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Evaluating the Geotechnical Properties of Stabilized Problematic Soil by Utilizing Reed Ash and Lime Mixture

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Keywords:
Unconfined Compressive Strength; Problematic Soil; Reed Ash; Lime; Soil Stabilization.

Highlights:

- *The influence of using different percentages of two types of additives (lime and reed ash) to stabilized of soft soils.*
- *The additives changed the compaction parameters. The addition of lime and reed ash decreased the optimum moisture content and increased the maximum dry unit weight.*
- *The addition of lime and reed ash increased the unconfined compressive strength (UCS) the strength indices of the mixtures with increasing lime and reed ash content.*
- *The modification of soft soils using lime and reed ash can be a viable and innovative method for reducing environmental pollution by decreasing CO2 emissions during phases of production and providing cost savings.*

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Abstract: Stabilization of problematic soil poses a significant challenge in civil engineering projects, especially in regions with prevalent soft clay soils. This study was carried out to study the impact of using a blend of reed ash and lime on improving and stabilizing problematic soil. A sample of soil was obtained from a location in the south of Iraq, specifically in Al-Muthanna Governorate. The treatment involved adding different proportions of reed ash (3%, 5%, 7%, and 9.0% of the soil's dry weight) along with 5% lime, which was determined as the optimal percentage based on previous research. Various laboratory tests were conducted to assess the characteristics of the treated soil, including compaction and unconfined compressive strength (UCS). The findings indicated a notable enhancement in UCS and the maximum dry density (MDD). It was observed that UCS and MDD increased with increasing the reed ash and lime mixture proportion, reaching an optimal level. Beyond this percentage, the strength started to decline. It was found that the incorporation of lime and reed ash (5% lime and 7% reed ash) into the treated soil significantly improved its strength, up to about 10 times compared to untreated soil after 28 days of curing. This approach offers additional benefits, such as reducing environmental pollution by decreasing CO_2 emissions during phases of production and providing cost savings because of the affordability of the materials used.

تقييم الخصائص الجيوتقنية للتربة ذات المشاكل بالاستقرارية من خلال الاستفادة من رماد القصب ومزيج الجير

زيد حميد مجيد، حسنين موسى جعفر، إبتهاج طه جواد
قسم الهندسة المدنية / كلية الهندسة / جامعة بابل / الحلة – العراق.

الخلاصة
تثبيت التربة ذات مشاكل الاستقرارية يشكل تحديًا كبيرًا في مشاريع الهندسة المدنية، خاصة في المناطق التي تعاني من تربة طينية ناعمة شائعة. تم إجراء هذه الدراسة لدراسة تأثير استخدام مزيج من رماد القصب والجير في تحسين وتثبيت التربة ذات المشاكل بالاستقرارية. تم الحصول على عينة من التربة من موقع في جنوب العراق، تحديدًا في محافظة المثنى. شمل العمل إضافة نسب مختلفة من رماد القصب (٣٪، ٥٪، ٧٪، و ٩,٠٪ من الوزن الجاف للتربة) بالاضافة الى ٥٪ من الجير، والذي تم تحديده كنسبة مثلى استنادًا إلى البحوث السابقة. تم إجراء مختلف الاختبارات المختبرية لتقييم خصائص التربة المعالجة بما في ذلك الكبس والقوة الضاغطة غير المحصورة. أظهرت النتائج تحسينًا ملحوظًا في القوة الضاغطة غير المحصورة والكثافة الجافة العظمى. لوحظ ايضاً أن القوة الضاغطة غير المحصورة والكثافة الجافة العظمى زادت مع زيادة نسبة مزيج رماد القصب والجير، ووصلت إلى المستوى الامثل حيث بعد هذا المستوى، بدأت القوة تتراجع. وجد ايضاً أن دمج الجير ورماد القصب في التربة المعالجة (٥٪ جير + ٧٪ رماد القصب) قد تحسن بشكل كبير قوتها، حتى اجتازت العشر اضعاف قوة الضغط مقارنة بالتربة غير المعالجة بعد مرور ٢٨ يوم من الانضاج. توفر هذه الطريقة مزايا إضافية مثل تقليل التلوث البيئي عن طريق تقليل انبعاثات ثاني أكسيد الكربون أثناء مراحل الإنتاج وتوفير التكاليف بسبب تكلفة المواد المستخدمة المعقولة.

الكلمات الدالة: القوة الضاغطة غير المحصورة، التربة ذات مشاكل الاستقرارية، رماد القصب، الجير، تثبيت التربة.

1.INTRODUCTION

Problematic soil, particularly soft clay, is a widespread issue in the southern region of Iraq. Civil engineering projects worldwide face challenges with various types of problematic soil, including soft organic clay, clay, clayey sand, and silty clay. The soft clay properties, including high compressibility, low bearing and shear strength, and poor permeability, make it a well-known problem in the field [1]. Construction on such soft soil can lead to serious issues like significant instability during excavation and embankment construction, post-construction settlement, and foundation collapse. Furthermore, issues such as quick conditions, shrinkage within clay, piping within silts, and ground heave exacerbate the concerns [2, 3]. These difficulties may impact structures built on this soil because the load is transferred to the surrounding or underlying soil, which is affected by the soft soil's geotechnical engineering properties [4]. When soft soil is present at a building site, remediation is required. This may entail replacing the problematic soil physically or altering the design to account for the soil condition. However, remodeling isn't always a possibility, and it may be quite costly to replace poor soil [5, 6]. Soil stabilization has emerged as a feasible substitute as a consequence of the demand for more economical and effective techniques [7]. The process of fixing soft soil's undesirable characteristics is known as "soil stabilization." This can be done chemically by adding stabilizers or mechanically by making physical changes [2]. In order to improve the soil's overall performance, this method may also be used to improve engineering qualities, including strength, permeability, and durability [8]. Numerous studies have been conducted to stabilize soft soils using various additives. In the past, traditional materials like rice husk ash, cement, silica fume, lime, mineral additives, and fly ash have been employed to enhance soft soils [9]. Among these, lime has been regarded as a more cost-effective stabilizing material. In general, quicklime (CaO) and hydrated lime ($Ca(OH)_2$) are the two forms of lime that can be used to stabilize soil. However, CaO has preferable characteristics, including a high content of free lime (about 25%), good heat generation ability, and great density, which lead to the reaction's acceleration [10]. Lime is suitable for stabilizing all types of fine-grained soils, but it particularly brings about significant improvements in clay soils with moderate to high plasticity [5]. Reed ash has several functions that tolerate using it for stabilizing the problematic soil, such as its natural binding properties [11] and its ability to improve stability [12], reduce plasticity, enhance drainage, and reduce swelling and shrinkage. In addition, reed ash is a sustainable [13], cost effective, and abundant material [14]. Yarbaşi et al. [15] studied the addition of lime and fiber to improve the strength characteristics of low-plasticity clayey soil. The research showed that lime and fiber additions significantly increased the soil's strength and reduced its compressibility. In summary, research on the application of lime for soil stabilization and its possible advantages for enhancing geotechnical qualities is presented in the literature. Even though there hasn't been much study done, especially on utilizing reed ash and lime together to stabilize soil, what is known about this innovative mixture offers a solid basis for assessing the geotechnical characteristics of stabilized problematic soil. The purpose of this study is to examine the effects of using a new binary blended mixture of lime and reed ash to stabilize unstable soil. The effectiveness of mixture will be assessed in terms of increasing soil strength, reducing compressibility, and enhancing durability. The study also provides practical insights into the potential use of reed ash and lime as a sustainable solution for soil stabilization in construction projects.

2.MATERIALS AND METHODS

Samples of the tested soil were collected from a specific site located in As Saiyid Alib (31 32 10.3 N 45 17 30.7 E), approximately 280 km south of Baghdad, near Al-Samawah City in Al-Muthanna Governorate, southern Iraq. The collection was carried out using disturbed sampling techniques from borrow pits at a depth of 1.0 m. The characteristics of the studied soil are presented in Table 1. This table provides information on the properties, including classification, index properties, and grain size fractions, of the soils employed in the current investigation. The oxide contents were determined through X-ray fluorescence spectrometry (XRF) analysis using Shimadzu's EDX-720 Energy Dispersive X-Ray Fluorescence Analyzer.

Table 1 Physical and Chemical Properties of the Soils.

Characteristic	Standard	Value and description
Organic content (%)	*ASTM D2974 – 20E1*	1.05
Specific gravity	*ASTM D854 – 14*	2.74
pH	*ASTM D4972 – 19*	4.02
Clay fraction (%)	*ASTM D422 – 07*	36.3
Silt fraction (%)	*ASTM D422 – 07*	31.2
Sand fraction (%)	*ASTM D422 – 07*	32.5
Liquid limit index (%)	*ASTM D4318 – 17E1*	49
Plasticity index (%)	*ASTM D4318 – 17E1*	25
Linear shrinkage (%)	*ASTM D4943 – 18*	8.24
Unified soil classification(USCS)	*ASTM D2488 – 17E1*	*CH*
Optimum water content(%)	ASTM D698-12	22.18
Maximum dry unit weight(*kN/m3*)	ASTM D698-12	16.56
Unconfined Compression Stress(*kPa*)	*ASTM D2166 – 06*	74
Chemical composition		
SiO_2 (%)		57.13
Al_2O_3 (%)		23.34
Fe_2O_3 (%)		8.43
MgO (%)		0.73
CaO (%)		0.04
TiO_2 (%)		1.9
Na_2O (%)		0.31
K_2O (%)		2.91

2.1.Sample Preparation and Curing Conditions

Five varying proportions of reed ash and lime (3%, 5%, 7%, and 9%) were incorporated into the soft soil to assess their impact on the Atterberg limits of the soft soil. The unconfined compressive strength test was performed following the American Society for Testing and Materials (ASTM D 698-12) for two types of soil: untreated compacted soil and soil treated with reed ash and lime at concentrations of 3%, 5%, 7%, and 9%, relative to the dry weight of the soil. UCS measurements were obtained utilizing an automated unconfined compressive strength testing machine. Plates 1 and 2 show some photos of the samples preparation for the UCS test. The compaction process involved inserting tubes (D = 38 mm) into the soil by a machine of compression. These tubes were then used to extract specimens, which were subsequently cut into pieces with a length of 89 mm. Specimens were prepared after determining specific densities and moisture contents, which were dependent on the results of compaction tests specific to each respective percentage of reed ash and lime. These specimens were created using a constant volume mold and subjected to a static load applied manually through a hydraulic jack. Following the compaction process, the specimens were removed from the mold, weighed, and subsequently encased in cling film. They were then sealed within airtight plastic bags and stored at room temperature, maintained at 20 ± 2°C, to facilitate the curing process. Four sets of specimens were arranged, each designated for a specific curing duration (0, 7, 14, and 28 days). For each of these specified curing periods, two specimens were meticulously prepared for every percentage of reed ash and lime to ensure the reliability of the results. After preparing all specimens, tests were conducted based on ASTM (D2166-06) procedures. Lime is available in various forms for construction applications and is produced by calcinating natural materials at temperatures up to 900°C. For this research, all the lime used was purchased from CAO Industries Sdn. Bhd., located in Selangor, Malaysia. The lime incorporated in this research was a laboratory-grade hydrated the lime. Table 2 presents lime chemical composition that was tested in the laboratory, while Table 3 provides further details regarding lime.

Table 2 Chemical Properties of Lime.

Composition	Percentage (%)
CaO	72.3
SiO_2	1.31
Al_2O_3	0.71
K_2O	0.10
MgO	0.68
Fe_2O_3	0.27

Table 3 Details of Hydrated Lime Used.

Product Info	Details
Quicklime/ Lime	Synonym
Formula	CaO
Weight of Molecule	57.03 g/mol
Quality Level	200
Grade	Reagent Grade
Form	Powder
pH	12.5
Boiling Point	2850 $°C$ $(lit.)$
Density	3.3 g/mL at 25 $°C$ $(lit.)$

The primary improvement admixture employed in this research was reed ash, collected from Al-Muthanna Governorate. The reed plants were initially spread on the ground and left to air-dry, which facilitated their burning process. Once dried, the reed plants were burnt to create ash, which was then sieved through a 75μm sieve to eliminate any impurities and obtain a very fine reed ash. Subsequently, the sieved ashes were over dried for 3 hours at 800°C. The physical characteristics and chemical composition are listed in Table 4.

Table 4 Physical Properties and Chemical Composition of Reed Ash.

Composition	Percentage (%)
SiO_2	63.1
Fe_2O_3	2.3
Al_2O_3	11.9
CaO	5.2
P_2O_5	0.03
TiO_2	0.15
MnO	0.04
$G.S$	2.39
$L.O.I$	1.69

3.RESULTS AND DESCUSSION

Figures 1 and 2 illustrate the relationships between MDD and OWC of the improvement admixture, which consists of reed ash and lime. The optimum water content of the untreated natural soil was 22.18%, while MDD was 16.56 kN/m3. However, when 5% lime was added, MDD decreased because the soil particles were replaced with lighter particles of lime composite. The specimen was coated by the particles of lime, leading to larger particles with additional voids, leading to a decrease in density (Sharma et al.,2007). Stabilizing agent filled with voids in the treated samples [15]. MDD of soil samples incorporating reed ash decreased with increasing reed ash content from 0% to 9%, as depicted in Fig 1. This increase can be attributed to pozzolanic reactions occurring when reed ash is mixed with lime in the soil, causing the agglomeration of larger particles. It was found that OWC increased with adding 5% lime to the untreated soil; as illustrated in Fig 2. This could be demonstrated due to the coverage of soil particles by lime particles and linking them together through coagulation and aggregation, which reduces the available surface area for water absorption. Additionally, the pozzolanic reaction between the silica (SiO2) from the reed ash and the Ca++ from the soil results in the formation of cementitious components (CSH). As the proportion of reed ash increased from 0% to 9%, there was a decrease in the optimum water content, further influenced by pozzolanic reactions. The results of the Atterberg limits of the untreated and treated soil with 5% lime and reed ashes are presented in Fig 3. The liquid limit (LL) of the untreated soil was 49%, while its plasticity index (PI) was 25%. It was noticed that LL increased and PI decreased due to the addition of 5% lime to the soil without reed ashes. However, increasing reed ash content in the mixture led to a decrease in LL and PI. LL decreased from 52% to 47% due to the incorporation of reed ashes up to the maximum value of 9%. Consequently, the PI decreased from 22% to 16%. This plasticity decrement can be attributed to the change in the soil's nature, transitioning to a more granular state after flocculation and agglomeration. The resulting soil exhibited characteristics similar to those of silt soil, becoming crumbly in texture. The results of the UCS of untreated and treated samples of soil are presented in Fig. 4. It can be observed that an increase in the amount of improved admixture resulted in a significant increase in UCS. The data in Fig. 4 shows a consistent trend of increasing UCS as the improved admixture content increased. This rise in strength can be attributed to the pozzolanic reactions between particles of lime and soil. During these reactions, the free silica and alumina from the reed ash react with the calcium from the lime, forming cementitious components. As a result, the strength of the specimens increases over time.

Plate 1 UCS Sample Preparation.

Plate 2 Unconfined Compressive Strength Testing.

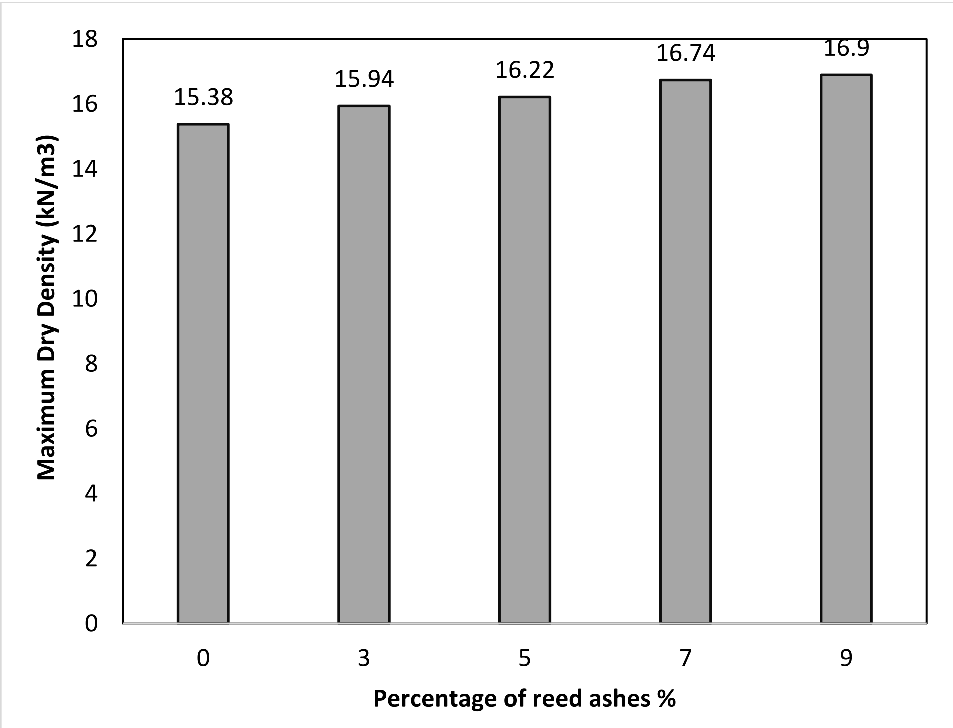

Fig. 1 Effect of Improvement Admixture on the Maximum Dry Density.

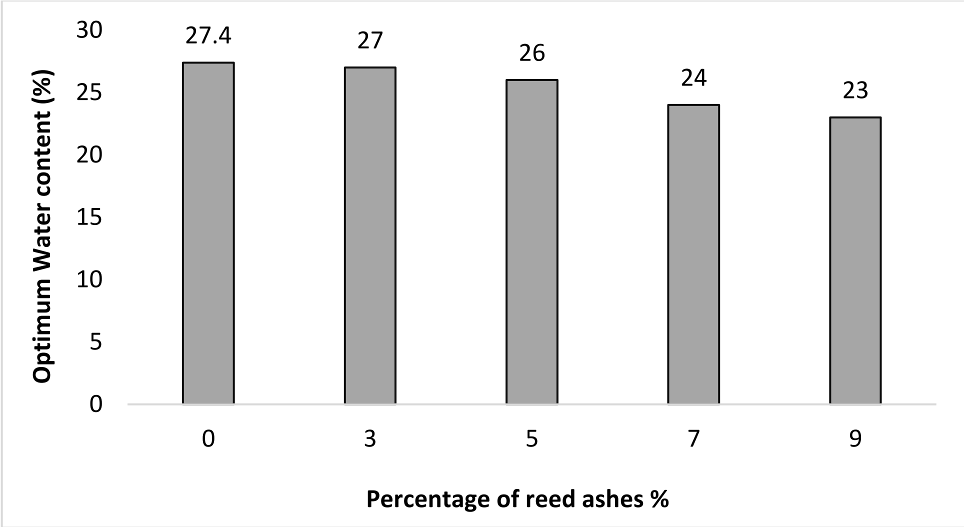

Fig. 2 Effect of Improvement Admixture on the Optimum Water Content.

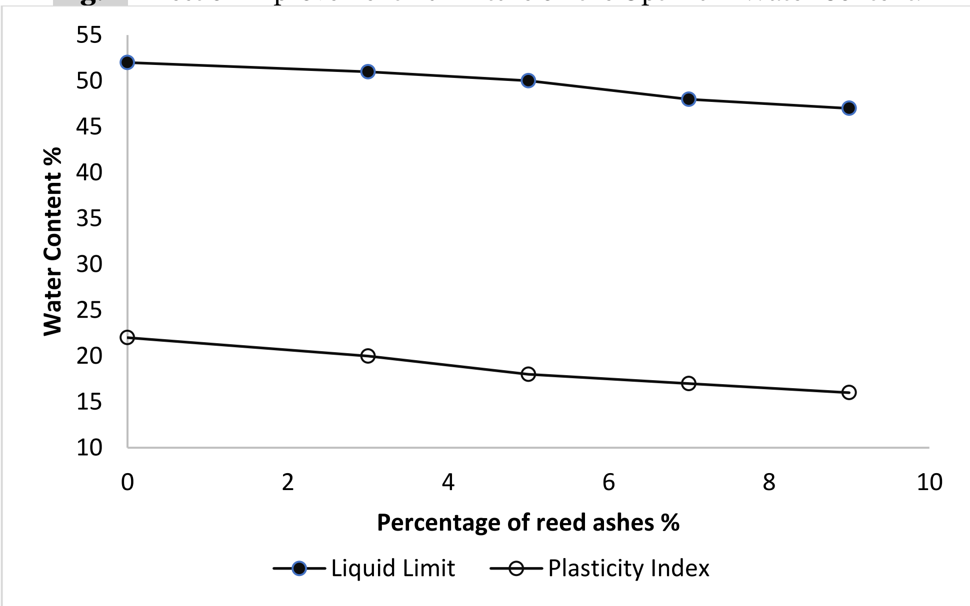

Fig. 3 Effect of Improvement Admixture on the Atterberg Limits.

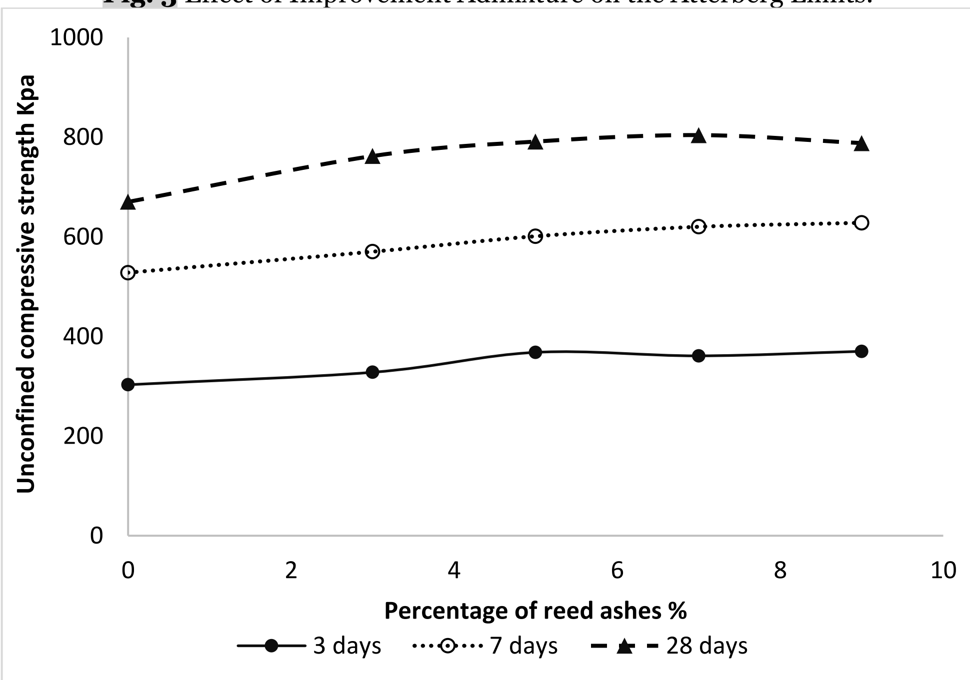

Fig. 4 Effect of Improvement Admixture on the Unconfined Compressive Strength.

The chemical reaction between the soil particles and improvement admixture explains the rise in unconfined compressive strength. However, an increase in the improvement admixture beyond the optimum limit could potentially be attributed to a decrease in one of the pozzolanic process components in the soil, especially alumina.

4.CONCLUSIONS

This study aimed to investigate the impact of adding an improvement admixture, comprising lime and reed ashes, on the geotechnical properties of problematic soil. The main conclusions could be summarized as follows:

- The dry unit weight, MC, and UCS of the soil were analyzed. As the percentage of improvement admixture increased, the dry density of the soil also increased.
- Conversely, the MC of the soil mixtures decreased with higher improvement admixture percentages. Furthermore, when the improvement admixture percentage surpassed the optimum level, particle agglomeration was observed, which adversely affected soil mechanical characteristics.
- However, adding improvement admixture resulted in an increase in the UCS of the soil. Additionally, incorporating the improved admixture resulted in an overall enhancement of the soil's geotechnical properties, including increased CS and improved durability for all soil specimens.
- The incorporation of lime and reed ash into the treated soil significantly improved its strength, up to 10 times compared to untreated soil after 28 days of curing.
- These findings provide valuable insights for researchers aiming to enhance soil strength and other soil properties.

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