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A Comprehensive Study of Stabilization of Clayey Soil with Lime

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Abstract—*All structures are supported on soils through their foundations. The supporting soil needs to be sufficiently strong to withstand the loads without failure. The strength of the soil varies from location to location, so it is not necessary that the soil at every location will be able to support the loads. Because of their vulnerability, clayey soils, especially soft clays, demonstrate an inability to support the applied loads. It is therefore necessary that these soils should be improved. Based on the type of soil and construction activity, numerous methods are being used to improve soils, with stabilization being one of them. Stabilization can be done in the field with various materials such as cement, lime, fly ash, bitumen, or a combination of these. In this study the lime has been used to stabilize the clayey soli. A series of laboratory tests, including the Atterberg's Limits, California Bearing Ratio (CBR), Triaxial test, and Proctor compaction test, were conducted to assess the improvement in the geotechnical properties of the clayey soil. The addition of lime to the soil improves its CBR values and shear strength by 128% and 25% respectively. The Optimum Moisture Content increased by 44.24% and the Maximum Dry Density decreased by 14.28%. Hence lime is more cost-effective when used with soil for pavement subgrade.*

Keywords — *Soil stabilization, Lime, California Bearing Ratio, Shear strength, Maximum dry density, Optimum moisture content, Liquid limit, Plastic limit.*

1. INTRODUCTION

Engineers are required to use locally available soils for the pavement foundation while developing and constructing rural highways. This requirement is frequently imposed by the scarcity of high-quality materials, the complexity of traveling, and economic factors. Poor-quality soils exhibit undesirable engineering behaviour, such as low bearing capacity, a tendency of shrinkage and expansion, and high sensitivity to moisture. Pavement construction on poor soil subgrades exhibits early effects that lead to the pavement's early disintegration. It is common practice to stabilize these types of soils using various additives because using high-quality soils as a replacement for the existing foundation material is no longer cost-effective. These sorts of soils are stabilized using a variety of additions, including lime, cement, fly ash, bitumen, and other chemicals [1]. According to several scholars, lime is effective for stabilizing expansive soils [2]. The objective of this experimental study is to determine the amount of improvement in CBR value and shear strength using lime stabilizer to expansive soils. To make weak soil, such as expansive clay, stable and suitable for a certain purpose, soil stabilization includes creating or increasing certain desired features in the soil. It is essential to know about the stabilizing process of the addition to apply soil stabilizers successfully [3]. Lime is commonly used to enhance the qualities of expansive soils. Clay soils can be stabilized by adding lime in the form of quicklime (calcium oxide, CaO), hydrated lime, or lime slurry. Calcium carbonate (limestone, $CaCO_3$) is chemically converted into calcium oxide to create quicklime. When quicklime and water interact chemically, hydrated lime is produced [4].

Clay properties are permanently altered by lime stabilization. Several processes, including cation exchange, pozzolanic reaction, and carbonation, occur when lime is mixed with wet clay [5]. The aggregation of the soil particles, which results in early strength development, is caused by the cation exchange. The pozzolanic reaction, which happens gradually, causes ultimate strength growth. Many factors, including soil type, lime type, lime proportion, and curing conditions (time, temperature, and moisture), affect the characteristics of soil-lime combinations. It was noticed that lime makes the soil more workable and lowers the plasticity index. Further the interaction of lime with soil results in an alteration of the moisture-density relationship, which is dependent on both the soil and the amount of lime used. It was also observed that the compaction curve with lime had a greater density value and lower moisture content than without [6]. Lime is more pozzolanic in nature and reacts with expansive clay more quickly than do other chemical agents; a lower percentage is generally adequate [7].

The UCS was increased by 5.45% with curing period of 7 days and 28 days with lime of 4% [8]. The strength of soils is affected by mineralogical constituents and surrounding environment. The optimum amount of lime for maximum strength gain in stabilizing soil with lime is 4 to 6% for Kaolinite, about 8% for illite and montmorillonite [9]. At 8% and 10% lime content, the addition of lime lowers the plasticity index. The lime-stabilized clay's California bearing ratio (CBR) rises for lime contents of 2–8%, reaching its maximum value at 8%, whereas a reduction in the CBR was seen at 10%. The surplus lime in the clay that was not needed for the early strength gain carried on by flocculation may be the cause of the decrease in CBR at 10% [10]. According to Utami (2014), 10% lime content is effective for enhancing CBR and reducing swelling [11]. The Unconfined compression strength test (UCS), and California bearing ratio test (CBR) were also performed. The CBR value was found to be 5.31% and the UCS value was found to be 36.52 N/cm^2. The liquid limit was found to be 57.2%. It was also observed that the value of MDD and OMC was 1.525gm/cc and 26% respectively [12]. The addition of lime affects its plasticity and also increases the OMC, decreases the MDD, and enhances the CBR [13]. The strength and stiffness are increased by cement and lime, whereas cohesion is significantly enhanced by cement [14]. The maximum dry density and free swell decrease as lime and fly ash content increases, but optimum moisture content and CBR value improve [15]. By adding lime, CBR values at the end of 28 days are increased 16–21 times over those at the start of the experiment. The thick top most layer of the roadways would be reduced by the significant increases in soaking CBR values. Unconfined compression and plate loading tests demonstrate similar improvements [16]. Lime as one of best stabilizing materials [17]. At 14% lime concentration by dry weight of shale, the liquid limit, plasticity index, and maximum dry density decreased; however, the plastic limit, unconfined compressive strength (UCS), and CBR value increased [18]. The combined effects of lime and natural pozzolana can successfully stabilize soft soils. It is cost-effective to use natural pozzolana rather than lime when building a structure [19].

2. MATERIALS AND METHODOLOGY

The main objective of the current investigational study is to stabilize the clayey soil using lime and fly ash to use it safely for a variety of geotechnical and highway engineering tasks, such as having embankments, replacing low-quality soil, filling in depressions, and constructing highways as subgrade material.

The experimental effort was done to accomplish the study's goals. Several laboratory tests were performed on untreated soil and after mixing different percentage of lime to the clayey soil.

2.1 Materials Used

The expansive soil and lime were used as testing materials in the lab. The materials have been collected in Aligarh from various areas.

2.1.1 Soil

The clayey soil was collected for study from the Aligarh. The soil sample was taken from a depth of 2.0 meters below the natural ground's surface. The soil was then pulverized after being dried in an oven. According to the gradation and consistency limit as per IS:2720 (part-4 and part-5)-2013, the soil is categorized as clayey soil compressibility, or CI soil. The soil was air dried, grinded and passed through a 4.75-mm sieve before testing. This soil was then oven dried and passed through a 425-micron sieve. The soil retained on 425-micron was used for different laboratory tests. The geotechnical properties of the clayey soil used are given below in Table 1.

Table 1: Geotechnical properties of plain clayey soil

S. No.	Properties	Values
1	Specific gravity	2.7
2	Optimum moisture content	17.2 %
3	Maximum dry density	16.8 kN/m^3
4	Liquid limit	36.4 %
5	Plastic limit	19.6 %
6	Plasticity index	16.8 %
7	Cohesion	32 kPa
8	Angle of internal friction	4.5°
9	Classification of soil	CI
10	CBR Value	5.1 %

2.1.2 Lime

The lime used in this investigation is a high-grade hydrated lime purchased from local market which fulfils the standard specifications for use in construction. Table 2 shows the chemical properties of lime**.**

Table 2: Chemical properties of lime

S.No.	Element	Weight (%)	Atomic Wt. (%)
1	O	59.37	78.17
2	Na	0.50	0.46
3	Mg	0.76	0.66
4	Si	0.57	0.42
5	S	0.30	0.20
6	K	0.05	0.03
7	Ca	37.42	19.67
8	Mn	0.61	0.23
9	Fe	0.43	0.16
Total		**100.00**	**100.00**

2.2 Methodology

Atterberg limits, specific gravity, and grain size analyses tests were carried out on plain clayey soil and plain clay stabilized with varying proportions of lime (1%, 2%, 3%, 4%, 5%, and 6%).

Standard Proctor compaction, California Bearing Ratio (CBR), and Triaxial shear strength tests were carried out on plain clay and plain clay treated with lime (1% to 6%). The CBR tests were conducted on unsoaked samples. Triaxial shear strength tests were conducted at three confining pressures of 50, 100 and 150 kPa. The soil samples were prepared at OMC as obtained from Proctor test.

3. RESULT AND DISCUSSION

Before laying the foundation of the structure, a geotechnical engineer must perform an accurate analysis of the soil to be used for the design of a structure resting on clayey soil. To analyze and design a foundation, it's essential to know the geotechnical characteristics of the soil where it's constructed

The laboratory tests results of the index properties (grain size analysis and Atterberg's limits) as well as the strength tests (compaction, California bearing ratio, and triaxial shear strength) are explained as follows.

3.1 Effect of lime on Atterberg's limits

Table 3 illustrates the Plasticity Index observations for both plain clayey soil and lime-stabilized clayey soil. For plain clayey soil, the observed liquid limit, plastic limit and plasticity index are 36.4%, 19.6% and 16.8% respectively. Therefore, the soil can be described as clay with medium plasticity. Table 3 demonstrates that the plasticity index of lime stabilized clayey soil decreases by the addition of lime up to certain percentage and then increases. At 4% of lime it achieves a minimum value of 10.2%. Thus, the soil behaves like a clay with low plasticity.

Table 3: Atterberg's limits of plain clayey soil and clay-lime mixes with different proportions of lime

S. No.	Materials	WL (%)	WP (%)	IP (%)
1	Clayey soil	36.4	19.6	16.8
2	99% Clay + 1% Lime	35.8	20.2	15.5
3	98% Clay + 2% Lime	34.3	20.7	13.6
4	97% Clay + 3% Lime	33.4	21.9	11.5
5	**96% Clay + 4% Lime**	**32.9**	**22.7**	**10.2**
6	95% Clay + 5% Lime	33.0	22.3	10.7
7	94% Clay + 6% Lime	33.9	21.9	12.0

3.2 Effect of lime on strength properties

3.2.1 Compaction characteristics

The optimum moisture content (OMC) and maximum dry density (MDD) of plain clayey soil are given in Table 4. It shows that when amount of lime increases, the MDD decreases. Since lime has a lower specific gravity than clayey soil therefore addition of lime to clayey soil significantly reduces the MDD**.**

Further as the amount of lime added to the plain clay increases, the OMC of the clay-lime mixes increased. The hydration processes between the cations of the clay particles and the lime are responsible for the increased OMC.

Table 4. OMC & MDD of plain clayey soil and clay-lime mixes with different proportions of lime

S. No	Materials	OMC (%)	MDD (kN/m^3)
1	Clayey soil	17.2	16.8
2	99% Clay + 1% Lime	21.3	15.6
3	98% Clay + 2% Lime	21.8	15.3
4	97% Clay + 3% Lime	22.0	14.9
5	96% Clay + 4% Lime	23.4	14.6
6	95% Clay + 5% Lime	23.6	14.4
7	94% Clay + 6% Lime	24.8	14.3

3.2.2 California Bearing Ratio

Table 5 shows the CBR values of plain clayey soil and soil-lime mixes of unsoaked soil samples. The addition of lime to the clayey soil in that lime-stabilized clay increases CBR. The addition of lime up to 4% results in an increase of 129% in the unsoaked CBR value. This procedure is thought to be both essential and highly beneficial for giving a more effective subgrade. This increase in CBR may be due to the presence of pozzolanic material in the lime. A decrease in the CBR was seen after 4% lime, too. This decrease in CBR may be brought on by extra lime in the clay that was not needed for the early strength increase carried on by flocculation.

Table 5: CBR values of plain clayey soil and soil- lime mixes at different proportions

S. No	Materials	CBR values(%)
1	Clayey soil	**5. 1**
2	99% Clay + 1% Lime	7.3
3	98% Clay + 2% Lime	8.0
4	97% Clay + 3% Lime	10.2
5	**96% Clay + 4% Lime**	**11.7**
6	95% Clay + 5% Lime	10.9
7	94% Clay + 6% Lime	9.9

3.2.3 Triaxial Shear strength

Table 6 demonstrates the variation of shear strength with addition of lime to the clayey soil. Triaxial shear strength was shown to have significantly increased as a result of lime stabilization. The increase in strength depends on how much lime is used. The expansive soil under examination has a triaxial shear strength that increases from 34.6 kN/m^2 (untreated) to 43.40 kN/m^2 (after 4% lime), thus an increase of shear strength by 25% was observed. By increasing the lime content after 4%, the triaxial shear strength value was decreased to 42.2 kN/m^2 at 6% of lime. The soil's strength was likely reduced by the addition of more finely ground lime.

Table 6. Shear strength for clayey soil- lime mixes at different proportions

S. No	Materials	c (kPa)	ϕ (deg)	τ (kN/m^2)
1	Clayey soil	31.8	4.5	34.6
2	99% Clay + 1% Lime	33.1	6.2	36.9
3	98% Clay + 2% Lime	34.7	7.7	39.5
4	97% Clay + 3% Lime	36.1	9.1	41.7
5	**96% Clay + 4% Lime**	**37.5**	**10.4**	**43.4**
6	95% Clay + 5% Lime	36.4	11.4	42.8
7	94% Clay + 6% Lime	34.7	12.6	42.2

4. CONCLUSIONS

A number of laboratory tests were carried out on plain clay and lime mixed samples of soil for determining the effect of lime on various engineering properties. The outcome of laboratory study is summarised below:

- The results obtained indicate that lime helped to enhance the strength properties of expansive soil.
- The strength and Atterberg limits of the expansive soil were significantly increased by the addition of lime. Furthermore, wherever it is easily accessible and inexpensive, lime should always be used for stabilization.
- Some factors, such as compaction and shear strength parameters, have a significant influence on the strength observed by the CBR and shear strength tests of the lime-treated soil and must be considered while doing earthwork with such materials.
- When the amount of lime increases, the liquid limits decrease, the plasticity index decreases, and strength increases, with 4% lime being the optimum lime amount.
- The use of high-quality lime is advised for treating clays with moderate to medium expansive clays based on economic considerations.
- Lime has immediate effects on soil that could contribute to a decrease in plasticity, less moisture retention, and improved compaction qualities that lead to strength benefits.
- It has been observed that the type of clay mineral present affects how much lime is required to adequately treat the soil to generate higher strength and lower Atterberg's limits.

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