STUDY OF SOIL STABILIZATION BY CHEMICAL ADMIXTURES AND SAND

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CERTIFICATE

This is to certify that project report entitled “**Study of Soil Stabilization By Chemical Admixtures And Sand**” submitted by Mohit Rana and Ashish Agarwal in partial fulfillment for the award of degree of Bachelor of Technology in Civil Engineering to Jaypee Universityof Information Technology, Waknaghat, has been carried out under my supervision.

This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

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ABSTRACT

Soil stabilization refers to the change in the physical and chemical properties of soil . It aims at improving soil strength and increasing resistance to softening by water through bonding the soil particles together, water proofing the particles or combination of the two . Usually, the technology provides an alternative provision structural solution to a practical problem. There are many techniques for soil stabilization like compaction , dewatering , adding material to the soil. We have focused on adding chemicals (lime , cement) and sand to the soil as well. We have performed tests like CBR , Light Weight Proctor test etc to notice the change in properties of soil . Different admixtures have different effect on soil properties. We have determined which admixture is very suitable for specific property of soil.

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Chapter 1: Soil Stabilization

1.1 Introduction

Soil stabilization is a way of improving the weight bearing capabilities and performance of in-situ sub-soils, sands, and other waste materials in order to strengthen road surfaces. The prime objective of soil stabilization is to improve the California Bearing Ratio of in-situ soils by 4 to 6 times. The other prime objective of soil stabilization is to improve on-site materials to create a solid and strong sub-base and base courses. In certain regions of the world, typically developing countries and now more frequently in developed countries, soil stabilization is being used to construct the entire road.

In the past, soil stabilization was done by utilizing the binding properties of clay soils, cement-based products, and/or utilizing the "rammed earth" technique and lime. As technology evolved, there have now emerged new types of soil stabilization techniques, many of which are classified as "green technologies".

Some of the ‘green technologies’ are: enzymes, surfactants, biopolymers, synthetic polymers, co-polymer based products, cross-linking styrene acrylic polymers, tree resins, ionic stabilizers, fibre-reinforcement, calcium chloride, sodium chloride and more. Some of these new stabilizing techniques create hydrophobic surfaces and mass that prevent prevents road failure from water penetration or heavy frosts by inhibiting the ingress of water into the treated layer

However, recent technology has increased the number of traditional additives used for soil stabilization purposes. Such non-traditional stabilizers include: Polymers Based Products (e.g. cross-linking water-based styrene acrylic polymers that significantly improves the load-bearing capacity and tensile strength of treated soils), Copolymer Based Products, fibre reinforcement, calcium chloride, and Sodium Chloride.

Traditionally and widely accepted types of soil stabilization techniques use products such as bitumen emulsions which can be used as a binding agents for producing a road base. However, bitumen is not environmentally friendly and becomes brittle when it dries out. Portland cement has been used as an alternative to soil stabilization. However, this can often be expensive and is not a very good "green" alternative. Cement Fly Ash, Lime Fly Ash (separately, or with Cement or Lime), Asphalt, Bitumen, Tar, Cement Kiln Dust (CKD), Tree resin and Ionic stabilizers are all commonly used stabilizing agents.

There are advantages and disadvantages to many of these soil stabilizers.

Many of the "green" products have essentially the same formula as soap powders, merely lubricating and realigning the soil with no effective binding property. Many of the new approaches rely on large amounts of clay with its inherent binding properties. Bitumen , tar emulsions, asphalt, cement, lime can be used as a binding agents for producing a road base. When using such products issues such as safety, health and the environment must be considered. The process of soil stabilization refers to changing the physical properties of soil in order to improve its strength, durability, or other qualities. Typically, this is important for road construction, and other concerns related to the building and maintenance of infrastructure. Soil that has been stabilized will have a vastly improved weight bearing capability, and will also be significantly more resistant to being damaged by water, frost, or inclement conditions

1.2 Types of Soil Stabilization Techniques

Different types of soil stabilization have been performed for thousands of years; it wasn’t too long after roads were developed that primitive engineers began looking for ways to improve them. Believe it or not, some of the original methods (or at least their spiritual descendants) are still employed today. Let’s take a look at the three basic types of soil stabilization and how they work:

a) Mechanical – The oldest types of soil stabilization are mechanical in nature. Mechanical solutions involve physically changing the property of the soil somehow, in order to affect its gradation, solidity, and other characteristics. Dynamic compaction is one of the major types of soil stabilization; in this procedure a heavy weight is dropped repeatedly onto the ground at regular intervals to quite literally pound out deformities and ensure a uniformly packed surface. Vibro compaction is another technique that works on similar principles, though it relies on vibration rather than deformation through kinetic force to achieve its goals.

Fig 1: Mechanical Stabilization

b) Chemical – Chemical solutions are another of the major types of soil stabilization. All of these techniques rely on adding an additional material to the soil that will physically interact with it and change its properties. There are a number of different types of soil stabilization that rely on chemical additives of one sort or another; you will frequently encounter compounds that utilize cement, lime, fly ash, or kiln dust. Most of the reactions sought are either cementitious or pozzolanic in nature, depending on the nature of the soil present.

Fig 2: Chemical Stabilization

c) Polymer/Alternative – Both of the previous types of soil stabilization have been around for hundreds of years, if not more; only in the past several decades has technology opened up new types of soil stabilization for companies to explore. Most of the newer discoveries and techniques developed thus far are polymer based in nature, such as those developed by Global Road Technology. These new polymers and substances have a number of significant advantages over traditional mechanical and chemical solutions; they are cheaper and more effective in general than mechanical solutions, and significantly less dangerous for the environment than many chemical solutions tend to be. **In our project we are stabilizing the soil using chemical admixture. So, we discuss it one by one in upcoming chapters.**

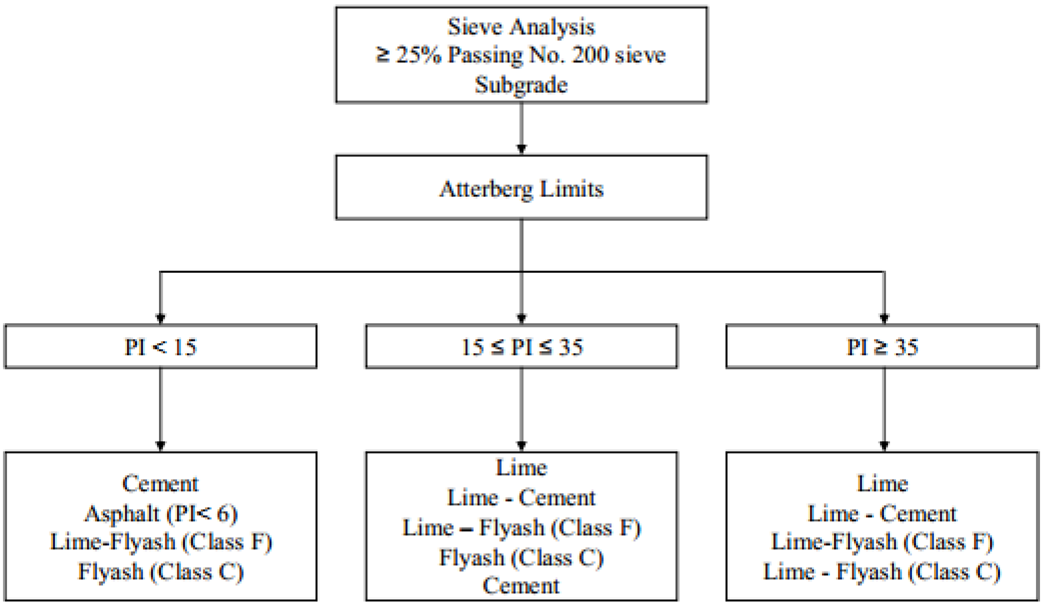


Fig 3: Decision tree for selecting stabilizers for use in sub-grade soils

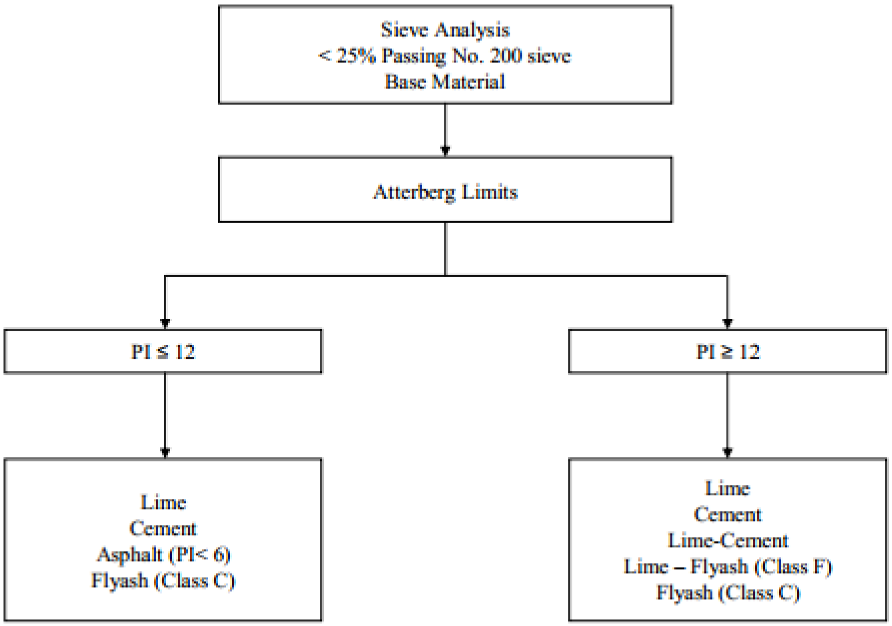


Fig 4: Decision tree for selecting stabilizers for use in sub-grade soils

Chapter 2: Literature Review

2.1. General

Extensive research has been completed pertaining to the use of traditional stabilizers, namely lime and cement. The stabilization mechanisms for lime and cement are well documented, and the effectiveness of these traditional stabilizers has been demonstrated in many applications. However, relatively little research documenting the use of nontraditional stabilizers such as lignosulfonates, synthetic polymers, and magnesium chloride is available, and their performance record is varied. Although much promotional material exists attesting to the effectiveness of nontraditional stabilizers, such materials often lack documentation of measured engineering properties, and often they do not explain the stabilization mechanism involved. This literature review focuses on the known properties of both traditional and nontraditional stabilizers, as relevant to this research. The literature review also discusses factors influencing development of the laboratory test procedures used for this research.

2.2 Lime Stabilization

2.2.1 Stabilization mechanism

Laboratory testing indicates that lime reacts with medium, moderately fine, and fine-grained soils to produce decreased plasticity, increased workability, and increased strength (Little, 1995). Strength gain is primarily due to the chemical reactions that occur between the lime and soil particles. These chemical reactions occur in two phases, with both immediate and long-term benefits. The first phase of the chemical reaction involves immediate changes in soil texture and soil properties caused by cation exchange. The free calcium of the lime exchanges with the adsorbed cations of the clay mineral, resulting in reduction in size of the diffused water layer surrounding the clay particles. This reduction in the diffused water layer allows the clay particles to come into closer contact with one another, causing flocculation/agglomeration of the clay particles, which transforms the clay into a more silt-like or sand-like material. Overall, the flocculation and agglomeration phase of lime stabilization results in a soil that is more readily mixable, workable, and, ultimately, compactable. According to Eades and Grim (1960), practically all fine-grained soils undergo this rapid cation exchange and flocculation/agglomeration reactions when treated with lime in the presence of water.

The second phase of the chemical reaction involves pozzolanic reactions within the lime-soil mixture, resulting in strength gain over time.

When lime is combined with a clay soil, the pH of the pore water increases. When the pH reaches 12.4, the silica and alumina from the clay become soluble and are released from the clay mineral. In turn, the released silica and alumina react with the calcium from the lime to form cement, which strengthens in a gradual process that continues for several years (Eades and Grim, 1960). As long as there is sufficient calcium from the lime to combine with the soluble silica and alumina, the pozzolanic reaction will continue as long as the pH remains high enough to maintain the solubility of the silica and alumina (Little, 1995). Strength gain also largely depends on the amount of silica and alumina available from the clay itself; thus, it has been found that lime stabilization is more effective for montmorillonitic soils than for kaolinitic soils (Lees et. al, 1982). In addition to pozzolanic reactions, carbonation can also lead to long-term strength increases for soils stabilized with lime. Carbonation occurs when lime reacts with carbon dioxide from the atmosphere to produce a relatively insoluble calcium carbonate. This can be advantageous since after mixing, the slow process of carbonation and formation of cementitious products can lead to long-term strength increases (Arman and Munfakh, 1970). However, prior to mixing, exposure of lime to air should be avoided through proper handling methods and expedited construction procedures in order to avoid premature carbonation of the lime (Chou, 1987).

2.3 Cement Stabilization

2.3.1 Stabilization Mechanism

Strength gain in soils using cement stabilization occurs through the same type of pozzolanic reactions found using lime stabilization. Both lime and cement contain the calcium required for the pozzolanic reactions to occur; however, the origin of the silica required for the pozzolanic reactions to occur differs. With lime stabilization, the silica is provided when the clay particle is broken down. With cement stabilization, the cement already contains the silica without needing to break down the clay mineral. Thus, unlike lime stabilization, cement stabilization is fairly independent of the soil properties; the only requirement is that the soil contains some water for the hydration process to begin. Similar to lime stabilization, carbonation can also occur when using cement stabilization. When cement is exposed to air, the cement will react with carbon dioxide from the atmosphere to produce a relatively insoluble calcium carbonate. Thus, similar to lime, proper handling methods and expedited construction procedures should be employed to avoid premature carbonation of cement through exposure to air.

2.3.2 Mixture Design and Strength Characteristics

Unlike lime stabilization, the goal of mixture design using cement stabilization is to find the lowest cement content that will produce a desired strength. Ingles and Metcalf (1972) indicate that strength gain of soil-cement mixtures increases linearly with cement content. Accordingly, many mixture design procedures involve molding and curing specimens at varying cement contents until the lowest cement content which provides the required strength is achieved. However, it was shown by Miura et al. (2002) for soil-cement prepared by the deep mixing method that the primary factor governing the behavior of cement-stabilized soil is the water cement ratio. The water-cement ratio is defined as the ratio of moisture content of the soil to the cement content, with both the moisture content and cement content expressed in terms of dry weight of soil. Test results indicated that increasing water-cement ratio produced decreasing strength of the cement-stabilized soil. For Hong Kong clay, the 28-day unconfined compressive strength, qu, was related to the water-cement ratio, w/c, by the equation qu = 2461 kPa/1.22w/c (Miura et al., 2002). It has also been shown by Mitchell et al. (1974) that the unconfined compressive strength of soil-cement mixtures increases with increasing cement content according to:

qu(t) = qu(t0) + K log t/t0

where : **qu(t)** = Unconfined compressive strength at t days, kPa

qu(t0) = Unconfined compressive strength at t0 days, kPa

K = 480 Aw for granular soils and 70 Aw for fine-grained soils

Aw = Cement content, percent by mass

t = Curing time

Chapter 3: Properties of Sample Soil

3.1 Sample Soil Properties (Black cotton soil)

Fig 5: Black Cotton Soil

We have chosen Black cotton soil for our project work which has been taken from Guna, Madhya Pradesh. Black cotton soils are inorganic clays of medium to high compressibility and form a major soil group in India. They are characterized by high shrinkage and swelling properties. This Black cotton soils occurs mostly in the central and western parts and covers approximately 20% of the total area of India. Because of its high swelling and shrinkage characteristics, the Black cotton soil has been a challenge to the highway engineers. The Black cotton soil is very hard when dry.

Black cotton soils owe their specific properties to the presence of swelling clay minerals, mainly montmorillonite. As a result of the wetting and drying, massive expansion and contraction of the clay minerals takes place. Contraction leads to the formation of the wide and deep cracks. These cracks can be wide enough to make the terrain treacherous for animals. The cracks close after rain when the clay minerals swell. During expansion of the clay minerals high pressures are developed within these soils, causing a characteristic soil structure with wedge shaped aggregates in the surface soil and ‘planar’ soil blocks in the subsoil.

Various tests have been performed on this soil to know its properties. These are as follows:

3.2 Sieve Analysis (IS: 460-1962)

Fig 6: Sieves

Dry and Wet Sieve Analysis of the soil was performed in accordance with IS 2720 (Part 4)-1985 and were classified in accordance with IS 1498-1970.

Classification of soil

- Sieve No 75micron
- Wt. of Soil retained above (W1)= 327gm
- Wt. of Soil that passed (W2) = 673 gm
- Percentage of mass passing = W2/(W1 + W2) = 67%
- It can be classified as a Fine soil

3.3 Specific Gravity determination of Black Cotton Soil (IS : 2720(Par t IV) 1985)

Fig 7: Pycnometer

Wt. of empty pycnometer	W1	446.93 g
Wt. of pycnometer + soil	W2	696.94 g
Wt. of pycnometer +soil +water	W3	1376.42 g
Wt. of pycnometer + water	W4	1220.72 g

Table 1: Pycnometer Test Readings

- Specific Gravity= 2.65

3.4 Liquid Limit (IS : 9259-1979)

Fig 8: Liquid Limit Apparatus

- Mass of soil taken= 120 g
- Mix passing through 425µ sieve is mixed thoroughly with distilled water.

Number of blows	Mass of empty container (g)	Mass of container + soil (g)	Mass of container + dry soil (g)	Moisture content (%)
19	26.1	35.8	39.8	41.15
27	26.4	35.8	39.6	40.33

Table 2: Liquid Limit Test Readings

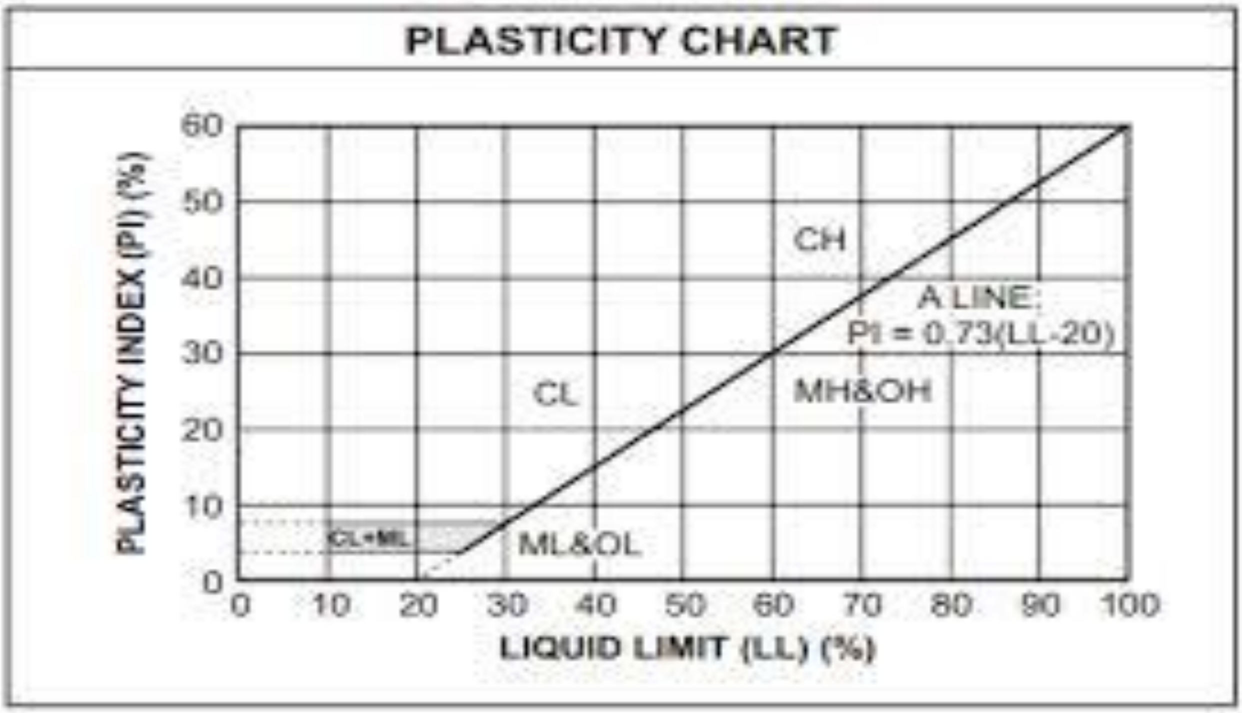
- Formulae used: WL= Wn/(1.3213 – 0.23 log n)
- (For blows between 15-35)

Number of blows	Liquid limit by formulae
19	63.9
27	71.6

Table 3: Liquid Limit Test Readings

Therefore , Liquid Limit = (63.9 +71.6)/2= 67.7 %

3.5 Casagrande's Plasticity chart (USCS)



Graph 1: Plasticity Chart

It is MH (Silt of high Liquid Limit) type of soil according to USCS.

3.6 Plastic Limit Test (IS : 2720(Part V) 1985)

Fig 9: Threads (3mm)

S.No.	Mass of container (g)	Mass of container + wet	Mass of container + dry	Moisture content (%)

		soil (g)	soil (g)	
1.	19.30	20.67	20.25	46.67
2.	19.60	22.45	21.60	42.5

Table 4: Plastic Limit Test Readings

Therefore, plastic limit =(46.67 +42.5)/2 = 44.6 %

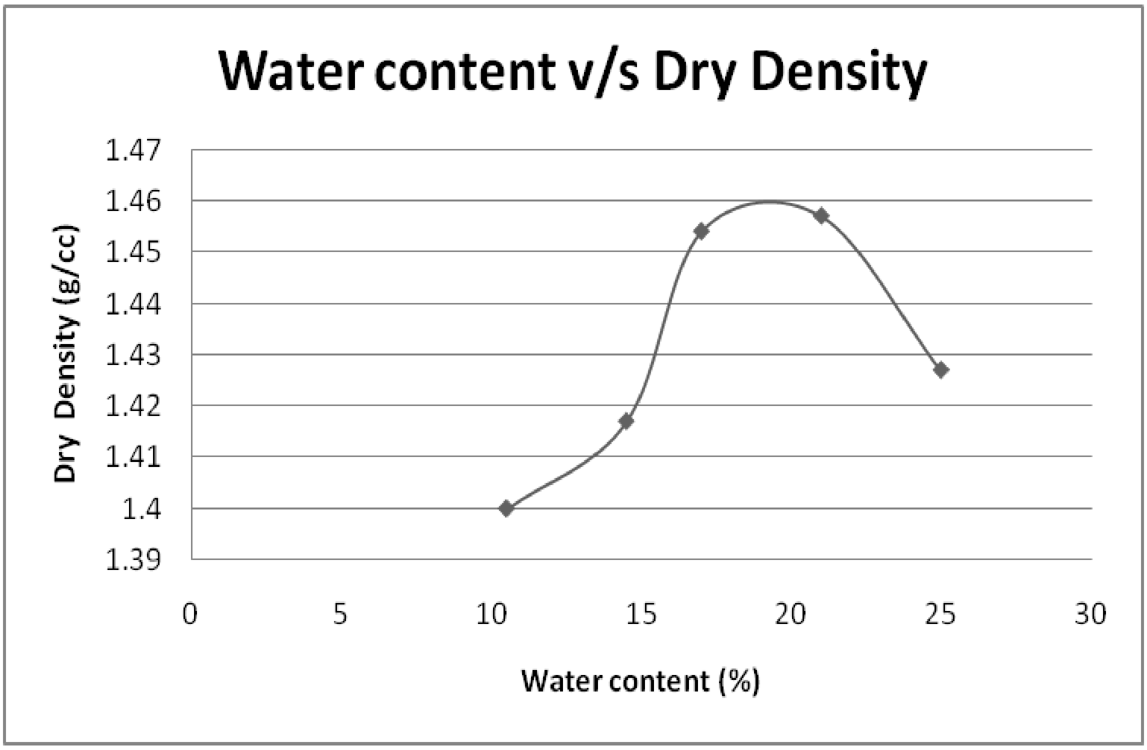
Plasticity Index = 67.7-44.6 = 23.1%

3.7 Proctor Test (IS : 2720(Part VII) 1985)

Fig 10: Proctor Test

S.No.	Water content (%)	Dry density (g/cc)
1.	10.5	1.4
2.	14.5	1.417
3.	17	1.454
4.	21	1.457
5.	25	1.427

Table 5: Proctor Test Reading



Graph 2: Water content v/s Dry Density

From the graph:

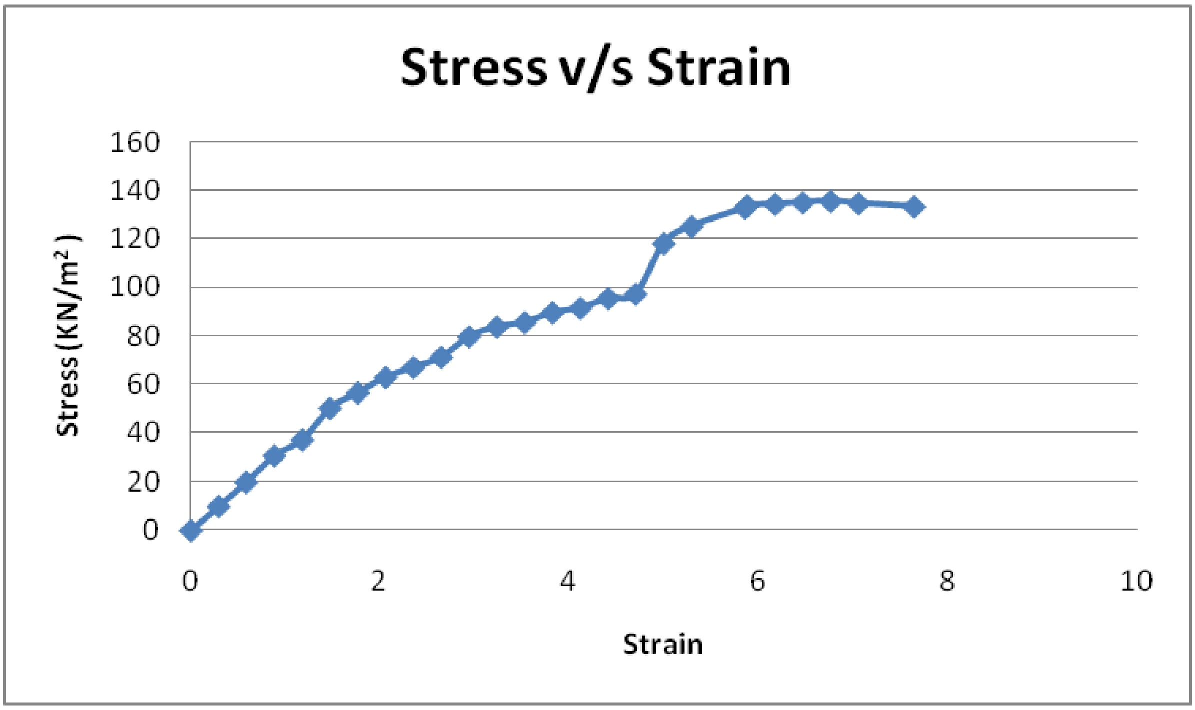
- Value of OMC =18.7 %

3.8 Unconfined compression test (IS : 2720(Part X) 1991)

Fig 11: UCS Machine

Estimated consistency	Ucs (ton/ft2)
Very soft	<0.25
Soft	0.25-0.50
Medium	0.50-1
Stiff	1-2
Very stiff	2-4
Hard	>4

Table 6: Consistency and Ucs Relationship



Graph 3: Stress v/s Strain

Unconfined compressive strength of soil = 135.75 KN/m^2

So, from the table it is stiff type of soil.

3.9 Summary Table

S.No.	Properties	Value
1.	Liquid Limit	67.7 %
2.	Plastic Limit	44.6 %
3.	Plasticity Index	23.1 %
4.	OMC	18.7 %
5.	MDD	1.46 g/cc
6.	UCS	135.75 KN/m^2

Table 7: Summary Table

Chapter 4: Soil Stabilization Using Sand

Fig 12: Sand

First, we determine the basic properties of sand .Then, we have added sand to the Black cotton soil and performed various test to check its properties.

4.1 Sieve Analysis

- Soil is dried in oven for 24 hr
- Mass of soil taken = 1kg

IS Sieve	Mass retained on each sieve (g)	% retained	Cumulative % retained	% finer
4.75 mm	10	1	1	99
2 mm	120	12	13	87
1 mm	210	21	34	66
600 µm	150	15	49	51
425 µm	100	10	59	41
300 µm	65	6.5	65.5	34.5
212 µm	110	11	76.5	23.5
150 µm	120	12	88.5	11.5
75 µm	100	10	98.5	1.5
PAN	10	1	99.5	0.5

Table 8: Sieve Analysis Readings

- D60= 0.8 mm, D30= 270 µm, D10=130 µm
- Coefficient of Uniformity= D60/D10=2.96 (approx)
- Coefficient of curvature=sq(D30)/D10*D60 =0.7 (approx)
- Since, it has fines < 5% and 50 % of soil is passing 4.75mm sieve.
- Therefore, it is well graded sand .

4.2 Liquid limit test

- Mass of soil taken= 120 g
- Mix passing through 425µ sieve is mixed thoroughly with distilled water.

Number of blows	Mass of empty container (g)	Mass of container + soil (g)	Mass of container + dry soil (g)	Moisture content (%)
20	26.4	38.8	35.9	30.5
30	25.3	46.6	41.5	31.5

Table 9: Liquid Limit Test Readings

- Formulae used: WL= Wn/(1.3213 – 0.23 log n)
- (For blows between 15-35)

Number of blows	Liquid limit by formulae
20	30.9
30	30.5

Table 10: Liquid Limit Test Readings

WL= Liquid Limit   Wn= Moisture content   N= Number of blows

- Therefore , Liquid Limit =(30.9+30.5)/2 = *30.7 %*

4.3 Plastic Limit Test

S.No.	Mass of container (g)	Mass of container + wet soil (g)	Mass of container + dry soil (g)	Moisture content (%)
1.	25.3	31.8	30.8	18.1
2.	26.2	30.2	29.6	17.6

Table 11: Plastic Limit Test Readings

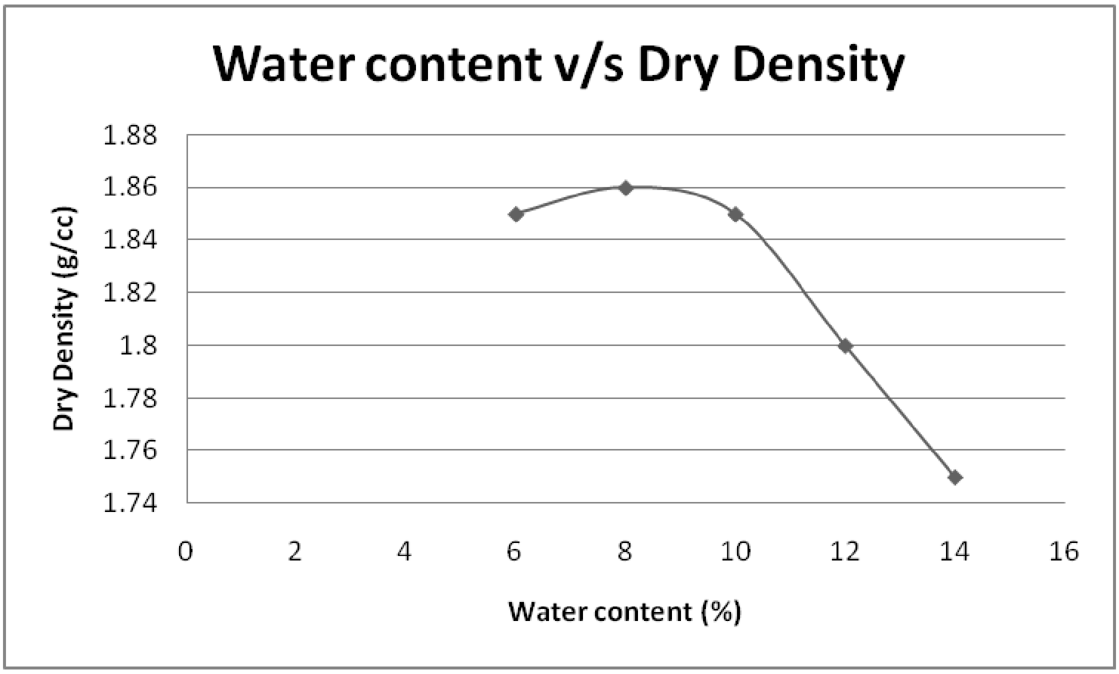
- Therefore, plastic limit =(18.1 +17.6)/2 = 17.8 %
- Plasticity Index = 30.7-17.8 = 12.9%

4.4 Proctor Test (Light Weight)

- IS: 2720 (Part VII) 1980/87
- Height = 12.75 cm
- Internal Diameter = 10 cm
- Rammer mass = 2.6 Kg
- Drop height = 31 cm
- Mass of empty mould = 5520 g
- Mass of soil taken = 2500 g

S.No.	Water content (%)	Mass of soil + cylinder (kg)	Density (g/cc)	Dry density (g/cc)
1.	6	7.500	1.98	1.85
2.	8	7.530	2.01	1.86
3.	10	7.560	2.04	1.85
4.	12	7.540	2.02	1.80
5.	14	7.520	2	1.75

Table 12: Proctor Test on Sand



Graph 4: Water content v/s Dry density

- From the Graph: Value of Optimum Moisture Content (OMC) = 8%

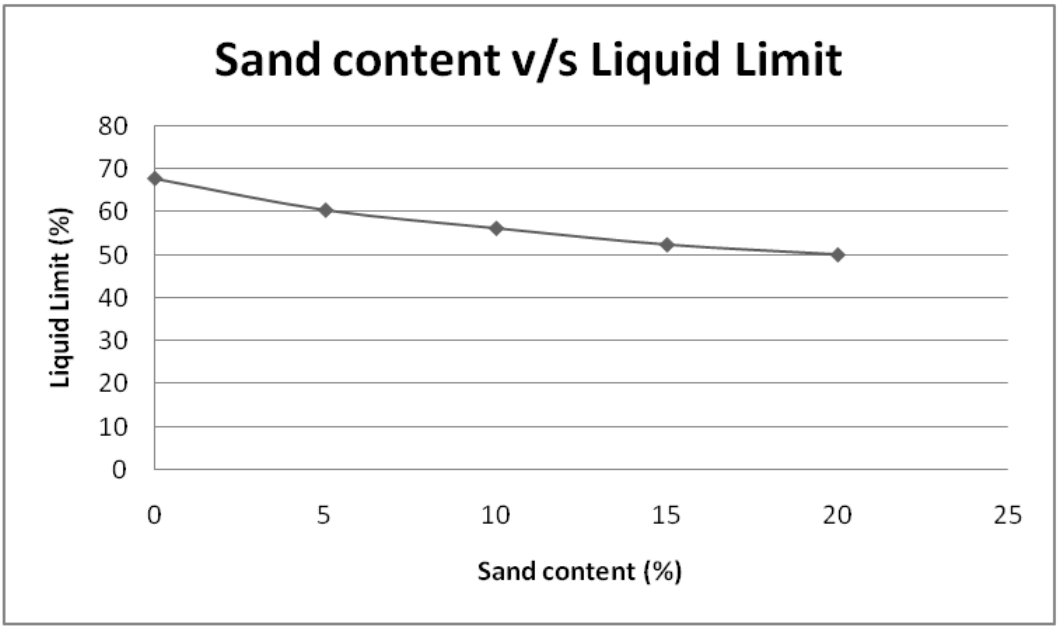
4.5 Tests with Sand

4.5.1 Liquid Limit Test

- Mass of soil taken= 120 g
- Mix passing through 425 µm sieve is mixed thoroughly with distilled water.

S.No.	Sand content (%)	Liquid Limit (%)
1.	0	67.7
2.	5	60.4
3.	10	56.2
4.	15	52.4
5.	20	50.1

Table 13: Effect of Sand content on Liquid Limit

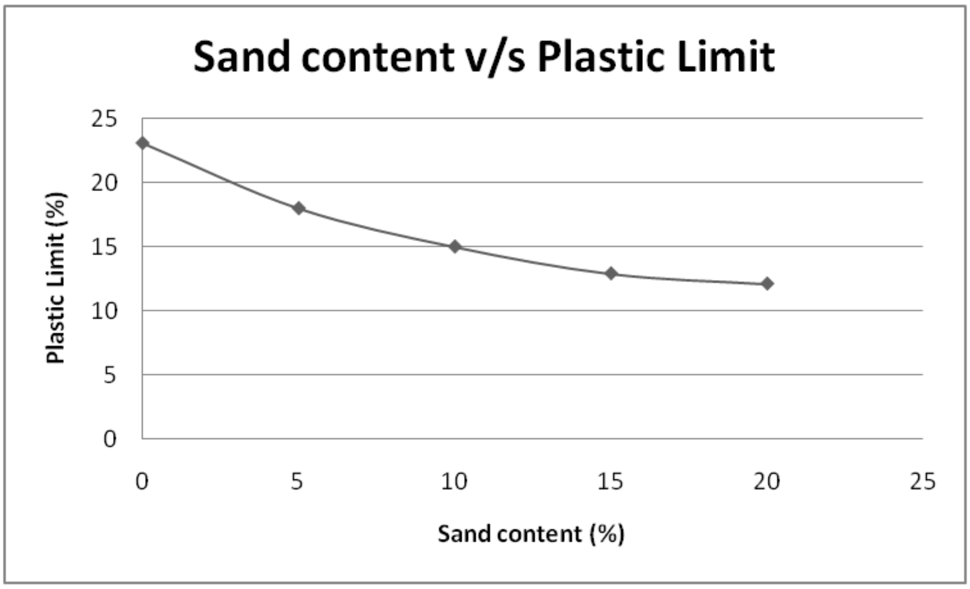


Graph 5: Sand content v/s Liquid limit

4.5.2 Plastic Limit Test

S.No.	Sand content (%)	Plastic Limit (%)
1.	0	44.6
2.	5	42.4
3.	10	41.2
4.	15	39.5
5.	20	38

Table 14: Effect of Sand content on Liquid Limit

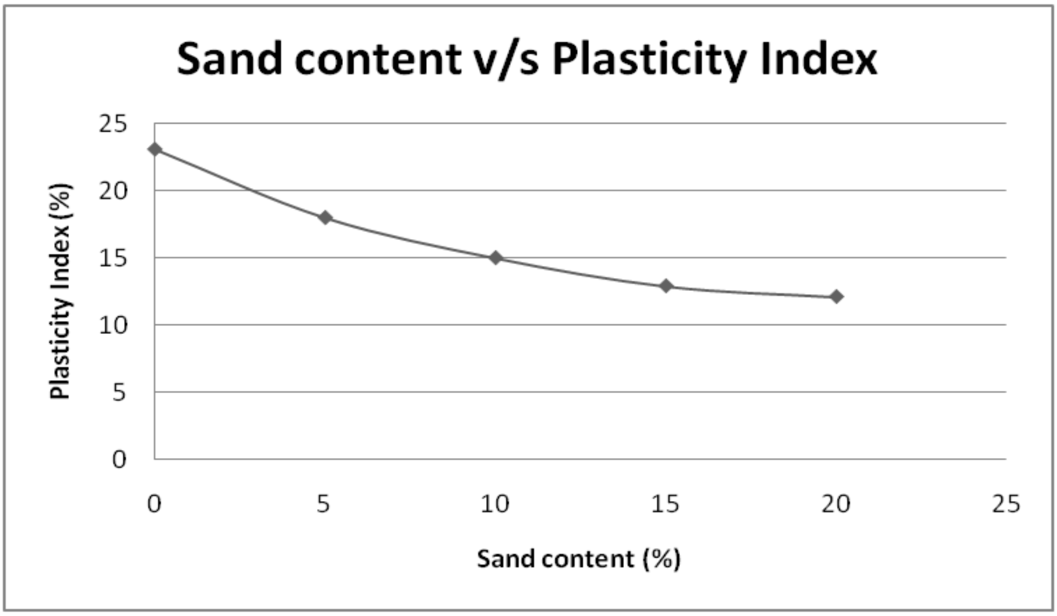


Graph 6: Sand content v/s Plastic limit

4.5.3 Sand content v/s Plasticity Index

S.No.	Sand content (%)	Plasticity Index
1.	0	23.1
2.	5	18
3.	10	15
4.	15	12.9
5.	20	12.1

Table 15: Effect of Sand content on Plasticity Index



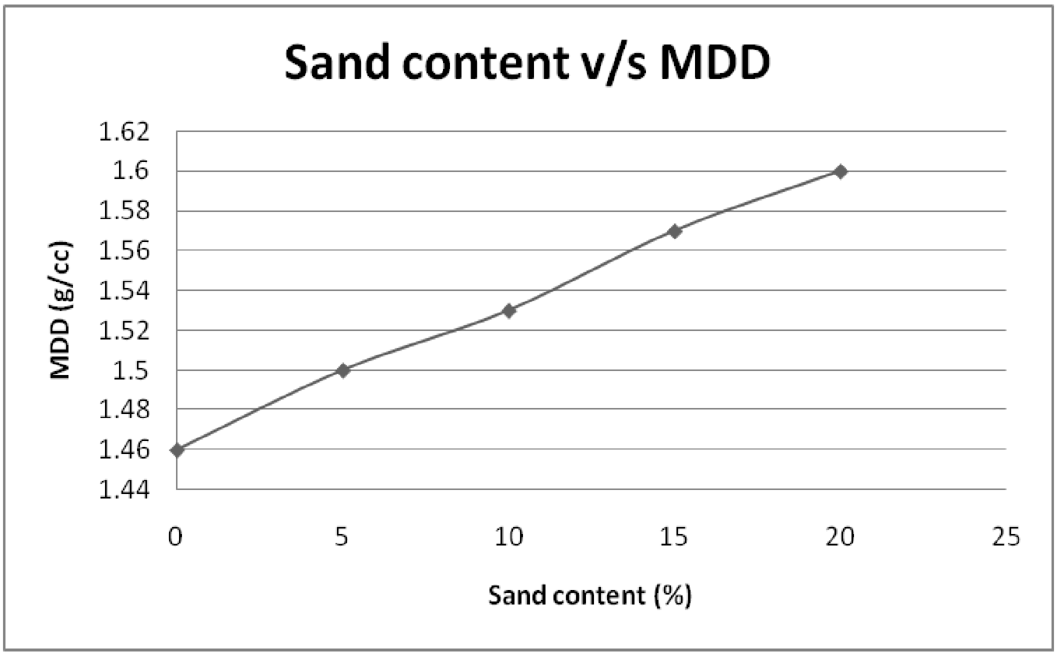
Graph 7: Sand content v/s Plasticity index

4.5.4 Sand content v/s Maximum dry density

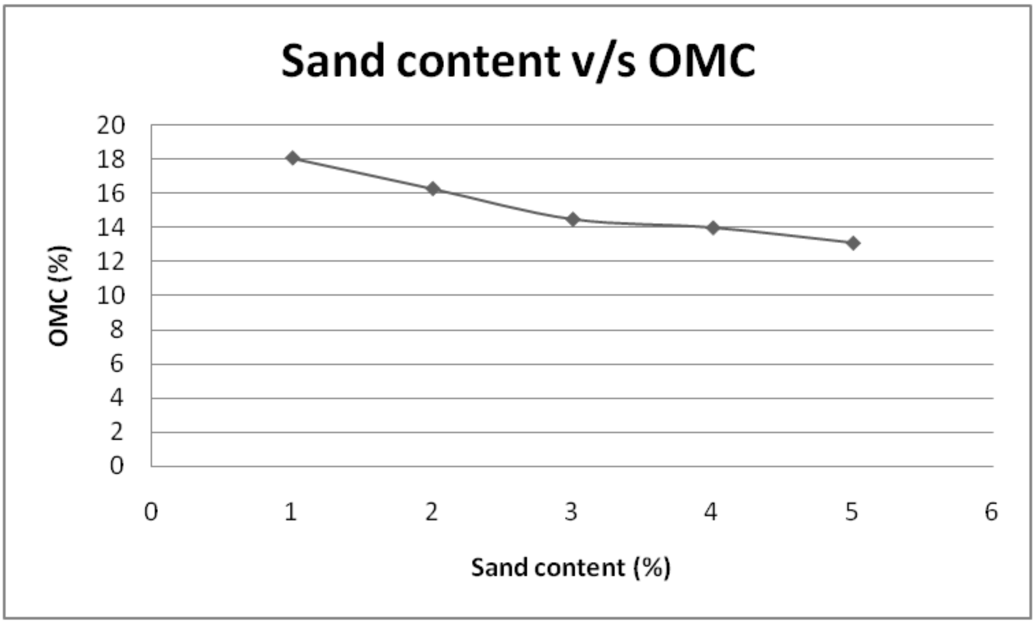
- Weight of soil taken = 2.50 kg

S.No.	Sand content (%)	Maximum dry density (g/cc)	OMC (%)
1.	0	1.46	18.1
2.	5	1.50	16.3
3.	10	1.53	14.5
4.	15	1.57	14
5.	20	1.60	13.1

Table 16: Effect of Sand content on MDD and OMC



Graph 8: Sand content v/s MDD



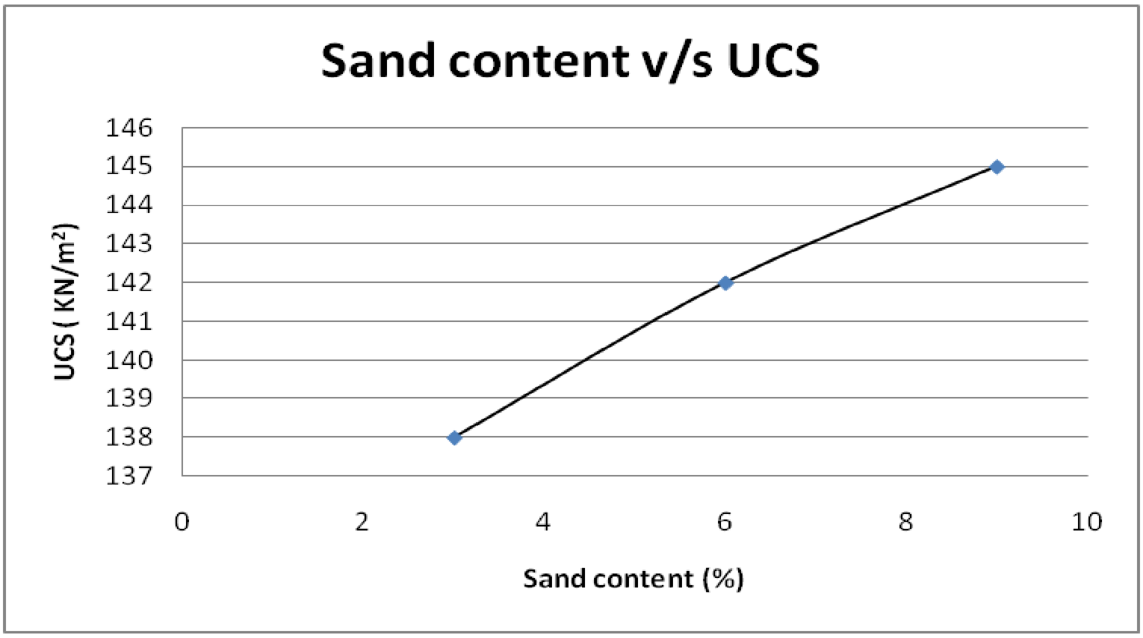
Graph 9: Sand content v/s OMC

4.5.5 Unconfined compression test

Unconfined compressive strength of soil=134.61 KN/m^2

Sand content (%)	1 day **(KN/m^2)**
3	138
6	142
9	145

Table 17: Effect of Sand content on UCS



Graph 10: Sand content v/s UCS

Chapter 5: Soil Stabilization Using Lime

Fig 13: Lime Stabilization

5.1 General

a) Drying: If quicklime is used, it immediately hydrates (i.e., chemically combines with water) and releases heat. Soils are dried, because water present in the soil participates in this reaction, and because the heat generated can evaporate additional moisture. The hydrated lime produced by these initial reactions will subsequently react with clay particles .These subsequent reactions will slowly produce additional drying because they reduce the soil's moisture holding capacity. If hydrated lime or hydrated lime slurry is used instead of quicklime, drying occurs only through the chemical changes in the soil that reduce its capacity to hold water and increase its stability.

b) Modification: After initial mixing, the calcium ions (Ca++) from hydrated lime migrate to the surface of the clay particles and displace water and other ions. The soil becomes friable and granular, making it easier to work and compact. At this stage the Plasticity Index of the soil decreases dramatically, as does its tendency to swell and shrink. The process, which is called "flocculation and agglomeration," generally occurs in a matter of hours.

c) Stabilization: When adequate quantities of lime and water are added, the pH of the soil quickly increases to above 10.5, which enables the clay particles to break down. Silica and alumina are released and react with calcium from the lime to form calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrates (CAH). CSA and CAH are cementitious products similar to those formed in Portland cement. They form the matrix that contributes to the strength of lime-stabilized soil layers. As this matrix forms, the soil is transformed from a sandy, granular material to a hard, relatively impermeable layer with significant load bearing capacity. The process begins within hours and can continue for years in a properly designed system. The matrix formed is permanent, durable, and significantly impermeable, producing a structural layer that is both strong and flexible.

5.2 Immediate Effect

A reduction in the plasticity index: The soil suddenly switches from being plastic (yielding and sticky) to being crumbly (stiff and grainy). In the latter condition it is easier to excavate, load, discharge, compact and level. An improvement in the compaction properties of the soil: 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. Improvement of bearing capacity: In most cases, two hours after treatment, the CBR (California Bearing Ratio) of a treated soil is between 4 and 10 times higher than that of an untreated soil.

5.3 Lime properties

5.3.1 Chemical properties

Quick limes	High Calcium	Dolomitic
Primary Constituents	CaO	$CaO \cdot MgO$
Specific Gravity	3.2-3.4	3.2-3.4
Bulk Density (Pebble Lime), lb./cu. ft.	55-60	55-60
Specific Heat at 100° F., Btu/lb	0.19	0.21
Angle of Repose	55°	55°

Hydrates	High Calcium	Normal Dolomitic	Pressure Dolomitic
Primary Constituents	$Ca(OH)_2$	$Ca(OH)_2 \cdot MgO$	$Ca(OH)_2 \cdot Mg(OH)_2$
Specific Gravity	2.3-2.4	2.7-2.9	2.4-2.6
Bulk Density, lb./cu. ft.	25-35	25-35	30-40
Specific Heat at 100° F., Btu/lb.	0.29	0.29	0.29
Angle of Repose	70°	70°	70°

5.3.2 Sieve Analysis

- Mass of Lime taken = 100 g
- It is sieved through 75 µm sieve
- Mass retained = 4 g
- Mass passed = 96 g
- Hence, it is fine in nature.

5.4 Tests with Lime:

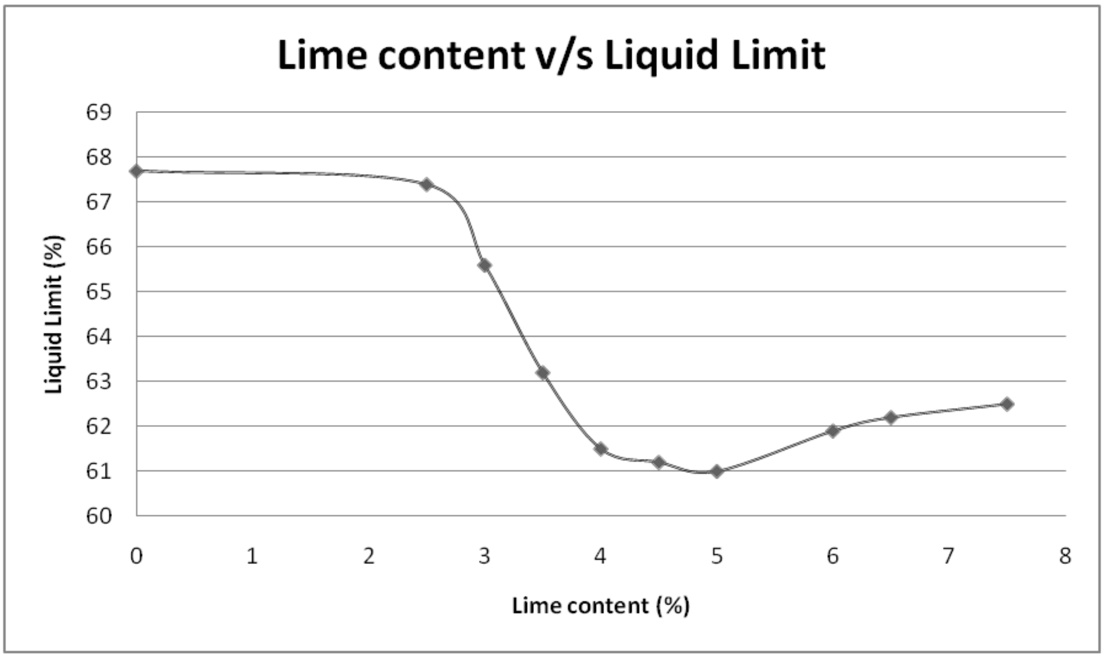
5.4.1 Liquid limit test results

- Mass of soil taken= 120 g
- Mix passing through 425µ sieve is mixed thoroughly with distilled water.

Lime content (%)	Liquid Limit (%)
0	67.7
2.5	67.4
3	65.6
3.5	63.2
4	61.5
4.5	61.2
5	61
6	61.9
6.5	62.2

7.5	62.5

Table 18: Effect of Lime content on Liquid Limit

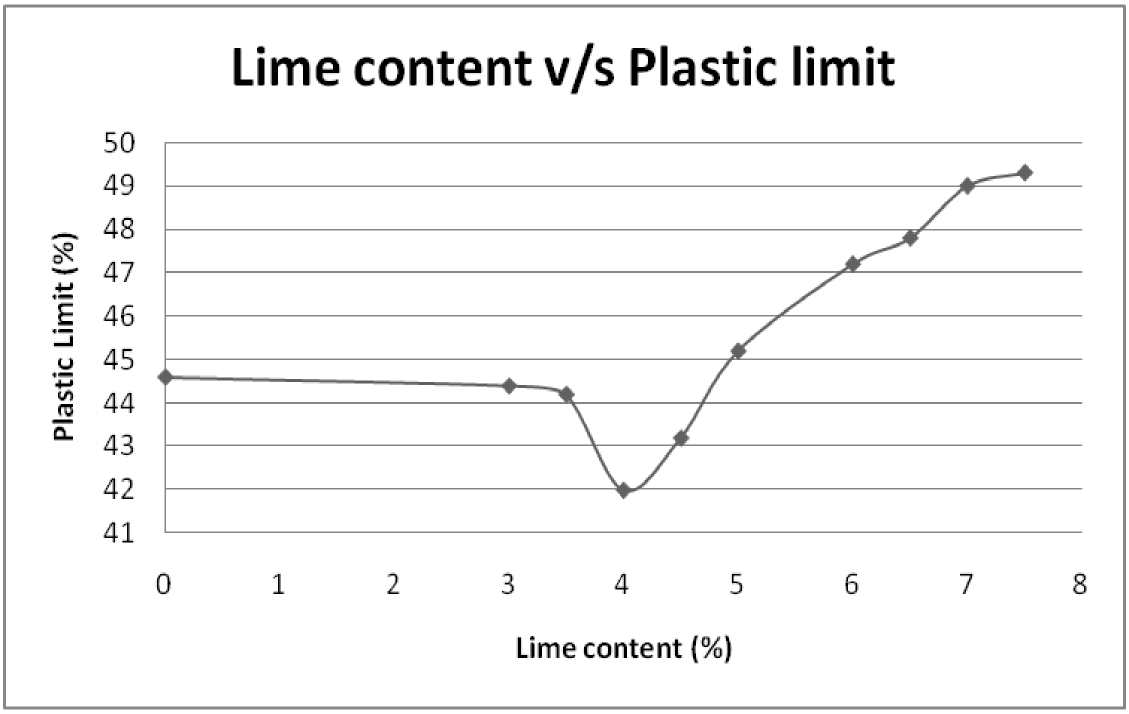


Graph 11: Lime content v/s Liquid limit

5.4.2 Plastic Limit Test results

Lime content (%)	Plastic Limit (%)
0	44.6
3	44.4
3.5	44.2
4	42
4.5	43.2
5	45.2
6	47.2
6.5	47.8
7	49
7.5	49.3

Table 19: Effect of Lime content on Plastic Limit

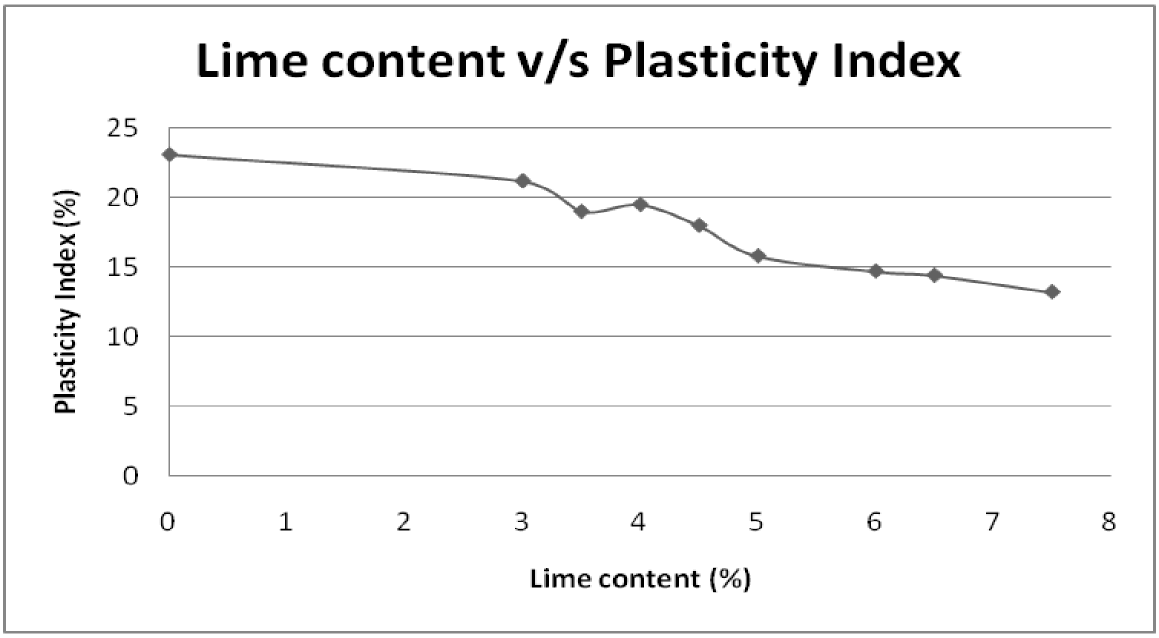


Graph 12: Lime content v/s Plastic limit

5.4.3 Lime content (%) versus Plasticity Index (%)

Lime content (%)	Plasticity Index (%)
0	23.1
3	21.2
3.5	19
4	19.5
4.5	18
5	15.8
6	14.7
6.5	14.4
7.5	13.2

Table 20: Effect of Lime content on Plasticity Limit



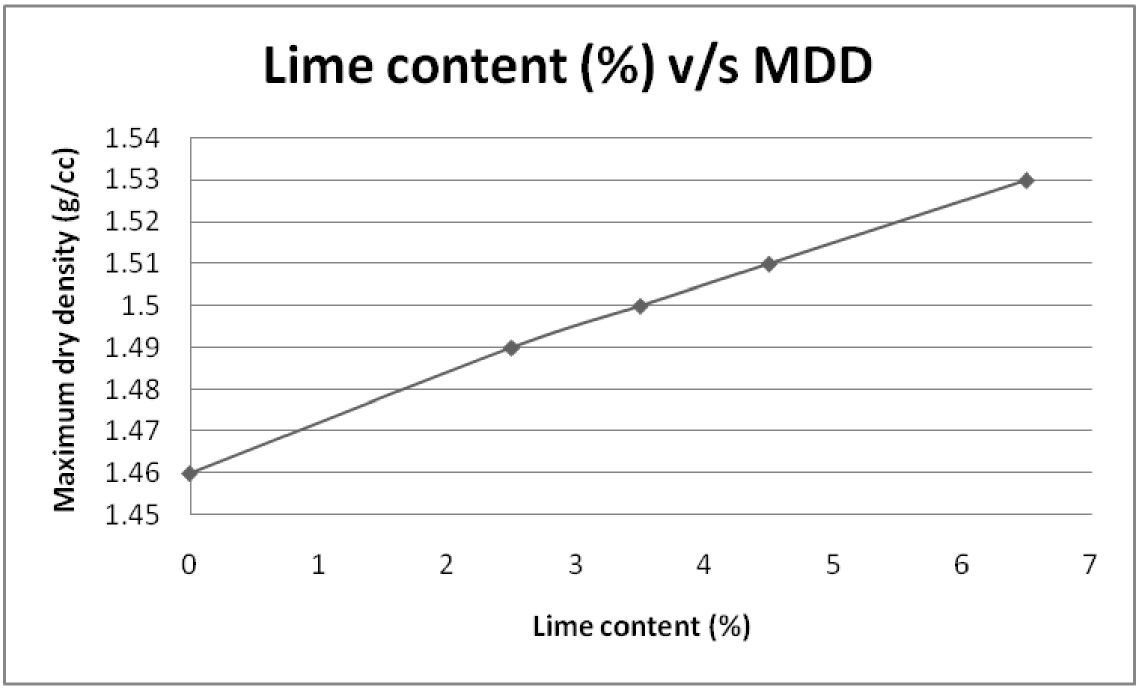
Graph 13: Lime content v/s Plasticity Index

5.4.4 Proctor Test with different lime contents

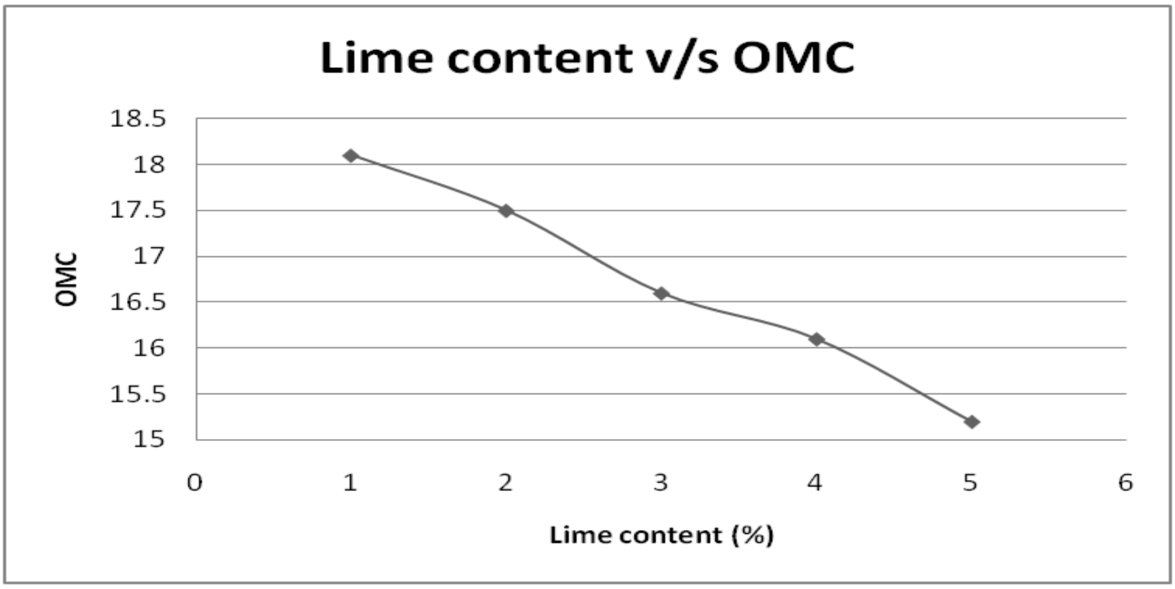
- Mass of soil taken (oven-dried soil) = 2.50 kg

Lime content (%)	Maximum dry density (g/cc)	OMC (%)
0	1.47	18.1
2.5	1.49	17.5
3.5	1.50	16.6
4.5	1.51	16.1
6.5	1.53	15.2

Table 21: Effect of Lime content on MDD and OMC



Graph 14: Lime content v/s MDD

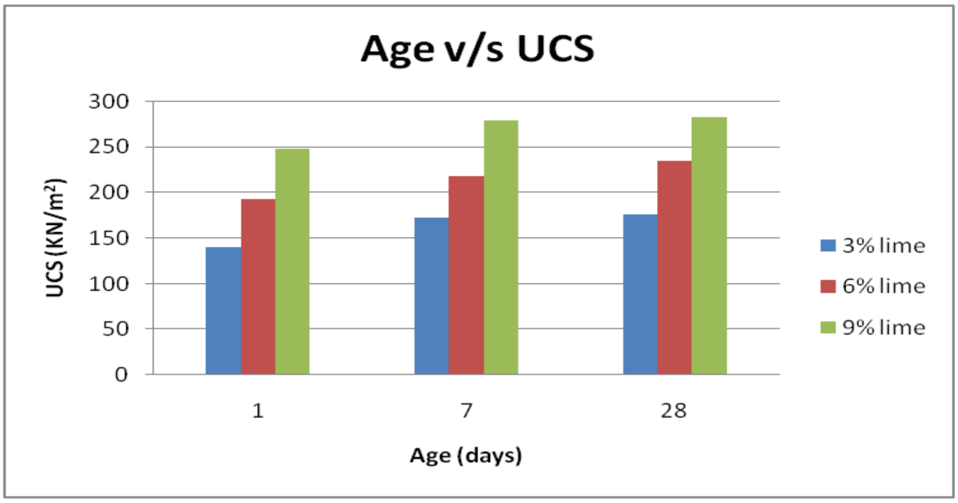


Graph 15: Lime content v/s OMC

5.4.5 Unconfined compression test

Lime content (%)	1 day (**KN/m^2**)	7 days (**KN/m^2**)	28 days **(KN/m^2)**
3	140	192	247
6	172	217	278
9	176	234	282

Table 22: Effect of Lime content on UCS



Graph 16: Age v/s UCS

Chapter 6: Soil Stabilization Using Cement

Fig 14: Cement Stabilization

6.1 General

Soil cement is a construction material, a mix of pulverized natural soil with small amount of portland cement and water, usually processed in a tumble, compacted to high density. Hard, semi-rigid durable material is formed by hydration of the cement particles.

Soil cement is frequently used as a construction material for pipe bedding, slope protection, and road construction as a sub-base layer reinforcing and protecting the sub grade. It has good compressive and shear strength, but is brittle and has low tensile strength, so it is prone to forming cracks.

Soil cement mixtures differ from Portland cement concrete in the amount of paste (cement-water mixture). While in Portland cement concretes the paste coats all aggregate particles and binds them together, in soil cements the amount of cement is lower and therefore there are voids left and the result is a cement matrix with nodules of uncemented material.

6.2 Types of soil cement

a) Cement-modified soils (CMS)

A **cement-modified soil** contains relatively small proportion of Portland cement. The result is caked or slightly hardened material, similar to a soil, but with improved mechanical properties - lower plasticity, increased bearing ratio and shearing strength, and decreased volume change.

b) Soil-cement base (SCB)

A **soil-cement base** contains higher proportion of cement than cement-modified soil. It is commonly used as a cheap pavement base for roads, streets, parking lots, airports, and material handling areas. Specialized equipment, such as a soil stabilizer and a mechanical cement spreader is usually required. A seal coat is required in order to keep moisture out. For uses as a road construction material, a suitable surface coating, usually a thin layer of asphalt concrete , is needed to reduce wear.

In comparison with granular bases, soil cement bases can be thinner for the same road load, owing to their slab-like behaviour that distributes load over broader areas. In-place or nearby located materials can be used for construction - locally found soil, stone, or reclaimed granular base from a road being reconstructed. This conserves both material and energy.

The strength of soil-cement bases actually increases with age, providing good long-term performance.

c) Cement-treated base (CTB)

A **cement-treated base** is a mix of granular soil aggregates or aggregate material with Portland cement and water. It is similar in use and performance to soil-cement base.

d) Acrylic copolymer (Rhino Snot)

Developed for the U.S. Military in desert conditions and commercially trademarked, "Rhino Snot" is a water soluble acrylic copolymer applied to soil or sand which penetrates and coats the surface.

When dry, it forms a waterproof, UV-resistant, solid bond which binds the soil together reducing dust. In higher concentration it creates a durable surface that can withstand heavy traffic allowing existing soil to be used for roads, parking lots, trails and other heavy traffic areas.

6.3 Factors Affecting Soil Cement Stabilization

During soil cement stabilization the following factors are affecting.

1. **Type of soil**: Cement stabilization may be applied in fine or granular soil, however granular is preferable for cement stabilization.
2. **Quantity of cement:** A large amount of cement is needed for cement stabilization.
3. **Quantity of water**: Adequate water is needed for the stabilization.
4. **Mixing, compaction and curing**: Adequate mixing, compaction and curing is needed for cement stabilization.
5. **Admixtures:** Cement has some important admixtures itself which helps them to create a proper bond. These admixtures pay a vital role in case of reaction between cement and water.

6.4 Advantages of Cement Stabilization

1. It is widely available.
2. Cost is relatively low.
3. It is highly durable.
4. Soil cement is quite weather resistant and strong.
5. Granular soils with sufficient fines are ideally suited for cement stabilization as it requires least amount of cement.
6. Soil cement reduces the swelling characteristics of the soil.
7. It is commonly used for stabilizing sandy and other low plasticity soils. Cement interacts with the silt and clay fractions and reduces their affinity for water.

6.5 Disadvantages of Cement Stabilization

1. Cracks may form in soil cement.

2. It is harmful for environment.
3. It requires extra labor.
4. The quantity of water must be sufficient for hydration of cement and making the mixture workable.

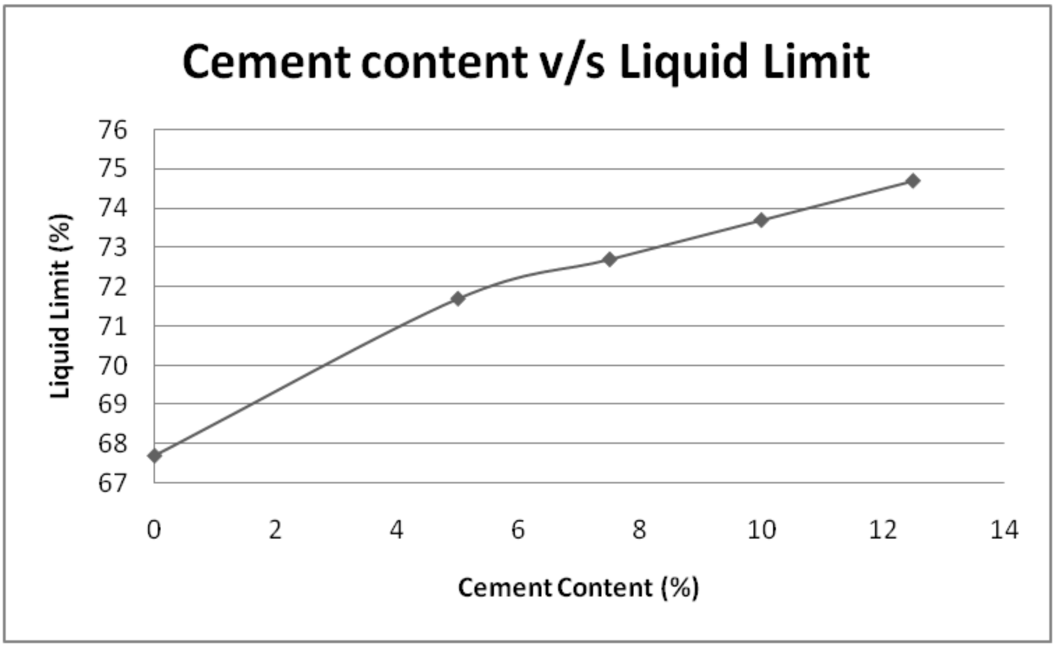
6.6 Tests with Cement :

- We have taken PPC (fly ash based IS: 1489 (Part I)) to perform tests on black cotton soil.

6.6.1 Liquid limit test

S.No.	Cement content (%)	Liquid Limit (%)
1.	0	67.7
2.	5	71.7
3.	7.5	72.7
4.	10	73.7
5.	12.5	74.7

Table 23: Effect of Cement content on Liquid Limit

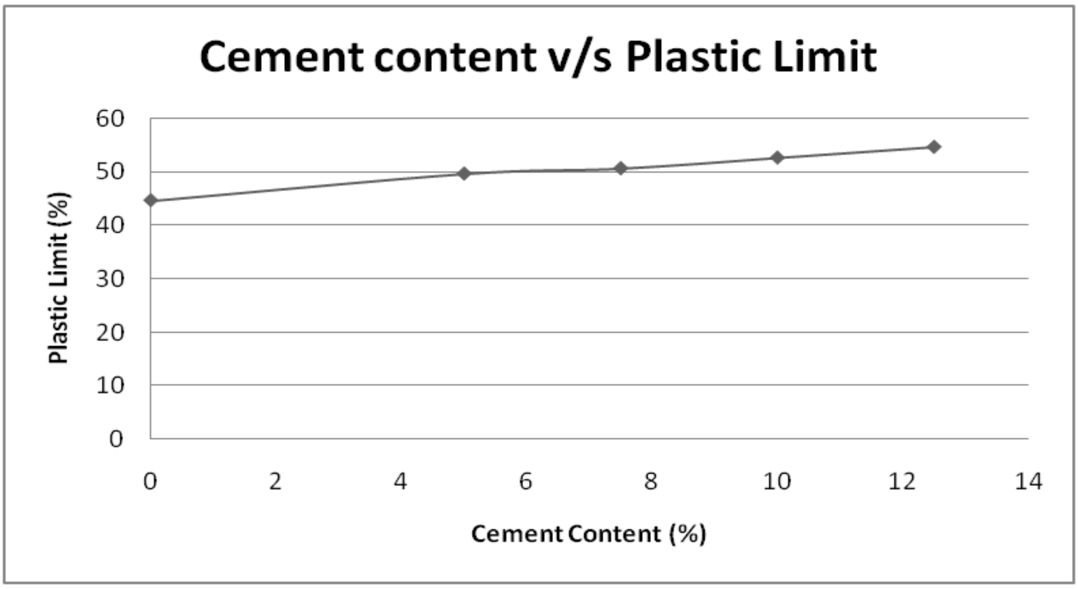


Graph 17: Cement content v/s Liquid Limit

6.6.2 Plastic limit test

S.No.	Cement content (%)	Plastic Limit (%)
1.	0	44.6
2.	5	49.6
3.	7.5	50.6
4.	10	52.6
5.	12.5	54.6

Table 24: Effect of Cement content on Plastic Limit

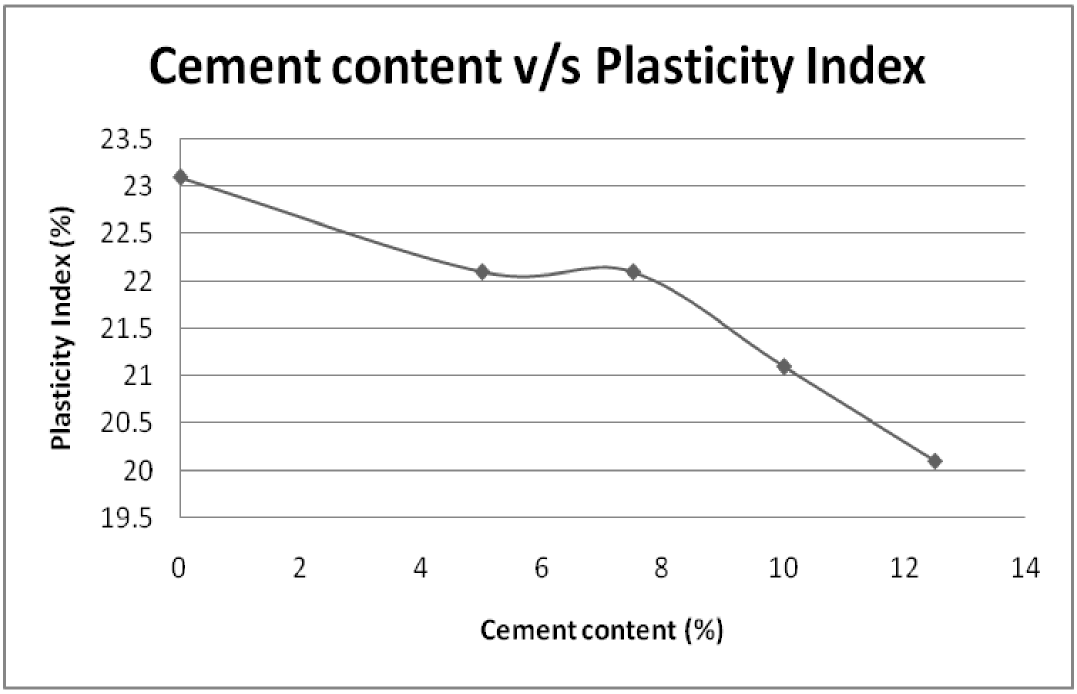


Graph 18: Cement content v/s Plastic Limit

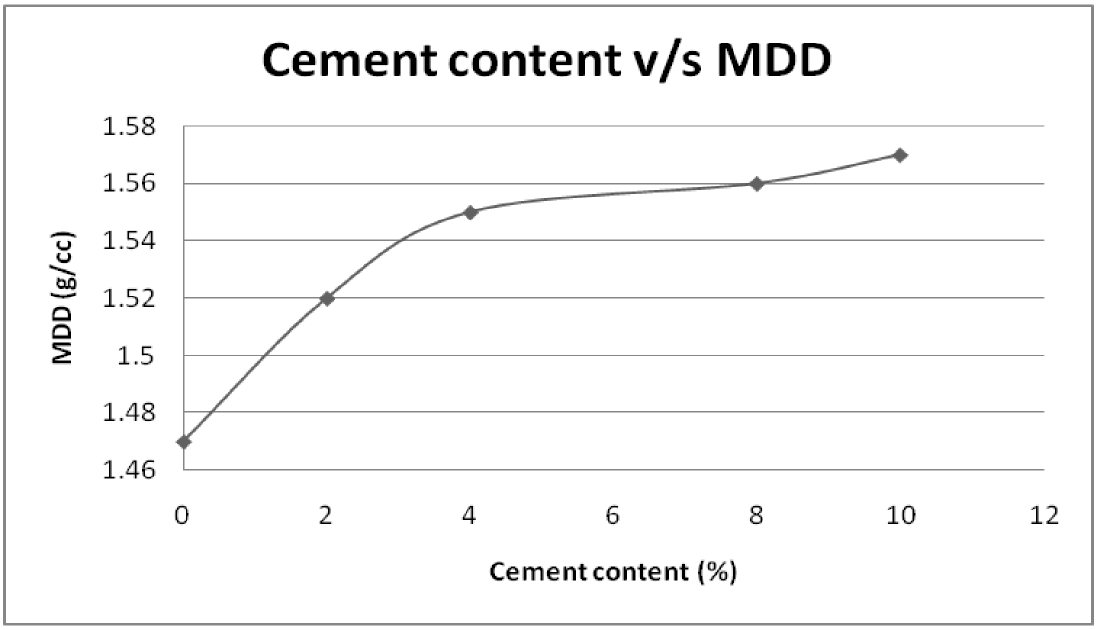
6.6.3 Plasticity Index

S.No.	Cement content (%)	Plasticity Index (%)
1.	0	23.1
2.	5	22.1
3.	7.5	22.1
4.	10	21.1
5.	12.5	20.1

Table 25: Effect of Cement content on Plasticity Index



Graph 19: Cement content v/s Plasticity Index

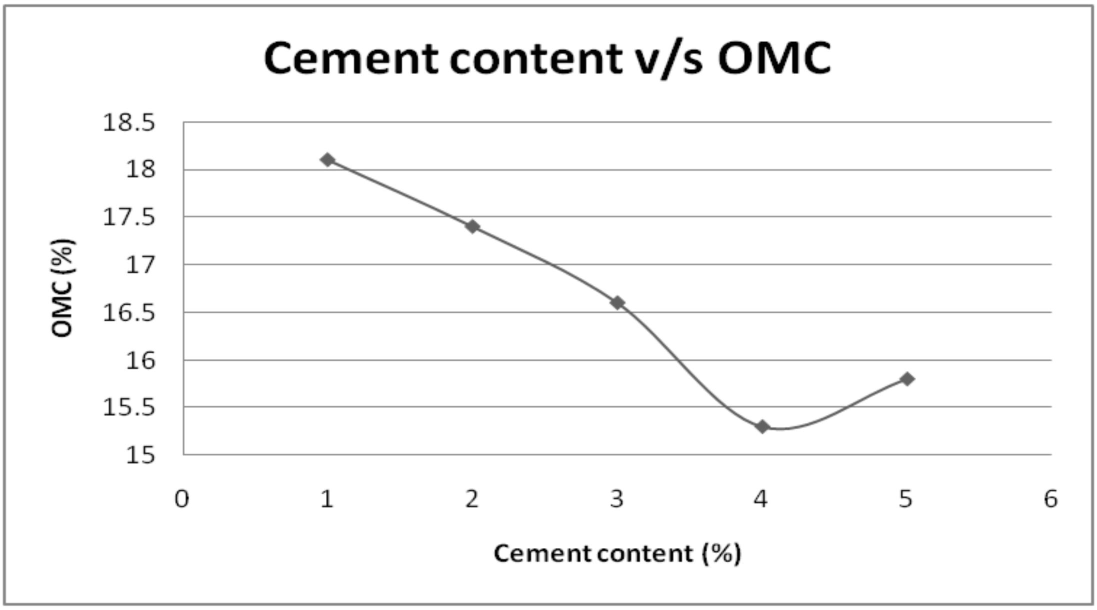


Graph 20: Cement content v/s MDD

6.6.4 Proctor Test with different cement contents

Cement content (%)	Maximum dry density (g/cc)	OMC
0	1.47	18.1
2	1.52	17.4
4	1.55	16.6
8	1.56	15.3
10	1.57	15.8

Table26: Effect of Cement content on MDD and OMC

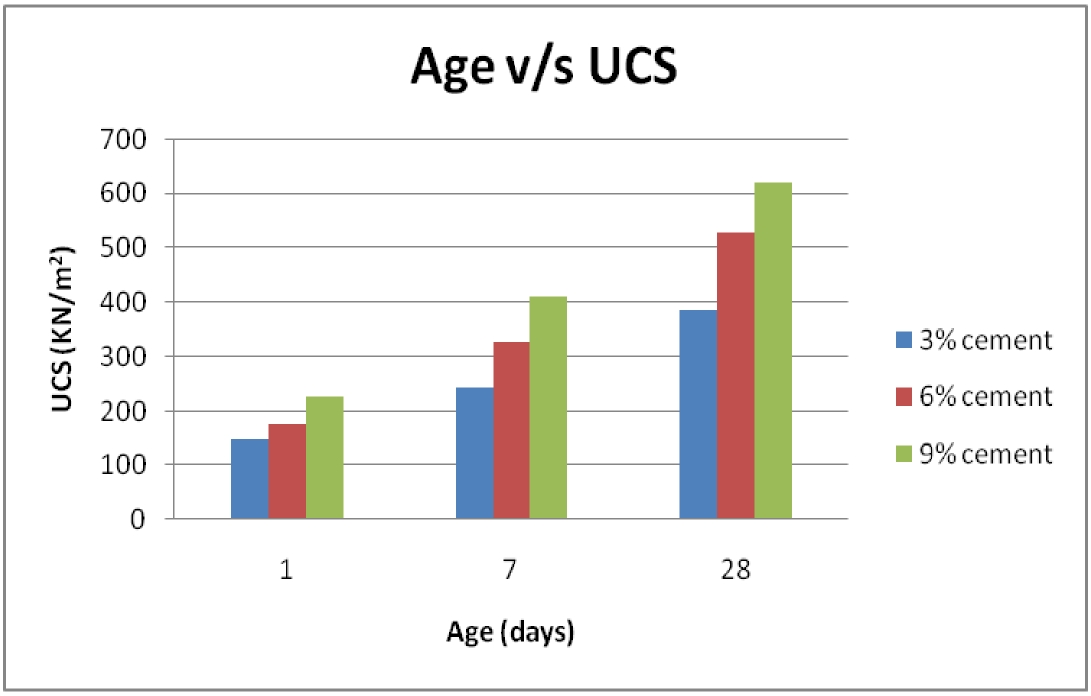


Graph 21: Cement content v/s OMC

6.6.5 Unconfined compression test

Cement content (%)	1 day **(KN/m^2)**	7 days **(KN/m^2)**	28 days **(KN/m^2)**
3	147	175	227
6	242	325	410
9	385	526	620

Table 27: Effect of Cement content on UCS



Graph 22: Age v/s UCS

Chapter 7: Conclusion

a) Sand Stabilization:

- From the figures it is clear that liquid limit, plastic limit and plasticity index decreases with increase in sand content.
- Soil may be designated as ML from MH after adding sand content 20% or more.
- Also, dry density increases with increase in sand content.

b) Lime Stabilization:

- Value of liquid limit varies from 67.7% (at 0% lime content) to 61% (at 5% lime content).
- The optimum lime content is between 4.5-5% for maximum effect on liquid limit.
- Value of plastic limit varies from 44.6% (at 0%lime content) to 42% (at 4% lime content) .
- The optimum lime content is between 4- 4.5% for maximum effect on plastic limit.
- Value of liquid limit decreases gradually from 23.1 % (at 0% lime content) to 13.2% (at 7.5% lime content) .
- Maximum dry density remains constant with variation in lime. So lime did not improve the compaction characteristics of soil.

c) Cement Stabilization:

Liquid limit and plastic limit of soil increases gradually with the increases in percentage of cement content. This improvement of liquid limit attributed that more water is required for the cement treated soil to make it fluid and the increase of plastic limit implies that cement treated soil required more water to change it plastic state to semisolid state. This change of Atterberg limit is due to the cation exchange reaction and flocculation–aggregation for presence of more amount of cement, which reduces plasticity index of soil. A reduction in plasticity index causes a significant decrease in swell potential and removal of some water that can be absorbed by clay minerals.

It is noticeable that cement-stabilized soils exhibit higher initial UCS values than those stabilized with lime. In terms of compressive strength, cement yields prominent enhancement for the natural soils. There is a relative increment in the strength, as well as the stiffness of the cement-treated soils. When the cement content is higher, more cement particles would hydrate and create rather strong bonds between the various mineral substances and formed a matrix, which efficiently encloses the non-bonded soil particles, thus generating higher UCS. The addition of cement would produce significant increment in strength and modulus of deformation, as well as stiffness of the soil, but simultaneously the clay material would be changed to brittle material. The pozzalonic behavior of cement makes the treated soil coarser than original soil samples due to the agglomerations of cement and soil particles. This improvement changes the naming of soil from clay to silt.

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