of exposure, resulting in varying behaviours. But, durability against exposure to seawater needs more research to better explain the behaviour of such stabilized soils in the aforementioned conditions.

This investigation reveals some interesting information that can be researched in future investigations. The existence of boundaries in stabilization stages for ESA can be researched (like ICL or OLC exists for lime). The effect of the ratio of ESA/lime when lime content is below ICL, between ICL and OLC, and above OLC can be further researched for a better understanding of optimizing ESA in lime stabilization. With decreasing sources of good quality water, the potential of seawater as a potential hydrating agent as well as a curing agent can be studied in future investigations.

Acknowledgment

The authors are grateful to SSN Trust, India for financial support.

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