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Review on Use of Lignosulfonate Additives for Soil Stabilization

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ABSTRACT

Compressible soils present a major obstacle in geotechnical engineering due to their tendency to expand and contract. This leads towards damages that may surpass the collective impact of floods, hurricanes, tornadoes, and earthquakes. The management of these soils during construction projects has become increasingly costly. However, employing suitable stabilization techniques may enhance their properties. The current study aimed to evaluate mechanical and chemical methods in order to stabilize expansive soils, considering factors, such as efficiency, environmental impact, and cost-effectiveness. The absence of standardized protocols to treat swelling soils complicates engineering practices. This highlights the need for collaboration among specialists. The study focused on lignosulfonate, an industrial by-product, for subgrade stabilization. Furthermore, it also explored the impact of lignosulfonate on soil properties and its environmental-friendly nature. Previous research indicates positive outcomes, with lignosulfonate effectively improving soil properties through ion exchange processes. Despite various challenges, lignosulfonate presents a promising approach to soil stabilization and also offers technical effectiveness and environmental sustainability.

Keywords: Calcium lignosulfonate, infrastructure, mechanical stabilization, sodium lignosulfonate, soil properties, traditional additives,

1. INTRODUCTION

Soil is made up of a mixture of minerals, organic matter, gases, liquids, and various living organisms which are essential for the sustenance of life on earth. Through ongoing physical, chemical, and biological processes,

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soil undergoes continuous development including weathering and erosion. The majority of stabilization efforts are concentrated on soft soils, such as clayey, silty, organic soils or peat, to attain desired properties of engineering. Granular materials that are finely grained are particularly amenable to stabilization due to their extensive area relative to the size of a particle, with clayey soils possessing a notably significant area owing to their flaky and rod-like particle shapes. Conversely, silty materials may react to slight changes in moisture levels, presenting challenges while stabilizing. Peatlands and organic-rich soils exhibit high moisture content, porosity, and organic matter. Peat soils vary in consistency from muddy to fibrous, often with shallow deposits, however, occasionally extending at depths of several meters. Organic-rich soils, with their strong ion exchange capacity, can impede the hydration process through the retention of calcium ions released amidst cement hydration. This necessitates careful selection plusdosage of binders for successful stabilization [1]

In soil science, structure encompasses both the bonding mechanisms and the geometric arrangement of particles. The "organization" of a medium particle describes the arrangement of solid elements and the spaces between them. Within substances, such as large-grained sands and gravels, the particles exhibit loose binding tendencies and often arrange themselves into densely-packed formations with minimal energy. Nevertheless, most soils exhibit a hierarchical structure, wherein primary mineral particles, frequently accompanied by organic materials, assemble into small groupings referred to as first -order aggregates,. This subsequently amalgamate to form larger clusters termed as second -order aggregates, and so on. This hierarchy is characterized not only by increasing the aggregate size, however, also by different bonding mechanisms between particles at each level. Hierarchical structure is essential for medium to fine-structured soils, such as loams and clays, to prevent almost complete impermeability to liquids and gases. Without them, these soils would have mechanical strength that may inhibit the growth of plant roots and soil organisms at typical moisture levels. Therefore, this arrangement is crucial to allow the movement of water, gases, and solutes within the environment. This creates a suitable substrate for the growth of plants and other organisms. Structured soils have a different physical appearance when compared to "puddled" or unstructured soils [2]

The composition of soil, known as soil texture, exerts a significant influence on various properties and is regarded as one of the foremost physical attributes. The appearance of soil means the distribution among 3 mineral particles inside the soil, namely sand, silt, and clay, which together comprise the tiny granular component (as shown in Table 1). Grains bigger than 2 mm in diameter, known as the coarse mineral fraction, are not considered in texture assessment, however, they may occasionally affect water retention and other properties. The proportion of various particle sizes in soil defines its texture categorization which includes clay, loam, sandy loam, and others.

Table 1. Diameter of Four Soil Particles

Soil Particle	Diameter
Gravel	>2.0
Sand	0.05-2.0
Silt	0.002-0.05
Clay	<0.002

This texture is created by weathering, a physical and chemical breakdown of rocks and minerals. Changes in composition and structure cause materials to weather at different rates which affects the resulting properties of soil. For instance, shale weathers easily and produces clayey soils and while granite. This weathers slowly and typically produces sandy, coarse soils. Given the gradual nature of weathering, soil texture generally remains the same and does not change significantly with management practices [3].

Soil stabilization is the process of introducing and mixing extra materials into soils to boost their compression rigidity and bearing capacity. This procedure is required when the current soil is unable to support structural loads. Its objective is to reduce soil permeability and compressibility during earthworks and increase shear strength which leads towards the reduction of structural settlement [4]. Stabilization involves the use of polymers as stabilizers in fragile soils to enhance geotechnical attributes, such as elasticity, resilience, transparency, and sturdiness.

This process enhances the strength, reduces permeability, and decreases compressibility of the stabilized soil as compared to the native soil [5]. Stabilization can be accomplished through two methods:

- *In-situ* Stabilization
- *Ex-situ* Stabilization

In-situ modification enhances soil stability directly at its original location, utilizing techniques, such as the deep mixing method. In this method, binders are injected into the soil for stabilization. Wet mixing uses slurry binders, while dry mixing blends dry binders with moist soil, monitored through automated systems for quality assurance. This method is applied in foundation support, hydraulic barriers, retaining walls, excavation support, and seismic risk mitigation. Conversely, *ex-situ* modification treats soils removed from their site, as seen in dredging, with treated sediments reused or disposed of based on logistics and demand. Deep stabilization is economical, energy-efficient, and effective in improving soil properties while integrating seamlessly with structures [6].

It is important to note that stabilization is not a one-size-fits-all solution to improve all soil properties. The decision to employ this technique depends on which soil properties need modification. Engineers typically focus on soil properties, such as volume stability, strength, compressibility, permeability, and durability [7]. Engineers focus on crucial soil properties including shear strength, compressibility, permeability, and compaction. Few stabilization methods are mentioned as follows:

- Mechanical Stabilization
- Chemical Stabilization

2. MECHANICAL STABILIZATION

Adjusting the gradation may change the qualities of soil. This can be accomplished by procedures, such as soil compaction or mechanical energy application utilizing compactors, rammers, vibratory techniques, and, in rare cases, explosion. With this approach, the resilience of ground is determined by its natural qualities. Mechanical stabilization entails combining or blending two or more types of natural soils to make a composite that outperforms the individual components and fits particular specifications. Mechanical stabilization operations include soil formation, grading and compaction, prewetting, watering and blowing processes, bolstering and the effective use of garbage. Mechanical strengthening of dense soils aims to lower the expansive stress (SS) and expansive potential while maintaining the soils chemical properties [8].

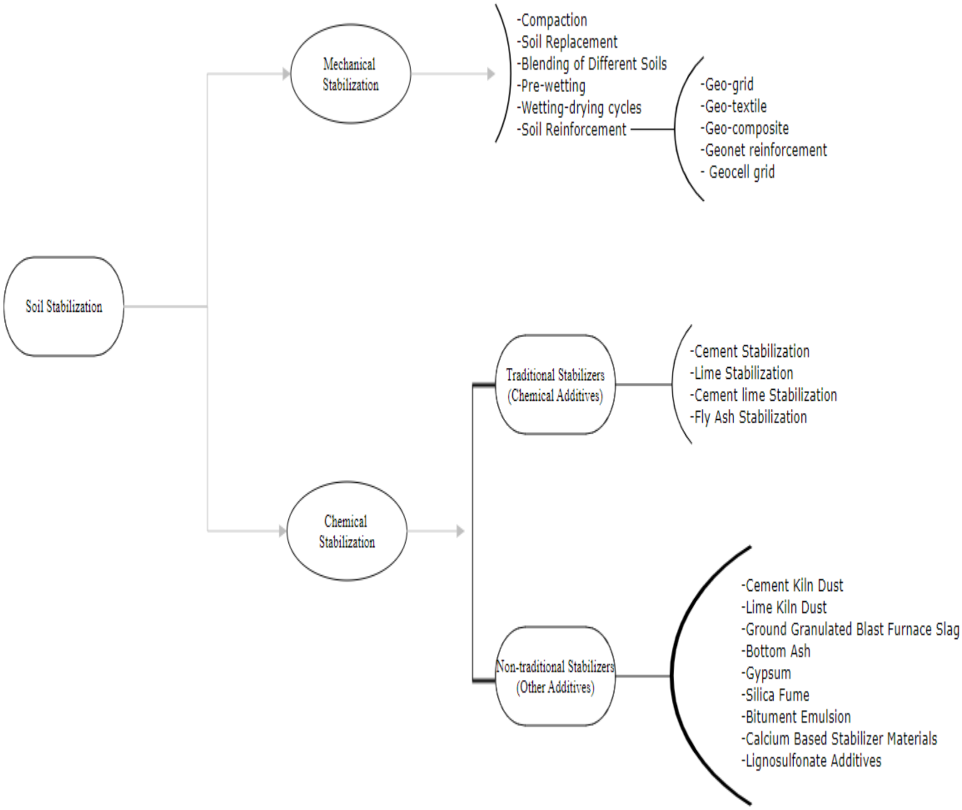

Figure 1. Techniques of Soil Stabilization

2.1. Compaction

Soil compaction primarily aims to meet three essential criteria:

- Firstly, to mitigate subsequent settlement under live loads;
- Secondly, to reduce permeability, thus preventing water-induced stresses that could lead towards liquefaction, influencing the water level of the earth.
- Lastly to improve the soil's load carrying ability and strength against shear.

Compaction's impact on soil properties is mostly determined by the structure that is created during the process. The optimal water content (WOP) and maximum dry density ($\gamma dmax$) are frequently found using the compaction curve. For partially saturated fine-grained clay soils, a quantitative approach using differential functions (∂) and graphical approaches is suggested by [9]. This method helps estimate these values. Findings show that, for partially saturated soils, the changes (Δ) in WOP and γdmax are usually small less than 0.5%, yet significant. A 15% reduction in swelling stress (SS) can be achieved by compaction at WOP. The shear strength of compacted soil is also influenced by the swelling parameters and the geotechnical properties of expansive soils, with the kind of clay mineral having a major effect. Studies have shown that the swelling potential (SP) of soils increases with plastic limit (PL) increment. Investigations on various compacted expansive soils have revealed a reduction in SP with increased initial water content (Wi). Similarly, semi-empirical correlations have shown that SP diminishes with increasing Wi, however, SS at WOP increases with a higher Wi. The SS and dry unit weight relationship exhibits a positive exponential relationship, while it is -ve with moisture content. Correlations between SS and soil suction demonstrate values ranging from 177 kilopascals-326 kilopascals at WOP, significantly greater than the standard load-bearing capacity (approximately 40 kilopascals) for lightweight footings. Strong correlations were observed between SS and soil suctions, indicating a coefficient of determination (R^2) exceeding 80%. Furthermore, predictive models, such as the one proposed by [10], may aid in the assessment of soil moisture deficiency.

2.2. Soil Replacement

One of the most often used mechanical methods to stabilize soil is soil replenishment. The depth of standard processes, building codes, soil profile, and active zone are some of the elements that affect the depth of soil replacement [11]. Materials used for backfill need to be impermeable and non-expandable. Moreover, appropriate compaction criteria should be used for the replacement and compaction of backfill materials, especially those composed of altered in situ soil [12]. The replacement soil material may create differential displacement that is similar to what is observed at the surface if it is permeable, such as coarse sand or gravel. This could happen if surface moisture is transferred to the expanding clay layer.

Consequently, replacing soil materials with sand and gravel is prohibited [13]. However, it appears that replacing problematic soil with a substance that may sustain loads more effectively is the best course of action.

2.3. Mixing of Different Soils

For mechanical stabilization, native soil is mixed with soil that has different compositions to get the required composition in the final combination. Before the mixture is transported to the building site, it might be blended on-site or at many locations. There, it is dispersed and compacted until the required density is reached. Moreover, the process to stabilize soil may involve mixing soils with pre-assigned quantities of materials that might alter properties including gradation, texture, shear strength, and plasticity, or function as agents for soil cementation [14, 15]. The results show that blending soils lowers swelling capacity and increases compaction characteristics (optimum water content, maximum dry unit weight) with an expanded polystyrene (EP) mix instead of expansive soils.

2.4. Pre-wetting

Pre-soaking expansive soil has been a common practice in engineering for many years. The underlying concept of this approach is to induce soil swelling through saturation before the commencement of construction activities. Thereby, it minimizes the potential for subsequent variations in soil volume by maintaining a consistently high water content [16]. In a study on pre-wetting expansive soils (ES), observations indicated that maintaining elevated moisture levels is essential to prevent variations in soil volume [17]. However, maintaining soil at a consistently high moisture level under field conditions is challenging. This renders the technique impractical and is generally not recommended [18]. The effectiveness of the method was underscored in situations where pre-moistened soils exhibit adequate hydraulic conductivity to enable swift water infiltration within a constrained duration. Nonetheless, doubts arise regarding the efficacy of the pre-wetting method for swelling soils with low hydraulic conductivity. Surfactants, commonly used to accelerate water drainage through swelling soil layers, are often employed in this practice [19].

2.5. Moisture Fluctuation Cycles

It is not typically recognized as a standard method of stabilization. Yet, it can be utilized to lessen the retention of ES in particular construction endeavors [20]. Multiple researches have examined the impact of moisture fluctuation cycles on ES. Based on the conclusions drawn from these investigations, repetitive cycles may lead towards either an augmentation or reduction in expansion potential. Studies suggest that soils prone to swelling undergo a notable reduction in expansion potential when subjected to successive drying and wetting [21–23]. On the contrary, alternative studies have noted a contrasting outcome, wherein the repetitive moisture fluctuation cycles result in a notable rise in SP. Moreover, moisture fluctuation sequences are employed to evaluate the endurance of chemical additives utilized in stabilization of soil. This seeks to comprehend the time-sensitive effectiveness of such materials under real-world scenarios by subjecting stabilized soil samples to alternating moisture fluctuation conditions [24–26].

2.6. Soil Reinforcement

Soil reinforcement entails integrating either synthetic or natural additives to enhance soil characteristics. This procedure might entail adding materials with elevated stretching capability, such as fibers, to bolster the soils ability in order to withstand shear forces [17, 28]. Additionally, reinforcing substandard soils often entails utilizing fibrous materials, such as geosynthetics (e.g., geotextile, composite, geonet,geogrid, and cellular geo-structures) or randomly dispersed strands of either artificial or organic origin [29].

A study investigated how two varieties of discarded carpet materials influenced the swelling characteristics of compacted clay. Class#1 was composed entirely of brief nylon strands sourced from sheared carpet piles. While, Class#2 was a combination of polypropylene, wool obtained from carpet trimmings, and polyester. Results showed that when clay was compacted with 10% activated sodium bentonite content at γdmax and WOP, the SS decreased by 20% with a 1% inclusion of class#1 fibers. However, SS increased with the other fiber contents. Notably, for Class#2 fibers, SS notably increased, peaking at around 83% with 3% fiber content. Moreover, SS decreased with the rising water content at a constant γd and increased with increasing γd at a constant water content [30].

Hay fibers were added to wide soils (ES) in another investigation in order to improve their characteristics. It was discovered that the Atterberg boundary changed very little when hay fibers were added. On the other hand, γdmax dropped with the addition of hay and WOP decreased up to a 1.0% hay content before starting to decrease. Additionally, when the amount of hay rose, the direct shear stress greatly increased but the uniaxial compressive stress dropped. Hay was added to the air-dried mixes, increasing their tensile strength, however, decreasing their elongation [31].

2.7. Limitations and Merits of Mechanical Stabilization

Studies examined the stabilization of ES and certain benefits were highlighted. These benefits include:

- during periods of heavy rainfall,
- stabilizing the soil able to reduce climate-related delays, and
- allowing site work to proceed.

Soil stabilization positively influences the construction schedule and saves costs associated with waiting for favorable weather conditions to resume work. Additionally, it presents an effective waste handling system alternative to dumpsites, garbage dumps, and rubbish tips through the application of discarded substances. Moreover, it poses no significant environmental risks from the release of potentially harmful compounds. The process can be expedited when the engineering properties of the soil are not crucial and it does not necessitate lengthy standardized laboratory tests if additives are excluded. The implementation of the process is fairly simple and does not demand highly trained personnel for its execution [32–35]. Mechanical stabilization has limitations, which often requires complementary chemical methods and faces delays to ensure quality. Soils with critical conditions are not suitable, such as upheaval, and may yield unreliable results during pre-moistening cycles [32, 33, 35].

3. CHEMICAL STABILIZATION

Chemical soil stabilization offers a means to augment the bearing capacity of soil. It involves the utilization of admixtures to improve soil properties, categorized as either traditional or non-traditional. Traditional methods employ long-standing additives, such as cation exchange, agglomeration, carbonate cementation, flocculation, and pozzolanic reaction. In contrast, non-traditional agents, developed more recently, interact chemically with the soil in the presence of sufficient moisture. This results in the formation of physicochemical interactions within the soil. The aim to chemically stabilize soils is to improve their stability through methods, such as enlarging the granular dimensions of soil substances, reducing the plastic limit, minimizing swelling-shrinking potential, and enhancing solidification. Soil reinforcement involves the addition of a precise amount of a particular chemical substance to the modified soil.

3.1. Traditional Additives

Traditional soil stabilization additives include lime, cement, bitumen, fly ash, and gypsum, which enhance soil strength, durability, and workability across various applications.

3.1.1. Cement Stabilization. Portland cement undergoes an oxidative reaction that hardens when water is added. Making soil cement by mixing soil particles with cement is a popular chemical restoration technique. Soil, water, and a certain amount of Portland cement are combined to create soil cement, which is subsequently pressed to the appropriate density. The use of Portland cement is meant to boost and modify soil quality by transforming it into a cementitious mass with increased durability and shear strength [36]. Concrete treatment marginally raises the γdmax of sands and highly flexible clays while decreasing the γdmax of silts. Cement improves WOP and reduces γdmax in sandy soil. Additionally, adding cement causes the yield limit (LL) to decrease, the plastic limit (PL) to increase, and ultimately the plasticity index (PI) to decrease [37, 38].

3.1.2. Lime Stabilization. It is a common practice to intentionally apply lime to broad clay soils in order to further enhance their technological properties. Limestone-treated fine-particle soils typically exhibit less compositional variation, increased flexibility, and less fluidity. To improve soil characteristics, three types of lime are commonly used: hydrating lime sludge ($Ca\ (OH)_2$), lime (CaO), and hydrated lime ($Ca\ (OH)_2$). In ES, lime raises the shrinkage threshold, strength, and maximum WOP. However, it decreases the rigidity limit, growth potential, and γdmax [36]. Additionally, lime increases the subsoils compressibility and workability [39]. Moreover, lime decreases the flexibility parameter γdmax and SP of soil materials while increasing the shear strength, WOP, and shrinkage limit [40].

In general, lime reacts with medium- and fine-grained dirt to raise shear stress, decrease expansion, and make the soils more workable. Three fundamental chemical reactions lead to improved soil properties: cementation (pozzolanic reaction), carbonation, and flocculation-flocculation and exchange of ions [41]. The breaking strength values and modulus of elasticity values of soil constituents rise by approximately 20% and 10%, respectively when soil is stabilized with lime. Even after prolonged stress and surroundings, the strength keeps growing over time (self-healing). This guarantees a long life of a few generations even in challenging conditions [42].

3.1.3. Stabilization with Cement and Lime. During construction, the hydro-mechanical and gripping qualities of soils are enhanced with the application of cement and lime [7]. One useful method to minimize expansion and shrinkage is to combine cementitious elements, such as cement and calcium carbonate with soft or ES. Large-scale soil stabilization was achieved using various ratios and blends of lime and pozzolana cement. Methods, such as the expanding stress method and the constant volume approach were used to assess SP. The outcomes demonstrated how variations in chemical additions altered the behaviour of the soil and reduced the amount of SP in the stabilized soil components. In particular, lime reduces SP, whereas cement increases SP [25, 43].

3.1.4. Fly Ash (FA). Fly ash (FA) is extracted from flue gases of pulverized coal furnaces using filter bags or electrostatic precipitators. Its calcium content determines its classification into two types. Class F fly ash (FFA) is created by burning bituminous coal and usually contains more than 10% lime. Whereas, Class C fly ash (CFA) is produced by burning subbituminous coal and normally contains more than 20% of lime. A study examined the behaviour of ES to determine if adding lime and FFAs improved the situation [43, 44]. The study investigated how to stabilize ES using cement and FFAs. A mixture of three and nine volumes of FFAs was shown to stabilize the soil more effectively than 12 volumes by itself [45]. Furthermore, another research looked into how CFA addition affects large soils. The findings differ depending on the geotechnical parameters studied [46–48].

3.2. Non-traditional Stabilizers (Other Additives)

Non-traditional soil stabilizers, such as polymers, enzymes, geopolymers, nano-materials, biopolymers, industrial byproducts, and ionic solutions, offer eco-friendly, cost-effective, and durable alternatives to traditional methods, improving soil strength and performance.

3.2.1. Cement Kiln Dust (CKD). One byproduct that the cement industry produces in vast quantities is cement kiln dust, or CKD. Many facets of CKD use have been investigated over time, such as how it affects initial pH and how it is applied in soil stabilization. A study examined the impact of CKD on ES's hydraulic characteristics. A range of CKD contents, from 0% to 25% of the soil dry mass, were evaluated on soil samples. The California Bearing Ratio (CBR) and unconfined compressive strength (UCS) values significantly increased, according to the data.

Furthermore, a noteworthy reduction in SP was noted, rising from 31% to 5%. The results of compression testing indicated that the WOP significantly dropped from 20.04% to 10.94% and the γdmax rose from 1.73 g/cm3 to 2.03 g/cm3. The permeability rose from 4.80 x 10^-4 cm/s to 1.43 x 10^-3 cm/s. To sum up, CKD enhanced ESs desired fluid-mechanical characteristics [49].

3.2.2. Lime Kiln Dust (LKD). The effectiveness of reworking on a road stabilized with lime kiln dust (LKD), with a minimum service life of 5 years, was assessed through extensive field investigations. To assess the strength and rigidity of the stabilized swelling soil (ES), six locations were chosen for drop weight deflectometer testing, standard penetration tests, and dynamic cone penetration tests. Additionally, soil samples were taken with a split spoon sampler, examined in a lab for geotechnical indicator factors, and contrasted with natural soil material values. The addition of LKD was found to considerably lessen the soil materials flexibility.

Lime from LKD was found in the soil material even after 11 years of road surface use, indicating long-term soil improvement. To sum up, LKD is a trustworthy and efficient non-conventional stabilizer for pavement substrates that improves quality control for both building and maintenance projects [50].

3.2.3. Grinding of Fine Granulated Blast Furnace Slag. Research has looked into the impact of including CKD in ES components. The findings demonstrated that the inclusion of CKD raised γdmax and decreased WOP. The free extension rate (FSR) value dropped from 31% to 5% and the soils expansion was evident in the decline in SP from a high to a low value. Additionally, after soaking, the CBR value arose with the addition of CKD content. The CBR increases from 1.514% to 3.54% when 25% CKD is added to ES. Additionally, from 4.80x10^-4 cm/s to 1.43x10^-3 cm/s, soil permeability rose. UCS improved with the addition of CKD and stable soil sample values rose from 142 to 178 kN/m2 [49]. Various time periods were used for the tests.

The conclusion showed that soil was improved by the inclusion of CKD during the solidification process [51]. A number of tests, such as the Unconfined Compressive Strength (UCS) Test, California Bearing Ratio (CBR) Test, Consistency Limit Test, and Proctor Compression Test, were used to assess the geotechnical strength. Various bottom ash ratios of 30%, 25%, 20%, 15%, 10%, and 5% were used to create soil samples [52]. Findings indicate that the stabilized ES with 30% bottom ash addition has superior compaction capability (excellent water content in WOP and maximum dry density γdmax) than natural soil. Furthermore, stable ES with a 30% ash addition has a uniformity limit that is smaller than the reference value.Furthermore, the inclusion of 30% bottom ash to stabilized estrogen results in a UCS value that is higher than that of natural soil. The conclusion showed that increasing the WOP and pH level and adding silica powder to soil stabilization decreased CEC and SSA as well as the γdmax. Additionally, when the silica content rose, so did the SP and SS. Furthermore, by decreasing the expansion even during the dry-wet cycle, the application of silicone powder may aid in boosting the strength of ES. Interpretation [53].

3.2.4. Lignosulfonate Additives. The current study investigated the potential use of lignosulfonates, a byproduct of industrial processes, to meet the growing need for substrate stabilizing materials. Lignosulfonates are part of a group of organic polymers derived from lignin, a waste product obtained from wood and commercial paper. The current global lignosulfonate production is approximately 1.8 million tons per year. Lignosulfonates are used in many areas as dispersants, concrete additives and flocculants, however, their potential for large-scale use in geotechnical applications has not yet been determined. This study investigated the role of lignosulfonates as soil stabilizers and examined their effects on shear strength, penetration, erosion resistance, compressive strength, and stability. Salt is environment-friendly, corrosion resistant, and non-toxic. Although, lignosulfonates are widely used, especially in construction applications, there is a great potential for their increased use in geotechnical applications.

The use of lignosulfonate additives is environmental-friendly and is considered to be useful in solving the limitations of the use of additives. Many researchers have shown that the geotechnical properties of soil improve after lignosulfonate treatment, as shown in Table 2.

Table 2. Recent Attempts to Improve the Geotechnical Characteristics of Soils with Lignosulfonate

Soil Type	Outcome
Loess soil	Enhancement in unconfined compressive strength
Expansive soil	Decrease in swelling
Dispersive clay	Decrease in dispersiveness
Expansive clay	Reduced enlargement and an enlargement intensity.
Lateritic soil	Increased untamed strength at compression with a modest improvement in CBR
Clayey soil	Increase in rigidity and untamed strength
Lateritic soil	Improved resistance to erosion
Sand-clay mixture	Reduction in permeability and increased strength
Silty soil	Effectiveness in achieving optimal density with less energy
Sandy silt	Improvement in shear strength
Clayey sand	Reduction in erodibility
Clayey soil	Increased strength with less moisture resilience
Erodible soil	Improvement in shear strength parameters
Silty sand	Enhanced stiffness

3.2.4.1. Sodium Lignosulfonate. The chemical structure indicates the presence of coordinated monovalent sodium cations (Na+1). This indicates that lignosulfonate used can be classified as sodium lignosulfonate [54]. It is a yellow-brown powder that does not contain impurities. Furthermore, it has a high dispersion ability. The chemical is an anionic surfactant generated from wood pulp, with an average MW and a small glucose content. This product, as its initial water reducing agent, is inexpensive in cost, has low ash and oil content, is ecologically friendly, and can be used with a huge area of cement types.

Table 3. Composition of Sodium Lignosulfonate

Item	Sodium Lignosulfonate
Appearance	Yellow Brown Powder
Dry Matter %	92 min
Lignosulphonate %	60 min
Moisture %	7 max

Item	Sodium Lignosulfonate
Water insoluble matter %	0.5 max
Sulphate (as Na_2SO_4) %	4 max
PH Value	7.5-10.5
Percentage of Ca and Mg	0.4 max
Total reducing substances percentage	4 max
Percentage of Fe	0.1 max
Packing	Net 25kg PP bags: 550kg jumbo bags

Sodium lignosulfonate (also known as lignosulfonic acid, sodium salt) is used in food industry to reduce foam in the papermaking process and as a food additive. Moreover, it is also used as an additive in animal feed due to its antiseptic properties. Sodium lignosulfonate is also used in many industries, such as construction, ceramics, flame retardant materials, vulcanization of rubber, and organic polymerization. Its main function is to dissolve the water by dispersing the cement base. This process improves cement flow, reduces the need for water mixing, and helps save cement. Firstly, it can be applied to enhance soil in the engineering and building sectors. This would enhance engineering qualities including endurance, accessibility, and resilience. Furthermore, it has been discovered that sodium lignosulfonate increases soil resilience, which makes it particularly helpful in applications where soil must support large loads, such as building highways, embankments, or foundations. Additionally, additives may help reduce soil permeability which makes it less susceptible to water penetration and erosion. This is important to keep the stability of the surrounding soil different.

Sodium lignosulfonate, a sustainable byproduct of paper industry, is a versatile and eco-friendly soil stabilizer. It improves soil performance by reducing swelling, plasticity, and permeability while enhancing compressive, shear, and tensile strength. As compared to traditional stabilizers, such as cement or lime, it offers cost-effective solutions for construction and geotechnical projects. Research shows that treating expansive soils with varying percentages of sodium lignosulfonate significantly enhances their microstructural properties, strength, and stability. Analytical techniques, such as SEM, FTIR, and XRD confirm the formation of stabilizing bonds between soil and sodium lignosulfonate, making it a reliable additive for diverse engineering applications. This is substantiated by the UCS (unlimited compressive strength) test results (Table 4) [55].

Table 4. Unconfined Compressive Strength and Cohesion (28-day Curing)

% Stablizer Added	Unconfined Compressive Strength (qu) KN/m²	Cohesion KN/m²
0%	25.4	12.7
2% LS	24.6	12.3
4% LS	28.9	14.45
5% LS	38.7	19.35

When the dispersed clay comes into contact with water, it forms a colloidal structure that may be cleaned. The pore water of scattered clay is rich in sodium ions. Soil differences may cause substantial and non-destructive damage to earthen structures, such as dams and embankments. Modern clay crack mending involves the inclusion of chemicals, such as lime, cement, and pozzolans. These treatments have been proven to diminish the disparity in size and plasticity index while increasing strength (Figure 5). However, chemical stabilizers have always had negative consequences including environmental degradation, health hazards for those who come into touch with the materials, and the creation of inferior coatings. Therefore, a new zoning plan is urgently needed.

Table 5. Physical, Structural, and Chemical Properties of the Dispersive Clay Specimen

Properties of Soil	Value
Percentage of clay	46
Percentage of fine particles	32
Percentage of coarse particles	22
Fluid limit	35
Limit of plasticity	15
Plasticity range	20
Categorization of soil	CL
Highest achievable dry density	1.65
Ideal moisture content	19
Classification based on permeability	D_2
Rate of dispersion	89

Properties of Soil	Value
Strength under unconfined conditions	0.74
Acidity level	9.12
Overall dissolved solids	2771
Conductivity of electricity	4.33×10^3

Soils that are prone to dispersion and have abundant clay and sodium are quickly eroded by water at low salt concentrations. The use of chemical additions to stabilize dispersive soils is well-documented around the world. Applying 1.5% lignosulfonate to the dry mass of a strongly light clay treated with different concentrations of this renewable stabilizer decreases soil dispersion by 58%. Resultantly, the concomitant treatment with lignosulfonate addition successfully reduced the particle size of the previously highly dispersible clay by 65%, allowing it to be classified as non-dispersive [56].

3.2.4.2. Calcium Lignosulfonate. ES pose significant challenges to civil engineering projects due to their propensity for volumetric changes. This may adversely affect constructions, such as houses and pavements when built upon them. Typical solutions to mitigate these issues include deep and slab foundations [57, 58].

To mitigate the negative impacts of wide soils on construction, preparatory stabilization measures are frequently used. These treatments seek to improve the qualities of native soil till they meet the intended standards. Various normal additives and pozzolanic additives have traditionally been used for this purpose [36, 59, 60]. While these traditional stabilizers have historically performed satisfactorily, some may raise concerns by elevating the pore water pH above nine, posing serious hazards to alkaline-sensitive ecosystems [61]. In such cases, using more acidic stabilizers is desirable.

Lignosulfonates generated from oil have been shown to inhibit the diffusion of water between clay layers, hence increasing clayey soil compaction [62]. Furthermore, cation-containing additions, such as Ca2+ and Mg2+ promote clay floating, lowering soil flexibility, improving permeability, limiting expansion, and boosting bearing capacity.
A study investigated the stabilizing effects of stone dust, granite dust, marble dust, and calcium lignosulphonate on construction materials and natural soils for road construction. The primary objective was to improve

the soils engineer ing properties in order to ensure whether the pavement could effectively bear applied loads. Stabilizers were mixed with the soil in varying proportions, ranging from 5% to 50%, and tests were conducted to measure Atterberg limits, moisture content, and specific gravity. Results showed a decrease in optimal moisture content alongside increases in maximum dry density, CBR, and unconfined compressive strength. For untreated soil, CBR was 2.27%, which increased to 5.05% with 45% additives. With 50% additives, improvements of 30.21%, 17.42%, and 12.82% were observed in the liquid limit, plastic limit, and plasticity index, respectively. Overall, the addition of these stabilizers significantly enhanced the soils mechanical properties [63]. In another study, researchers explored the effect of lignosulfonate on the cyclic behavior of expansive clay using cyclic triaxial tests. Results showed that higher cyclic stress ratios (CSR) increased liquefaction risk, while reduced moisture content which improved resistance. LS treatment enhanced soil stability, increasing shear modulus by 64% and reducing the damping ratio by 22% [64].

4. CONCLUSION

Chemical stabilization offers significant cost savings by reinforcing the existing subgrades instead of replacing them with suitable soil. It also reduces the required thickness of asphalt paving base materials, further lowering costs [34]. Chemical alteration is an effective soil stabilization method, regardless of soil composition. This is because it relies on the rapid reaction of additives during initial mixing. Standardized laboratory methods ensure desired results with minimal additive use, enhancing cost-effectiveness. Additionally, it serves as a waste disposal strategy by repurposing industrial byproduct [35].

Chemical stabilization has drawbacks, such as reduced densification of clay soils, leading to decreased γdmax and increased WOP. Claims about effectiveness in clays are often unverified, highlighting the need for independent testing using consistent protocols to ensure reliability and cost-effectiveness before use [65]. Additionally, the effectiveness of a particular added substance blend can be decided through research facility testing on ES material [66]. Caution is advised when using harmful substances for soil stabilization, as they may generate toxic byproducts and pose risks of groundwater contamination. High costs and excessive quantities of chemicals may render this approach impractical, particularly if field conditions differ significantly from laboratory tests. Environmental risks, such as altered soil pH, harmful substance dispersal, and metal leaching, should be assessed based on additive quality. Unfavorable conditions, such as lime-sulfate reactions, may lead towards adverse effects including soil cracking [35].

CONFLICT OF INTEREST

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

DATA AVALIABILITY STATEMENT

The data associated with this study will be provided by the corresponding author upon request.

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