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A LABORATORY STUDY ON THE INFLUENCE OF LIME KLIN DUST ON THE GEOTECHNICAL PROPERTIES OF KAREWA SOIL

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ABSTRACT

The use of commercially available pozzolanic materials such as cement and lime for soil stabilization is declining due to their environmentally unfriendly nature. This has prompted researchers to look for alternatives. This study aims to evaluate the potential of lime kiln dust (LKD) in enhancing the geotechnical properties of a silty soil. A detailed experimental program was conducted, in which varying percentages of LKD (5%, 10%, 15%, and 20% by dry weight of soil) were added to examine its effects on geomechanical properties. Unconfined compressive strength (UCS) tests were carried out after curing the samples for 7, 14, and 28 days to assess strength improvements. The results indicated an increase in strength characteristics, reduced strain at failure, and a shift towards more brittle behavior in the LKD-treated samples. Strength improvement was observed up to 15% addition of LKD, beyond which a decrease in strength was noted. Furthermore, strength increased with curing time, irrespective of the LKD concentration in the soil. The strength gain is attributed to the formation of cementitious products due to hydration and pozzolanic reactions between the calcium oxide (CaO) in LKD and the oxides in silty soil. Utilizing LKD in the construction sector offers two benefits: reducing environmental degradation from its disposal and providing a cost-effective method for soil improvement.

Keywords: Silty soil, Lime klin dust, Soil stabilization, Geotechnical properties, Waste management.

1. INTRODUCTION

Soil stabilization is a critical technique in civil engineering, aimed at enhancing the engineering properties of soil to meet specific requirements for construction. This process is essential for increasing the load-bearing capacity, improving shear strength, and enhancing the overall durability and stability of the soil. Traditional methods of soil stabilization primarily involve the use of Portland cement and lime. While effective, these materials are associated with substantial environmental impacts, particularly high carbon dioxide emissions resulting from their production processes. Consequently, there is an increasing emphasis on finding sustainable and environmentally friendly alternatives. One effective method is to incorporate industrial by-products into soils to enhance their stability and performance[1-5].Among these industrial wastes that has shown considerable promise is Lime Kiln Dust (LKD). LKD is a by-product of the quicklime production process, generated during the calcination of limestone in hightemperature rotary kilns. The resulting fine particulate material is rich in calcium, making it a potential substitute for traditional stabilizing agents like lime and cement. Historically, LKD has been treated as a waste product, often disposed of in landfills. However, recent research has highlighted its potential utility in soil stabilization, providing a dual benefit of improving soil properties while promoting the recycling of industrial by-products.The use of LKD in soil stabilization offers several advantages. First, it leverages the high calcium content of LKD, which reacts with the silica and alumina present in soils to form cementitious compounds. These compounds enhance the strength and durability of the soil, similar to the effects achieved with traditional lime stabilization. Second, utilizing LKD addresses the environmental concerns associated with the disposal of industrial waste, thereby contributing to sustainable waste management practices.Third, the substitution of LKD for Portland cement in stabilization activities can significantly reduce the carbon footprint of construction projects, aligning with global efforts to mitigate climate change.

Karewa soils are primarily found in the Kashmir Valley of India, covering an area exceeding 5000 square kilometers. These soils are lacustrine deposits originating from ancient lake sediments. They exhibit distinctive geotechnical properties, characterized by a diverse mix of silt, clay, and fine sand. Significant variations in texture and mineral content occur depending on the location[6,7]. The low shear strength of Karewa soils makes them prone to deformation and failure under load. This poses considerable challenges for construction, particularly concerning foundation stability. Furthermore, Karewa soils are highly compressible, resulting in notable settlement when subjected to loads. This can lead to differential settlement in structures, causing structural damage to structures[8,9]. Karewa soils also demonstrate significant volumetric changes, swelling when wet and shrinking upon drying. These changes can jeopardize structural integrity, especially in regions with seasonal moisture fluctuations. The high plasticity of Karewa soils, attributable to their clay content, further deteriorates their engineering properties. This results in excessive deformation under stress. Consequently, improving the engineering properties of Karewa soils is imperative to ensure the safety and durability of construction projects.

Several researchers have explored various methods to improve the geotechnical properties of Karewa soils[10,11]. One significant approach has been the use of chemical and natural additives to stabilize the soil. Shah, Mir, and Sofi (2017)[12] studied the effects of Gliment, a mixture of glass powder and lime, on the California Bearing Ratio (CBR) of Karewa soils. Their research demonstrated that adding Gliment significantly improved the CBR values, making the soils more suitable for use in subgrades of pavements.

Kakrasul *et al.* (2022)[3] demonstrated the effectiveness of Lime Kiln Dust (LKD) in improving the properties of pavement subgrades. Their study indicated that LKD significantly enhances the strength of subgrade soils through pozzolanic reactions, achieving strength gains of 149% to 257% after several years of use. Daita *et al.* (2017) highlighted that the incorporation of LKD into soils leads to a substantial increase in compressive strength. This improvement is attributed to the pozzolanic reactions between the lime content in the dust and the soil particles, forming cementitious compounds that bind the soil particles together.

The reviewed studies consistently demonstrate that lime klin dust is an effective stabilizer for various soil types. Its high lime content facilitates pozollanic reactions, leading to improved compaction, increased strength, and enhanced load-bearing capacity. These benefits make marble dust a viable alternative to traditional soil stabilizers.

2. MATERIALS AND METHODS

2.1 MATERIALS

In this study, the materials specified below were employed and tested in the laboratory following standard codal procedures..

2.1.1 Karewa soil

Undisturbed and disturbed samples of Karewa soil were collected from the saffron fields near Lethpora in Pulwama, J&K, India, at a depth of 1.0 meter below the natural ground surface. The purpose of collecting undisturbed soil samples was to analyze the in-situ characteristics, such as natural moisture content, field dry density, and in-situ shear strength parameters. Special care was taken to retrieve and preserve these undisturbed samples, which were then transported to the testing laboratory in airtight plastic bags. The disturbed soil samples were oven-dried and sieved through a 4.75mm IS sieve for subsequent testing. The soil obtained from the site was finegrained and brownish in color. Table 1 lists the physical characteristics of the soil and Table 2 shows chemical composition of soil.

2.1.2 Lime klin dust

The lime klin dust utilized in this study was sourced from a lime klin in Rajasthan, India. Lime kiln dust (LKD) is produced as a byproduct during the manufacturing of quicklime (calcium oxide) in lime kilns. It is a white powder with cementitious properties. The chemical composition of the lime klin dust was analyzed using X-ray fluorescence (XRF) technique, as detailed in Table 2. The primary oxides present in lime klin dust dust are calcium oxide (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). The high concentration of CaO in the lime klin dust contributes to the hardening and strengthening of the Karewa soil samples treated with it.

2.2 TESTING METHODOLOGY

An extensive experimental program was conducted to test marble dust treated Karewa soil. The tests included gradation, specific gravity, chemical analysis, Proctor compaction tests, and shear strength tests. All samples were prepared and tested according to the relevant standards[13]. Karewa soil test specimens were treated with varying LKD levels from 5% to 20% (in 5% increments by dry weight of soil) at 0.95dmax and optimum moisture content (OMC) as determined from standard Proctor tests. The moisture content corresponding to OMC is typically adequate to support compaction and cementitious reactions during soil stabilization. The LKD-treated soil samples were preserved in a desiccator for moisture retention and subjected to UCS tests for strength evaluation after 7, 14, and 28 days.

3. PHYSICAL AND ENGINEERING PROPERTIES OF UNTREATED KAREWA SOIL

Karewa soil under study is brownish in colour and is silt dominated. The particle size distribution of the soil is shown in Fig.1. It depicts that 83% of particles by weight have a size less than 75µm. As per the Indian soil classification system (ISCS)[14], it is classified as silt with intermediate plasticity (CI). The oxide composition of the soil was determined using the X-ray fluorescence technique (XRF). The main oxides of Karewa soil were found to be silica (as SiO2), alumina (as Al_2O_3), iron oxide (as Fe_2O_3), and calcium oxide (as CaO). The (SiO_2 + Al_2O_3 + CaO + Fe_2O_3) fraction of soil is more than 85% of its total content and can be classified as a pozzolanic material. A similar oxide composition of Karewa soil has been reported in the literature[15,16].

Owing to the fine-grained nature of soil particles, the density bottle method was used to determine the specific gravity of soil particles. Kerosene, being a better wetting agent, was used in place of distilled water to find the specific gravity of soil particles. The average specific gravity value of soil particles was found to be 2.67, which is in agreement with the standard value of specific gravity for Karewa soils. The standard Proctor compaction test was conducted on Karewa soil and the maximum dry unit weight (MDU) of untreated Karewa soil was found to be 17.2 kN/m^3 and the optimum moisture content (OMC) was found to be 19.5%.

Unconfined compression strength tests was conducted on three untreated samples of soil and the average value of UCS was found to be 110 kN/m2. CBR tests were carried out on the remoulded and untreated soil samples as per the standard codal procedures[17] and the values of unsoaked and soaked CBR were found to be 7.2% and 3.6%, respectively.

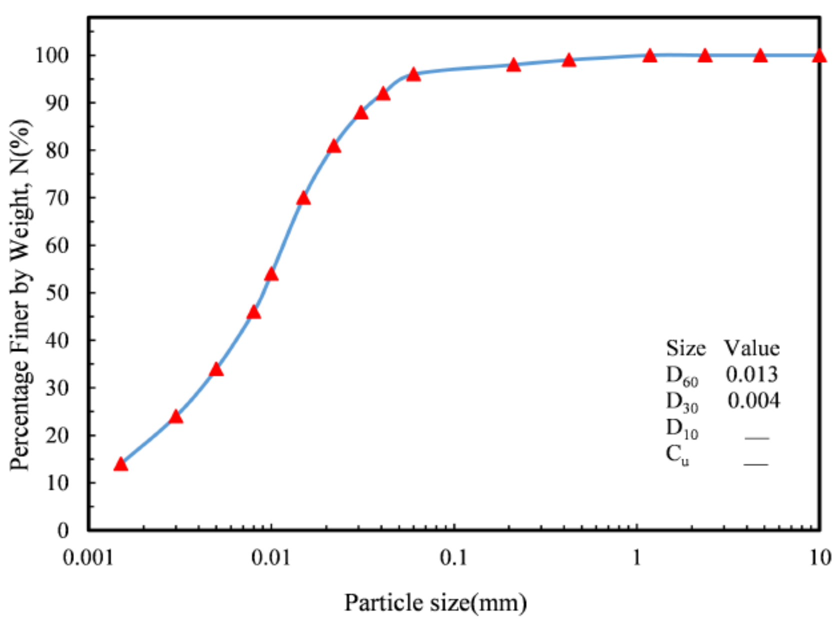

Fig. 1: Particle size distribution curve of Karewa soil

Table 1: Physical and mechanical properties of Karewa soil

S.No.	Property	Soil
1	Natural moisture content (%)	17.5
2	Field dry density (kN/m3)	16.6
3	Gravel (%)	0
4	Sand (%)	3
5	Silt (%)	80
6	Clay (%)	17
7	Liquid limit (%)	38
8	Plastic limit (%)	25
9	Plasticity index (%)	13
10	Specific gravity, G	2.67
11	Colour	Brownish
12	Classification	CI
13	Std. Proctor, maximum dry unit weight (kN/m^3)	17.1
14	Optimum moisture content (%) DST parameters (remoulded) at OMC and $0.95\gamma_{dmax}$	19.5
15	Cohesion, c (kN/m^2)	32
16	Angle of internal friction, ϕ ()	16
17	Unconfined compressive strength, UCS (kN/m^2)	110
18	Unsoaked CBR (%)	3.4
19	Soaked CBR (%)	7.2

Table 2: Oxide Composition of Karewa soil and MD

Composition (by wt. %)	Soil	LKD
SiO_2	51.8	7.2
Al_2O_3	18.3	1.5
Fe_2O_3	8.71	0.8
CaO	9.37	53.2
MgO	5.46	4.3
K2O	3.11	0.61
Na_2O	1.13	0.73
$CaSO_4$	-	-
SO_3	-	0.16
TiO_2	0.62	-
P_2O_5	0.22	-
LOI	1.28	31.5

4 PHYSICAL AND ENGINEERING PROPERTIES OF LKD TREATED KAREWA SOIL

4.1 EFFECT OF LKD STABILIZATION ON PLASTICITY CHARACTERISTICS OF KAREWA SOIL

The essential parameters used to define the plasticity characteristics of soil are the liquid limit (LL), plastic limit (PL), and plasticity index (PI). The liquid limit decreases from 38% to 30.5% with a 20% replacement of soil by lime klin dust. This reduction is mainly due to the coarser particles of lime klin dust compared to the silt and clay particles in Karewa soil. Similarly, the plastic limit drops from 25% to 22.5% with a 20% replacement by lime klin dust. As a result, both the LL and PL decrease with the increased proportion of marble dust, causing the plasticity index to reduce from 13% to 8.0% at 20% lime klin dust replacement. All the tests have been carried as per the relevant code of practice for determination of plasticity characteristics[18].

4.2 EFFECT OF LKD STABILIZATION ON COMPACTION BEHAVIOUR OF KAREWA SOIL

Compaction is the process of increasing the unit weight of a material by bringing its particles closer together, thereby reducing air content. This process decreases the soil's compressibility, increases its shear strength, and reduces its permeability. The compacted unit weight is influenced by factors such as soil type, compaction method, and the water content present during compaction. In this study, standard Proctor compaction tests were performed on Karewa soil treated with varying percentages of marble dust (5%, 10%, 15% and 20%) by dry weight of soil as per the relevant code of practice[19].

It was observed that the MDU of lime klin dust-treated Karewa soil increases while the OMC decreases as the lime klin dust percentage rises from 5% to 20%, without showing an optimum value. This finding aligns with other researcher observations that lime klin dust addition significantly affects the compatibility of the soil-lime klin dust mixture[20,21]. The increase in the unit weight of the mixture is attributed to the higher specific gravity of lime klin dust.

4.3 EFFECT OF LKD STABILIZATION ON UCS CHARACTERISTICS OF KAREWA SOIL

Evaluation of strength parameters of soil are prerequisite for its application in various civil engineering projects. In this study, unconfined compressive strength tests were carried out to evaluate the impact of lime klin dust addition to the strength characteristics of Karewa soil. Cylindrical soil samples with 50mm diameter and 100 mm height with different percentages of LKD ranging from 5-20% were prepared using static compaction method at $0.95\gamma_{dmax}$ and optimum moisture content. The prepared samples were placed in the desiccator for subsequent UCS testing after 7, 14, and 28 days of curing as shown in Fig.2.

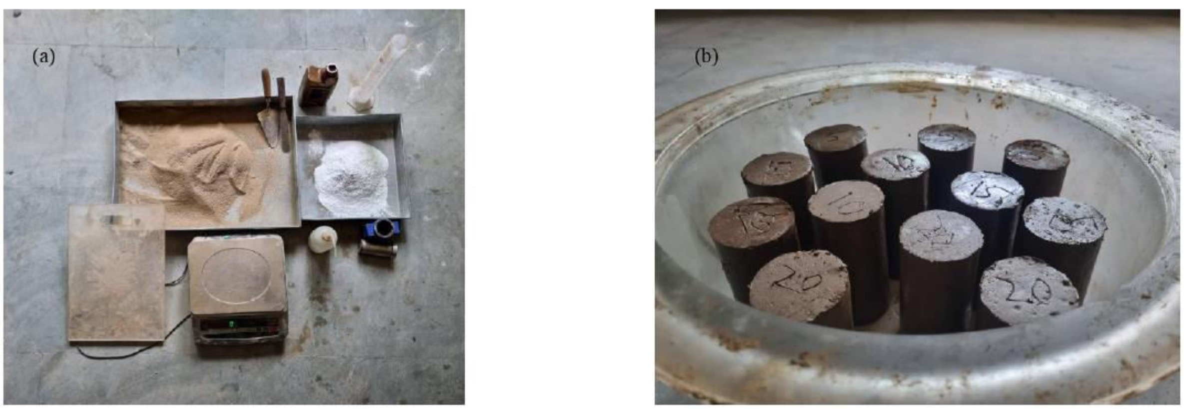

Fig.2 (a) Sample preparation for UCS (b) UCS samples in desiccator for curing.

All the samples were tested for UCS strength as per the relevant code of practice[22].

From the test results of UCS, it can be depicted that the elastic modulus and the peak strength of marble dust treated samples of Karewa soil improve significantly. The UCS strength of the samples improves further, as the samples were cured for 14 and 28 days. However, the stress-strain behaviour of LKD treated samples changes into a brittle one particularly at higher contents of lime klin dust.

5. CONCLUSION

In this study, the influence of lime klin dust addition to Karewa soil was investigated in order to improve its performance for use in various applications of geotechnical engineering. Based on the test results, the broad findings of this study are summarized below:

- The addition of lime klin dust to Karewa soil proved to be an effective means of improving its strength characteristics. The gain in strength was mainly found to depend on LKD content and the curing period.

- Marble dust addition of 20% in standard Proctor tests resulted in the increase of MDU of Karewa soil from 17.2 kN/m3 to 17.9 kN/m3 and a decrease in OMC from 19.5% to 17.6%.
- The unconfined compressive strength of Karewa soil was found to increase up to 15% of LKD addition, beyond which the UCS strength dropped. The value of UCS at 15% LKD treatment to silty soil was found to be equal to 542 kPa.
- The peak strength and elastic modulus of LKD treated soil are higher, but the stress-strain behaviour represents brittle failure, especially at higher LKD content. Therefore, use of LKD treated soil should be approached with caution as it may lead to sudden failure of structures composed of this material. For researchers, it is suggested to improve the ductility behaviour of LKD treated soil by introducing fibres into it. Further, cyclic triaxial testing needs to be carried out to understand the susceptibility of LKD treated silty soil to liquefaction.

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