EXPERIMENTAL INVESTIGATION OF LIME AS SUBGRADE STABILIZER FOR RAVI-CHENAB CORRIDOR STRATA

A project report submitted in partial fulfillment

Of the requirements for the degree of

BE CIVIL ENGINEERING

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This is to certify that the Final Year project

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DEDICATION

We dedicate this research to our parents and mentors who are an endless source of guidance and inspiration, and their prayers have always been inspiring and instigating for us.

ACKNOWLEDGEMENTS

We are much obliged to Almighty Allah, who gave us strength and patience to finalize our research. We would like to pay our sincere gratitude to our supervisor Brig Dr Sarfraz Ahmad, for his continuous support, motivations, enthusiasm and delivering his immense knowledge, whose instructions and guidance helped us in all stages of the research.

I would like to pay my thanks to all our companions for their kind-heartedness and support in every part of this research work. We are also grateful to transportation engineering lab and geo-technical engineering lab staff for their time and helping hand during the laboratory experimental work.

In the end, we pay our earnest gratitude to our beloved Parents for their support in every part of our life.

ABSTRACT

This study focuses on review of modern techniques/ technologies for improving trafficability of combat roads/ tracks with special emphasis on Ravi Chenab corridor and Pukhlian Salient in Central Comd AOR. The research work is primarily a lab-cum-field study for soil improvement using pozzolanic additives especially lime. In-situ soil conditions are evaluated through detailed investigation and identifying zones with similar soil profiles. Suitable percentages of soil stabilizer will be determined through array of tests to ascertain optimum blends for different types of soils present in the study area.

Wide range of soil modification techniques; including but not limited to geo-synthetics, geo-grides and pozzolanic additives (lime, fly ash, baggas ash etc) are reported in literature for soil improvement/ stabilization with varying degree of success. However, various research studies have found lime outperforms all other modifiers for clayey soils, thus making it a preferred choice for our study to treat A-7-6, Clay, being the most problematic soil found in the study area.

Soil treated with lime exhibits a significant decrease in Atterberg's limit (**plasticity index reduced by 79.96 %**) of soil by lime modification. Classification of soil changed from AASHTO A-6 soil to A-4 soil and its behavior from **clayey to silty soil**, thus improving its trafficability class. Significant strength improvement (un-confined compressive **strength increase by 37.05 %**) of soil in soaked and unsoaked condition with the 4 % lime. In the light of the results obtained, it is concluded that 4 % lime can be used efficiently for improvement of weak subgrade (clayey) soils of the area of study.

LIST OF ABBREVIATIONS

AASHTO	– American Association of State Highway & Transportation Official
ASTMAS	– American Society for Testing and Materials
CAH	– Calcium Aluminate Hydrates
CBR	– California Bearing Ratio
CH	– High Plastic Clay
CL	– Low Plastic Clay
CSH	– Calcium Silicate Hydrates
CSR	– Composite Schedule of Rates
GSD	– Grain Size Distribution
HMA	– Hot Mix Asphalt
LL	– Liquid Limit
MDD	– Maximum Dry Density
ML	–Silt
MRS	– Market Rates System
NHA	– National Highway Authority
NLA	– National Lime Association
NS	– Natural Soil
NSL	– Soil Lime Mix
NSLW	– Soil, Lime and WSA Mix
OMC	– Optimum Moisture Content
PI	– Plasticity Index
PL	– Plastic Limit
UCS	– Unconfined Compressive Strength
USCS	– Unified Soil Classification System

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 General

Subgrade is the existing natural material below a constructed road pavement or railway track, also termed as formation level. The subgrade serves as foundation for pavement structure. Inadequate subgrade soil conditions do not support pavement and reduce its life. Removal of poor subgrade and placing of new material is sometime not economical so poor subgrade is improved or stabilized by adding different type of chemical additives like lime, cement, bitumen or any waste material like rice husk ash, fly ash, slag etc. depending on type of soil or type of waste material. Utilization of waste material is one of the most used technique for soil stabilization. Also due to economic, environmental, sustainable development and engineering properties enhancement point of view many researchers have worked on different waste materials and their effect on different type of subgrade soils.

Lime is the oldest and most common stabilizing agent due to low cost and high stabilizing potential. It significantly increases soil strength and properties. Lime stabilization is achieved through cat-ions exchange, flocculation/agglomeration, lime carbonation and pozzolanic reactions. This reaction continues for years and produce long lasting strength in soil.

1.2 Need of Research

Soil stabilization is an economical and feasible solution for poor subgrades in highway construction relative to other techniques like replacement of material with high strength material. Soil stabilization not only increases strength but also reduces pavement thickness.

Corps of Engineers uses both conventional and unconventional methods and techniques to ensure the mobility of combat forces. However, the job will be much more challenging in NCWF that demands urgent support with limited resources. Now, there are new technologies, systems, and materials that could be used to build and improve combat roads/ tracks, improve vehicle/ soil interaction and traction, identify mobility hazards, and predict mobility in complex environments. Therefore, there is a need to review existing technology and techniques being used by the Corps of Engineers for improving combat roads/ tracks, vehicular/ soil interaction, detect dynamic mobility hazards, and propose new technologies and techniques for quick repair and construction of combat roads/ tracks

In this paper, we shall make a systemic study for clayey soils with Lime treatment to improve bearing capacity of soil. Lime with different percentages will be used in the expansive soil, and the detailed study for the physical and mechanical properties of modified lime treated soil will be done. Finally, the proportion for Lime will be optimized. On the basis of the optimized proportion, different analysis ways will be used to investigate and compare the structural characteristics of modified expansive soil before and after addition of lime.

Figure 1-1 Application of Lime on Subgrade

1.3 Research Objectives

The proposed study aims at the following research objectives:

- **To Investigate** and **classify problematic soils of Ravi-Chenab Corridor** according to the USCS and AAHTO soil classification system.
- **To evaluate Effectiveness** of **stabilizer/** lime with particular focus on the bearing capacity/ strength characteristics of treated soils.
- **To Suggest site specific integrated maps** for the quick estimation of stabilization additive for the soil of a particular zone.

1.4 Scope and Methodology

- Wide range of soil modification techniques; including but not limited to geo-synthetics, geo-grides and pozzolanic additives (lime, fly ash, baggas ash etc) have been reported in literature for soil improvement/ stabilization with varying degree of success.
- However, various research studies have found lime outperforms all other modifiers for clayey soils, thus making it a preferred choice for our study to treat A7-6, Clay, being the most problematic soil found in the study area.

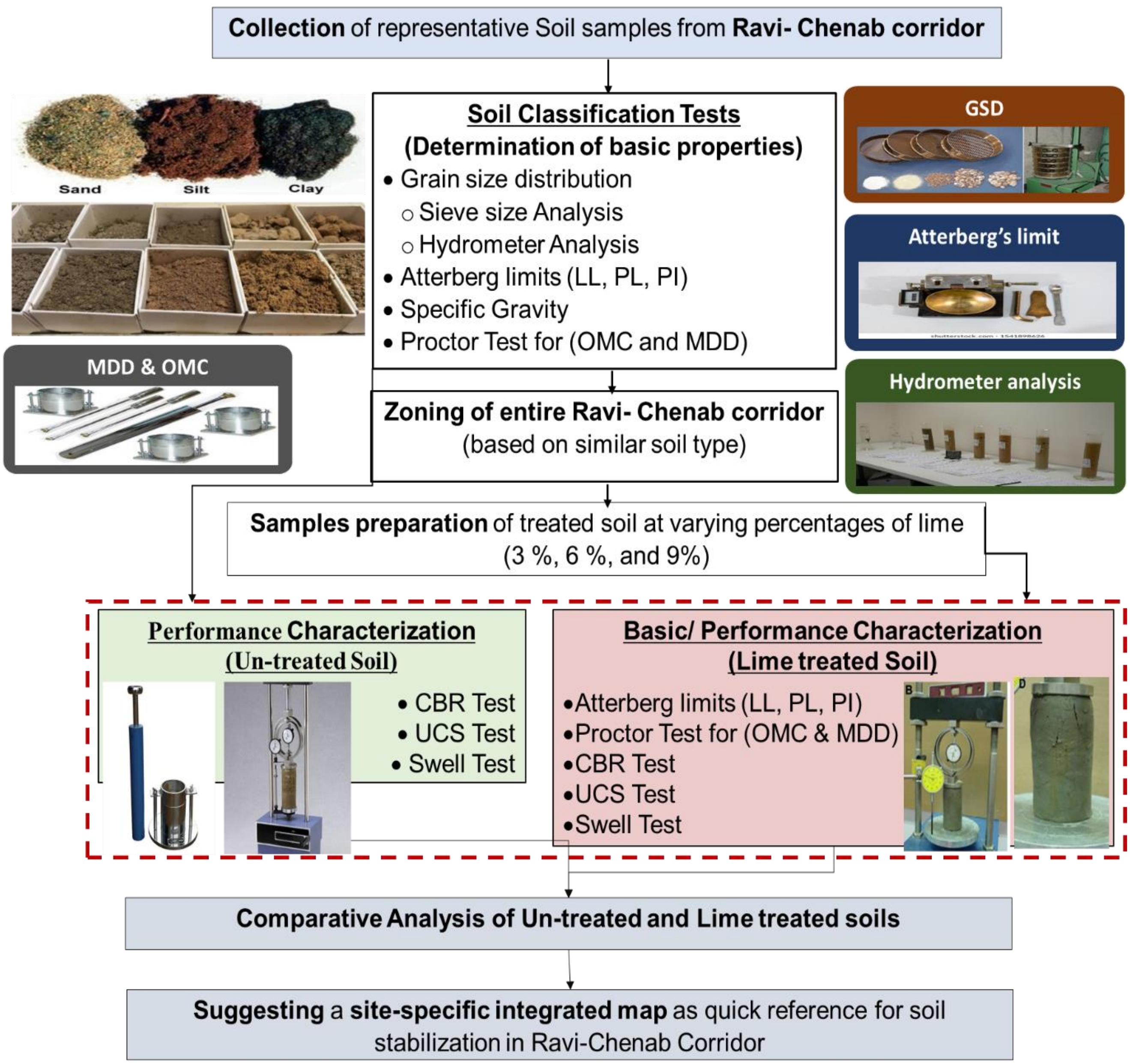


Figure 1-2 Research Methodology Matrix

1.5 Organization of Thesis

This final year project report is organized in five chapters; summary of all the chapters is discussed below:

- Chapter 1 includes the introduction to Subgrade stabilization, Problem statement, research objectives and the scope of the study.
- Chapter 2 describes the literature review of materials and process of stabilization. It also includes past studies carried out by various researchers.
- Chapter 3 describes the research approach taken up to achieve the goals of this study. It explains in detail the material selection, characterization and procedures for determining optimum lime
- Chapter 4 presents the details and analysis of test results obtained by conducting all the tests described in Chapter 3.
- Chapter 5 enlightens the outcomes derived from the current research as well as recommendations for the future research.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Subgrade is very important for efficient transfer of load to the subsoil. Subgrade stability depends on soil strength and its behavior under repeated loading. Soil type has huge impact on type of road and its design. Weak soil like expansive clays, low strength soils etc. can result in premature failures of the road structure. So proper treatment of these types of soils is very important before laying down a road structure.

2.2 Soil Stabilization

Soil stabilization is a collaborative term for physical, chemical or biological method applied individually or together to improve engineering properties of natural soil (Winterkorn and Fang 1991). Soil stabilization can also be defined as enhancement of required engineering properties of soil by chemical or mechanical means.

Soil stabilization is different from soil modification that is improvement of soil properties like plasticity, moisture content etc. to facilitate construction operations. While stabilization improves strength and durability of soil. Modification occurs shortly after mixing.

2.3 Methods of Soil Stabilization

Soil stabilization is generally separated into following two main procedures.

2.3.1 Mechanical Stabilization

Mechanical stabilization involves physical process that involves compaction, geo-synthetics, ill-suited soil replacement with higher strength material/soil and adding barriers, nailing or piling in some cases.

Mechanical stabilization is longstanding method but such methods are expensive and incur higher cost due to replacement of material. Chemical stabilization is new method for enhancing soil strength properties introduced by researchers (Bell 1993, Rogers, Glendinning et al. 1997).

2.3.2 Chemical Stabilization

Chemical stabilization involves improvement of soil strength using different chemical stabilizers. Main types of chemical stabilizers used are lime, cement, bitumen, fly ash etc. are used with different ratio for soil stabilization.

Chemical stabilization is done by using two methods ex-situ stabilization and in-situ stabilization. Mechanism of soil stabilization is dependent on type of applied stabilizer (Little and Nair 2009). Same type of stabilizer cannot be used for every type of soil so we have to check separately the stabilizer best for a certain type of soil. Stabilizer selection depends on the properties of soil needed to achieve. Characteristics that needed to be on safer side for transportation engineers mainly involves durability, expansion, permeability, and strength and cost effectiveness. To evaluate these properties laboratory as well as field tests may be required to estimate the effectiveness of a binder for particular type of soil.

2.4 Constituents of Stabilization

Different types of binders are used for stabilization of soil e.g., bitumen, lime, pozzolanic materials like fly ash, rice husk ash etc. Main constituents of stabilization in this research are Clay and Lime

2.4.1 Clayey Soils

Soil has been used since centuries as a construction material. Clayey soils are very fine grained material. Rock particles breakdown by mechanical and chemical means to particles size less than 0.002mm forming clays having mineral content same as of parent rock. Clays are made up of small crystalline particles composed of small group of minerals known as clay minerals.

2.4.1.1 Clay Mineralogy

Clay soils consist of various types of minerals with different proportions. Commonly known clay minerals are Kaolinite, Illite, Montmorillonite and non-clay minerals are quartz, organic matter, and colloidal matter. Clay minerals may greatly influence physical properties of clay. Minerals with poorly ordered crystallinity and good ordered crystallinity both have different properties.

2.4.1.1.1 Kaolinite Group

Kaolinite group also called 1-1 or two layer group made of one silica and one alumina sheet join together to form kaolinite group. The forces between bonding layers are van der wall forces and hydrogen bonding.

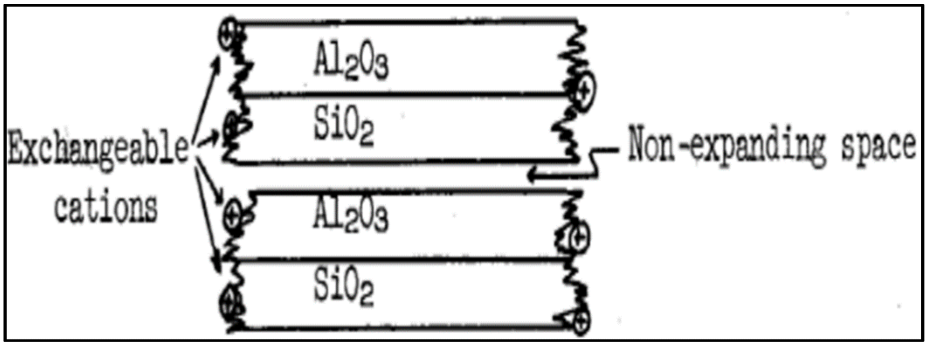


Figure 2-1 Kaolinite Structure (Holeman 1965)

2.4.1.1.2 Montmorillonit Group

Montmorillonite is an also 2:1 structure. The unused OH- side of alumina sheetin Kaolinite mineral sometimes attract unsatisfied face of other silica sheet to form three layers stack. The forces between sheets are common attraction of cations and van der wall forces. The negative charge on surfaces of the silica sheet attract water in the space between two basic units. This outcomes in a development of the mineral.

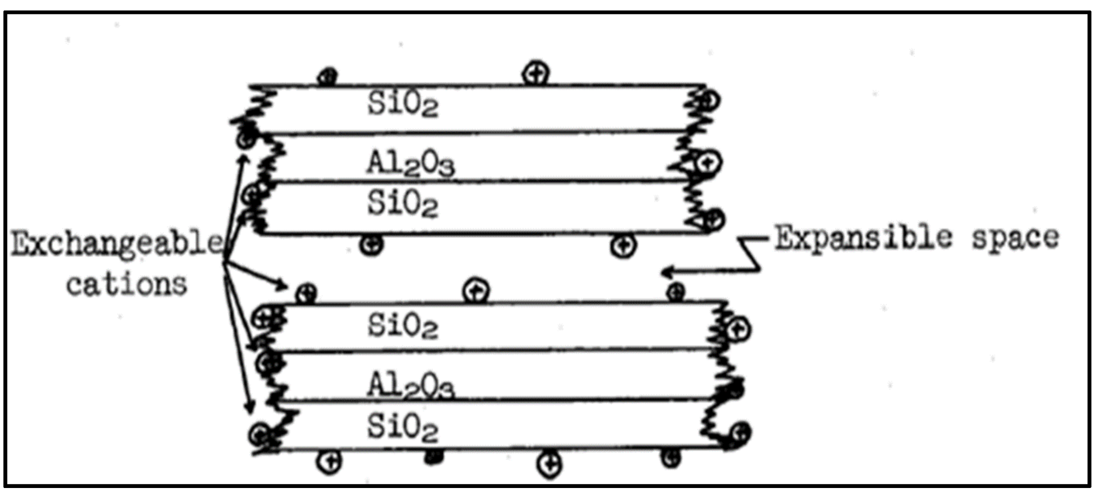


Figure 2-2 Montmorillonite Structure (Holeman 1965)

2.4.1.1.3 Illite Group

Illite group also known as 2:1 mineral is made up of single alumina sheet bonded among two silica sheets. Potassium ions bond layers firmly (Mitchell 1993).

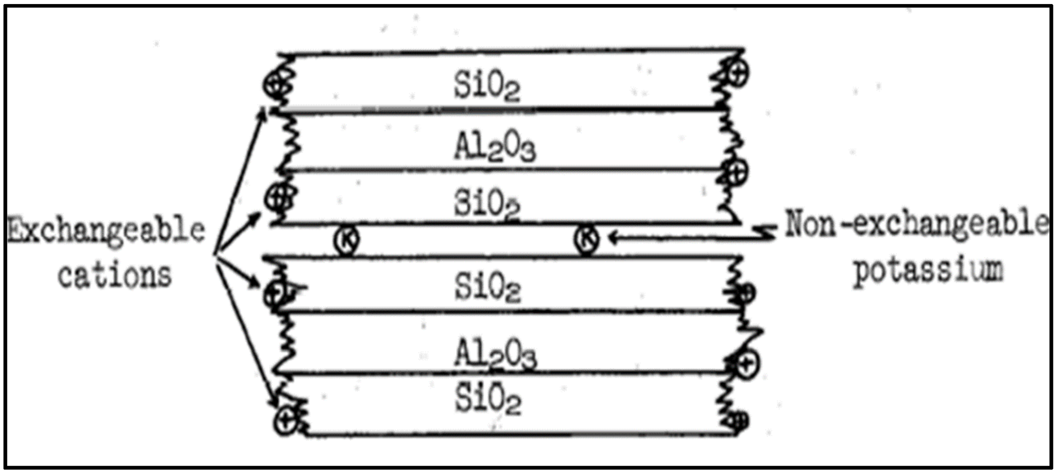


Figure 2-3 Illite Structure (Holeman 1965)

2.4.1.2 Clay Structure

Structure of clay mineral is comprised of two basic units the silicon tetrahedron or silica sheet and the aluminum octahedron or the alumina sheet (Mitchell 1993).

2.4.1.2.1 Silica Tetrahedral Sheet

In silica tetrahedron unit, silica (Si^{+4}) forms a tetrahedron with four oxygen ions (O^{-2}) and has net negative charge of -4. Silica is centrally positioned and oxygen ions are bonded strongly to the core atoms. Silicon has valency of +4 and oxygen has -2. Tetrahedron sheet is formed by sharing of O^{-2} between units (as shown in Figure 2-4). Corner O^{-2} is shared creating the new tetrahedron unit. There is net negative charge at the top of tetrahedral sheets. Silica tetrahedral sheet is symbolically represented with a trapezoid. Shorter and longer faceface of trapezoidal shape represent unsatisfied and satisfied oxygen atoms respectively.

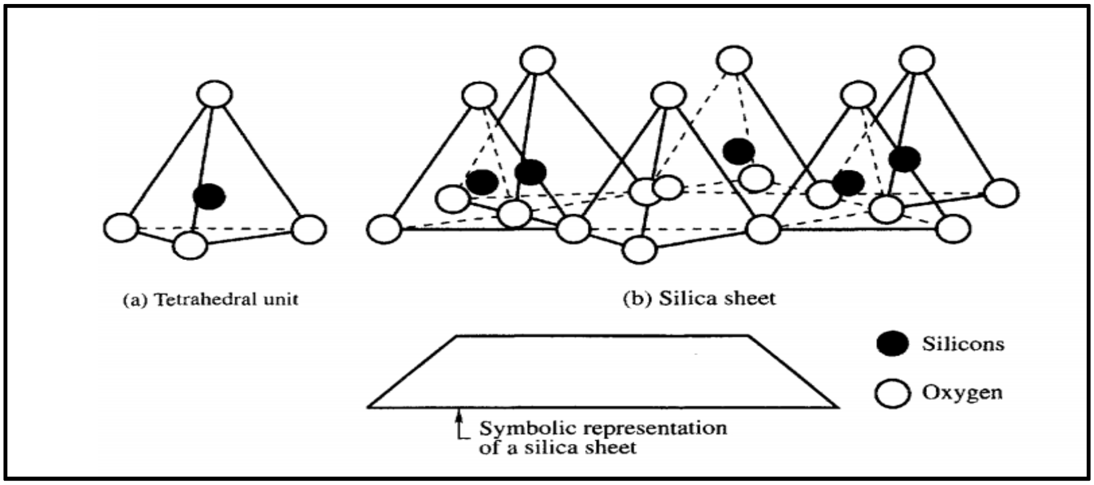


Figure 2-4 Arrangement of Silica Sheet (Grim 1959)

2.4.1.2.2 Alumina Octahedral Sheet

In aluminum octahedron unit, Aluminum ion (Al^{+3}) is bonded with six oxygen ion or hydroxyl ions. As aluminum has combining power of +3 and oxygen has -2. Oxygen is left with charge of -1.5, after Al^{3+} shares +0.5 of its charge with each of the oxygen ions surrounding it (as shown in Figure 2-5). Octahedral sheet are formed by each oxygen being bonded to two aluminum ions (Al^{+3}) leaving oxygen ion with net one -ve charge. Aluminum octahedron sheet is symbolized with a rectangle with top and bottom faces having the same characteristics of exposed hydroxyl ions. At times, instead of aluminum, magnesium or iron is imbedded in this octahedral coordination. Sometimes seldomly chromium, lithium, manganese or other ions may take this position. In the alumina layer only two-third of the existing central locations are occupied with Al atoms (Holeman 1965).

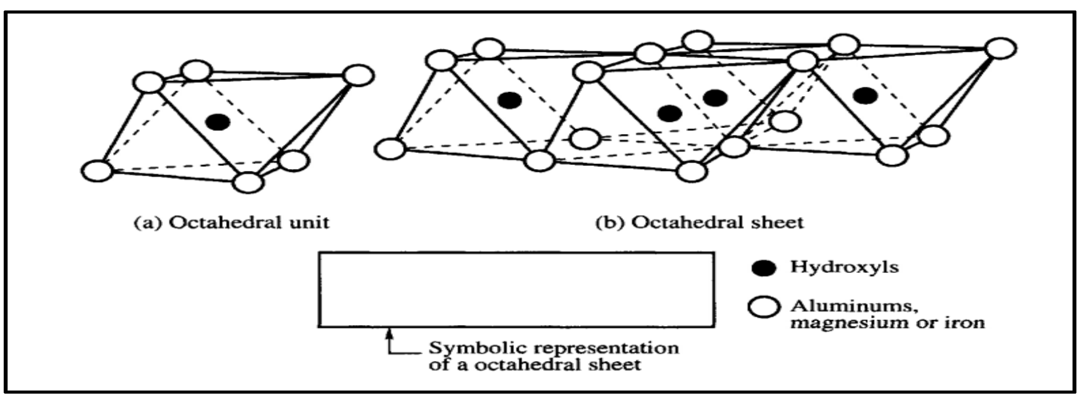


Figure 2-5 Arrangement of Alumina Sheet (Grim 1959)

2.4.2 Lime

Lime is the oldest and most common stabilizing agent being used (Mallela, Quintus et al. 2004). Soil-Lime mixtures were used to stabilize earth roads in ancient Mesopotamia, Egypt and by Greeks and Romans (McDowell 1959). Lime is almost useful for stabilizing many types of soils. Commonly applications of lime are for soil modification and soil stabilization of subgrades, bases and subbases under pavement. The appropriate percentage usually ranges from about 3 to 8 percent (Murthy 2002). Lime stabilization is benefit for strength and deformation properties, resilient properties, durability properties, fatigue properties (Little 1998). All strength properties of stabilized mixes namely UCS, CBR and BTS increase with the lime content and curing period (Dahale, Nagarnaik et al. 2016).

2.4.2.1 Lime Stabilization Process

Lime stabilization process occurs in three parts:

- **Drying:**

During initial mixing of water and lime to the soil the hydration process occur and soil become dry.

- **Modification**

After initial mixing Cat-ionic exchange between clay, lime and water occur, which starts flocculation and agglomeration process.

- **Stabilization**

When optimum quantities of lime and water are added the pH of the soil lime mixture quickly increases to up to 12.4, which breaks down clay particles. Cementitious products like CSH and CAH are formed due to pozzolanic reaction. These products form a matrix and soil is transformed from weak soil to relative less expansive soil with significant bearing capacity. The matrix formed is permanent, durable, and significantly impermeable, producing a structural layer that is both strong and flexible

2.4.2.2 Lime Soil Chemical Processes

Clay and lime mixture reacts in presence of water forming new compounds in presence of water through the process of cationic exchange, flocculation, carbonation and pozzolanic reaction (Al-Rawas, Hago et al. 2005).

- **Cat-Ionic Exchange**

In this reaction, surplus Ca^{++} cat-ions from hydrated lime are replaced by monovalent cations (Na^{+} or H^{+}) reaction (George, Ponniah et al. 1992). This process makes the clayey soil much less affected by moisture (less change in volume). It is a quick reaction and happens instantly after addition lime in soil.

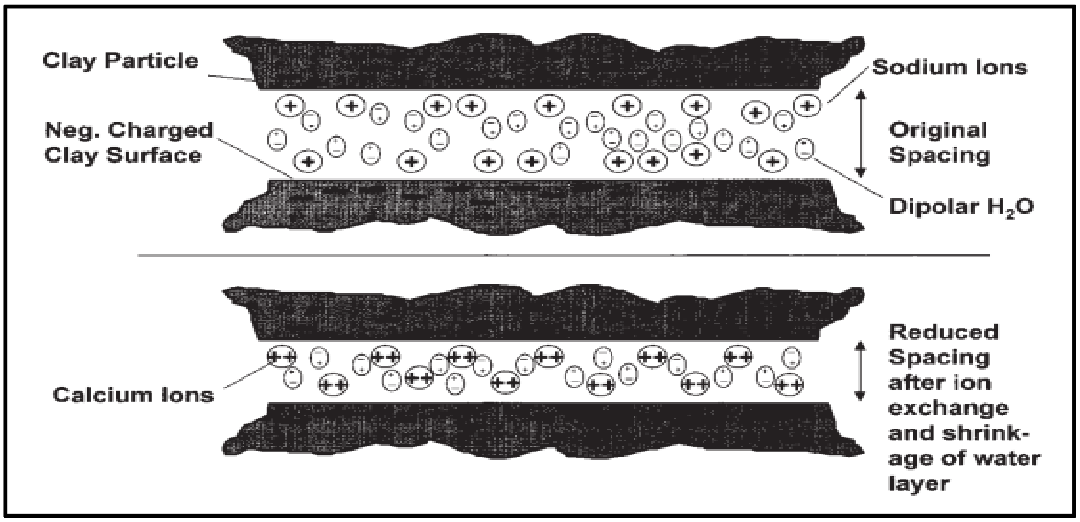


Figure 2-6 Cat-Ionic Exchange (Prusinski and Bhattacharja 1999)

- **Flocculation-Agglomeration**

A change in texture and gradation is created after cat-ion exchange reaction. Clay particles join together forming larger particles/flocs and this process is called as flocculation. This process plays primary role in modification of engineering properties of lime treated expansive soil (Ghobadi, Abdilor et al. 2014).

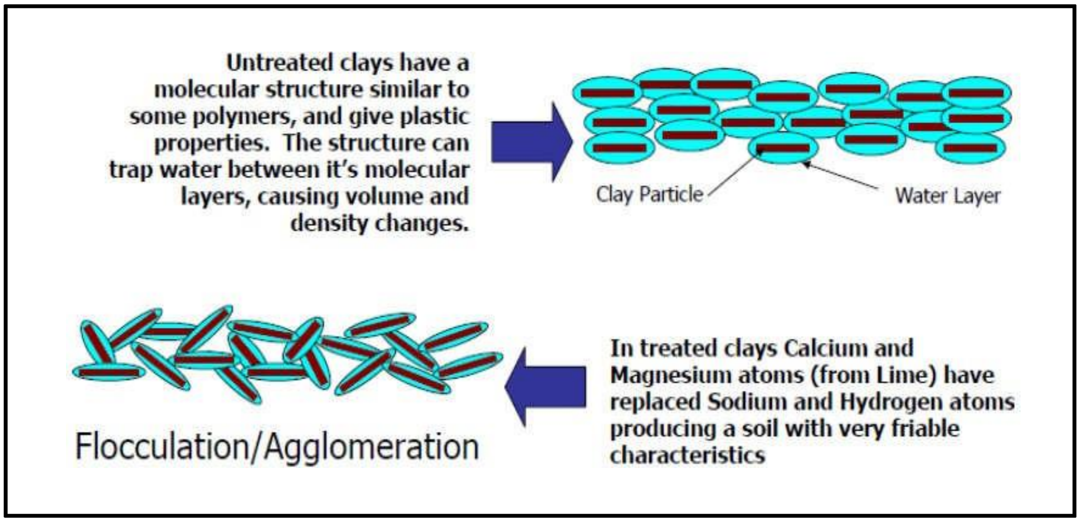


Figure 2-7 Clay Particles Before and After Lime Stabilization
(Prusinski and Bhattacharja 1999)

- **Carbonation**

Carbonation is an unwanted reaction. In this lime upon addition into soil does not react with soil, but reacts with CO_2 from air or soil and forms calcium carbonate. Main reason for carbonation reaction are excessive amount of lime content or inadequate amount of pozzolanic clay.

- **Pozzolanic Reactions**

After the initial reaction, alumina and silica in clay mineral become free when pH of 12.4 is reached (Eads and Grim, 1960). Reaction between Ca^{++} cat-ions (available due to hydration of lime) and Silica and Alumina of clay form cementitious materials like Calcium-Silicate-Hydrates (CSH) and Calcium Aluminate Hydrates (CAH) (Eisazadeh, Kassim et al. 2012). These reactions are written as follow:

$$Ca(OH)_2 + SiO_2 \rightarrow CaO - SiO_2 - H_2O$$

$$Ca(OH)_2 + Al_2O_3 \rightarrow CaO - Al_2O_3 - H_2O$$

Pozzolanic reactions are time dependent and results in a long-term strength gain. This strength gaining process is called autogenous healing and can continue for years.

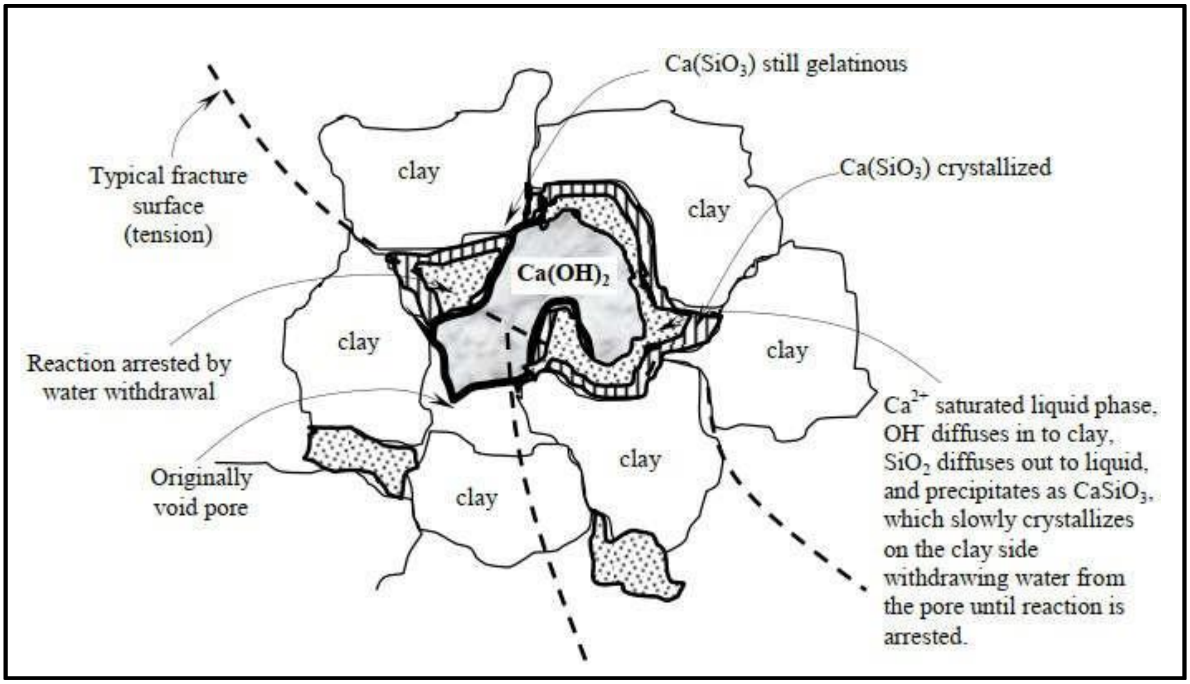


Figure 2-8 Reaction Mechanism of Stabilization Clay (Ingles and Metcalf 1972)

2.4.2.3 National Lime Association Approach for Lime Stabilization

The mixture design and testing protocol was developed to produce a mixture that has desired structural properties and durability in a pavement layer. NLA procedure is used to measure critical engineering properties of subgrade soils stabilized with lime for better performance as pavement layer. This approach was presented by Little 2000. Outline of this approach is presented below:

- Optimization of lime content
- To simulate field conditions optimum moisture content and maximum dry density are determined using modified proctor test.
- Unconfined compressive strength tests are conducted as per ASTM D5102. Samples are prepared at OMC and curing is done for 7 days at 40°C.For soaked samples moisture conditioning is done using capillary soak. Samples are subjected to capillary soak for 24 to 48 hours

2.4.2.4 Effect of Lime on Soil Properties:

2.4.2.4.1 Grain Size Distribution

Changes in GSD start occurring immediately after addition of lime. Soils become coarser due to agglomeration and flocculation reaction. Lund and Ramsey 1959 reported decrease in clay content due to increase in particle size with addition of lime.

2.4.2.4.2 Atterberg's Limit

Many researchers reported reduction in plasticity index due to reduction in liquid limit and rise in plastic limit of the soil. However, it depends on the type of soil as different researchers regarding liquid limit have reported conflict behavior. Decrease in PI of soil due to decrease in LL and increase in PL of soil was observed as reported by Jan and Walker 1963.

2.4.2.4.3 Moisture Density Relationship

Moisture content needed to achieve maximum dry density increases due to addition of lime and as a result decrease maximum dry density of the soil. Increase in OMC is due to hydration and pozzolanic reaction with lime. While decrease in MDD is due to flocculation and agglomeration reaction. Hausmann 1990 reported that MDD is reduces by 3-5 lb/ft^3 and OMC increases by 2-4 percent with addition of lime.

2.4.2.4.4 Unconfined Compressive Strength

Lime has significant effect on unconfined compressive strength of soil. Many researchers reported a significant increase in both soaked and unsoaked UCS of lime soil mixtures. Strength gain in lime soil mixes may depend on soil type and its mineralogical properties.Little, Thompson et al. 1987 carried out lime stabilization of soil and concluded that strength of lime soil mixture increases more than 100 psi.

2.4.2.4.5 California Bearing Ratio and Swell Potential

CBR test is used to determine need of subgrade stabilization and overall thickness above subgrade. CBR and swell potential of lime treated soils are also greatly improved. CBR of soil lime mixture increases from 3-4 times while swell of lime treated soils reduces to less than 0.1% after 96 hours of soaking as mentioned by Little, Thompson et al. 1987.

2.5 Economic Benefits

Now-a-days pavement and highway designers are trying to develop appropriate design procedure based on many factors. These factors involve feasibility, strength, economy and various other factors. Economic factor has gained attention. Designer try to develop a design that satisfies all engineering properties and yet has low cost for construction and maintenance of structure. Cost Analysis process can be done to find out economic benefits for all design procedures including application of stabilizers in subgrade sub-base and base.

Use of lime to increase the subgrade CBR from 8% to 15% yielded a saving of 20% of overall project cost while constructing an interstate highway in Pennsylvania (Carmeuse 2002). The increased CBR resulted in a reduction of layer thicknesses. Combine use of lime and WSA will be economically beneficial.

2.6 Summary of Research Already Carried Out on the Proposed Topic

The following table exhibits the level of research already carried out on the proposed topic as well as the preliminary literature review already done.

Author / Year	***Test Matrix***	***Performance Test Conducted***	***Research Findings***
(P.P.Dahale, 2016) Construction and Building Materials **IF (6.141)**	**Studied effect of lime and flyash on clay soil (%finer 92, PI 35.53, CH) (At 8% Lime)**	**Atterberg's MDD & OMC UCCT CBR**	• UCS increased **(Upto 50%)** • MDD significantly decreased • CBR significantly increased
(Hayder Hassan, 2016) Construction and Building Materials **IF (6.141)**	**Studied effect of lime and bagasse ash on clay soil (%finer 81.64, PI 49, CH) (At 6% lime)**	**Atterberg's MDD & OMC UCCT**	• MDD significantl decreased • UCS significantly increased
(Azhan Zukri, 2014) Construction and Building Materials **IF (6.141)**	**Studied effect of lime on clay soil (%finer > 50%) (At 9% Lime)**	**Atterberg's MDD & OMC UCCT CBR**	• OMC significantly increased • MDD significantly increased • UCS increased **(67.56%)**
(M.R Asgari, 2013) Construction and Building Materials **IF (6.141)**	**Studied effect of lime and cement on clay soil (%finer 98, PI 9, CL) (2-9% lime)**	**Atterberg's MDD & OMC UCCT CBR**	• PI significantly decreased • MDD significantl decreased • UCS increased **(37.23%)**

2.7 Summary

This chapter presents literature review of subgrade, clay and sandy soil its structure and stabilizers used in this research. Different types and methods of soil stabilization techniques are discussed. Effect of lime on different geotechnical properties of clay has been discussed in later section of the chapter. Furthermore, literature review is presented by mentioning different works carried out in past by different researcher using lime and other additives.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 General

This systematic experimental investigation is intended to stabilize weak subgrade soil using Lime. This Chapter notifies the research methodology adopted to accomplish the research objectives as discussed in Chapter 1. To assess the behavior of subgrade soil laboratory testing was conducted in four phases. In the first phase classification of natural material using sieve analysis and Atterberg's limits was determined and its strength properties using UCS and CBR were determined. In second phase soil behavior by adding different lime content was checked and optimum lime content was determined. Third phase comprises of evaluating soil lime mix. Finally fourth phase different properties of treated subgrade soil were evaluated.

All the experiments were performed by following ASTM standards. NLA approach was used for soil stabilization using Lime.

3.2 Materials

Details about material i.e. subgrade soil and lime is summarized below.

3.2.1 Soil

Soil used in this research was weak subgrade low plastic clay. Oven dried soil sample was used throughout the research testing process.

3.2.2 Lime

Quick lime was used for soil stabilization process. Locally available lime from open market was used in the research process. Lime used was in powdered form. Lime was kept and stored in an air tight bag to avoid reaction of lime with air due to natural moisture present in air.

3.3 Methodology

Research methodology consists of five phases. Material testing was carried out in three phases.

Phase I: Properties of Natural/ Untreated soil sample

Phase II: Optimization of Lime content

Phase III: Properties of treated soil

3.3.1 Phase I: Properties of Natural/ Untreated soil sample

The first phase in this research was intended to determine the properties of natural or untreated soil or without any stabilizer. Engineering properties were determined and soil was classified based on GSD and Atterberg's limits. Strength properties of soil were also determined using CBR and UCCT. Following tests/procedure was adopted to find properties of natural soil.

3.3.1.1 Sample Collection

Soil sample was collected from 2-feet depth to reduce the chances of organic matter, roots and other impurities.

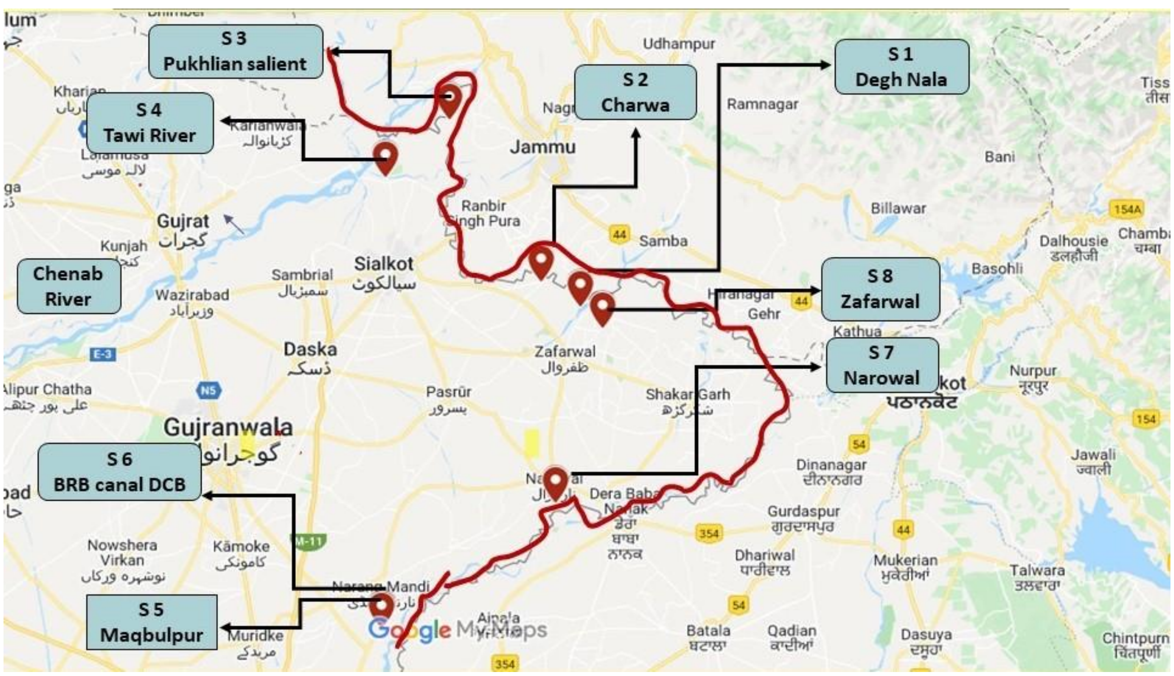


Figure 3-1 Sample collections in the area of study

3.3.1.2 Grain Size Distribution

Sieve analysis was performed by following ASTM D 422. A 300g of soil sample was taken, pulverized and then washed on sieve#200. Soil passing through sieve#200 and soil retained on sieve#200 was determined.

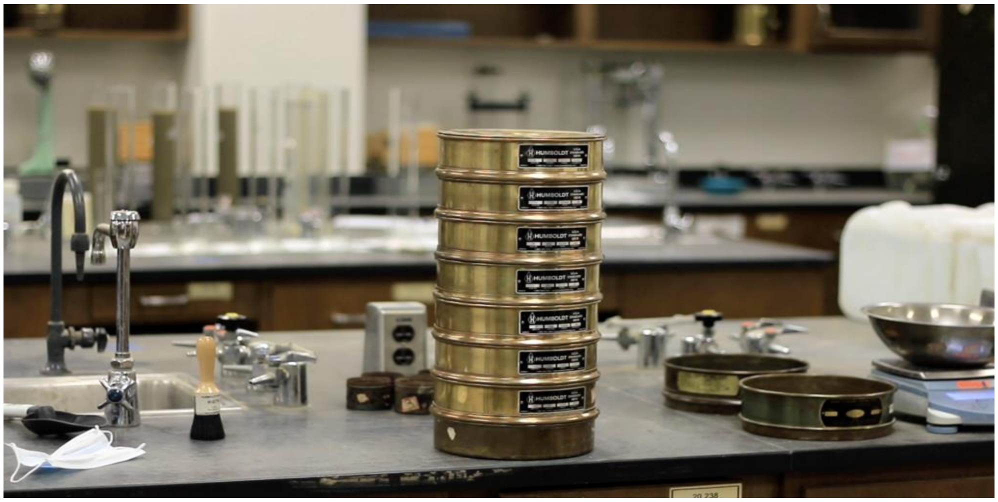


Figure 3-2 Sieve analysis

3.3.1.3 Atterberg's Limits of Soil

Atterberg's limits were determined according to ASTM D 4318. Soil passing through sieve#40 was used to determine liquid and plastic limit. Soil was classified using AASHTO and USCS systems using Atterberg's limits. Also plasticity index of soil serves as an indicator of feasibility of soil with lime.

Figure 3-3 Atterberg's limit of soil

3.3.1.4 Specific Gravity of Soil

Specific gravity is a significant parameter of soil since it can be associated with the soil mineral composition and weathering. It is also used to derive several parameters such as porosity, the dry and saturated density and degree of saturation, Specific Gravity was determined by following ASTM D 854. Soil passing through sieve#4 was used as per ASTM.

Figure 3-4 Specific gravity of soil

3.3.1.5 Moisture Density Relationship of Soil

Modified Proctor Test method was used to find moisture density relationship of natural soil. Soil was placed in five layers and compacted with 25 blows per layer using 10lb hammer with 18 inch fall. Test was performed as per ASTM D 1557.

3.3.1.6 Unconfined Compressive Strength of Soil

UCCS of soil was determined by following ASTM D 2166. According to ASTM D 2166 height to diameter ratio must be 2:1. Mold used was of height 10cm and diameter 5cm. Soaked and unsoaked unconfined compressive tests were performed. Samples were made at optimum moisture content and maximum dry density taken from modified proctor test.

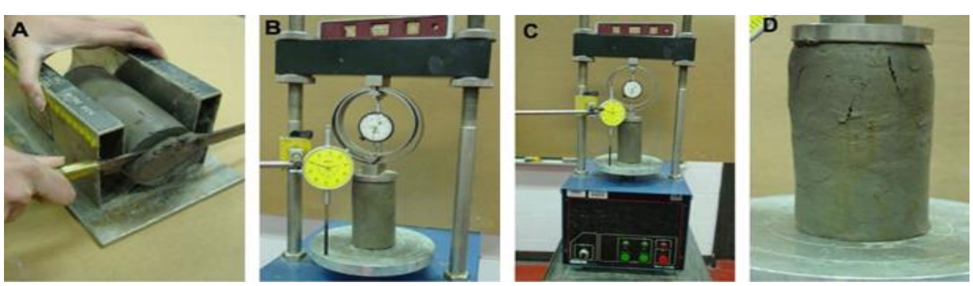


Figure 3-5 (a,b) UCC Testing of Natural Soil

3.3.1.7 California Bearing Ratio and Swell Potential of Soil

CBR test was performed according to ASTM D 1883. CBR samples were prepared at OMC to achieve maximum dry density and were compacted in five layers with 25 blows per layer. Soaked and unsoaked CBR was conducted.

For soaked CBR sample was soaked for 96 hours in a water tank. A gauge was attached to measure swell potential of the soil.

Figure 3-6 (a,b) CBR Testing

3.3.2 Phase II: Optimization of Lime content

Second Phase of the research was to find optimum lime content. Quick lime from open market was used. Different samples were prepared by adding 2%, 4%, 6% lime content.

3.3.2.1 Moisture Density Relationship at Various Lime Content

Different samples were prepared by adding 2, 4, 6% lime. OMC and MDD were found for each sample using modified proctor tests. All experiments were carried out as per ASTM D 1557.

3.3.2.2 Unconfined Compressive Strength at Various Lime Content

Unconfined compressive strength test samples were prepared at for 2%, 4%, 6% lime content. The samples were prepared at OMC and MDD already determined by modified proctor test. All tests were performed in accordance with ASTM D 5102. Height to diameter ratio was kept 2:1. Special mold of height 6" and diameter 3" was used for UCS testing and no of blows were adjusted as 20 blows. Maximum change in strength due to addition of lime was observed after 7 days of curing. All test samples were wrapped up in airtight plastic bags to prevent moisture loss and cured at 40^{o}C for 7 days. After 7 days of curing, samples were tested and the lime percentage resulting in the highest improvement in UCS was selected as optimum lime content.

3.3.2.3 California Bearing Ratio Test at Optimum Lime Content

CBR test was performed at lime content resulting in highest improvement of UCS. Test was performed according to ASTM D 1883. Soaked CBR was conducted and swell potential was also determined by using swell measuring gauge.

3.3.3 Phase III: Properties of Treated Soil

Once the optimum content for both lime were established, Atterberg's limits, moisture-density relationship, UCS at 7 days curing, CBR and swell potential of soil were determined for lime.

3.3.3.1 Atterberg's Limits of Treated Soil

LL and PL of soil for optimum lime was determined. Effect of optimum lime on soil was observed. All tests were performed in accordance with ASTM D 4318.

3.3.3.2 Moisture Density Relationship of Treated Soil

Modified proctor test ASTM D 1557 was used to find the moisture-density relationship for treated soil. OMC and MDD was found for optimum lime.

3.3.3.3 Unconfined Compressive Strength of Treated Soil

UCS tests were performed on samples with optimum lime content and samples with optimum lime content after 7 days of curing. Samples were prepared at OMC and MDD. Two test samples were prepared for each test and their average value was reported.

Samples were wrapped up in air tight plastic bags for the preservation of moisture and cured at room temperature for the respected curing period.

3.4 Summary

Detailed methodology of research has been presented in this chapter. First part of chapter describes characterization and evaluation of different geotechnical properties of natural soil. Later parts present methodology adopted to find out different soil properties of lime treated soil. And the last part presents procedure and experiments carried out to analyse geotechnical properties of treated soil. Detailed about test procedure, test samples, and experimentation setup is also discussed in this chapter.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 General

Weak Subgrade soil possess a major problem for pavements. This research was intended to study the use of lime as stabilizers for weak subgrade soil. Detail result analysis is presented below.

4.2 Phase I: Properties of Natural/ Untreated soil sample

4.2.1 Grain Size Distribution

Grain size distribution was carried out using wash method to determine percent passing through sieve#200. Tests were performed by following ASTM D 422. A 300g of soil sample was taken, pulverized and then washed on sieve#200.

Table: 4-1 Grain Size Distribution through sieve analyses

Sieve No	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8
# 4	98.18	98.5	99.5	83.5	89.16	94.33	99.76	70.23
# 10	95.85	96.96	98.7	76.92	85.23	91.3	99.68	60.09
# 20	95.35	96.16	97.86	72.25	83.2	88.96	99.6	49.18
# 40	16.49	95.36	96.56	36.88	82.8	87.7	99.51	28.13
# 60	7.3	94.43	93.53	22.36	82.6	86.7	99.42	12.02
# 100	1.6	93.06	87.36	8.77	82.43	84.66	99.36	4.41
# 200	0.4	91.7	79.43	3.36	82.33	81.23	99.33	1.31
Pan	0	0	0	0	0	0	0	0

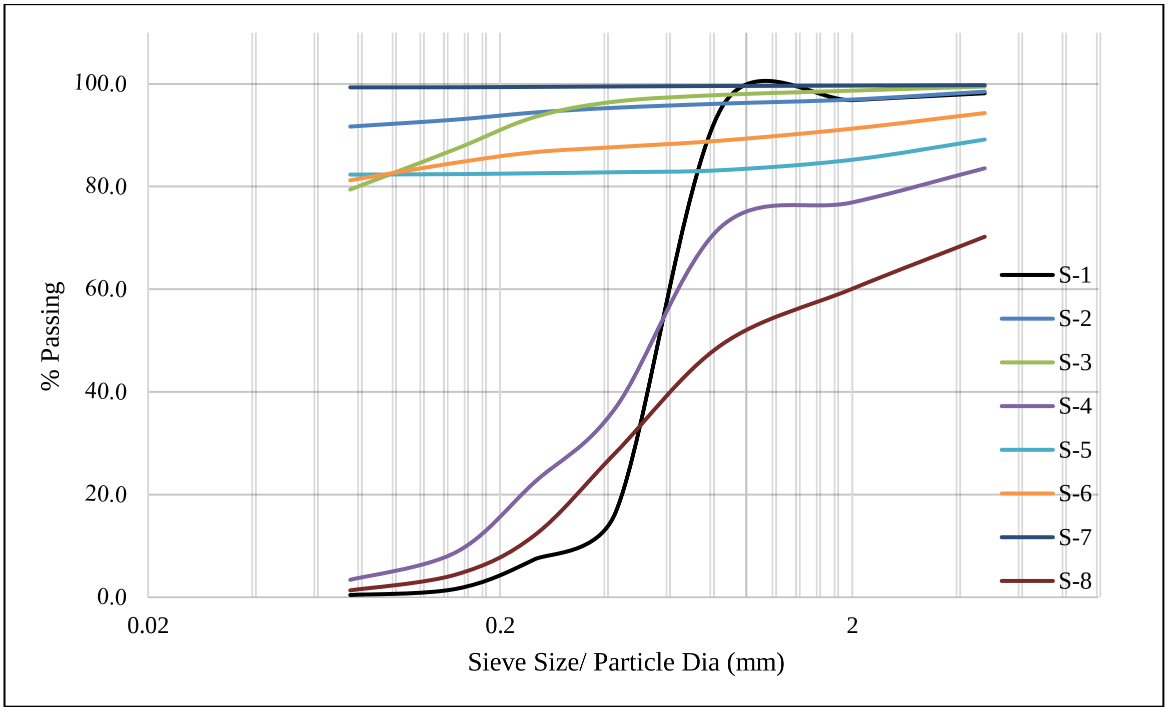


Fig 4-1 Grain Size Distribution

4.2.2 Atterberg's Limits of Soil

Casagrande apparatus was used to find out liquid limit and plastic limit of the soil as per ASTM D 4318. Plastic limit was determined by making threads of 1/8" thickness. And liquid limit was determined by finding moisture content at 25 blows as per ASTM. Soil was classified based on GSD and Atterberg's limits.

Table - 4-2 Atterberg's Limit

Sample ID	Liquid Limit	Plastic Limit	Plasticity Index
S-1	**Non Plastic**		
S-2	45	22.03	22.97
S-3	30.33	22.44	7.89
S-4	**Non Plastic**		
S-5	35	20.9	14.1
S-6	25.5	17.7	7.8
S-7	34.3	23.68	10.62
S-8	**Non Plastic**		

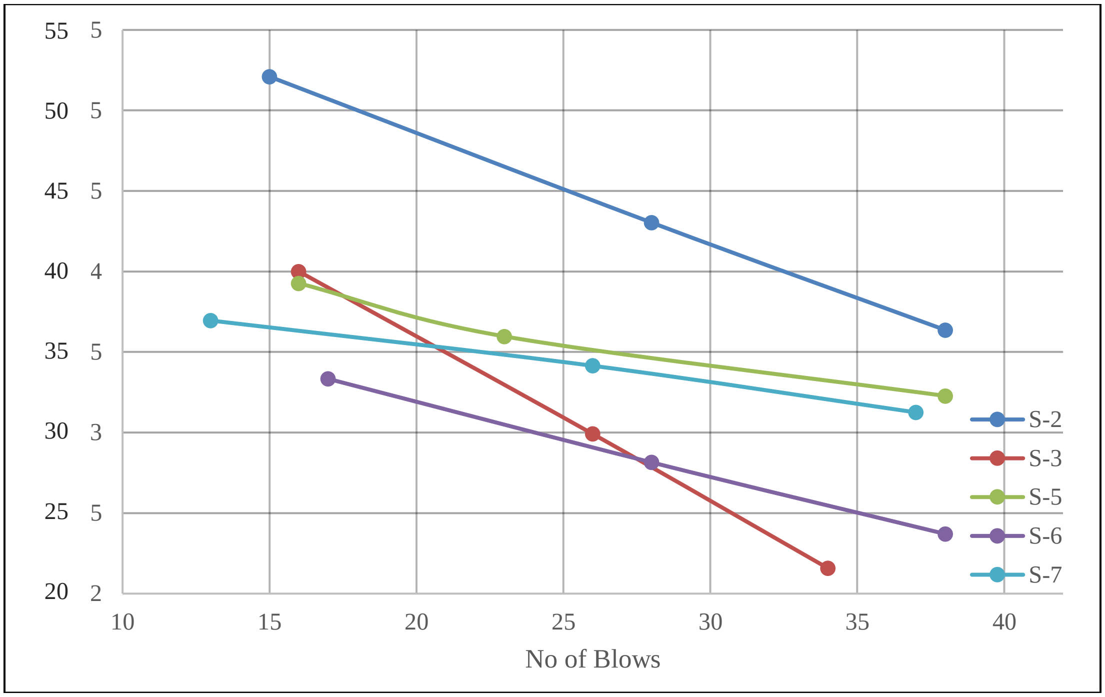
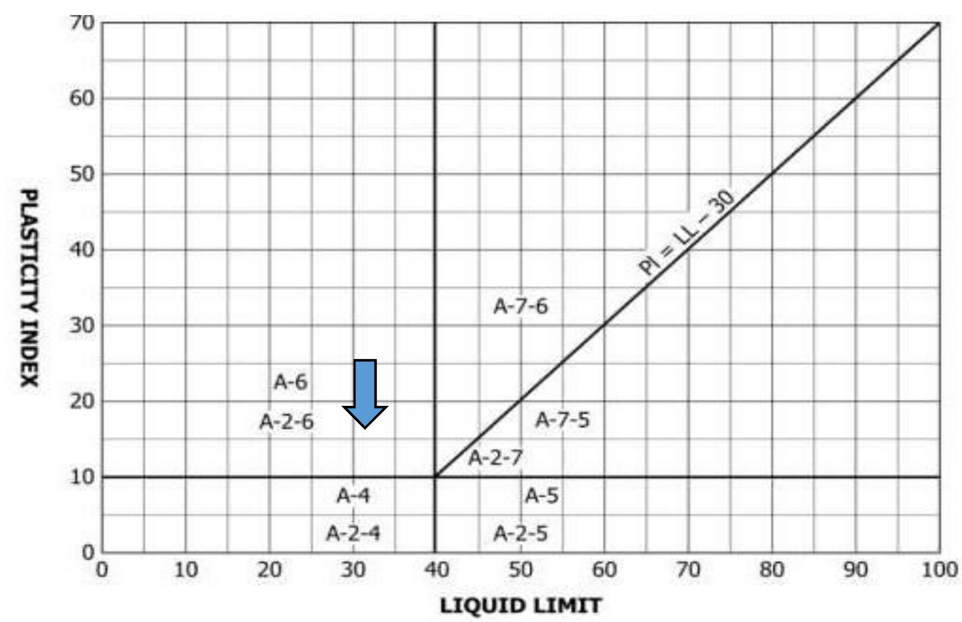


Fig 4-2 Atterberg's Limit



(Note: A2 Soils contain less than 35% finer Sieve#200)

Figure 4-3 Soil Classification (ASTM D3282)

4.2.3 Specific Gravity of Soil

Specific gravity of soil was determined from soil passing through sieve#4 was used as per the standard procedure following ASTM D 854.

. **Table - 4-3** Specific Gravity of Soil

Sample ID	Specific Gravity
S-1	2.625
S-2	2.636
S-3	2.47
S-4	2.465
S-5	2.577
S-6	2.44
S-7	2.485
S-8	2.526

4.2.4 Moisture Density Relationship of Soil

Different samples were prepared. OMC and MDD were found for each sample using modified proctor tests. All experiments were carried out as per ASTM D 1557.

Table – 4-4 Moisture Density Relationship

SAMPLE ID	MDD (PCF)	OMC %
S-1	118.4	12.3
S-2	121.8	12.9
S-3	113.2	12.7
S-4	123.6	8.7
S-5	119.8	10.8
S-6	124.3	9.9
S-7	124	10.5
S-8	125.2	8.6

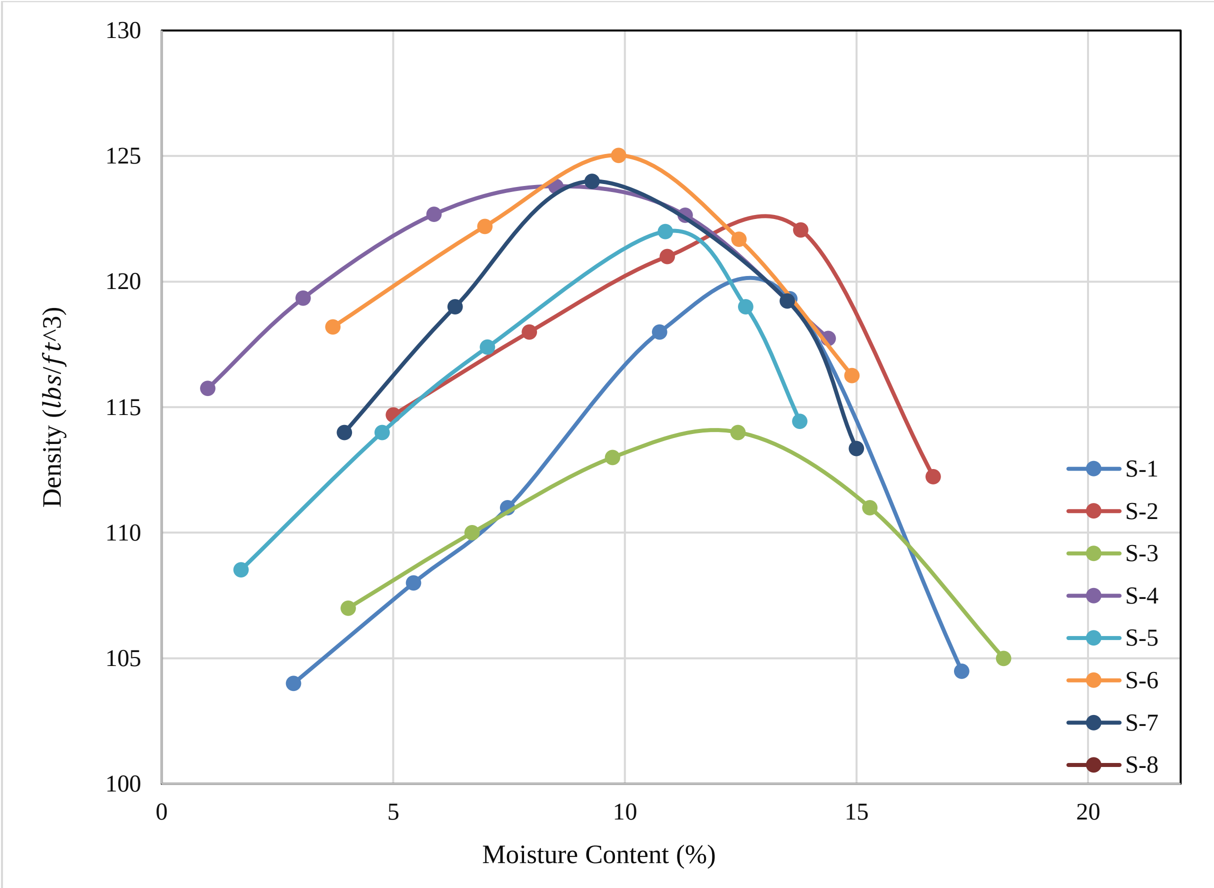


Fig 4-4 Moisture Density Relationship

4.2.5 Unconfined Compressive Strength of Natural/Untreated Soil

Samples to find UCS were prepared for both soaked and unsoaked condition and lab tests carried out in order to obtain the compressive strength. All samples were prepared at OMC and MDD already determined by modified proctor test. All tests were performed in accordance with ASTM D 5102.

Table – 4-5 Unconfined Compression Strength of Soil

	Sample - 1	Sample - 2		Sample - 3		Sample - 4	Sample - 5		Sample - 6		Sample - 7		Sample - 8
Dial Reading		**Strain %**	**Axial Load**	**Strain %**	**Axial Load**		**Strain %**	**Axial Load**	**Strain %**	**Axial Load**	**Strain %**	**Axial Load**	
0	**SANDY SOIL**	0	0	0	0	**SANDY SOIL**	0	0	0	0	0	0	**SANDY SOIL**
25		0.25	0.24	0.25	0.03		0.25	0.05	0.25	0.31	0.25	0.3	
50		0.5	0.41	0.5	0.05		0.5	0.09	0.5	0.46	0.5	0.5	
75		0.75	0.58	0.75	0.06		0.75	0.14	0.75	0.49	0.75	0.74	
100		1	0.73	1	0.08		1	0.17	1	0.63	1	0.98	
125		1.25	0.89	1.25	0.09		1.25	0.2	1.25	0.72	1.25	1.28	
150		1.5	1.03	1.5	0.12		1.5	0.25	1.5	0.84	1.5	1.55	
175		1.75	1.16	1.75	0.14		1.75	0.28	1.75	0.91	1.75	1.83	
200		2	1.28	2	0.19		2	0.32	2	0.94	2	2.07	
225		2.25	1.39	2.25	0.23		2.25	0.37	2.25	0.91	2.25	2.31	
250		2.5	1.48	2.5	0.29		2.5	0.4	2.5	0.83	2.5	2.54	
275		2.75	1.57	2.75	0.36		2.75	0.46	2.75	0.61	2.75	2.72	
300		3	1.62	3	0.44		3	0.51			3	2.91	
325		3.25	1.68	3.25	0.52		3.25	0.57			3.25	3.05	
350		3.5	1.71	3.5	0.62		3.5	0.62			3.5	3.12	
375		3.75	1.75	3.75	0.73		3.75	0.68			3.75	3.16	
400		4	1.74	4	0.85		4	0.76			4	3.18	
425		4.25	1.72	4.25	0.98		4.25	0.83			4.25	3.16	
450		4.5	1.66	4.5	1.1		4.5	0.93			4.5	3.08	
475				4.75	1.23		4.75	1.02					
500				5	1.35		5	1.13					
525				5.25	1.44		5.25	1.2					
550				5.5	1.55		5.5	1.31					
575				5.75	1.64		5.75	1.38					
600				6	1.71		6	1.48					
625				6.25	1.76		6.25	1.57					
650				6.5	1.76		6.5	1.62					
675				6.75	1.62		6.75	1.62					
700				7	1.39		7	1.59					
725							7.25	1.55					

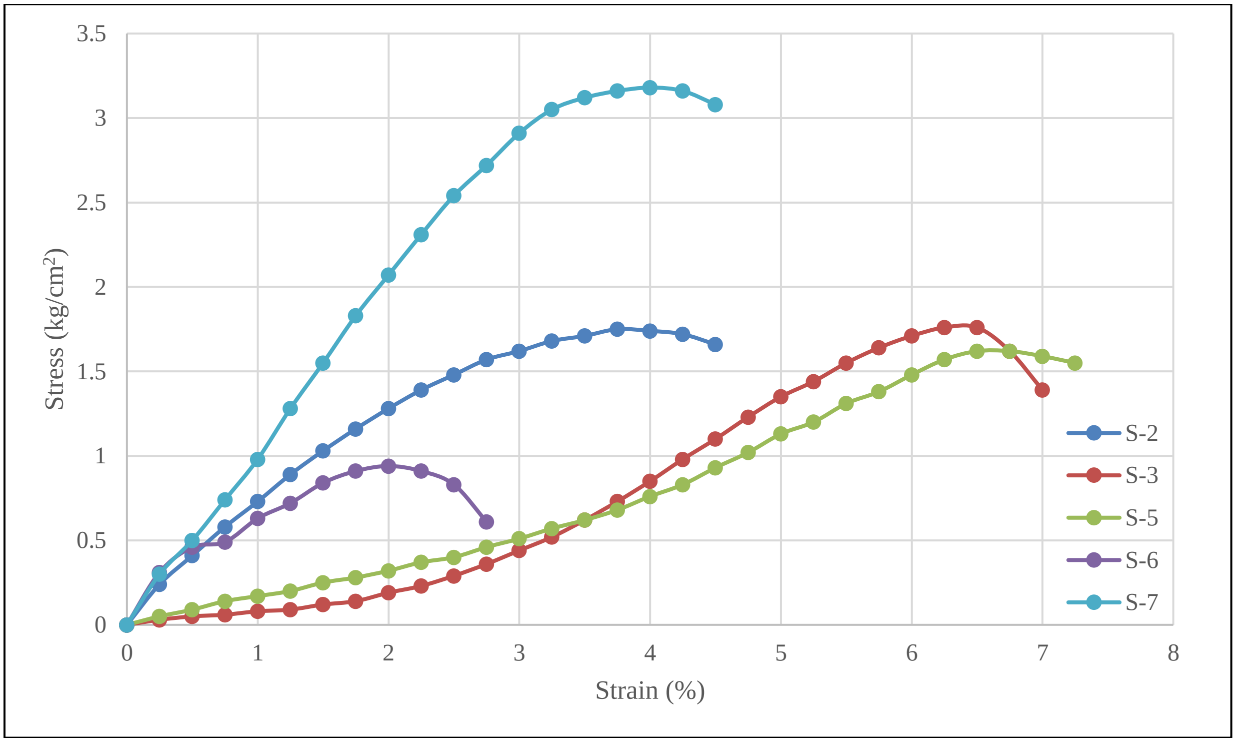


Fig 4-5 Unconfined Compression Strength of Soil

- The consistency of soil samples 2, 3 & 5 (S-2, S-3 7 S-5) have been observed as stiff, having compression strength from 1-2 kg/cm^2, sample 2 was observed having plastic behavior
- Sample 6 (S-6) carrying compressive strength of 0.94 kg/cm^2 is identified as firm soil and displayed a ductile behavior
- Sample 7 (S-7) with a compressive strength of 3.18 kg/cm^2 is observed as very stiff and plastic material

4.2.6 California Bearing Ratio and Swell Potential of Soil

Soaked and Unsoaked CBR both were performed for natural/untreated soil as per ASTM D 1883. CBR test was conducted and swell potential was determined by using swell measuring gauge.

Table – 4-6 California Bearing Ratio (Soaked)

SAMPLE NO	Stress		CBR %	
	At 0.1"	At 0.2"	At 0.1"	At 0.2"
S-1	124	296.3	12.402	20
S-2	41.3	75.8	4.134	5
S-3	44.1	64.8	440	4
S-4	385.8	1033.5	38.58	69
S-5	46.9	96.5	4.68	6
S-6	28.8	38.6	2.48	3
S-7	55.1	95.1	5.12	6
S-8	53.7	130.9	5.37	9

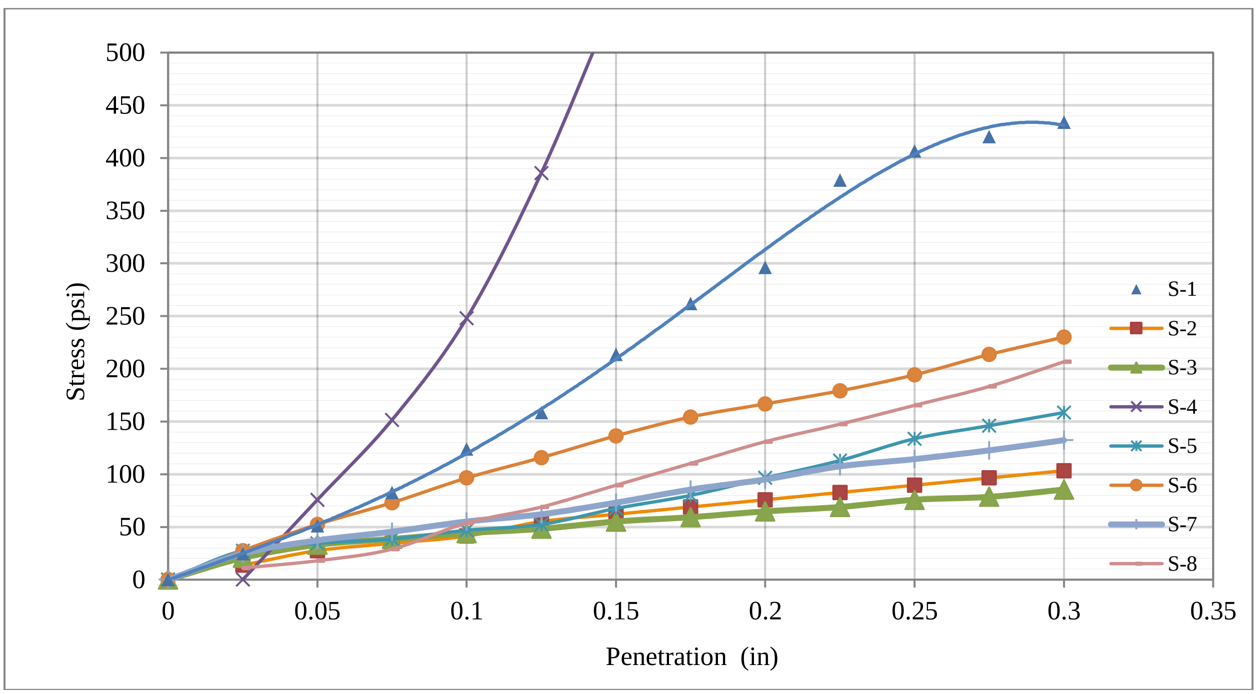


Fig 4-6 California Bearing Ratio (Soaked)

Table - 4-7 California Bearing Ratio (UnSoaked)

SAMPLE NO	Stress		CBR %	
	At 0.1"	**At 0.2"**	**At 0.1"**	**At 0.2"**
S-1	130.9	420.3	13.091	28
S-2	181.9	241.2	18.18	16
S-3	246.7	275.6	24.66	18
S-4	633.9	1336.7	63.38	89
S-5	62	96.56	6.2	6
S-6	96.5	166.7	9.64	11
S-7	137.8	268.7	13.78	18
S-8	100	175	10	12

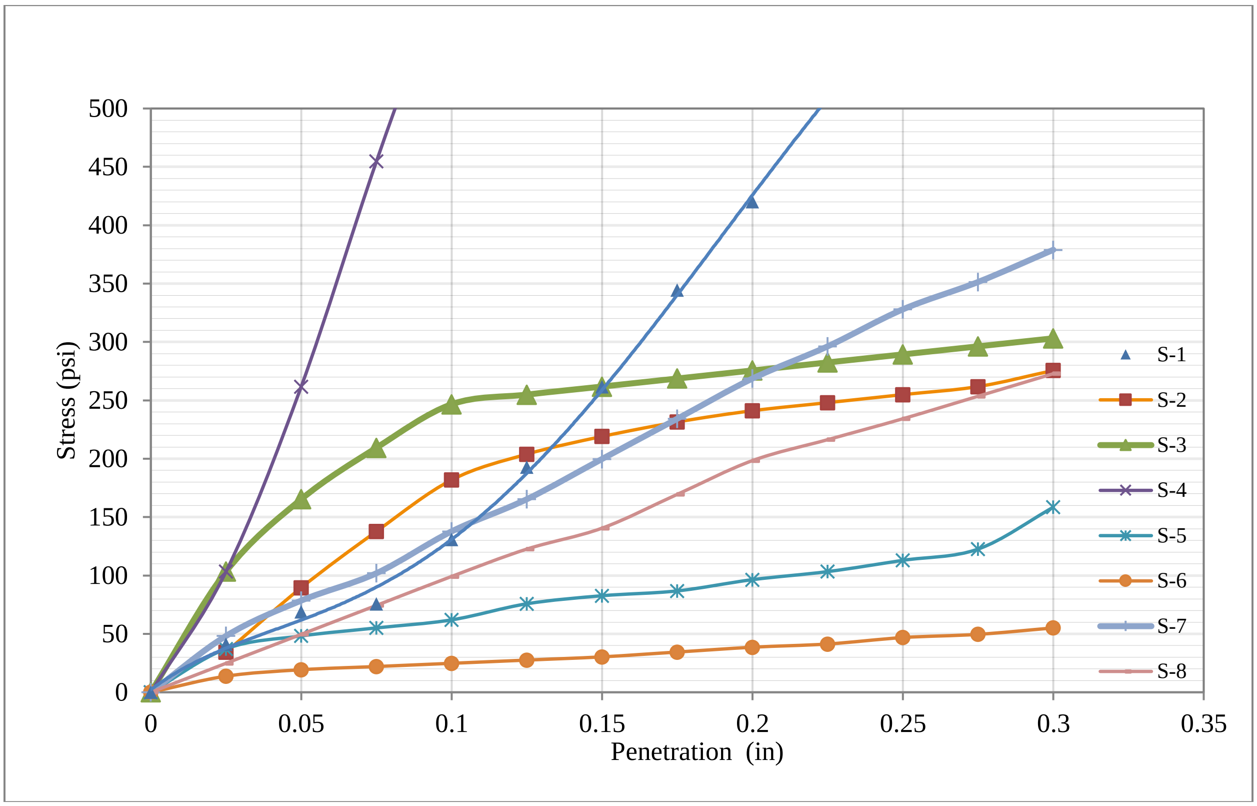


Fig 4-7 California Bearing Ratio (UnSoaked)

4.2.7 Brief Summary

Detailed methodology of research has been presented in this chapter. A brief summary of the natural subgrade soil strata distributed into eight different samples properties is given below.

Table – 4-8 Brief Summary of Soil Classification Based on Test Performed

PROPERTIES	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	SAMPLE 7	SAMPLE 8
% PASSING SIEVE #200	0.4	91.7	79.43	3.36	82.33	81.23	99.33	1.31
LIQUID LIMIT	**Non Plastic**	45	30.33	**Non Plastic**	35	25.5	34.3	**Non Plastic**
PLASTIC LIMIT		22.03	22.44		20.9	17.7	7.8	
PLASTICITY INDEX		22.97	7.89		14.1	7.8	10.62	
OMC	12.3	12.9	12.7	8.7	10.8	9.9	10.5	8.6
MDD (pcf)	118.4	121.8	113.2	123.6	119.8	124.3	124	125.2
SPECIFIC GRAVITY	2.62	2.63	2.47	2.46	2.57	2.44	2.48	2.52
UCCT (kg/cm^2)	**Sandy Soil**	1.75	1.76	**Sandy Soil**	1.62	0.94	3.18	**Sandy Soil**
CBR SOAKED (%)	12.4	5	4	69	6	3	6	9
CBR UNSOAKED (%)	13.09	16	18	89	6	11	18	12
SOIL TYPE AASHTO	A-1-b	A-7-6	A-4	A-1-b	A-6	A-4	A-6	A-1-b
SOIL TYPE USCS	SP	CL	CL	SP	CL	CL	CL	SP

4.3 Phase II: Optimization of Lime content

Eads and Grim pH test was conducted to carry out approximate optimization of lime. UCS test was used as main criteria for finding the optimum lime content and to cross check the optimum lime content obtained from pH test. Quantity of lime that gives best result for UCS will be optimum lime content.

4.3.1 Moisture Density Relationship at Various Lime Content

MD relationship was established for various lime content. Sample were prepared by adding lime 2%, 4% and 6% .OMC and MDD was determined for each soil sample Table and Figure 4-9 presents the moisture-density behavior of the soil.

Compaction test results on the soil indicate a gradual increase in moisture content and decrease in MDD of the soil. Reduction in MDD is due to flocculation and agglomeration of soil with the lime. These flocculated and agglomerated particles occupy greater space which reduce the dry density of clay soil. While contrarily increase in OMC is due to fineness of lime and also due to hydration reaction of water with the soil that is pozzolanic activity of lime.

4.3.2 Unconfined Compressive Strength at Various Lime Content

Special mold of height 6” and diameter 3” was used for UCS testing of lime soil mixture. Height to diameter ratio of samples was kept 2:1. No of blows were adjusted and calculated. No of blows per layer were 22. Unconfined compressive strength samples were prepared for various lime contents at their OMC as found by modified proctor test. Samples wrapped in plastic sheet to avoid moisture loss were kept 3 and 7 days for curing and at 25^{o}C then tested. Lime percentage giving maximum unconfined compressive strength is optimum lime content. UCS test indicate that soil sample with 4 % lime content possess maximum strength

4.4 Phase III: Properties of Treated Soil

Once the optimum lime and WSA content was determined different soil properties i.e. Atterberg’s limit, CBR, swell potential etc. were determined to check the potential of Lime on weak subgrade soil.

4.4.1 Grain Size Distribution

Effect of lime on Grain Size Distribution was determined and Sieve analysis was carried out following ASTM D 422. Soil passing through sieve#200 and soil retained on sieve#200 was determined.

Table 4-9 Sieve Analyses of Sample A-7-6 Soil treated with varying percentages of Lime

SIEVE NO	0 %	2%	4%	6%
# 4	98.50	100	100	100
# 10	96.97	99.36	97.9	99.2
# 20	96.17	98.76	95	97.96
# 40	95.37	97.7	93.4	95.9
# 60	94.43	95.96	91.4	92.86
# 100	93.07	92.86	89.4	89.5
# 200	91.70	89.4	88.2	87.5
PAN	0	0	0	0

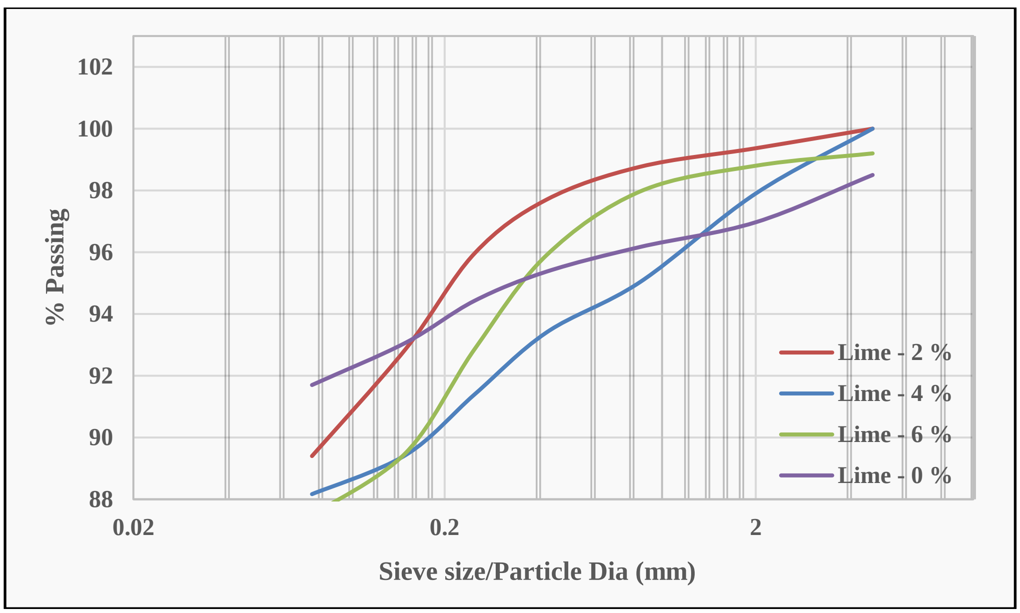


Fig 4-8 Grain Size Distribution

4.4.2 Atterberg's Limit of Treated Soil

Effect of lime on atterberg's limit was determined and test performed according to ASTM D 4318. Soil passing through sieve#40 was used to determine liquid and plastic limit. Soil was classified using AASHTO and USCS systems using Atterberg's limits. Also plasticity index of soil serves as an indicator of feasibility of soil with lime.

Table 4-10 Atterberg's Limit Based on Lime %

SER	LIME %	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX
1	0	45	22	22.9
2	2	45	32.7	12.3
3	4	37.01	32.27	4.74
4	6	32	22.03	9.97

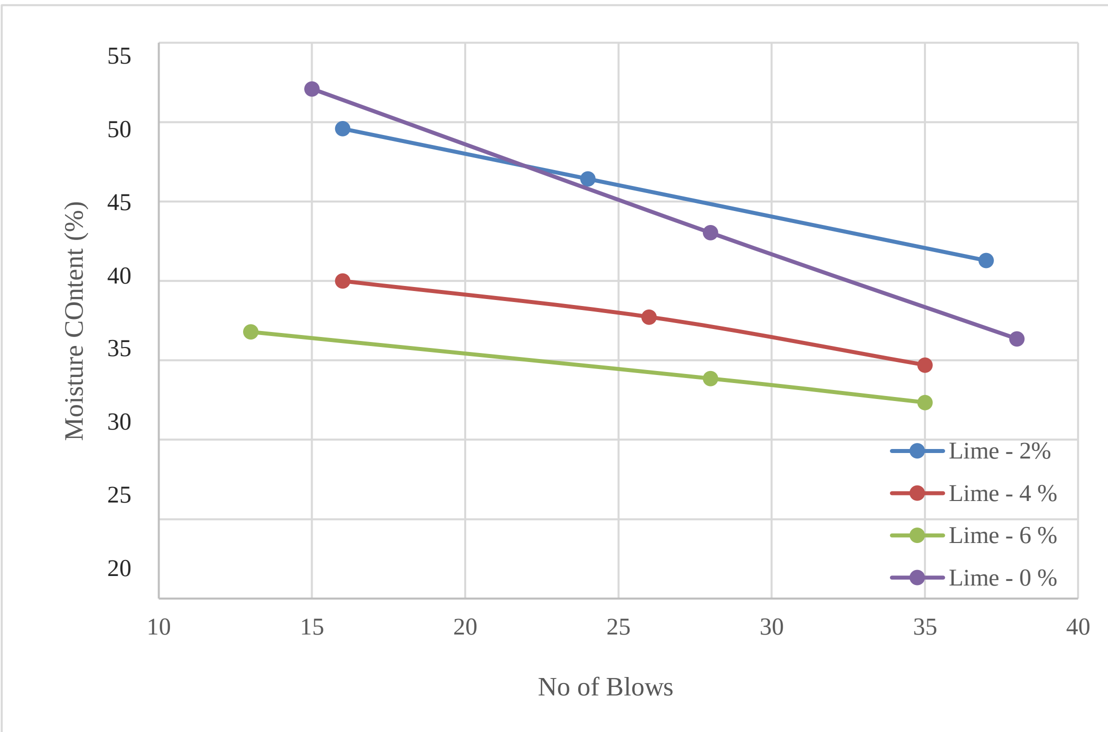


Fig 4-9 Atterberg's Limit Based on Lime %

4.4.3 Moisture Density Relationship of Treated Soil

Sample A-7-6 was prepared by adding 2, 4, 6% lime. OMC and MDD were found for each Lime content using modified proctor tests. All experiments were carried out as per ASTM D 1557.

Table 4-11 Moisture Density Relationship Soil-Lime Mix

LIME	MDD (PCF)	OMC %
0%	121.8	12.9
2%	114.7	12..6
4%	112.2	12.9
6%	115.5	9.8

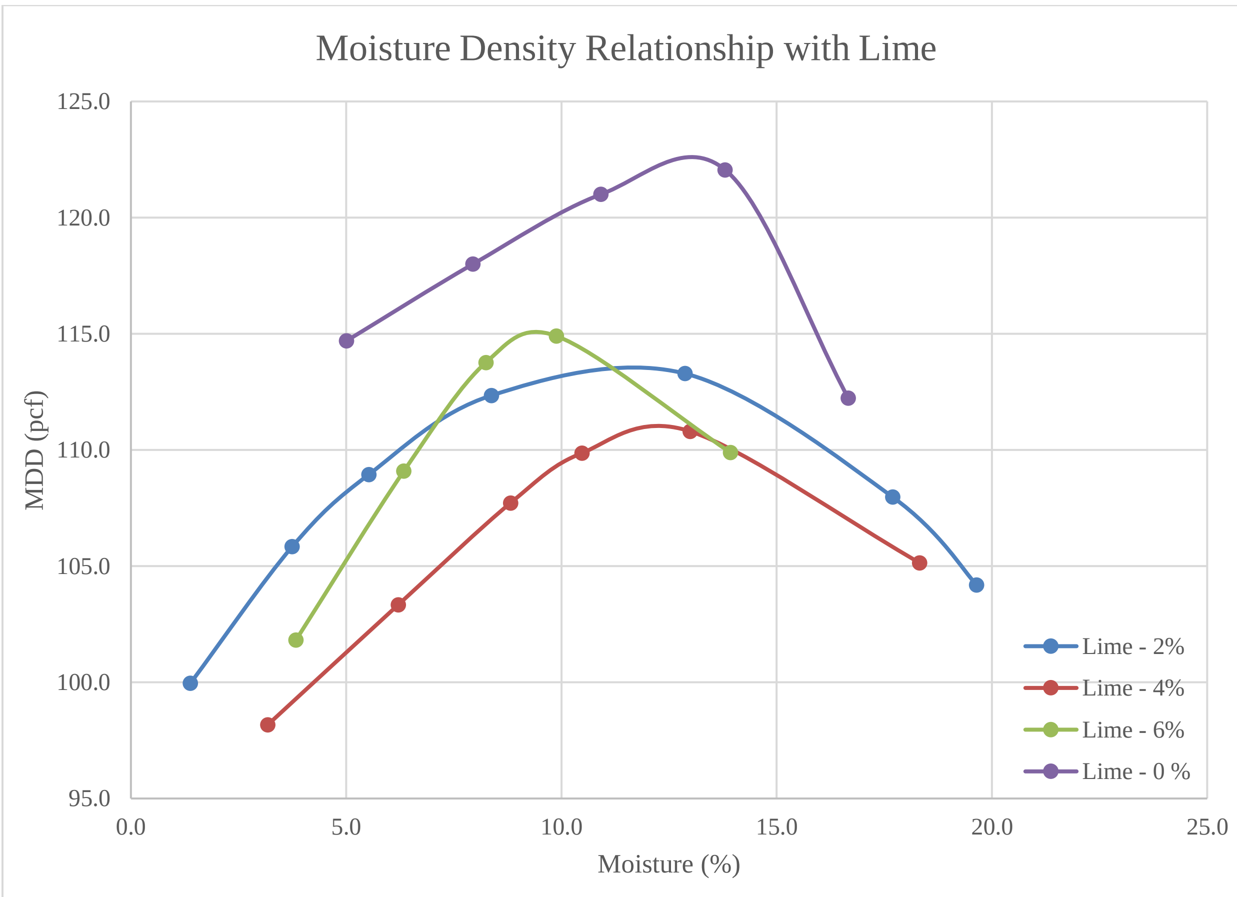


Figure 4-10 OMC at Various Lime Content

4.4.4 Unconfined Compressive Strength of Treated Soil

Unconfined compressive strength tests in both soaked and unsoaked condition were carried out on samples after 7 days. Soaked testing was carried out to assess the behavior of soil in moist condition. Unsoaked unconfined compressive strength tests result for untreated and treated soil at optimum lime content are shown below

Table 4-12 UCC Results Based on varying percentages of Lime

CURING PERIOD	**0 Days**	**3 Days**	**7 Days**	**0 Days**	**3 Days**	**7 Days**	**0 Days**	**3 Days**	**7 Days**
% LIME	**2%**			**4%**			**6%**		
UCCS (kg/cm^2)									
UCC UNSOAKED	2.92	9.3	16.07	3.8	4.23	6.54	2.78	3.71	3.89
UCC SOAKED	2.11	6.34	10.5	2.49	1.81	1.41	2.37	1.19	0.9

4.5 Summary

In this chapter, detailed results and discussions were presented. The results of all lab experiments carried out are presented with the help of graphs. The curves showing trend and effect of lime on clay soil are discussed in detailed.

Table 4-13 Sample **A-7-6** Summary of Results with varying percentages of Lime

LAB TESTS WITH LIME %		**0%**	**2%**	**4%**	**6%**
SIEVE ANALYSES	Coarse Fraction	8.3	5	7.2	10.9
	Fine Fraction	91.71	95	92.8	89.1
HYDROMETER ANALYSIS	Silt %	91.7	89.4	88.2	87.5
	Clay %	0	1.88	1.84	1.78
LIQUID LIMIT		55.5	45.1	37.01	32
PLASTICITY LIMIT		33.5	32.8	32.27	22.03
PLASTICITY INDEX		22.97	12.3	4.74	9.97
MDD (pcf)		121.8	114.7	112.2	115.5
OMC		11.4	12.6	12.9	9.8
SPECIFIC GRAVITY		2.63	2.29	2.49	2.44

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Experimental study concludes a **significant decrease in Atterberg's limit (**plasticity index **reduced by 79.96 %)** of soil by lime modification. Classification of soil changed from AASHTO **A-6 soil to A-4** soil and its behavior from **clayey to silty** soil, thus improving its trafficability class. Significant strength improvement (un-confined compressive strength **increase by 37.05 %**) of soil in soaked and unsoaked condition with the 5% lime. In the light of the results obtained, it can be concluded that 5% lime can be efficiently improvement of weak subgrade (clayey) soils of the area of study.

5.2 Conclusions

- Significant improvement of UCCS of soil in soaked and unsoaked condition with the use of lime. There was almost **37 % increase in unconfined compressive strength of soil with 4% lime**. This improvement in strength is due to cat-ionic exchange, flocculation agglomeration and pozzolanic reactions between soil-lime and soil
- Atterberg's limit tests were performed for both treated and untreated soils. Results shows **80% decrease in plasticity index** of soil by the use of 6% lime. This change is associated with the flocculation and agglomeration of soil particles. Classification of soil changed from **AASHTO A-6 soil to A-4 soil. Soil behavior changed from clayey to silty soil**
- **MDD of the treated soil decreased by 7.88% after using lime, 11.6% increase in value of OMC** is observed. Decrease in dry density is due to flocculation of soil particles. While the rise in optimum moisture content indicates decrease in soils moisture susceptibility.
- In the light of the results obtained, it can be concluded that 5% lime can be efficiently used for improvement of weak subgrade (clayey) soils

5.3 Recommendations

- Lime was used for stabilization of clayey soil. It is recommended to investigate **different type of modifier for treatment of other type of soils present in the study area.**
- California Bearing Ratio was determined using one point CBR test by preparing samples at OMC and MDD as determined in modified proctor test. The recommendation is to **determine CBR value for various moisture contents to determine soils moisture sensitivity.**
- **Field investigations** should be carried out to implement the findings of research. Trial sections can be planned in coordination with **HQ Engrs 30 Corps and NHA**

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