Enhancing Soil Stabilization in Soft Soils Through The Addition of Sand to Soil-Cement Piles: a Comprehensive Study

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Abstract

Applying a soil-cement mixture to treat soft soil is an effective solution and is being widely applied in many countries around the world. In Vietnam, this method has also been used in many projects, especially in areas with weak soil such as riverside and coastal areas. The soil-cement mixture is made up of natural soil and cement. When cement is mixed with soil, the cement particles will react with water and minerals in the soil, forming a hard bond. The polymerization of this material is equivalent to the curing time of cement. This article focuses on researching the mixing of soil and cement materials to reinforce weak soil in Ben Tre province. Instead of just using cement for reinforcement, the article suggests adding sand and ECO-CSB or ECO-CSSB additives to the soil-cement mixture. Experimental results show that when sand and additives are added, the hardness and load-bearing capacity of the soft ground increase significantly. This method is especially suitable for treating soft soil contaminated with salinity in Ben Tre province. When adding ECO-CSB additives for non-saline soils and ECO-CSSB for saline soils, the amount of cement needed is reduced by 30% while still ensuring uniaxial compressive strength compared to when using only cement.

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Introduction

Currently, various methods are employed to stabilize and treat weak soil in construction projects, including the use of sand piles, well points, drainage mats, reinforced concrete piles, and geotextiles. Soil stabilization methods are commonly applied in projects such as roads, levees, dams, airports, warehouses, and storage yards. The use of soil-cement mixtures through the jet grouting method has been proven to be both economically and technically effective in reinforcing road foundations and civil structures.

Cement used in soil-cement mixtures is typically of grade 425 or slag cement. The cement content in the mixture ranges from 7% to 15% by weight of the stabilized soil or is approximately 180 kg/m³ to 250 kg/m³ of stabilized soil. The water/cement ratio in the cement slurry can range from 0.4 to 0.5.

According to laboratory test results on soil-cement samples, the density of the cement-stabilized soil is higher than that of the natural soil by 0.7% to 2.3%, with a lower water content. The unconfined compressive strength typically ranges from 500 to 4000 kPa. The tensile strength is in the range of 0.15-0.25 times the unconfined compressive strength. The cohesion is (0.2 - 0.3) times the unconfined compressive strength, and the internal friction angle is between 20^{o} and 30^{o}. The deformation modulus E50 is in the range of 120-150 times the unconfined compressive strength. The permeability coefficient k is between 10^-7 and 10^-6 cm/s. For soil-cement-sand mixtures, the unconfined compressive strength experiences a significant increase. The strength increases from 518 kPa for uncompacted samples to 778 kPa for compacted samples, showing an increase of nearly 50%.

In recent years, cement piles have been applied to construct buildings on weak ground in regions such as Hanoi, Hai Phong, Nam Dinh, and the Mekong Delta.

Challenges and Future Directions: While cement piles contribute to the enhancement of soil strength, their effectiveness on-site may vary due to factors such as material homogeneity, environmental conditions, and construction practices. The inconsistency between laboratory results and field conditions suggests the need for further research and optimization.

Several challenges and limitations need to be addressed in the application of cement piles. The composition and properties of soil, water conditions, and environmental factors can impact the strength of the soil-cement mixture. The quality of cement and construction processes are crucial factors affecting the available strength of the mixture. Moreover, the particle composition is identified as the most critical factor determining the strength of the stabilized soil-cement mixture. In areas with significant organic mud or waste, humic acid in the soil can disrupt the solidification process. In saline soils, the presence of NaCl may lead to the formation of unstable hydroxides during cement hydration, causing cracking in the piles.

Therefore, the strength of cement piles depends entirely on the particle composition and the physical, chemical, and mechanical properties of the soil. Soil exploration should be conducted at a high density to achieve economic efficiency. Despite the challenges, cement piles have potential and should be further studied and optimized to ensure their effectiveness and suitability for both theoretical and practical applications in construction projects. Research and development efforts should focus on improving the mixing processes to ensure the uniformity and stability of the soil-cement mixture. The use of additives to enhance the physical, chemical, and mechanical properties of the soil-cement mixture, such as bonding agents or foaming agents, is recommended.

In conclusion, the study introduces a new solution - "adjusting the particle composition of the soil along with cement and additives" - to address weak ground conditions in the salty and non-salty areas of Bến Tre province and similar regions. Further research and development are necessary to refine and enhance this method to ensure its efficiency and alignment with both theoretical principles and practical construction conditions.

Method of soil stabilization using inorganic binders

Soil stabilization is a vital aspect of maintaining and enhancing the technical characteristics and overall performance of soil. It encompasses a range of measures, involving the selection of various inorganic stabilizing agents to reinforce the soil and the construction of pertinent information related to the design and testing of cement-soil mixes. The effectiveness of soil stabilization is contingent upon several factors, with construction equipment and added components being pivotal elements. The choice of construction equipment, including drilling rigs, soil compactors, control systems, graders, and mixing equipment, plays a crucial role and must be tailored to the specific type of soil under consideration. These equipment selections are integral to achieving optimal soil stability during construction activities. Stabilizing agents employed in the process serve multiple purposes, including altering permeability, enhancing strength, reducing soil degradation, minimizing harmful salt content, and decreasing water content.

The successful integration of these agents depends on achieving homogeneity in the mixed phase, influencing the overall quality of the soil mixture. Achieving the desired homogeneity is crucial for ensuring the consistent and reliable performance of the stabilized soil. The accurate description and classification of soil are prerequisites for the selection of suitable stabilizing materials and equipment. Table 1 provides a comprehensive guideline to facilitate the selection of an appropriate treatment method for each type of soil and its specific purpose. This systematic approach ensures that the stabilization process is tailored to the unique characteristics and requirements of the soil, optimizing its performance and longevity.

Soil stabilization involves a multifaceted approach that considers various measures, inorganic stabilizing agents, and the careful construction of information related to cement-soil mixes. The choice of construction equipment and components, coupled with the judicious selection of stabilizing agents based on soil characteristics, is crucial for achieving effective soil stabilization. This comprehensive understanding and application of soil stabilization techniques contributes to the overall success and sustainability of construction projects in diverse soil conditions.

Table 1. Method of soil stabilization using inorganic binders

Purpose	Soil Type	Treatment Options
1/ Ground Stabilization		
a. Bearing Capacity and Regional Characteristics	Fine Grains	SA, SC, MB, C
	Coarse Grains	BA, SC, MB, C
	Low-Plasticity Clay	C, SC, CMS, LMS, SL, SCS
	High-Plasticity Clay	SL, LMS, SCS
b. Reduce Swelling	Fine Grains	CMS, SA, SC, LF
	Low-Plasticity Clay	CMS, SC, SL, LMS, SCS
c. Reduce Swelling and Shrinkage	Low-Plasticity Clay	CMS, SA, LMS, SL, SCS
d. Reduce Liquefaction	Low-Plasticity Clay	CMS, SC, C, LMS, SL, SCS
	High-Plasticity Clay	SL, SCS
e. Reduce Cohesion	High-Plasticity Clay	SL, LMS, SCS
	Soft Mud or Clayey Soil	SC, CMS, SCS
2/ Subgrade Stability		
a. Improve Non-standard Materials	Fine Grains	SC, SA, LF, MB, SCS
	Low-Plasticity Clay	SC, SL, SCS
b. Enhance Load-Bearing Capacity and Strength	Coarse Grains	SA, SC, SB, LF, SCS
	Fine Grains	SC, SA, LF, MB, SCS
c. Increase Water Permeability		SC, SA, LF, MB, Filter Fabric
3/ Dust Control		
Dust Suppression	Coarse Grains	CMS, SA, Bitumen or Asphalt, APSB
	Fine Grains	CMS, SL, LMS, APSB, DCA 70

Notes:

- SA: Chemical Clay
- SC: Mechanical Clay
- MB: Bimodal
- C: Sand
- BA: Pressure Mud
- LF: Filter Fabric
- SB: Stone Ballast
- CMS: Anti-wear Material
- LMS: Seismic Net
- SL: Silicification
- SCS: Foundation Clay
- APSB: Acrylic Polymer Soil Binder

Stabilizing Soil with Inorganic Binders: A Research Focus on ECO CSSB

Soil stabilization methods utilizing inorganic binders exhibit a diverse range of applications, each tailored to specific needs. This article focuses on the exploration of soil stabilization through the use of inorganic binders, with a particular emphasis on soil improvement via gradation by introducing sand and the environmentally friendly supplementary material known as ECO CSSB. The operational mechanism of the ECO CSSB supplementary material within the cement hydration process is elucidated as follows:

In environments with saline water containing NaCl, the dissolution of NaCl results in the formation of Na+ and Cl-. During the cement hydration process, when NaCl encounters cement containing Fe2O3, MgO, and Al2O3, it triggers the creation of unstable, porous hydroxides leading to extensive expansion. Sodium (Na) reacts with water to generate NaOH, which acts as an impediment to the cement hydration process. The amalgamation of paste and concrete is developed based on the principle of "Eliminating salt in soil, rock, water through the electrochemical method into inert blocks without expansive or shrinkage properties and transforming them into a construction material through chemical and cementitious methods." In essence, the introduced ECO CSSB supplementary material plays a crucial role in mitigating the adverse effects of saline water on the cement hydration process.

The presence of NaCl in saline water triggers the formation of unstable hydroxides and expansive reactions, leading to undesirable consequences. ECO CSSB intervenes by interacting with NaCl, preventing the formation of unstable hydroxides and hindering the expansion process, ultimately contributing to the effective stabilization of the soil. Furthermore, the methodology of eliminating salt through an electrochemical approach, converting it into inert blocks devoid of expansive or shrinkage properties, aligns with the overarching goal of creating a construction material through chemical and cementitious processes.

This dual approach ensures that the stabilized soil not only resists detrimental expansive reactions but also attains desirable structural characteristics suitable for construction purposes. The exploration of soil stabilization using inorganic binders, specifically focusing on the incorporation of ECO CSSB, reveals a nuanced understanding of the chemical processes involved. By elucidating the working mechanism of ECO CSSB in mitigating the impact of saline water on the cement hydration process, this research contributes valuable insights to the field of soil stabilization and sustainable construction practices.

Soil stabilization with soil-cement-sand mix

Research on construction projects involving soil-cement mixes, particularly drawing insights from actual cement-soil pile projects in the Mekong Delta region, indicates that soil-cement-sand mixes frequently demonstrate superior load-bearing capacity. This observation stems from empirical data gathered from real-world projects, providing valuable insights into the performance of soil-cement mixes in practical applications. To delve deeper into the factors contributing to the enhanced load-bearing capacity of soil-cement-sand mixes, the author conducted meticulous experimentation on soil samples.

These experiments involved the addition of sand to the soil, along with cement and the CSSB (eco-friendly supplementary material) additive. The comprehensive testing regimen encompassed parameters such as natural moisture content, natural density, specific gravity, and particle composition.

The inclusion of sand in the experimental setup is particularly noteworthy, as it introduces an additional variable that is known to influence the mechanical properties of soil-cement mixes. Sand, when combined with cement and the CSSB additive, can contribute to alterations in the composition and structure of the soil, thereby influencing its load-bearing capacity. The testing protocol, including the assessment of natural moisture content, provides insights into the water content present in the soil-cement-sand mixes. This is crucial in understanding how the hydration process may be affected, influencing the overall strength and stability of the mixture. Natural density measurements offer valuable information regarding the compactness of the soil-cement-sand mixes. Changes in density can directly impact the load-bearing capacity, making this parameter a critical aspect of the experimental analysis. Specific gravity, another key parameter under consideration, provides an indication of the density of the soil-cement-sand mixes relative to the density of water.

This measurement aids in evaluating the overall mass and compactness of the mixture. Additionally, the analysis of particle composition is fundamental in understanding the distribution of different particles within the soil-cement-sand mixes. Variations in particle composition can have significant implications for the mechanical properties of the mixture, influencing the load-bearing capacity and overall stability. By systematically conducting experiments and analyzing these crucial parameters, the author aims to uncover the underlying mechanisms that contribute to the observed higher load-bearing capacity in soil-cement-sand mixes. This research not only provides practical insights from real-world construction projects but also contributes to the broader understanding of soil stabilization techniques, paving the way for informed decision-making in construction practices in the Mekong Delta region and beyond.

Research on Weak Soil Improvement

The construction of cement-soil-cat mixes was undertaken in this study with a focus on improving soil gradation through the addition of sand and the CSSB (eco-friendly supplementary material) additive to cement. The research delved into multiple parameters, including cement content, curing time, and mix homogeneity, to comprehensively understand the effects and characteristics of these mixes.

To provide a robust foundation for the experimental investigation, soil samples were meticulously collected from both non-saline and saline areas in Ben Tre city and Binh Dai district, Ben Tre province. These distinct locations allowed for the examination of the proposed cement-soil-cat mixes under varying soil conditions, adding a layer of complexity and practical relevance to the study.

The experimental testing regimen on the soil samples covered a range of crucial parameters aimed at assessing the performance and properties of the cement-soil-cat mixes. These parameters included:

- Natural Moisture Content: This parameter sheds light on the amount of water present in the soil samples, a critical factor that can influence the hydration process and overall stability of the mixes.
- Natural Density: The determination of natural density provides insights into the compactness of the soil, offering valuable information about the structural characteristics of the mixes.
- Specific Gravity: Specific gravity measurements contribute to understanding the relative density of the soil-cat mixes compared to the density of water. This information is essential for evaluating the overall mass and compactness of the mixture.

Particle Composition: Analyzing the particle composition of the soil samples allows for a detailed examination of the distribution of different particles within the cement-soil-cat mixes. Variations in particle composition can significantly impact the mechanical properties of the mixes.

This systematic approach to experimental testing enables a comprehensive assessment of how the introduction of sand and the CSSB additive to cement influences the fundamental properties of the soil-cat mixes. The exploration of cement content, curing time, and mix homogeneity further adds depth to the study, providing insights into the optimization of these mixes for construction purposes. By conducting experiments on soil samples collected from diverse geographical locations, the study not only contributes to the understanding of the proposed cement-soil-cat mixes but also addresses the variability in soil conditions, making the findings more applicable and relevant to real-world scenarios in Ben Tre city and Binh Dai district.

Testing on soil samples

The experimental setup involved compacting samples in molds with a diameter of 50mm and a height of 100mm, organized into three layers. The variation in cement content spanned 200, 250, and 300kg/m3, accompanied by the inclusion of 0.1% CSSB additive based on the weight of cement. Sand ratios were introduced in volumes of 0, 100, 200, and 300 liters per m3 of natural soil. Curing of the samples took place under natural environmental conditions. The primary objective of the research was to assess both the compressive strength and physical properties of the soil-cement-sand mixes across diverse conditions.

The comprehensive investigation aimed to uncover the nuanced interactions and effects arising from variations in cement content and the addition of sand, with a specific focus on the potential of ECO CSSB as an environmentally friendly supplementary material in soil stabilization. The layer-wise compaction of samples in the specified molds ensured a consistent and controlled experimental setup. By altering the cement content and sand ratios, the study sought to understand the influence of these variables on the mechanical and physical characteristics of the soil-cement-sand mixes. The inclusion of 0.1% CSSB additive, based on the weight of cement, added a dimension of eco-friendliness to the experiment. This supplementary material was introduced to explore its impact on enhancing the overall stability and performance of the soil-cement-sand mixes.

By evaluating the compressive strength and physical properties under natural curing conditions, the research aimed to simulate real-world scenarios and provide practical insights into the potential applications of ECO CSSB in soil stabilization practices. In conclusion, the experimental design, encompassing variations in cement content, sand ratios, and the inclusion of ECO CSSB, offers a robust platform for assessing the complex interactions within soil-cement-sand mixes.

The findings of this study not only contribute to the scientific understanding of soil stabilization but also emphasize the eco-friendly aspects of utilizing supplementary materials like CSSB in construction practices.

Figure 1. Experimental Apparatus and Sample Tube

Uniaxial compression tests were conducted following ASTM D2166 standards. The apparatus and samples are illustrated in Figure 1. The compression test results for samples at 18 days and 28 days are presented in Table 2, Table 3, Table 4, and Table 5.

Results of experiments on non-saline soil samples

Table 2. Uniaxial compression test results for non-saline samples at 18 days

Cement Quantity/1m3	No additives + sand	No sand		100 liters/m3	200 liters/m3	300 liters/m3
200 kg	314.502	484.125		614.467	681.321	726.395
250 kg	413.698	532.172		693.774	785.314	816.22
300 kg	489.594	621.132		721.524	775.567	847.267

The table represents the compressive strength (qu) in kPa for different volumes of sand mixed with various amounts of cement (XM) per cubic meter.

Table 3. Presents the results of uniaxial compression tests for non-salt-contaminated samples at 28 days old.

Cement Amount (XM) per 1m3	Volume of Sand Mix	No Additive, No Sand	100 liters/m3	200 liters/m3	300 liters/m3
200 kg	470.655	621.292	710.292	881.321	921.136
250 kg	603.471	701.247	784.734	895.244	941.115
300 kg	654.133	705.674	754.285	975.567	997.313

This table represents the compressive strength (qu) in KPa for different volumes of sand mixed with various amounts of cement (XM) per cubic meter, with and without additives.

Results of salt-contaminated soil experiments

Table 4. Uniaxial compression test results for salt-contaminated samples at 18 days old.

Cement Amount (XM) per 1m3	Volume of Sand Mix	No Additive, Sand	No Sand	100 liters/m3	200 liters/m3	300 liters/m3
200 kg	182.142	537.332	626.548	781.457	826.247	
250 kg	214.539	686.217	753.854	798.847	891.410	
300 kg	289.853	697.487	765.472	813.454	947.247	

This table represents the compressive strength (qu) in KPa for different volumes of sand mixed with various amounts of cement (XM) per cubic meter, with and without additives.

Table 5. Shows the results of uniaxial compression tests for salt-contaminated samples at 28 days old.

Cement Amount (XM) per 1m3	*Volume of Sand Mix*	*No Additive, No Sand*	*100 liters/m3*	*200 liters/m3*	*300 liters/m3*
200 kg	214.212	814.415	882.724	928.542	961.658
250 kg	221.672	846.378	902.418	949.578	981.243
300 kg	319.326	866.426	921.164	957.264	1014.779

This table represents the compressive strength (qu) in KPa for different volumes of sand mixed with various amounts of cement (XM) per cubic meter, with and without additives.

The experimental findings presented in this study shed light on the intricate relationship between cement content, additives, and uniaxial compressive strength in various soil conditions, with a particular emphasis on non-saline, soil-cement, and saline soil samples.

In the case of non-saline soil samples, the uniaxial compressive strength exhibited a consistent upward trend with an increase in cement content. Specifically, augmenting the cement content from 200 to 250 kg per cubic meter of soil resulted in a noteworthy enhancement in compressive strength. However, a subsequent increase from 250 to 300 kg led to a more moderate improvement. Notably, the introduction of additives proved to be a crucial factor, contributing to a substantial 30% increase in compressive strength compared to samples devoid of additives.

When examining soil-cement-sand mixtures, it was observed that the uniaxial compressive strength experienced a significant boost, particularly when 250 kg of cement was utilized. Within the range of 0 to 200 liters of sand per cubic meter of mixed soil, the compressive strength exhibited a rapid escalation. However, beyond this point, as the amount of sand further increased, there was a discernible tendency for a slight decrease in compressive strength. The inclusion of 300 kg of cement in the mixture led to an increase in uniaxial compressive strength, although to a lesser extent.

Turning attention to saline soil samples, it was noted that, in the absence of additives, the compressive strength remained relatively low when escalating the cement content from 200 to 300 kg per cubic meter. Interestingly, the difference in compressive strength between the 18th and 28th days was minimal, hovering around 10%. The introduction of additives played a pivotal role in this context, as it resulted in a remarkable 300% increase in compressive strength compared to samples without additives. Nevertheless, the incorporation of sand demonstrated a slower pace of increase in compressive strength compared to non-saline soil samples from Bến Tre city, possibly attributable to the higher initial sand content in the Bình Đại samples.

In conclusion, the study underscores the nuanced interplay of factors influencing the uniaxial compressive strength of soil-cement mixtures, highlighting the significance of cement content, additives, and sand in shaping the mechanical properties of the soil. The findings contribute valuable insights for optimizing soil stabilization techniques in diverse environmental conditions, offering a foundation for future research and application in civil engineering and construction practices.

Conclusions

For saline soil, the use of salt-resistant additives significantly improves the load-bearing capacity of the soil. In soil-cement-sand mixtures with 20% sand and 25% cement, the uniaxial compressive strength is optimal. Increasing the cement content further results in a higher compressive strength, but not significantly and not economically feasible.

Overall Conclusion: The focus of this research is on optimizing the particle composition of natural soil to improve soil-cement reinforcement. The findings are expected to be applicable in treating weak and saline soils, such as in constructing pond dikes, preventing riverbank erosion, and rural road construction, ensuring cost-effectiveness while maintaining the durability and stability of the structures.

The experimental results demonstrate that soil-cement mixtures with added sand have higher uniaxial compressive strength. The optimal composition is found to be 20% sand and 25% cement with the addition of a small amount of additives. However, it's important to note that this study only considers uniaxial compressive strength, and further investigations are needed to explore other parameters such as density, friction coefficient, porosity, particle distribution, plasticity index, and hydraulic conductivity for a comprehensive understanding of the mechanical and physical properties of soil-cement mixtures. It is anticipated that the addition of sand to soil-cement mixtures may increase density, friction coefficient, and improve particle distribution, thereby potentially enhancing the overall compressive strength and other geotechnical properties of the natural soil.

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