Effect of Lime (Content & Duration) on Strength of Cohesive Soil

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Abstract - *With the availability of better research, materials and equipment, it is emerging as a popular and cost-effective method for soil improvement. Soil stabilization can be explained as the alteration of the soil properties by chemical or physical means in order to enhance the engineering quality of the soil. The main objectives of the soil stabilization is to increase the bearing capacity of the soil, its resistance to weathering process and soil permeability. The long-term performance of any construction project depends on the soundness of the underlying soils. Unstable soils can create significant problems for pavements or structures, Therefore soil stabilization techniques are necessary to ensure the good stability of soil so that it can successfully sustain the load of the superstructure especially in case of soil which are highly active, also it saves a lot of time and millions of money when compared to the method of cutting out and replacing the unstable soil. This paper deals with the complete analysis of the improvement of soil properties and its stabilization using lime.*

Key Words: **Lime, Soil Classification, UCS, Atterberg limits, OMC, MDD, Bearing Capacity.**

1. INTRODUCTION

Soil stabilization is a process of improving the engineering properties of soil up to desired values as per requirement. The main objectives of the soil stabilization is to increase the bearing capacity of the soil. Unstable soils can create significant problems for pavements or structures, Therefore soil stabilization techniques are necessary to ensure the good stability of soil so that it can successfully sustain the load of the superstructure especially in case of soil which are highly active, also it saves a lot of time and millions of money when compared to the method of cutting out and replacing the unstable soil. This paper deals with the complete analysis of the improvement of soil properties and its stabilization using lime.

Soil-lime has been widely used either as a modifier for clayey soils or as a binder. In several cases both actions of lime may be observed. When clayey soils with high plasticity are treated with lime, the Plasticity index is decreased and the soil becomes friable and easy to be pulverised, having less affinity with water. All these modifications are considered desirable for stabilization work. Lime also imparts some binding action even in granular soils. In fine-grained soils there can also be Pozzolanic action resulting in added strength.

When a clay is treated with lime, the various possible reactions are base exchange, coagulation or flocculation, reduction in thickness of water film around clay particles, cementing action and carbonation.

Fine clay particles react with lime and get flocculated or aggregated into larger particle groups which are fairly stable even under subsequent soaking. Plastic clay soils tend to agglomerate more than silty and sandy soils.

Due to this flocculation; the lime-treated clays indicate a different grain size distribution. The changes in plasticity, characteristics of soil-lime mixture also take place simultaneously; total lime required for the changes depends on several factors including soil type.

The maximum dry density of soil-lime mix is decreased by 2 to 3 per cent in terms of untreated soils; however this decrease in dry density with the addition of small proportion of lime does not cause reduction in strength.

Soil-lime is quite suitable as sub-base course for high types of pavements and base course for pavements with low traffic. As in the case of soil-cement, soil-lime also cannot be used as a surface course even for light traffic in view of its very poor resistance to abrasion and impact. Soft lime is quite suitable in warm regions; but it is not suitable under freezing temperatures.

2. OBJECTIVE AND SCOPE OF WORK

In this paper we have found out the suitable percentage of lime content for stabilizing the soil considering the curing period. Use of lime significantly changes the characteristics of a soil to produce long-term permanent strength and stability, particularly with respect to the action of water and frost. The mineralogical properties of the soils will determine their degree of reactivity with lime and the ultimate strength that the stabilized layers will develop. In general, clayey soils are considered to be good candidates for stabilization. Due to there is a reduction in the volume of voids which reduces the porosity and fills the voids that cannot be eliminated resulting in reduction in the permeability. Also there is an increase in the bonding between grains which result in increase in the mechanical strength of soil.

3. LITERATURE SURVEY

As per previous study it can be easily understood that cohesive soil such as clay have low load carrying capacity. So, to overcome this problem some stabilisation techniques are used to stabilise the soil.

Several reinforcing methods are available for stabilizing soils. Therefore, the techniques of soil stabilization can be classified into a number of categories such as physical stabilization, chemical stabilization and mechanical stabilization. There is a rich history of the use of soil stabilization admixtures to improve poor sub grade soil. Improvement in performance by controlling volume change and by increasing strength was in practice (Navale et al. 2016). [1]

According to Eades and Grim (1960), lime-soil chemical reaction has two stages. The first stage, which is known as immediate or short-term treatment, occurs within a few hours or days after lime is added (Locat et al., 1990; Abdi and Wild, 1993). Three main chemical reactions, namely, cation exchange, flocculation-agglomeration and carbonation occur at this stage. The second stage requires several months or years to complete and is thus considered the long-term treatment. Pozzolanic reaction is the main reaction at this stage. The drying of wet soil and the increase in soil workability is attributed to the immediate treatment, whereas the increase in soil strength and durability is associated with the long-term treatment (Locat et al., 1990; Wild et al., 1996; Mallela et al., 2004; Kassim et al., 2005; Geiman, 2005).[2]

The addition of lime to the soil water system produces (Ca^{+2}) and (OH^{-}). In cation exchange, bivalent calcium ions (Ca^{+2}) are replaced by monovalent cations. The Ca+2 ions link the soil minerals (having negative charge) together, thereby reducing the repulsion forces and the thickness of the diffused water layer. This layer encapsulates the soil particles, strengthening the bond between the soil particles. The remaining anions (OH^{-}) in the solution are responsible for the increased alkalinity (George et al., 1992; Mallela et al., 2004; Geiman, 2005). After the reduction in water layer thickness, the soil particles become closer to each other, causing the soil texture to change. This phenomenon is called flocculation-agglomeration (Locat et al., 1990; Geiman, 2005).[3]

The decrease in liquid limit with increasing lime content has been reported by Jan and Walker (1963) and Wang et al. (1963). Meanwhile, Zolkov (1962) reported that lime content increased the liquid limit. Croft (1964) explained that the increase in the liquid limit of lime-treated soil is related to the modification of the affinity of the clay surface to water; such modification is caused by hydroxyl ions. In the same context, Lund and Ramsey (1958) and Taylor and Arman (1960) reported that the increase or decrease in the liquid limit of lime-treated soil depends on the soil type. Nonetheless, the final resultant in all cases is a reduction in plasticity index. Consequently, the soil is converted into a more workable material for excavation, loading, discharging and levelling. In addition, the sensitivity of soil strength to moisture is reduced. [4]

4. THEORY

4.1. SOIL STABILIZATION

Soil stabilization a general term for any physical, chemical, mechanical, biological or combined method of changing a natural soil to meet an engineering purpose. Improvements include increasing the weight bearing capabilities, tensile strength, and overall performance of in-situ subsoils, sands, and waste materials in order to strengthen road pavements. On addition of lime to the soil, the soil suddenly switches from being plastic i.e. yielding and sticky to being crumbly i.e. stiff and grainy. In the latter condition it is easier to excavate, load, discharge, compact and level. The maximum dry density drops, while the optimal water content rises, so that the soil moves into a humidity range that can be easily compacted. This effect is clearly advantageous when used on soils with a high water content. A treatment with quicklime therefore makes it possible to transform a sticky plastic soil, which is difficult to compact, into a stiff, easily handled material. After compacting, the soil has excellent load-bearing properties.

Structures need a stable foundation for their proper construction and lifelong durability. Foundation needs to rest on soil ultimately, transferring whole load to the soil. If weak soil base is used for construction, with passage of time it compacts and consolidates, which results in differential settlement of structure. It may result in cracks in structure which can have catastrophic affect too. To avoid these future problems in weak soil, stabilized soil should be considered.

4.1.1. Methods Of Soil Stabilization:

1) Mechanical Method:

In this category, soil stabilization in achieved by physical process such as alteration and mechanical machines.

- By grading of soil particles i.e. changing composition of soil by adding or removing different soil particles.
- By compaction using devices such as rollers, tempers, rammers.

2) Chemical Stabilization:

In this category, soil stabilization depends on chemical reaction between stabilizer and soil mineral.

It is done to reduce permeability of soil, increase shear strength and enhance bearing capacity by using chemical agents such as, calcium chloride, sodium silicate, cement, lime, bitumen.

- **Calcium Chloride** – It is mainly used in road construction work for stabilizing base and sub base course.

- **Sodium Silicate** – It is mainly used for fine and medium sands. Sodium silicate together with water and calcium chloride is injected for stabling soil deposit which improves the shear strength of soil.

- **Cement** – Cement being the oldest binding agent, is also considered as a primary stabilizing agent and is used to stabilize a wide range of soils. Stabilization process starts when cement is mixed with water, which results in hardening phenomena (hydration of cement). Setting of cement will enclose soil as glue, without changing the structure of soil.

- **Lime** – lime is an economic way of soil stabilization, used mainly in black cotton soils which are highly unstable. Quicklime when mixed with wet soil, immediately takes up water from surrounding to form hydrated lime, generates heat which causes loss of water which in turn results into increased plastic limit of soil.

- **Flyash** – Flyash is byproduct of electric generation plants based on coal fire. These are cheaper, environment friendly and easily available. It has little cementitious property compared to that of lime and cement. But in presence of activator (sodium-based solution) it can react chemically and improve strength in soft soil.

3) Geosynthetics:

Geosynthetics are latest techniques used to stabilize soil strata, made from various types of polymers (Polyethylene, Polypropylene, Polyster, Nylon, and Polyvinyl Chloride)

- GEOTEXTILES are flexible, textile like fabrics of controlled permeability used to provide reinforcement in soil.

- GEOGRIDS are grid like sheets used primarily as reinforcement of unstable soil.

- GEOCELLS are honey combed shape sheets used as a sub base support in soil.

4.1.2. Types of Stabilization:

1) In Situ Stabilization:

The method involves on site soil improvement by applying stabilizing agents without removing the soil. This can be used for deep foundation, shallow foundation, and contaminated sites. This is done by using techniques like grouting and injecting. Grouting is a process in which stabilizers either in the form of a solution or suspension are injected into soil. The choice to either use dry or wet mix depends on in situ soil conditions, in situ moisture content, effectiveness of binders, and nature of construction. Depending on depth of stabilization it may be deep mixing or mass stabilization.

2) Ex Situ Stabilization:

It involves removing of the soil or sediments from the original position and moved to other places. These can be encountered during dredging of river channel and ports. It is normally not done for common structures. Stabilization of soil is very important as ultimately, it is soil which bears the complete load (dead, live, seismic, wind). A structure is finally safe if its foundation is safe. Stabilization of soil may cost you, though it's beneficial to improve the quality of soil if required, rather than to play with the safety of structure and feel guilty for the settlement of structure in near future.

4.2. LIME AS SOIL STABILIZER

Wet, weak, fine grain soil can prove to be a major challenge at many construction sites. Muddy site conditions make for difficult working conditions. Access is difficult for construction vehicles. It's difficult to reach the soil moisture and compaction requirements established by the project civil or geotechnical engineer. Wet, poorly compacted soil makes for poor pavement support and embankment/fill. At a construction site, lost time means lost money.

Lime quickly improves the soil condition during construction and can add long term improvements to key soil properties. Adding lime can cause three major soil improvements.

- Soil Drying – Reducing the soil moisture content
- Soil Modification – Reducing soil plasticity, aiding compaction and increasing early strength
- Lime Stabilization – Increasing long term strength and reducing swell potential

Lime can be used to stabilize pavement subgrade soil containing clay. Lime stabilization generates a long term pozzolanic strength-gaining reaction between lime and the silica and alumina minerals solubilized at high pH from the clay, forming calcium silicates and calcium aluminates. If the subgrade soil or aggregate base lacks suitable reactive clay, it is advantageous to add a coal fly ash pozzolanic material along with the lime.

4.2.1 Economical Benefits of Lime

1. Limitation of the need for embankment materials brought in from outside and the elimination of their transporting costs.
2. Reduction of transport movements in the immediate vicinity of the construction site.
3. Machines can move about with far greater ease. Delays due to weather conditions are reduced, leading to improved productivity. As a result, the overall construction duration and costs can be dramatically reduced.
4. Structures have a longer service life (embankments, capping layers) and are cheaper to maintain.

4.2.2 Advantages of Using Lime

Within few hours, an unstabilized soil can be transformed by lime into a stabilized soil by mixing lime with it which can carry the traffic load sufficiently. An added bonus is that the soil becomes less sensitive to moisture. The building of embankments using moist plastic soils treated with lime can result in considerable savings on materials brought in from elsewhere, often at great cost, and the inevitably high costs of waste soil disposal.

Lime treatment makes it possible to construct good quality capping layers and beds for roads, railway tracks, and runways. Because it is such a simple process, lime-stabilization of soil is easy to apply to "small" works, such as foundations for car parks, industrial platforms, and agricultural and forestry roads.

4.2.3. Factors Affecting Lime Stabilization:

The various factors on which the properties of soil-lime depend are soil type, lime content, compaction, curing and additives, if any.

1. Soil Type:

Various soil properties affect the base exchange characteristics and Pozzolanic action. The proportion of increase in strength in a soil-lime mix depends on the Pozzolane in the soil.

2. Lime Content:

Generally, an increase in lime content causes a slight change in liquid limit and a considerable increase in plastic limit resulting in reduction in plastic limit.

The rate of increase in plastic limit is first rapid and then the rate decreases beyond a certain lime content. This point is often termed lime fixation point.

This is the approximate lime content that is considered to be used up for modification of clay. During this range, the increase in stability of the clay-lime may not be noteworthy. When the lime content in the mix is further increased, there is a high rate of increase in stability.

However, when the lime content is increased beyond a certain proportion, the stability values generally start decreasing.

With proper lime treatment it is possible to make the clay almost non-plastic with plasticity index reducing to practically zero.

Increase in lime content also causes considerable reduction in swelling and increase in shrinkage limit, all these changes are desirable for stabilization of clay.

3. Types of Limes:

After long curing periods, all types of limes produce almost the same effects. However, quick lime (CaO) has been found to be more effective than hydrated lime [$Ca(OH)_2$]. But quick lime has a tendency to cause skin burns of unprotected workmen, and hence need careful handling and protection. Hydrated lime is therefore commonly used in stabilization work, either as a dry powder or by mixing with water.

4. Compaction:

The compacted density is important as regards the strength of soil-lime is concerned. Hence, compaction is done at OMC and maximum density is aimed at.

5. Curing:

The strength of soil-lime increases with curing period upto several years. The rate of increase in strength is rapid during the initial period of curing, which also depends on the curing temperature.

At low temperature the rate of strength gain decreases, considerably. Below the freezing point practically there is no gain in strength. The humidity of the surroundings during curing also affects the strength.

6. Additives:

Addition of lime alone with soil often does not increase the strength of the mix as desired. Portland cement and Pozzolanic materials like fly ash and surkhi are most promising materials in this respect.

Lime-fly ash stabilization is cheap and is a method with considerable scope for the construction of low cost roads in warm regions and where fly ash is available as a waste product.

Chemical additives like sodium metasilicate, sodium hydroxide and sodium sulphate are also found to be useful additives to soil-lime.

5. EXPERIMENTAL INVESTIGATIONS

5.1. EXPERIMENTAL PROCEDURE

The following experiments are conducted based on IS codes
1. Determination of soil specific gravity
2. Particle size distribution by sieve analysis

3. Liquid limit by Cassagrande's apparatus.
4. Plastic limit.
5. Determination of maximum dry density (MDD) and the corresponding Optimum Moisture Content (OMC) of the soil by standard proctor compaction test.
6. Determination of shear strength by unconfined compression test.

5.2. EXPERIMENTAL RESULTS

5.2.1. Results Obtained Without Lime

The Geotechnical properties of the soil obtained from the above experiments are as given below in the table.

Table -1: Geotechnical Properties of Soil

PROPERTIES	TEST VALUES
Specific gravity	2.53
Liquid limit (%)	51.5
Plastic limit (%)	24.89
Max. Dry density (gm/cc)	1.676
Optimum moisture content (%)	18.73
Unconfined Compressive Strength (KPa)	200

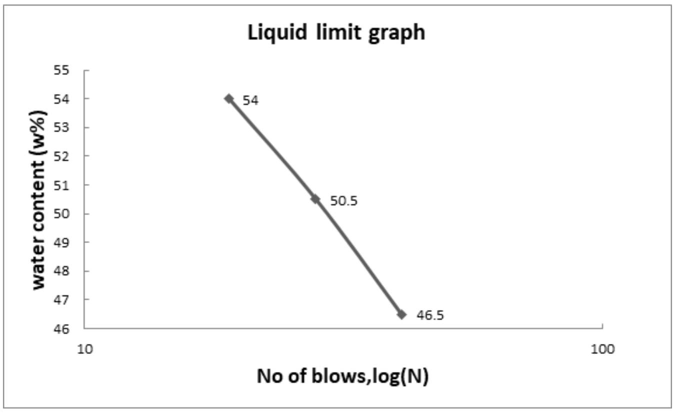

Chart 1: Liquid Limit Graph

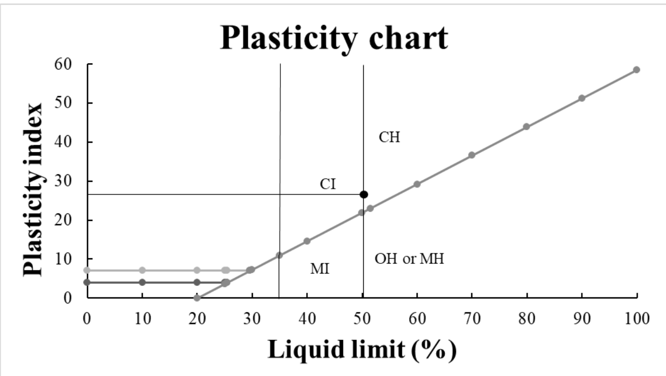

Chart 2: Plasticity Chart

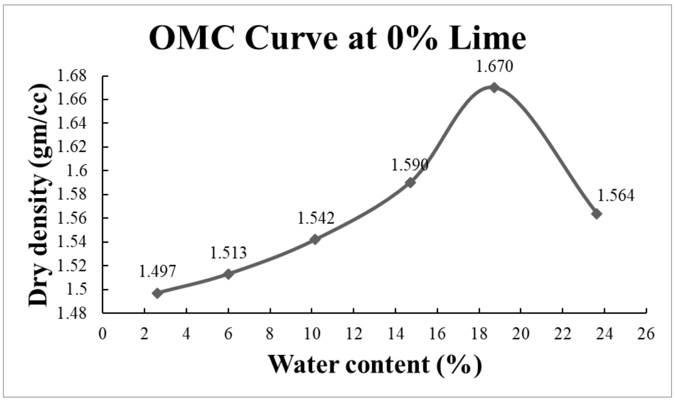

Chart 3: OMC Curve

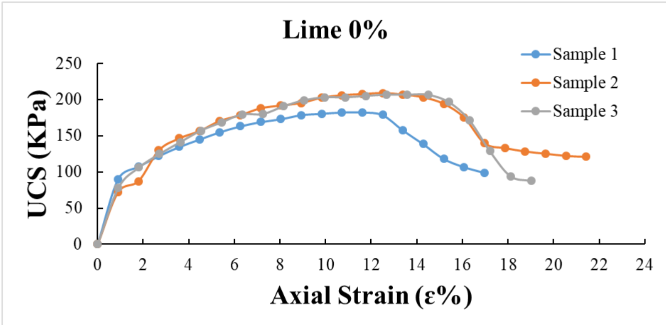

Chart 4: UCS Curve

5.2.2. Experimental Investigations After Mixing Lime

Mix proportion of lime and soil used for stabilizing the soil.
2% Lime by the weight of soil,
4% Lime by the weight of soil,
6% Lime by the weight of soil, and
8% Lime by the weight of soil

5.2.3. Results Obtained With Lime

Table -2: Atterberg Limits

Lime Content(%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index
0	51.50	24.89	26.61
2	43.60	21.54	22.04
4	43.30	21.86	21.44
6	44.40	19.59	24.81
8	46.20	18.68	27.52

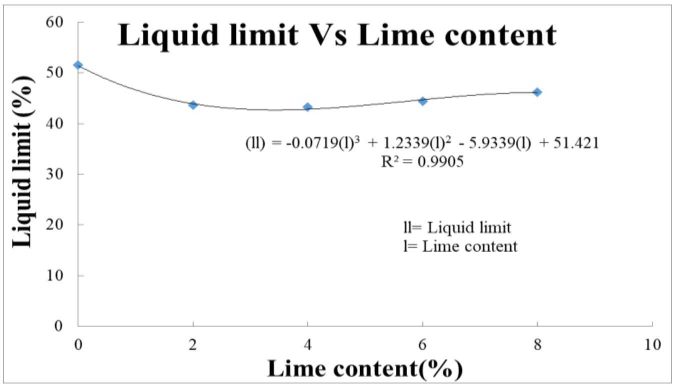

Chart 5: Liquid Limit vs Lime Content Curve

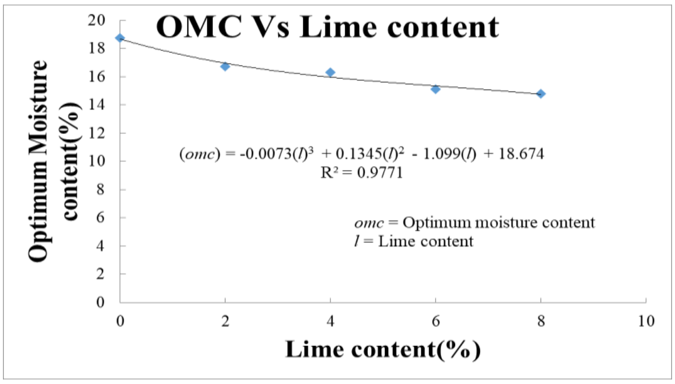

Chart 6: OMC vs Lime Content

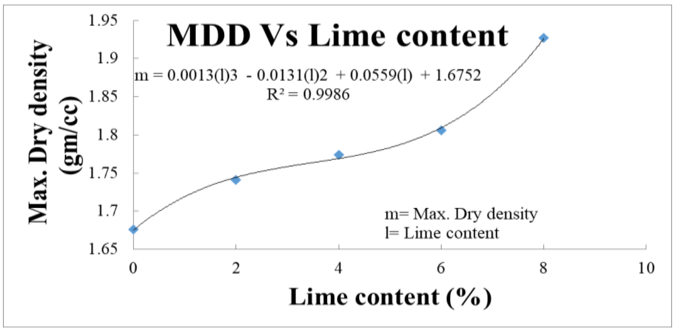

Chart 7: MDD vs Lime Content

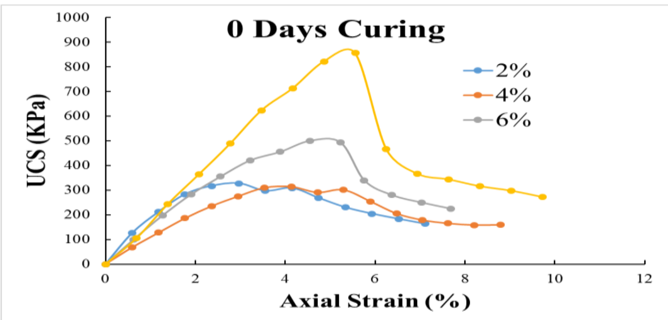

Chart 8: UCS Curve (0 Days Curing)

Table -3: UCS (0 Days Curing)

0 Days	
Lime content (%)	**UCS (KPa)**
2	314.034
4	327.582
6	500.014
8	855.706

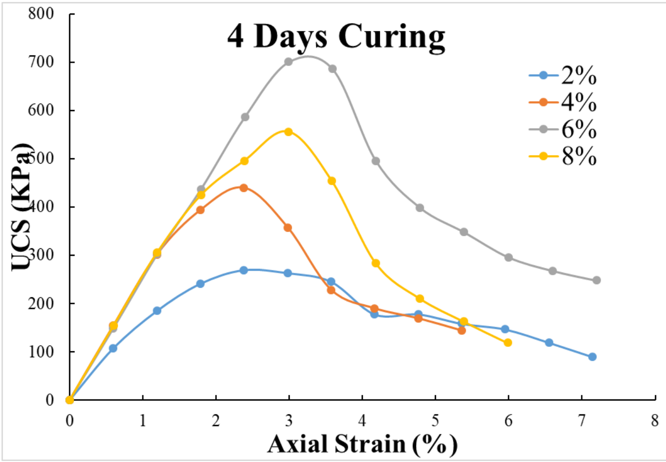

Chart 9: UCS Curve (4 Days Curing)

Table - 4: UCS (4 Days Curing)

4 Days	
Lime content (%)	**UCS (KPa)**
2	269.668
4	439.457
6	700.495
8	556.056

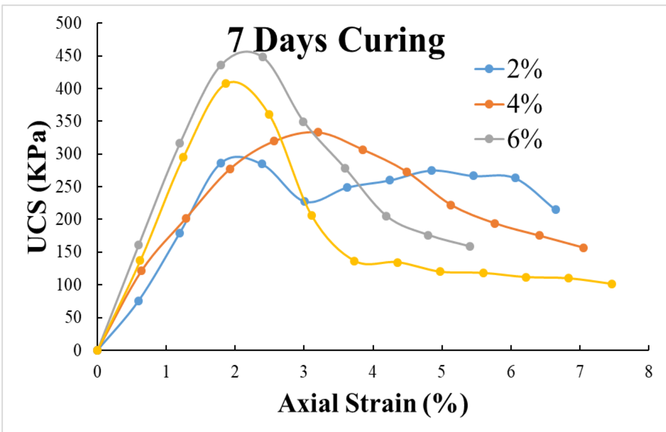

Chart 10: UCS Curve (7 Days Curing)

Table -5: UCS (7 Days Curing)

7 Days	
Lime content (%)	**UCS (KPa)**
2	286.628
4	333.042
6	447.856
8	407.998

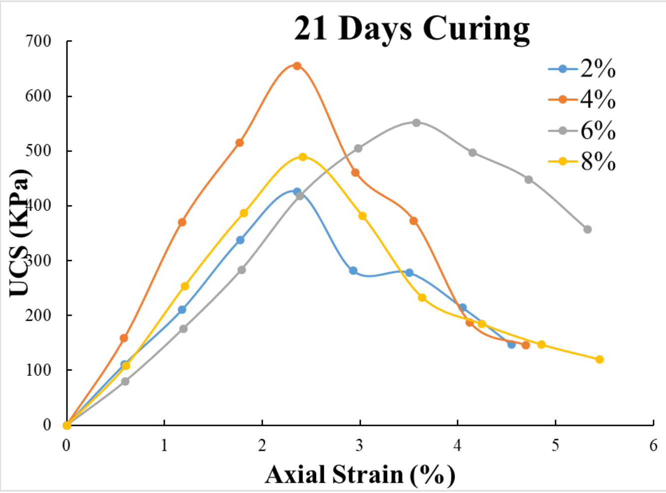

Chart 11: UCS Curve (21 Days Curing)

Table -6: UCS (21 Days Curing)

21 Days	
Lime content (%)	**UCS (KPa)**
2	427.176
4	655.392
6	521.825
8	488.853

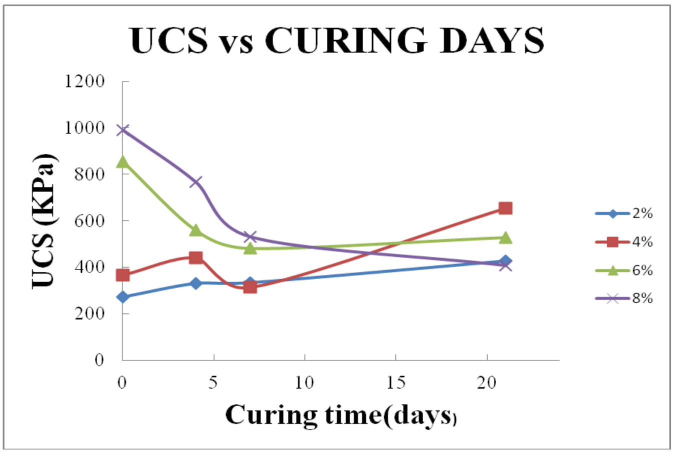

Chart 12: UCS vs Curing Days Curve

6. CONCLUSIONS

From the experimental investigation done on our soil collected from the banks of River Ganges near Belurmath, Kolkata. We found that our soil was fine grained soil from Seive and Sedimentation analysis. From further tests it was found that the soil was highly plastic clay (CH) as obtained by A-line curve having plasticity index of 26.66 which is above the plasticity index obtained by A-Line equation.

From the initial tests performed on the soil we got the value of Specific gravity as 2.53, Optimum moisture content as 18.73%, Maximum Dry density as 1.676gm/cc , Liquid limit as 51.5%, Plastic limit as 24.89%, Plasticity index as 26.66 and Unconfined compressive strength as 200 KPa.

Lime generally improves the engineering performance of soils. However, in some cases, lime has been reported to have an adverse effect. To develop an understanding of the possible mechanisms involved, a series of experiments through careful variation of different parameters were carried out, based on which the following conclusions are drawn:

1. When lime is added in small quantity, at approximately 2%, the strength improvement is practically negligible. Therefore, cementation is too weak, giving rise to marginal strength gain. With increased lime content, the pozzolanic reaction peaks, producing adequate amounts of cementitious compounds that result in visible strength increases.

2. With 4% lime content initially there is a gradual decrease in the strength upto 7 days and as the curing period progresses strength reaches to its maximum value at 21 days curing.

3. With 6% lime content strength increases gradually showing some deflection around 7 days of curing and after that it increases till 21 days of curing.

4. With 8% lime content a reduction in strength takes place that is more pronounced at prolonged curing. At this lime content the strength is maximum at 0 curing days.

After seeing the results one can observe that an excess amount serves as a lubricant to the soil particles and thereby decreases the strength. Lime produces cementitious gel that has substantial volume of pores upon reacting with soil. At very high lime content, an overall decrease in strength occurs from excessive formation of this gel material.

From the overall experimental observation we observed that the strength gained is maximum for about 4 – 6% lime content as the curing period progresses. As we all know that wherever there is a requirement of soil stabilization, the construction work will start after the curing period is over or we can say that after gaining the required strength to avoid any kind of failure. From our experiment we can say that after 21 days of curing the strength is maximum at 4-6 % lime content. Hence, the soil which we have tested should be treated with 4-6% lime and cured for about 21 days prior any construction activities on it.

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