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Review Article

Influencing the Efficacy of Widespread Use of Ionic Soil Stabilization Techniques for Improving Expansive Clay Soil Properties

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Abstract: *Background*: Geotechnical engineers working on the ground face a common obstacle of unsuitable soil. Expansive soil is one of the soils vulnerable to high loads and unstable. Properties such as high permeability, low bearing capacity, compression, swelling and shrinkage behavior, low strength and stiffness are all characteristics of an expanding soil. Expansive soil is weaker than other soil types due to these characteristics. *Objective*: This study aimed to review the efficacy of the widespread use of ionic soil stabilization techniques for improving expansive clay soil properties by using different dosage levels that affect the properties of expansive clay soil. *Results*: expansive soil's high sulfate content, experiences swelling and heaving when stabilized with cement, lime, and fly flash. Engineers developed a new stabilizer called ionic soil stabilization to address this issue, improving strength and stiffness while reducing expansive soil permeability, compressibility, swelling, and shrinkage. *Conclusion*: Ionic soil stabilizer is preferred for improving clay soil because of its high efficiency and environmentally friendly stabilizer material, and low cost.

Keywords: Ionic Soil Stabilization, Expansive Clay Soil, Improvement, Soft Soil, Swell-shrinkage, Stabilization

1. Introduction

Expansive soils can be found worldwide, except in the northern regions of the continent [1, 2]. Expansive soils exhibit swell-shrink behavior and a high degree of plasticity. Water absorbed into the soil weakens the soil's mechanical properties. As a result, they can harden when dry, resulting in the ground shrinking and splitting. Shrink-swell behavior describes this hardening and thinning [3]. A high air entry value is achieved in structured clay soils because smectite clay has small particle sizes, resulting in a high air entry value. Loading and unloading cycles influenced compacted earth shear behavior, as were clay and moisture content [3].

Stabilizers containing calcium, such as Portland cement lime, and fly ash, are used to stabilize soils are widely used across the globe in conventional applications. However, this causes significant swelling and heavy lifting when used in high sulfate-content soils, so alternative methods must be sought [4, 5]. Traditional soil stabilizers are also harmful to the environment. Soil pH can rise as high as 9 after treatment with traditional stabilizers, which have been shown to alter the acid-base balance in the environment. For farmers looking for a way to reduce their carbon footprint while simultaneously improving soil quality, traditional soil stabilizers may be the best solution [6-8]. To produce calcium-aluminum- sulfate hydrates, alumina creates ettringite and thaumasite. This is thought to be the cause of these failures. There is a significant increase in the reaction's volume because of this reaction. When dealing with high concentrations of sulfur, non-calcium soil stabilizers could be an effective alternative. Scientific research has developed new, more appropriate, environmentally friendly solutions that emit fewer harmful emissions. Using sustainable technologies such as ionic soil stabilization and others has resulted in environmentally friendly products [9].

Unfavorable physical properties of significant soils are commonly improved with ionic soil stabilizer use [10]. Increases foundation layer strength and stiffness; reduces deformation; increases compaction workability; makes the working table for construction equipment more stable; reduces the potential shrink and swelling caused by moisture fluctuations or frost action or manages dust on unpaved roads. According to most researchers, the void ratio, water content, and the presence of clay minerals are all thought to significantly impact soil volume change [11]. Before using these unusual chemical stabilizers, a water-dilution procedure is required, typically sold in concentrated liquid form [4, 12].

Ionic soil stabilizers like the Reynolds Road Packer were developed in the US in 1959 and quickly became popular worldwide under the Reynolds brand name. Many countries have gradually adopted the International Space Station (ISS) in the 1960s [13]. In civil engineering, ISS reinforcement technology is a construction method that is inexpensive and simple to implement. Due to its versatility, soil mass reinforcement is common in many construction projects [14-16]. Materials used in traditional soil stabilization are ineffective because of their large footprints and lengthy construction times. This makes them unsuitable for both construction and social development [14, 17]. New and appropriate ionic soil stabilization improved physical properties and reduced deformation in the experiment. For soils with a higher proportion of clay than 25%, the ionic stabilizer is a liquid containing active ions that can improve soil strength [5, 14, 15, 18, 19]. It is possible to remove clay-water mixtures from the soil using an electrochemical process after being inserted and interacted with it. As a result of the clay's increased density and water film's decreased permeability, soil engineering properties like strength and stuffiness were significantly enhanced [18]. On average, ionic Soil Stabilization Admixture is typically applied at a rate of 0.15liter per cubic meter of soil. Because there is so little information on how ionic soil stabilizers work, engineers are still hesitant to use them on a large scale, despite some encouraging past results. It's also worth noting that laboratory and field-testing methods have distinct differences. Current experimental evidence is insufficiently encouraging as a gauge of actual field performance. As ISS consistency increases, the plasticity index of expansive clay soil increases. This means that more ISS is not necessarily better.

2. Soft Soil

Because soft soils are always associated with poor loading performance, they are considered problematic [20]. They are also highly compressible, plastic, and sensitive; they have low shear strength and permeability and are susceptible to erosion. Following construction, these characteristics will result in high settlement and low bearing capacity [21]. Before it can be used in construction, clay soil needs to be treated and improved [22]. There are various methods for stabilizing soft soil by incorporating it with more substantial material. There are many examples of these techniques: compaction, vibration, jet grouting, and lightweight are just some. Soil improvements made possible by chemical additives are now routinely employed [23]. A new approach is required to develop the best idea for replacing current chemical soil improvement methods and creating materials that outperform previous research.

3. Swell-shrink Behavior of Expansive Soil

As a result of shrinking and swelling, construction is weakened and vulnerable to structural cracks. Seasonal fluctuations in moisture cause swell and shrink in structures built on soils that are expansive [24]. Experimental studies in the laboratory using cyclic suction control on wet and dry cycles provide a comprehensive picture of how expansive clays expand and contract.[25].

4. Mineralogy and Identification of Expansive Soil

Swelling and shrinkage in expansive soil caused by montmorillonite clay minerals [26]. It consists of two sheets of silicate bonded together by a van der Waals force. The cations in silicate sheets readily hydrate in the presence of water. Electrical charges are negative on the flat surface and positive on a typical expansive soil clay particle [27]. The relationship between expansive soil shear strength and compressibility parameters and their mineral properties is critical when determining soil strata's bearing and settlement capacity. There are several different methods for identifying expansive soils. According to the results of the tests listed below, this one is the most significant. Testing for plasticity indexes comes first, in this order of precedence. The free swell test is conducted after that. The third item is a potential volume change test that could be performed. The fourth item on the list is the index of expansion (EI). The coefficient of linear extensibility (COLE) test comes in at number five on the list of requirements. The sixth item on the list is the standard absorption moisture content (SAMC) examination. The CEC test, which appears as the seventh item on the checklist, is used to determine the cation exchange capacity of samples. A specific surface area (SSA) test, as well as a total potassium test (TP), were performed to complete the list of examinations [28]. There are other methods of identifying clay minerals that are less time-consuming and less expensive than these tests. SEM (scanning electron microscopy), thermal gravimetric analysis, and X-ray diffraction are some of the techniques used (TGA). Chemical soil property regression analysis has been used to develop a new method for detecting the presence of different clay minerals. These methods are significantly faster and significantly less costly compared to current procedures.

4.1. Mineralogical Properties

The mineralogy of the soil has a significant effect on the geotechnical properties of expansive soils, which vary significantly in composition and content from soil to soil and is highly variable from one soil to another [29]. It was calculated cation exchange capacity (EC), specific surface area (SSA), and total potassium content (TP) were higher in the experimental soil sample Eq. 1 than in the control soil sample [4].

4.1.1. Cation Exchange Capacity (CEC)

CEC examines soil samples to determine their ability to absorb positively charged ions from the environment. In this experiment, For the acidity test the acidity of soil was determined by placing 50g of oven-dried soil in 250 ml of 1 M ammonium acetate solution to determine the level of acidity in the soil. Ammonium acetate solutions and filtered soil were added to separate cylinders for storage after filtration. When purified, it was discovered that both soil and ammonium acetate solutions were colorless. Each cylinder was filled with one drop of copper nitrate solution (1 M). Colorless responses had been transformed into a light blueish hue after being previously colorless. Ultraviolet spectroscopy (UV) was used to determine the concentrations of copper present in the two solutions under investigation. This research looked at how many cations were switched to ammonium and remained (NH4). Figure 1 depicts the ultraviolet (UV) results of various samples. The CEC values in Table 1 were obtained from many soil samples collected in Bhavnagar [26].

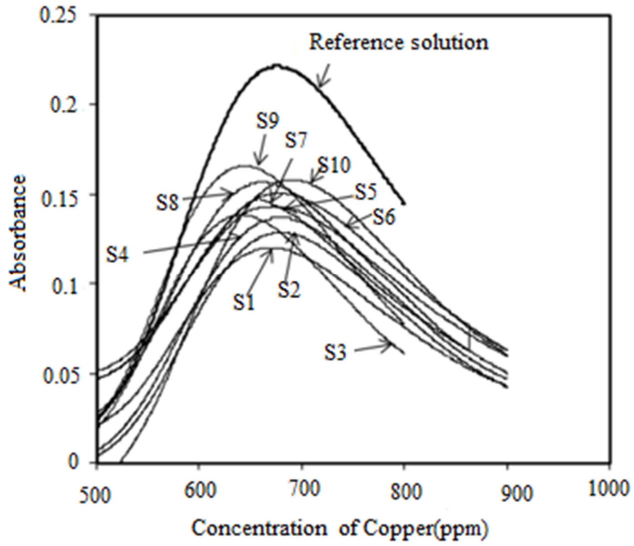

Figure 1. *UV spectroscopy results of Bhavnagar soil for CEC calculations [26].*

Table 1. *Bhavnagar soils' mineralogical properties affect their compressibility and shear strength [26].*

SN	DFSI	Mineralogical properties		Compressibility parameters		Swell pressure SP	Shear strength parameter		
		CEC (meg/100gm)	SSA (m^2/gm)	C_c	C_r	(kPa)	C (KPa)	Φ (deg)	S_u
S1	100	148	572	0.28	0.04	750	187	46	208
S2	97	135	538	0.26	0.06	550	221	44	240
S3	68	112	394	0.23	0.06	420	201	41	218
S4	67	123	405	0.17	0.05	400	197	37	212
S5	58	120	415	0.20	0.05	390	178	36	193
S6	55	102	389	0.16	0.02	230	115	39	131
S7	54	109	383	0.17	0.03	200	115	31	127
S8	52	93	388	0.20	0.02	180	108	36	123
S9	23	80	375	0.10	0.02	100	80	28	91
S10	29	92	380	0.16	0.01	80	36	28	47

4.1.2. Specific Surface Area (SSA)

It is possible to calculate the Specific Surface Area (SSA) of soil by multiplying its volume by its specific surface area (SSA). The specific surface area (SSA) of expansive and non-expansive soils is investigated in this research using a new method that is both planned and tested, and the results are presented in Table 1. Using this method, soil water retention curves can be analyzed (SWRC). Calculating the specific surface area (SSA) could be accomplished by measuring the amount of a probe substance that accumulates. It is lost when it is adsorbed on the soil interlayer/particulate surface due to loss of gas or liquid. In gas adsorption techniques for SSA determination, probe molecules such as nitrogen and water vapor are frequently used [30]. In most cases, clay minerals determine Specific Surface Area (SSA), but the SSA of different clays varies significantly. For example, Montmorillonite has an SSA of 810 m^2/g, whereas Kaolinites and other non-expansive soils have SSAs ranging from 10 to 40 m^2. This is taken into consideration because the impact of SSA on soil properties is highly dependent on the type of clay mineral present [31].

4.2. Identification of Expansive Soil

To identify clay minerals in the soil, techniques such as x-ray diffraction (XRD), SEM (Scanning Electron Microscopy), and Thermal Gravimetric Analysis (TGA) can be used, and these techniques are described in greater detail below.

4.2.1. x-ray Diffraction

To determine the mineral composition of the clay material, an X-ray diffractometer was used to analyze a sample of the clay. Preparing a pure clay fraction (2 microns) was necessary for X-ray semi-quantitative clay mineral identification. Some slides were dried using glycosylated drying, while others were dried using air drying techniques [32].

4.2.2. Scanning Electron Microscopic

SEMs are a great way to examine clay samples' structure, texture, and fabric. Interpenetration and crystallite interlocking mechanisms, crystal habits, twinning, helical growth are all revealed by the SEM [33].

4.2.3. Thermal Gravimetric Analysis

The weight of the sample as a function of temperature was determined using TGA. This test provides additional information about the clay's ability to remove moisture and organic materials from the environment. Mineral soil loses weight due to the evaporation of capillary and adsorbed water from the surface and interlayer of the mineral soil matrix. Mineral soil loses weight due to capillary and adsorbed water from the mineral soil surface and interlayer, and this weight loss can be traced back to the mineral soil surface and interlayer [34].

5. Expansive Soil Stabilization Using Ionic Soil Stabilization

There is potential to improve clay's undesirable physical properties and reduce the amount of deformation by introducing an electrochemical reinforcement derived from Ionic Soil Stabilizer (ISS) [35]. Ionic soil stabilizer was used to save resources and conduct environmentally friendly construction. Several research has been undertaken in light of the stabilized soil's high physical and mechanical qualities to understand the method by which it cures and how well it functions in a field application [36].

5.1. Mechanisms of Ionic Soil Stabilizer

When comparing the performance of stabilized soil engineering to that of unsterilized ground, it is possible to change soil properties such as total potassium content. A number of restrictions apply to the compressive and tensile strengths of chemically stabilized soils, as well as their other mechanical properties. Consider the following factors: strong shear force, good permeability, volume stability, as well as overall performance over an extended period [37].

5.2. Improving Mechanism of ISS

Many solid compounds can be found in the sulfonated Oil Resin (ISS). ISS disconnect and dissociates cations and anions in water after being incorporated into expansive clay soils, gradually replacing exchangeable cations on the clay surface with exchangeable anions due to physical and chemical reactions. Clay surface water film thickness varies depending on how thick a double electrode layer has been applied. It is possible to convert clay hydrophilicity to hydrophobicity. On the other hand, its polymer chain structure links structure units to form large aggregates [18].

5.3. The Optimum Ratio of Ionic Soil Stabilizer

find the optimal ionic soil stabilizer ratio for the control and ISS-treated soil samples by comparing them to one another, UCS tests were carried out. All five stabilization ratios (0.01%, 0.012%, 0.014%, 0.0016%, 0.0018%) were used in the treatment of the soil to achieve the desired results. Two levels of compaction were used to create the specimens (96% and 98%). Each stabilizer ratio and compaction degree were tested on seven different specimens. The results of the UCS test are presented in Table 2 and Figure 3, respectively. After receiving ISS treatment, samples with 96% and 98% compaction degrees showed significant improvement in UCS. The effectiveness of the strength increases in direct proportion to the degree of compaction. Soil strength increased rapidly and gradually as the ISS ratio rose [38]. Figure 2 shows an increase in ISS strength as the curing time lengthened. During the first 28 days, the gains were rapid, but after that, they slowed. To put it another way, there are two possibilities here. After adding the ISS solution, the first surface contact of clay particles occurs; second, expansive clay's hydraulic permeability takes time to penetrate and react with most soil particles [14, 35]. In direct shear tests, it was discovered that the shear strength and strength parameters (cohesion and angle of shear strength) of clayed soils had a time evolution similar to that of sandy soils, indicating that they had a similar time evolution [9].

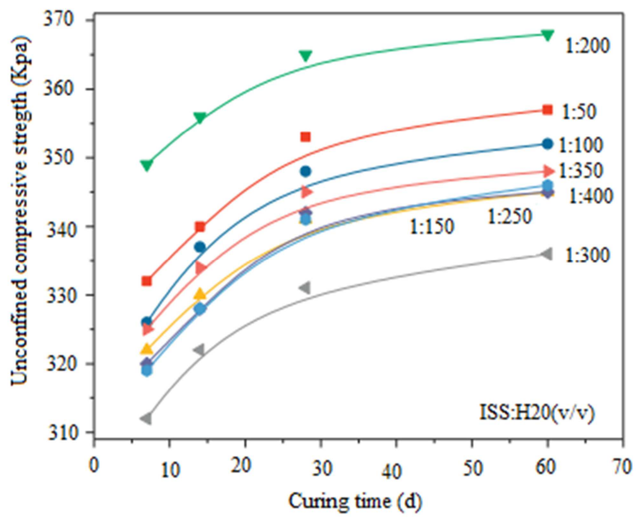

Figure 2. *Red clay's unconfined compressive strength with different ISS/H_2O ratios curing for additional days [9].*

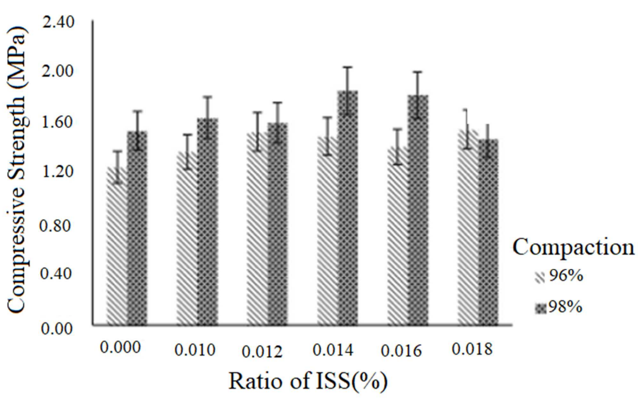

Figure 3. *The strength gained for treated soil with different stabilizer ratios [37].*

Table 2. *The UCS for treated soils with different ISS ratios within seven days [10].*

Compaction degree	**Incorporation of stabilizer (%)**					
	0	**0.010**	**0.012**	**0.014**	**0.016**	**0.018**
96%	1.25	1.37	1.52	1.49	1.41	1.54
98%	1.53	1.64	1.6	1.85	1.82	1.47

6. Equation

$$\%M=-2.87+0.08*SSA+0.26*CEC$$

$$\%I=\left[\frac{TP}{6}\right]*100 \quad (1)$$

$$\%K=100-\%I-\%M$$

7. Conclusion and Recommendation

This discovery was made after it was discovered that the unconfined compressive strength of expansive clay soil had increased significantly due to the configuration of ISS reinforcement. When soil becomes more solid over time, the intensity of the ISS in the soil becomes more variable. During the first 28 days of the curing process, the intensity levels are higher; however, after the 28th day, the intensity rate increases more slowly and at slower speeds. According to research, using ionic soil stabilizers can result in a significant reduction in the thickness of hydrated films and the distance between soil particles. As a result of the increased bonding strength, the structure became denser due to the increased density. Due to reduced slide destructive between binders, tensile strength was greatly improved. In water, the surface tension is reduced when ISS is dissolved, and the surface tension decreases as the concentration increases. To encourage the use of ionic soil stabilization, it is recommended that efforts be made, including establishing a standard protocol and evaluating in-situ properties.

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