Effect of pH and Curing Time Behaviour on Strength Properties of Soils

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Abstract - *Clay soils are commonly stiff in the dry state, but lose their stiffness when saturated with water. Soft clays are characterized by low bearing capacity and high compressibility. The reduction in strength and stiffness of soft clays causes bearing capacity failure and excessive settlement, leading to severe damage to buildings and foundations. The usual method for soil stabilization is to remove the unsuitable soil and replace it with a stronger material. The high cost of this method has driven researchers to look for alternative methods, and one of these methods is the process of soil stabilization. This paper presents the results of geotechnical and mineralogical investigations on clay soils from Telangana, and effects of pH variations on their shear strength parameters.*

Initially, lime was added in different percentages and laboratory experiments were conducted after curing times. The results indicate that these soils can be stabilized satisfactorily with the addition of about 7 % lime. Also, investigation of the relationship between lime-treated geotechnical properties and lime percentage and curing time demonstrates high regression coefficients for the proposed relationships. Several labo- ratory tests were performed on treated and untreated clay soils with lime mixed with pore fluids with different pH values including 3, 5, 7 and 9. The results of shear strength tests indicated that the undrained shear strength parameters for untreated clays increased considerably if the pore fluid had a high pH (pH = 9) or a low pH (pH = 3). It can also be found that for lime-treated soils, maximum cohesion and friction angle values are achieved at pH = 9.

Key Words: Clay, Lime, pH, Shear strength, hydrochloric acid, ammonia, void ratio

1. INTRODUCTION

Soil is a naturally available material which is used for civil engineering projects. For any structure, the foundation is very important to support the superstructure and therefore it transfers the loads from the superstructure to the substructure. Improving the engineering properties of the soil which is naturally available at the site is known as Soil Stabilization. Soils may be separated into three very broad categories: cohesion less, cohesive, and organic soils. Cohesive soils are identified by very small particle size distribution where surface chemical effects are predominant. The cohesive particles do tend to stick together with each other as a result of water- soil particle interaction and attractive forces between the soil particles. Cohesive soils are therefore both sticky and plastic in nature. Clayey soils cannot be separated by sieve analysis into size categories because no practical sieve can be made with openings so small; instead, particle sizes may be determined by observing settling velocities of the particles in a water mixture. Construction of highways and buildings over soft soils is one of the most common civil engineering problems in many parts of the world since soft soils generally show low strength and high compressibility. To improve the Bearing capacity and CBR by grouting various mineral admixtures are used

In recent years, scientific techniques of soil stabilization have been introduced . Stabilized soil is, in general, a composite material that results from combi- nation and optimization of properties in individual con- stituent materials (Basha et al. 2005). The techniques of soil stabilization are often used to obtain geotechnical materials improved through the addition of such cementing agents as cement, lime or industrial by-pro- ducts such as fly ash and slag, into soil. Extensive studies have been carried out on the stabilization of soils using various additives such as lime and cement. Lime is widely used in civil engineering applications such as road construction, embankments, foundation slabs and piles. Extensive studies have been carried out on the stabil- ization of clay soils using lime As investigated many significant engineering properties of soft soils can be beneficially modified by lime treatment, as lime decreases the plasticity index, increases the workability and shrinkage limit, reduces shrinkage cracking, elimi- nates almost all swelling problems, increases the Cali- fornia Bearing Ratio (CBR) and soil strength, as well as increases permeability of soils. In addition, lime can be extended at deep in situ levels, either in the form of lime column or lime injection.

Quick lime treatment on soft clayey soil improves sta- bility and bearing capacity of soft clay. Lime significantly reduces the swelling potential, liquid limit, plasticity index and maximum dry density of the soil, and increases its opti- mum water content, shrinkage limit and strength. The optimum addition of lime nee- ded for maximum modification of the soil is normally between 1 and 3 % lime by weight, and further additions of lime do not bring changes in the plastic limit, but increase the strength. However, other studies reported the use of lime between 2 and 8 % in soil stabilization .

When lime is added to clay soils in the presence of water, a number of reactions occur leading to the improvement of soil properties. These reactions include cation exchange, flocculation, carbonation and pozzolanic reaction. The cation exchange takes place between the cations associated with the surfaces of the clay particles and calcium cations of the lime. The effect of cation exchange and attraction causes clay particles to become close to each other, forming flocs; this process is called flocculation. Flocculation is primarily responsible for the modification of the engineering properties of clay soils when treated with lime. The lime–clay reactions depend on several factors, such as the mineralogical composition of the clay soil, the quantity of lime employed for treatment, the moisture content of the soil, the curing time and the temperature.

2. MATERIALS AND METHODS

The soil used for the study was clay collected from southern region of RangaReddy Dist Telangana. The studied soil is a residual soil that is collected at a depth of about 0.5 to 1 m, and is normally consolidated. The disturbed soil was excavated, placed in plastic bags, and transported to the laboratory for preparation and testing. Laboratory tests were performed on the clay soils to determine basic properties. The clay obtained was light brown in color, and extreme precautions were taken during sampling to keep the clay in its natural water conditions. A particle size distribution curve of telangana clay is shown in Fig.1. The grain size distribution of untreated (natural) soil samples indicates that the soil is composed of 12 % sand, 65 % silt and 23 % clay, which can be classified, according to ASTM (American Society for Testing and Materials) D422 (1990), as CL. Properties of untreated clay are shown in Table 1. The lime used for the study is hydrated lime or $Ca(OH)2$ in the form of fine powder.

In this work, a number of specimens from the natural clay samples were investigated. To investigate the effect of lime on geotechnical properties of these soils, lime was added to each specimen at room temperature, in the order of 1, 3, 5 and 7 % by weight. The lime was thoroughly mixed by hand until homogeneity was reached, and the mixture was quickly stored in a large plastic bag to prevent loss of moisture content. After preparing the mixture of soil and lime, curing time was allowed. At the end of the curing time (7, 15, 30 and 45 days), the remolding operation for specimens' preparation for uniaxial compressive and direct shear test in maximum dry density was performed, and lime-treated soil specimens were tested. The geotechnical experiments conducted in the present study include grain size analysis, unconfined compressive tests and compaction test. All tests were conducted in accordance with the ASTM (1990–2000).

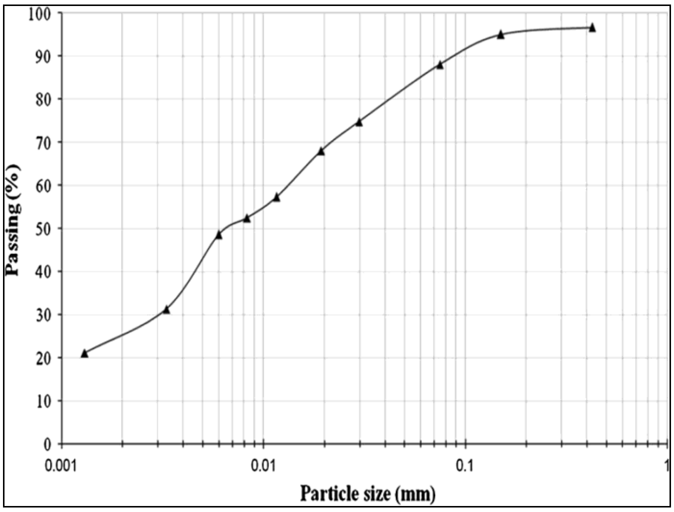

Fig -1: Grain size distribution

Table -1: Basic properties of untreated clay

Property	Value
Natural moisture content (%)	9.2
Color	Light brown
Clay (%)	23
Silt (%)	65
Sand (%)	12
LL (%)	32
LP (%)	22
IP (%)	10
Specify gravity	2.55
Maximum dry density (g/cm^3)	1.74
Optimum moisture content (%)	19.6
Uniaxial compressive strength (KPa)	14.2
Soil classification	CL

3. RESULTS AND DISCUSSION

3.1 Compaction test

The compaction characteristics of clay soils were studied in the laboratory using standard Proctor test based on the ASTM D698 (2000). Compaction tests to determine the effect of lime on maximum dry density and optimum moisture content were carried out on soils after 7, 15, 30 and 45 days, after mixing with 1, 3, 5 and 7 % lime by weight. The results are plotted in Fig. 2a, b in the form of maximum dry density and optimum moisture content versus lime content. The results obtained from the study show that with increasing lime content, maximum dry density shows a decreasing trend and reduced ratio depending on the lime content and curing time. It can also be seen from Fig. 2b that optimum moisture content increases with the increase of lime percent and curing time.

The following reasons could explain this behavior: (1) the lime causes aggregation of the particles to occupy larger spaces, and hence alters the effective grading of the soils; (2) the specific gravity of lime is generally lower than the specific gravity of soils tested; (3) the pozzolanic reaction between the clay present in the soils and the lime is responsible for the increase in optimum moisture content.

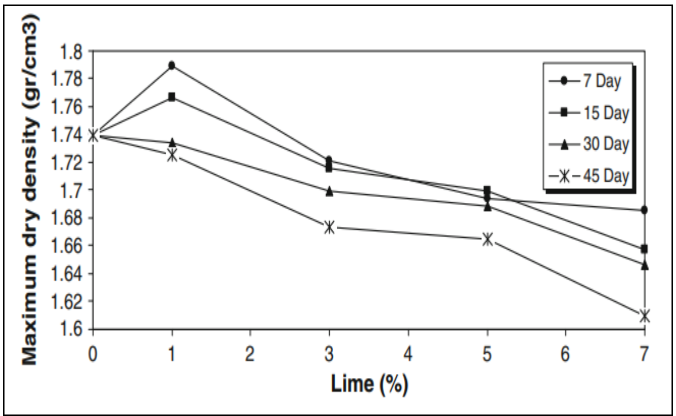

Fig -2-a: The effect of lime content on maximum dry density

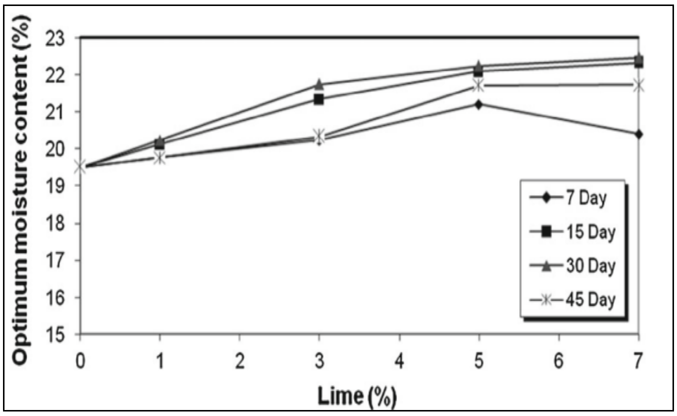

Fig -2-b: The effect of lime content on optimum moisture content

3.2 Uniaxial compressive strength

The uniaxial compressive strength (UCS) of untreated clay was estimated to be around 14.24 kPa, which indicates a very soft soil. In order to investigate the effect of lime on uniaxial compression strength of these soils, tests were carried out according to ASTM D2166 (2000) on clayey samples mixed with different percentages of lime. The amount of lime added to the clay was in the range of 1–7 %. To prepare the specimens for uniaxial compressive strength test, at the end of the each curing time, the samples were remolded in maximum dry density derived from compaction test (1.74 g/cm3), and then samples were tested. The results show that the stress–strain curves of untreated soils exhibit a continuous deformation until a steady state is reached; with no true failure points observed (Fig. 3). This is in agreement with the behavior of normally consolidated soils, which do not exhibit pronounced stress– strain peaks. Figure 3 also shows that the stress–strain curves of lime-treated soils exhibit gradual pronounced peaks, depending on the lime percent and curing time, which are attributed to the cementation of soil particles due to pozzolanic reactions mentioned earlier. It can also be seen from Fig. 4a, b that UCS increases with the increase of lime percent and curing time. For example, with the addition of 7 % lime, a considerable improvement in UCS was achieved after a curing time of 30 days. Therefore, the optimum lime content and proper curing time for lime-treated soils is at least 7 % and 30 days, respectively. Figure 5 also shows that elastic modulus (Es) increases with the increase of lime content. As shown in Fig. 4b, an increase in curing time has not resulted in any significant increase in strength of treated soil, and also there is a reduction in strength when curing time is 45 days. The reason for this phenomenon could be that because sample preparation, compaction and remolding is done after curing period, the bonds and cohesion between soil particles caused by the addition of lime may be destroyed.

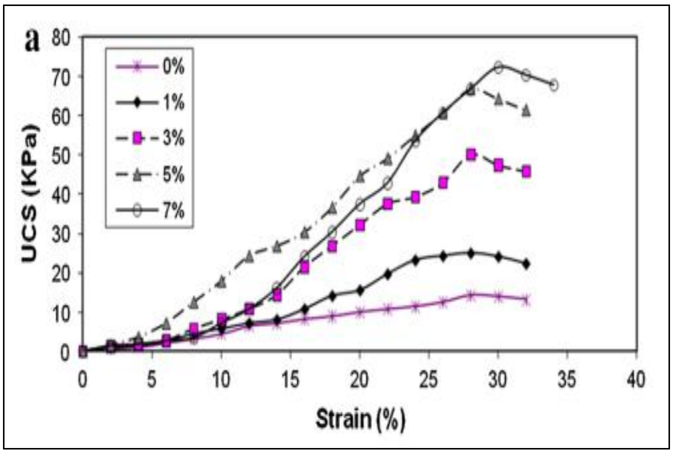

Fig -3-a: Stress-strain curves of untreated and lime-treated clay soils for curing time of 7 days

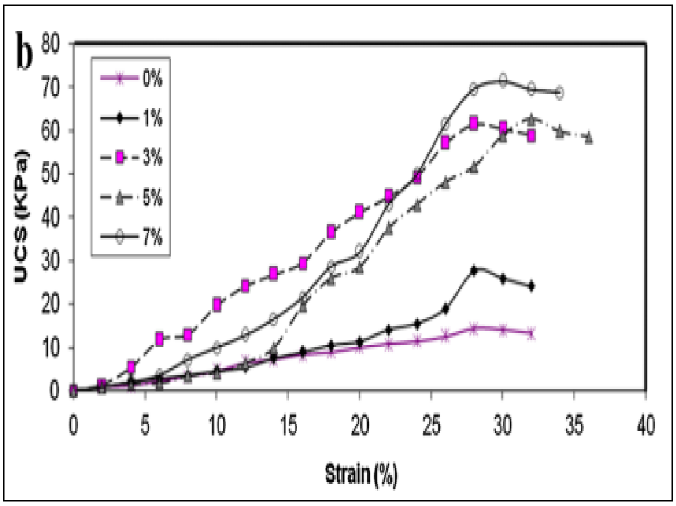

Fig -3-b: Stress-strain curves of untreated and lime-treated clay soils for curing time of 15 days

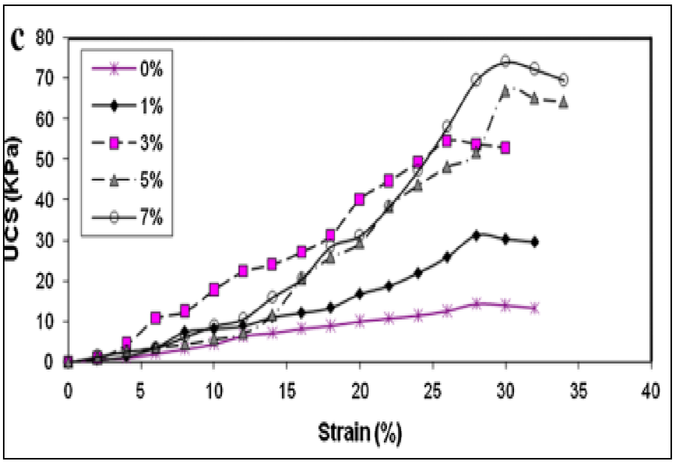

Fig -3-c: Stress-strain curves of untreated and lime-treated clay soils for curing time of 30 days

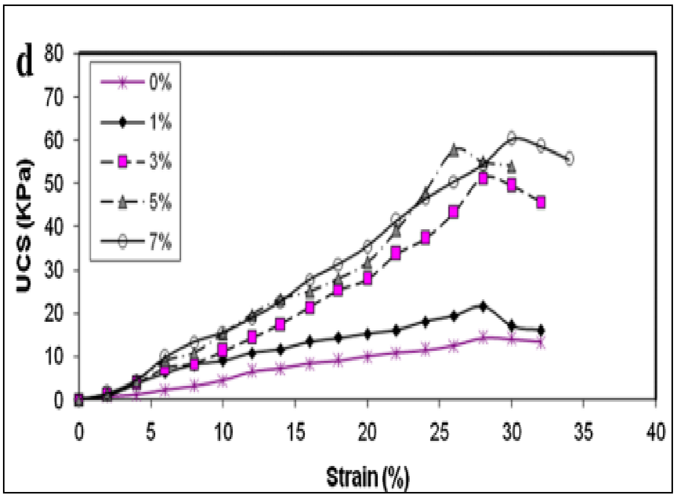

Fig -3-d: Stress-strain curves of untreated and lime-treated clay soils for curing time of 45 days

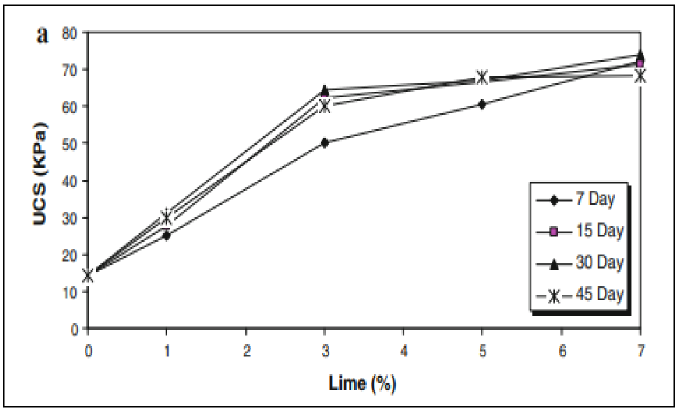

Fig -4-a: Effects of lime percent

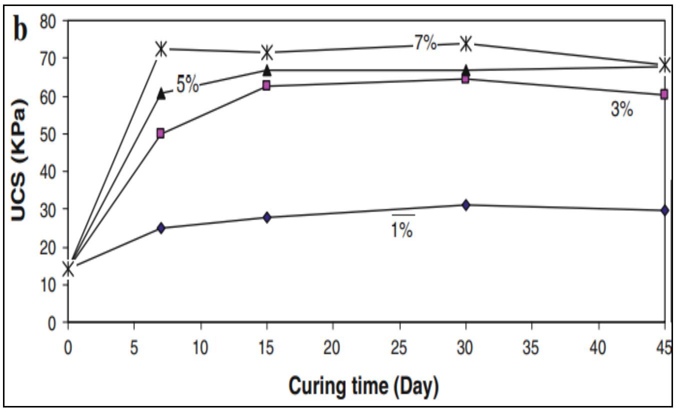

Fig -4-b: Effects of curing time on unconfined compressive strength

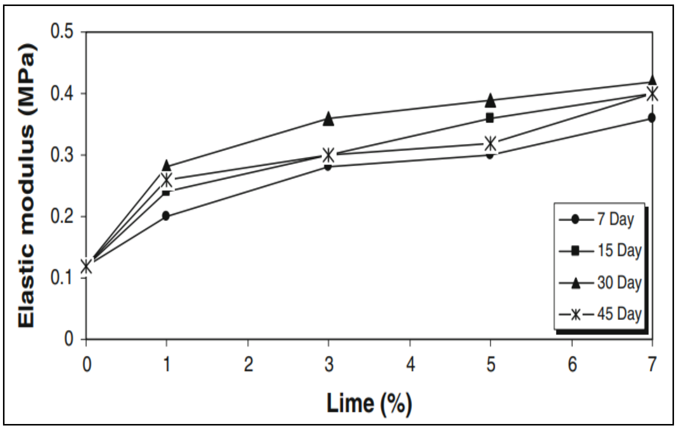

Fig -5: Effects of lime percent on the modulus of elasticity Effect of pH variations on soil shear strength

3.3 Effect of pH variations on soil shear strength

In this research, several laboratory tests were performed on untreated and treated lime clay soils mixed with pore fluids with different pH values. The pH was determined using a combined glass electrode (portable pH-meter). The pH values that were used in this study varied from 3 to 9 using 1 M HCl or 1 M NaOH solutions to control the pH.

In order to investigate the relationship between pH variations and shear strength parameters of untreated soils, direct shear tests were performed, and were conducted on treated and untreated samples compacted at maximum dry density and optimum moisture content. The normal stress was chosen to be 0.5, 1.0 and 2.0 kg for all the specimens. The results of tests indicate that the undrained shear strength parameters for untreated clays increased considerably if the pore fluid had a high pH (pH = 9) or a low pH (pH = 3). The results of undrained shear strength for untreated soils are shown Figs. 6 a & b. As can be seen in Fig. 6.a, for untreated clay soils at high and low pH, the undrained shear cohesion reaches 35 and 45 kPa. According to Jasmund and Lagaly (1993), through the addition of NaOH, a negative charge at the edges arises and edge (-)/face (+) contact occurs, such that the viscous resistance increases. This phenomenon has led to an increase in shear strength parameters of soils. The possible mechanism that could be accepted in relation to increasing shear strength parameters in low pH values has been explained by Brandenburg and Lagaly (1988). According to this assumption, due to occurrences of edge-to-face flocculation at pH lower than 4 and an increment in H+ concentration, the materials become slightly stiffer than when the pore fluid is only water.

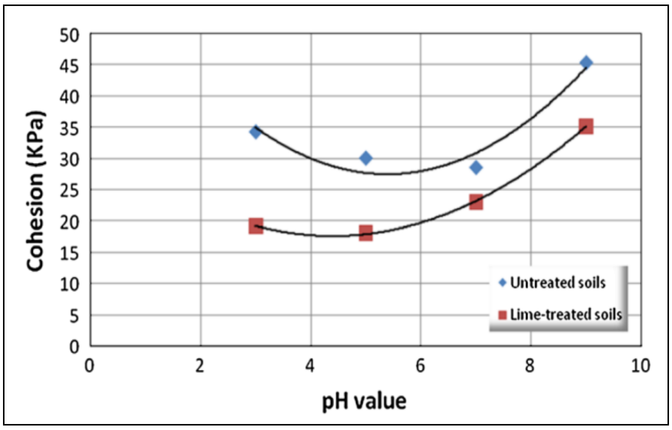

Fig -6-a: The relationship between pH pore fluids and undrained cohesion of clay soils

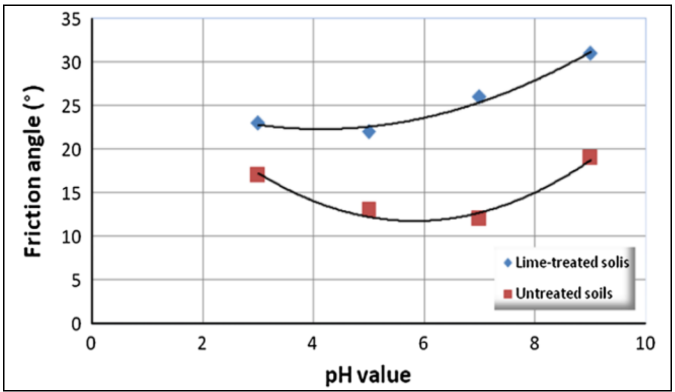

Fig -6-b: The effect of pH variations on the friction angle of clay soils

In order to investigate the pH effect on lime-treated soils, soils treated at curing time of 30 days and lime percent of 7 % were selected. Shear strength parameters of these soils were determined using direct shear tests in different pH values of pore water (pH = 3, 5, 7 and 9). The results of direct shear tests performed on lime treated soils are shown. With a decrease in pH, the free Ca2+ions were almost completely leached and the adsorbed Ca2+ ions began to leach. This change resulted in a significant decrease in the strength of the stabilized soils. The shear strength parameters decreased considerably when the pH values decreased to less than 3.0. The free and absorbed, even hydrated, Ca2+ ions were sharply released to leach under the increased acidic condition (pH = 3) and this reaction caused a great decrease in strength (Kamon et al. 1996). As can be seen in Figs. 6 a & b, the values of undrained cohesion and friction angle increased with an increase in the pH values of the pore fluid. The maximum cohesion and friction angle values were achieved at pH 9. This relationship explained the fact that the neutralization of lime-stabilized soils resulted in a decrease in shear strength parameters. It is evident that the alkalinity is an effective agent for stabilization of clay soils.

4. CONCLUSIONS

The results of geotechnical investigation on lime-treated soft clay soils from Telangana, were investigated and discussed. Lime was added in the order of 1, 3, 5 and 7 % by weight, and experiments after 7, 15, 30 and 45 days were conducted. Relationships that correlate the geotechnical properties of lime-treated soils were developed. In addition, the research explored the influence and the effect of the pH of pore fluids on the shear strength of clay soils. The study has led to the following conclusions regarding lime-treated clay soil. The results obtained from the study show that with increasing lime content, maximum dry density shows a decreasing trend and reduced ratio depending on the lime content. In addition, the unconfined compressive strength of soil can be increased by nearly five times by the addition of at least 7 % lime after a curing time of 30 days. Also, a remarkable improvement in modulus of elasticity can be achieved by the addition of lime, depending on the curing time. Overall, the research reported in this study proves that soft Telangana clay can be stabilized satisfactorily with the addition of at least 7 % lime after 30 days of curing time. In order to investigate the effect of pH on shear strength of treated and untreated soils, shear strength parameters of these soils were determined using direct shear test in different pH values of pore water (pH = 3, 5, 7 and 9). Based on the results of undrained shear strength tests for untreated clays, it was found that the undrained shear strength parameters would increase considerably if the pore fluid had a high pH (pH = 9) or a low pH (pH = 3). At an acid pH, this behavior could be related to the increased dissolution of Al3+, which acts as a coagulant increasing the internal resistance, whereas at an alkaline pH, the increasing ionic strength favors face-to-face aggregation. In order to investigate the pH effect on lime-treated soils, soils treated at a curing time of 30 days and lime percent of 7 % were selected. The results of direct shear test in different pH values of pore water (pH = 3, 5, 7 and 9) indicated that with a decrease in pH, the free Ca2+ ions were almost completely leached and the adsorbed Ca2+ ions began to leach. This change resulted in a significant decrease in the strength of the stabilized soils. The shear strength parameters decreased considerably when the pH values decreased to less than 3.0. It was also found that maximum cohesion and friction angle values were achieved at pH 9. It is evident that the alkalinity is an effective agent for stabilization of clay soils.

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