SUBGRADE STABILIZATION USING LIME AND WHEAT STRAW ASH

ADNAN ASAD
(00000171369)

A thesis submitted in partial fulfillment of
the requirements for the degree of

Master of Science

in

Transportation Engineering

School of Civil and Environmental Engineering (SCEE)
National University of Sciences & Technology (NUST)
Islamabad, Pakistan
(2019)

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS Thesis "Subgrade Stabilization Using Lime and Wheat Straw Ash" written by Mr. Adnan Asad, Registration No. 00000171369, of MS Transportation Engineering 2016 batch (SCEE), has been vetted by undersigned, found completed in all respects as per NUST statutes/regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS degree. It is further certified that necessary ammendments as appointed out by GEC members of the scholar have been incorporated in the said thesis.

Signature: ______________________

Name of Supervisor: Dr. Arshad Hussain

Date: ______________________

Signature **(HOD)**: ______________________

Date: ______________________

Signature **(Dean/Principal)**: ____________

Date: ______________________

SUBGRADE STABILIZATION USING LIME AND WHEAT STRAW ASH

by

Adnan Asad

(00000171369)

A Thesis

of

Master of Science

Submitted to

Department of Transportation Engineering

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST)

Islamabad

In partial fulfillment of the requirements for the degree of

Master of Science Transportation Engineering

2019

DEDICATION

I dedicate this research to my parents who are an endless source of guidance, inspiration and prayers for me and to my brothers and sisters for their love and prayers.

ACKNOWLEDGEMENTS

I am much obliged to Almighty Allah, who gave me strength and patience to finalize my research. I would like to pay my sincere gratitude to my supervisor Dr. Arshad Hussain, for his continuous support, motivations, enthusiasm and delivering his immense knowledge, whose instructions and guidance gave me a helping hand in all the stages of this research. I am also contented to my GEC members; Engr. Malik Saqib Mehmood and Engr. Kamran Mushtaq.

I would like to pay my thanks to all my companions for their kind heartedness and support in every part of this research work. I am 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, I pay my earnest gratitude to my beloved Parents for their support in every part of my life. Exceptional thanks to my siblings for their love and genuine prayers.

Engr. Adnan Asad

ABSTRACT

Subgrade is the bottom most layer of road pavement and acts as foundation for the road structure. Weak subgrade in pavement can result in premature failure and deterioration of road surface. Engineering properties of weak subgrade soil is improved using chemical or mechanical means. Replacement of weak subgrade material with high strength material is not possible many times due to more cost or unavailability of material. Another economical and efficient way to enhance weak subgrade soil properties is stabilization using different materials. The present research is to examine effect of lime and wheat straw ash on different engineering properties of weak subgrade soil. Lime is a white crystalline oxide produced by heating limestone. Wheat straw is naturally occurring material obtained from wheat crop. Ash obtained by burning wheat straw is a natural pozzolan and used in this research along with lime. Clayey soil was used. Atterberg's limit, compaction characteristics, unconfined compressive strength test and California bearing ratio of natural soil and soil treated with lime and wheat straw ash was determined.

Soil treated with lime exhibit decrease in plasticity index and liquid limit with addition of lime and wheat straw ash. Decrease in MDD and increase in OMC was observed for both soil lime mix and soil lime WSA mix. UCS of natural soil increased by addition of lime and WSA. Soaked UCS increased 16 times with addition of lime and 22 time with addition of lime along with WSA. 2 to 3 times increase in soaked CBR was observed for optimum lime and optimum WSA content. Reduction in layers thickness of pavement was observed due to increase in CBR. There was significant economic benefit as per cost analysis conducted by use of lime. There was no significant cost saving in use of WSA along with lime however there was more improvement in geotechnical properties of soil.

Keywords: Subgrade Stabilzation, Lime, Wheat Straw Ash

LIST OF ABBREVIATIONS

AASHTO	–	American Association of State Highway & Transportation Official
ASTM	–	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
WS	–	Wheat Straw
WSA	–	Wheat Straw Ash
XRF	–	X-Ray Fluorescence

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. It is also called 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.

Wheat is one of the most important grains with highest utilization value all over the world. During its processing waste material is produced in large quantities. Under controlled burning WSA contain > 70% silica content. Due to presence of high silica content WSA possess pozzolanic properties and hence upon reaction with soil it can significantly increase the strength. Many researchers have worked on WSA and its utilization in civil engineering works e.g. in mortar, self-compacting concrete etc. but little or no significant study has been done by utilizing wheat straw ash and its effect on poor subgrade soil. This study will be carried on individual and combine effect of these materials on poor subgrade 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. The effect of soil stabilization using different materials needs to be evaluated by proper experimental testing because effect of soil stabilization depends on type of soil and stabilizer. Most of soil stabilizing techniques are site specific and it may not be suitable for other type of soil. And also removing of material and importing other high strength material and other factors involve in mechanical stabilization cost a huge budget. Lime is a low cost material and has been evaluated and proven effective for many type of soils. Lime has also many practical applications in the field of transportation engineering for stabilization of road. Ash of agro waste materials like rice husk, bagasse and their usefulness in soil stabilization has also been used by many researchers due to their low cost and pozzolanic properties. A lot of researches has been carried out on lime but no specific study has been done on effect of lime and WSA on poor subgrade soil. So effect of wheat straw ash and its pozzolanic properties on engineering properties of weak subgrade soil need to be evaluated.

Figure 1-1 (a,b) Practical Application (a) Lime and (b) fly ash in Subgrade Stabilization

1.3 Research Objectives

The primary objective of this research is to characterize existing subgrade soil properties and improvement in strength parameters using soil stabilization techniques. The study will be specifically focusing on:

- Stabilization of subgrade soil using Lime and WSA.
- Determination of optimum percentage of Lime and WSA for subgrade soil stabilization
- To investigate the effect of Lime and WSA on different geotechnical properties of subgrade i.e. CBR, Resilient Modulus, UCS etc.
- Cost comparison of pavement with and without subgrade stabilizations

1.4 Scope and Methodology

Scope and methodology adopted in project has been highlighted in this section. Detailed methodology has been covered in Chapter 3 however scope and brief methodology is given below:

- **Phase I (Properties of Untreated / Natural Soil)**
  Chemical Analysis
  Grain Size Distribution
  Atterberg's Limits
  Specific Gravity of Soil
  Compaction Characteristic of Soil
  UCS Soaked
  UCS Unsoaked
  CBR and Swell Potential of Soil
- **Phase II (Optimization of Lime Content)**
  Chemical Analysis of Lime
  PH test for Lime optimization
  Compaction Test at various Lime content
  UCS at various Lime content
  CBR and Swell Potential at Optimum Lime Content
- **Phase III (Optimization of Wheat Straw Ash Content)**
  Chemical Analysis of Wheat Straw Ash
  Compaction tests at Optimum Lime and various WSA contents

UCS at optimum Lime and various WSA contents

- **Phase IV (Properties of Treated / Stabilized Soil)**
  Grain Size Distribution of Treated Soil
  Atterberg's Limits for Treated Soil
  UCS at for Treated Soil
  CBR and Swell Potential of treated Soil
  Cost Analysis
- **Phase V (Analysis and Conclusion)**
  Analysis and Discussion of Test results
  Conclusions and Recommendations

1.5 Organization of Thesis

This research 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 and WSA content.
- 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, Lime and WSA.

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. Degree of crystallinity also affects different properties of clay minerals. 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.

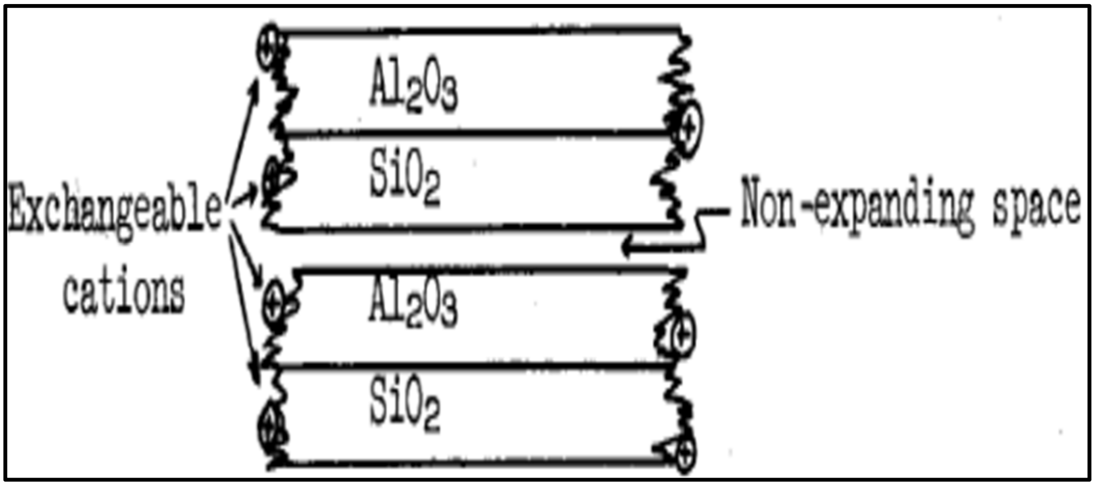


Figure 2-1 Kaolinite Structure (Holeman 1965)

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.

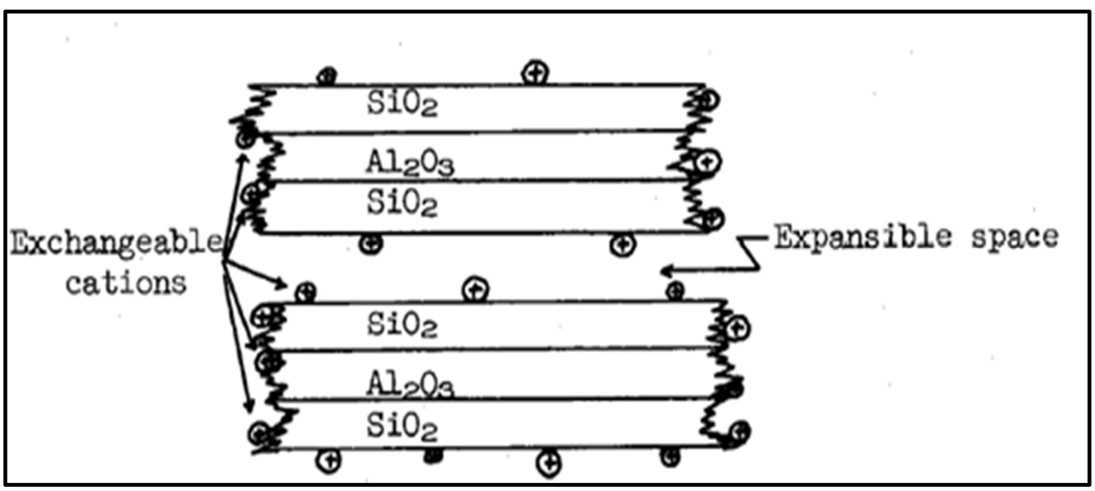


Figure 2-2 Montmorillonite Structure (Holeman 1965)

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).

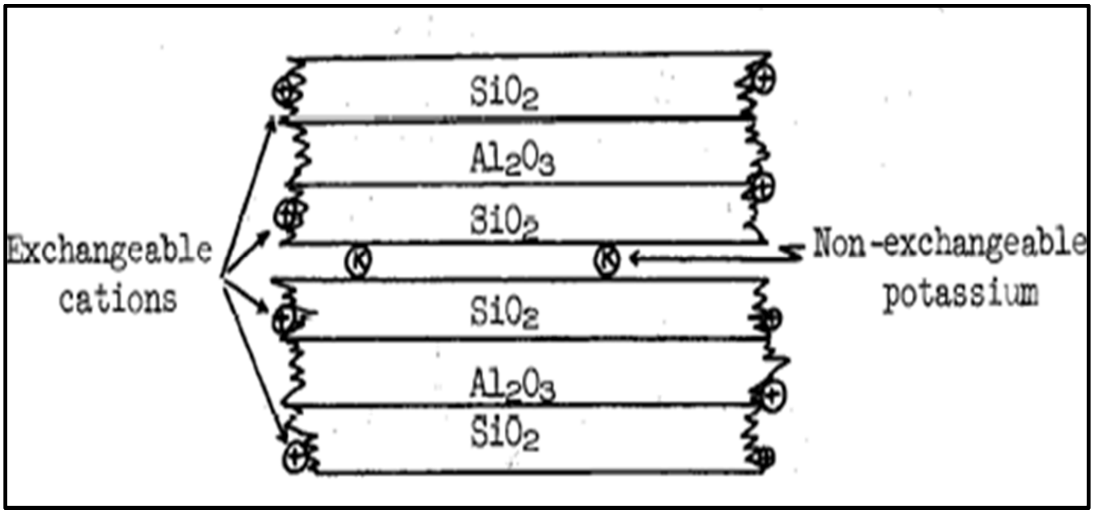


Figure 2-3 Illite Structure (Holeman 1965)

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.

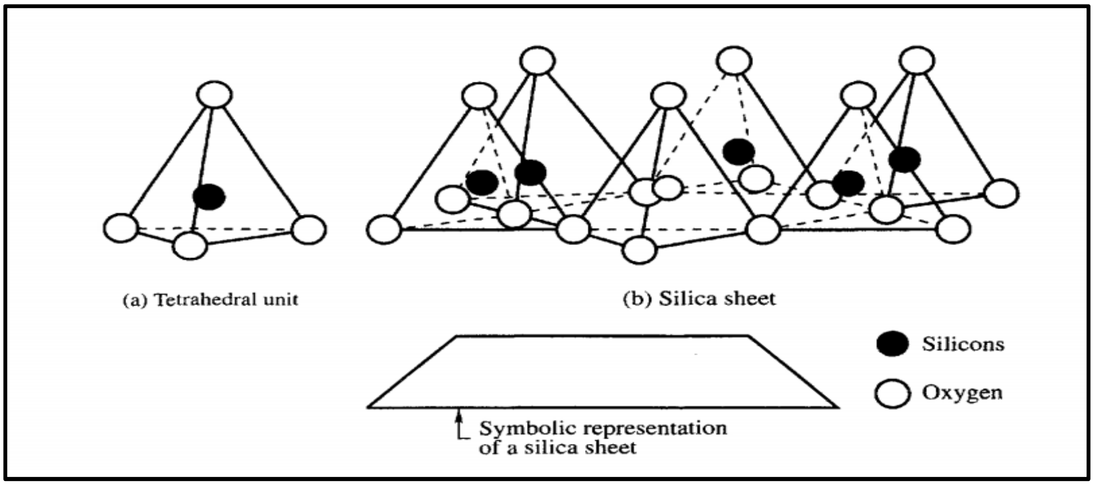


Figure 2-4 Arrangement of Silica Sheet (Grim 1959)

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).

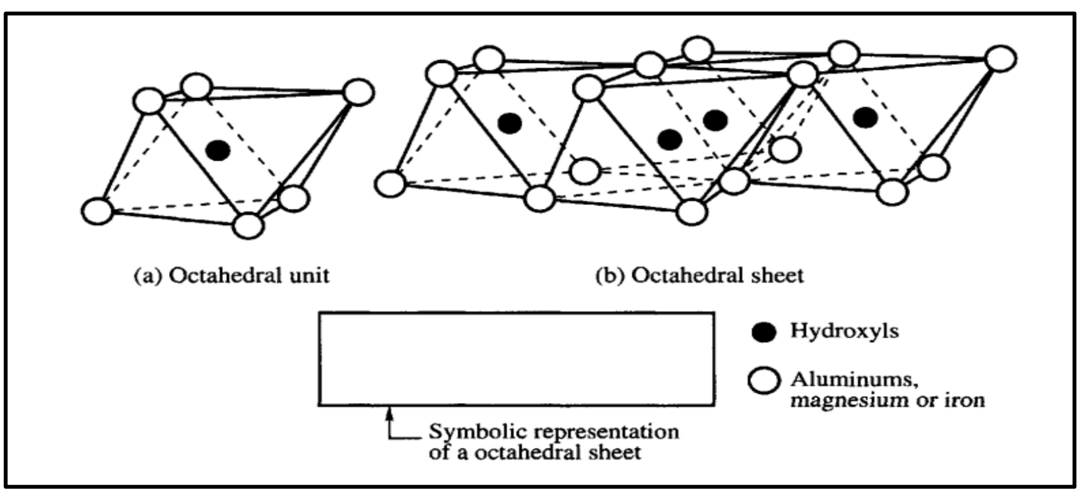


Figure 2-5 Arrangement of Alumina Sheet (Grim 1959)

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.

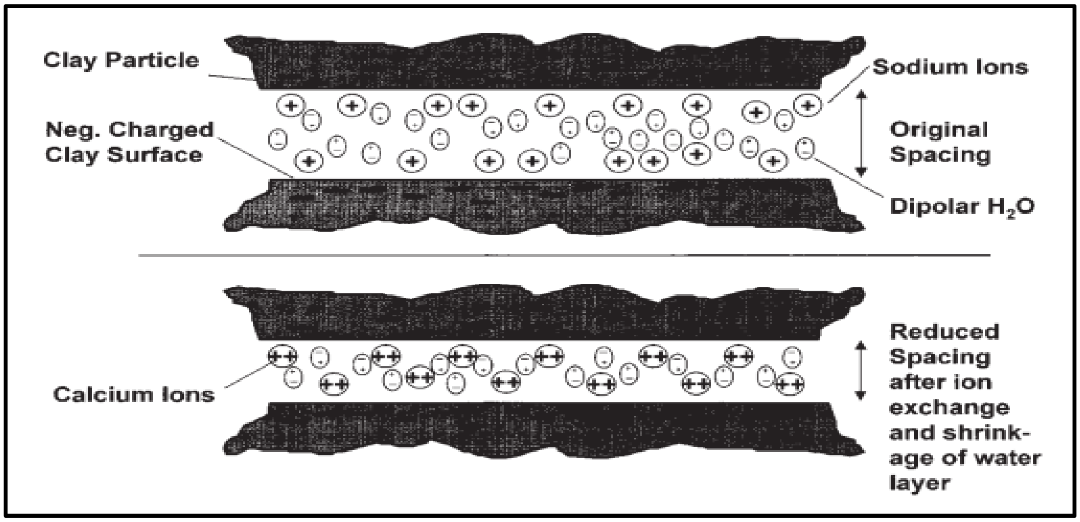


Figure 2-6 Cat-Ionic Exchange (Prusinski and Bhattacharja 1999)

- **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).

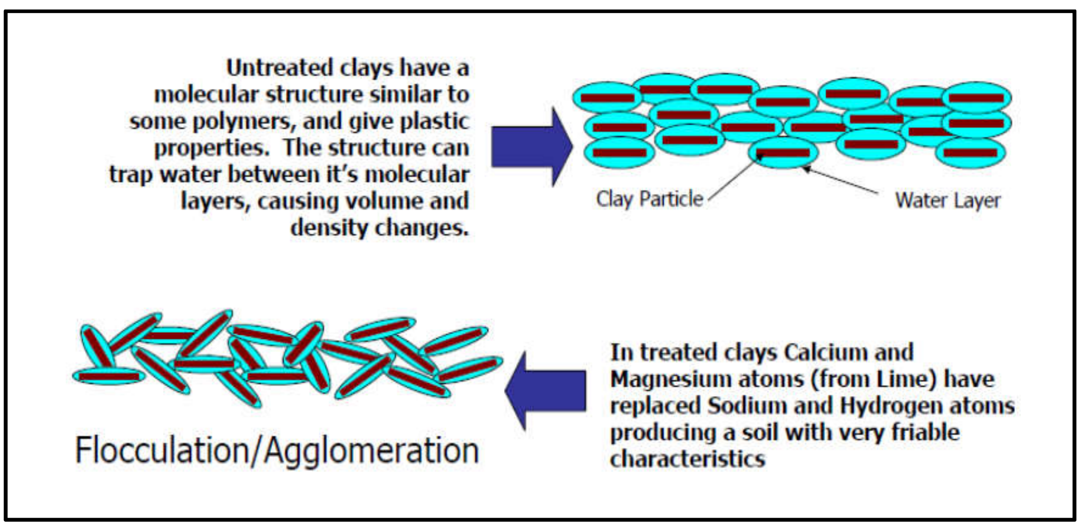


Figure 2-7 Clay Particles Before and After Lime Stabilization

- **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.

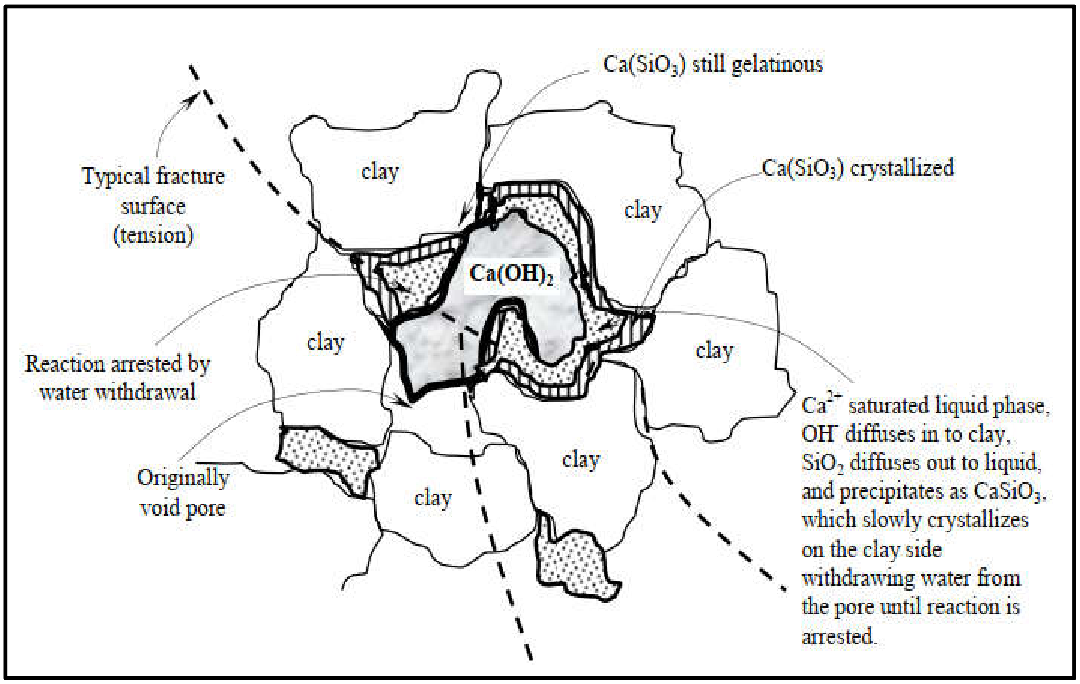


Figure 2-8 Reaction Mechanism of Stabilization Clay (Ingles and Metcalf 1972)

2.4.2.3 NLA 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 using Eads and Grim pH test as per ASTM D-6274.
- 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^{o}C.For soaked samples moisture conditioning is done using capillary soak. Samples are subjected to capillary soak for 24 to 48 hours.
- Perform resilient modulus testing as per AASHTO T294

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 conflict behavior has been reported by different researchers regarding liquid limit. 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.

2.4.3 Wheat and WSA

Wheat is main and most common agricultural product grown worldwide and also in Pakistan. Pakistan is an agricultural country. Wheat, rice, sugarcane, maize and cotton account for 23.60% of the value added in overall agriculture and 4.45% of GDP. The annual production of wheat is 25,492 thousand tons respectively (Pakistan Economic Survey 2017). During processing of these crops a large quantity of waste is generated.

Wheat straw consists of C, H, O, N, Si, Fe, Al, Ca, Mg, Na, K, P, Cu, Mn and Zn in various proportions. Burning of wheat straw produces ash with pozzolanic properties due to presence of inorganic minerals and high amount of silicates in it (Biricik, Aköz et al. 1999).

2.4.3.1 Pozzolan

Pozzolan according to ASTM C 125 is

"a siliceous or silicious and aluminous material which in itself possesses little or no cementitious value, but will, when finally divided dorm and in presence of moisture, chemically reacts with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties".

Pozzolans are classified into three classes, class F, Class C and Class N as per ASTM. Class C and Class F ashes are obtained or produced from bituminous and sub bituminous coals while Class N are raw or natural pozzolans. ASTM requirements for a material to be class N pozzolan are as follow:

Table 2-1 ASTM Requirements for Natural Pozzolan

Constitute	ASTM C-618 Requirement
Silicon Dioxide, (SiO_2)	Minimum 70%
Aluminum Oxide, (Al_2O_3)	
Ferric Oxide, (Fe_2O_3)	
Calcium Oxide, (CaO)	4% maximum
Magnesium Oxide, (MgO)	4% maximum
Sulfur Trioxide, (SO_3)	4% maximum
Potassium Oxide, (K_2O)	4% maximum
Moisture Content Loss On Ignition (LOI)	3% maximum 10% maximum

2.4.3.2 Pozzolanic Activity

Pozzolanic activity is defined as the measure of Pozzolanic reaction over time in presence of water. These reactions rate is dependent upon particle properties i.e. surface area of the pozzolan, chemical composition of the pozzolan and the reaction conditions.

2.4.3.3 Pozzolanic Reaction

The reaction among silica or silica and alumina with calcium hydroxide is known as pozzolanic reaction. In this process cementitious products are produced. Normally this reaction is written as:

$$CH + SH \rightarrow C\text{-}S\text{-}H$$
$$CH + AH \rightarrow C\text{-}A\text{-}H$$

Calcium silica hydrates (CSH) and calcium alumina hydrates (CAH) are cementitious products, which do possess very good cementitious properties.

2.4.3.4 Effect of Natural Pozzolans on Soil Properties

2.4.3.4.1 Atterberg's Limit

Addition of natural pozzolan reduce liquid limit and increase plastic limit resulting a reduction in plasticity index. While in some cases decrease in both liquid and plastic limit is observed. However, effect of such pozzolanic material on Atterberg's limits whether increase or decrease depends on the type of soil and natural pozzolan. Reduction in LL and PI while rise in PL was reported by Choobbasti, Ghodrat et al. 2010.

2.4.3.4.2 Compaction Characteristics

Max. dry density decreases with addition of natural pozzolan up to certain limit and OMC decreases. Choobbasti, Ghodrat et al. 2010 reported decrease in MDD of soil lime mix treated with rice husk ash because of fineness of lime and rice husk ash. He also reported that pozzolanic reaction resulted an increase in opt. moisture content.

2.4.3.4.3 Unconfined Compressive Strength

Increase in UCCS is observed by addition of natural pozzolan like bagasse ash, rice husk ash etc. is observed by different researchers. UCS increase up to certain limit of addition of natural pozzolan. Osinubi, Bafyau et al. 2009 successfully used bagasse ash for soil bagasse ash mixtures and reported increase in soil bagasse ash mixtures. This increase in strength with addition of natural pozzolan is due to pozzolanic reaction and formation of cementitious products.

2.4.3.4.4 California Bearing Ratio

Natural pozzolan are observed to increase CBR of soil and reduce swell potential due to formation of flocculated particles. Osinubi, Bafyau et al. 2009 reported increase in CBR of soil by using lime and bagasse ash mix for black cotton soil.

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 Previous Research Work

Ingles and Metcalf 1972 suggested quantity of lime for modification and stabilization of different types of soils. They suggested that up to 3% lime can modify silty clays, heavy clays and very heavy clays while 3-4% lime is required for stabilization of silty clays. They further mentioned that 3-8% lime is required for stabilization of heavy clays and very heavy clay soils. A thumb rule was also suggested that 1% lime for every 10% of clay soil can be considered however more exact prescription can be usually made by laboratory tests at and slightly each side of thumb rule percent of lime.

Tuncer and Basma 1991 carried out extensive study on effect of lime on volume change and compressibility of expansive clay and concluded that grain size distribution was greatly altered by addition of lime and coarser grained fraction increased while clay fraction decreased with increasing lime and curing time. They further concluded that plasticity index decreased with increasing lime content. It was reported that classification of treated soil changed from MH-CH at 3% and 6% lime for both soils respectively.

Bell 1996 carried out stabilization of different clay minerals using lime and reported that many of clayey soil properties can be enhanced by lime addition. Reduction in linear shrinkage was reported for each soil. Increase in CBR of upper boulder clay and tees laminated clay soils was reported. It was also concluded that optimum strength gain occurs between 4% to 6% lime content. Increase in strength was observed with increase in length of curing time but most notable increase in strength was observed within first 7-days of curing.

Rogers, Glendinning et al. 1997 performed modification of clay soils with lime and concluded that liquid limit is altered at low lime content while plastic limit requires greater lime addition. They also presented that different clay need different curing periods for modification however large changes occur with small addition of lime about 1% and within 6 hours.

Beeghly 2003 studied recent experiences with lime and fly ash stabilization of subgrade soil and presented that soil stabilization can not only reduce cost but also increase pavement life. He further concluded that lime stabilization reduces thickness of layers above subgrade due to increase in structural strength and stiffness which as a result reduces cost. He also concluded that stabilizing poor soil is more cost effective rather than removing and replacing weak soil with higher strength material.

Osinubi, Bafyau et al. 2009 studied behaviour of different engineering properties of expansive soil stabilized using lime and bagasse ash and reported improvement in strength of soil. He obtained highest CBR values by using combination of 8% lime and 4% bagasse ash.

Brooks 2009 observed soil stabilization by adding rice husk ash and fly ash and presented that unconfined compressive strength increased up to 106% and 50% for with 0 to 25% content of fly-ash. Similarly, UCS increased up to 97% for when RHA was increased from 0 to 12%. CBR increased by 47% for 12% RHA. He recommended 12% RHA and 25% fly ash as optimum.

Brooks 2009 also carried out cost comparison of subgrade soil stabilized with rice husk ash and fly ash and mentioned that sub-base layer thickness can be reduced due to increase in subgrade strength. He further mentioned that soil stabilization is economical and saving per mile was $1.4 million rupees for a heavy duty highway.

Harichane, Ghrici et al. 2011 carried out stabilization of high plastic and low plastic soils using lime and natural pozzolana and concluded that lime and natural pozzolana both reduce plastic index of soil. Soil type changes from CH and CL to ML for both type of soils. It was also reported increase in shear strength of soil-lime-natural pozzolana mix and highest cohesion was reported at 20% natural pozzolana and 8% lime.

Muhmed and Wanatowski 2013 observed effect of lime stabilization on strength and microstructural properties of clay and reported that plastic and liquid limit both decrease while plastic index decreases. It was also mentioned that OMC increase and MDD decrease when lime is added. Increase in UCS was reported with the rise in curing period but decrease in UCS was observed with increase in OMC. They performed SEM test of lime stabilized clay and it was presented cementitious products were formed due to pozzolanic reaction due to which soil strength increase.

Ghobadi, Abdilor et al. 2014 stabilized clay soils using lime and observed effect of pH variations on shear strength parameters. He concluded that clay soil can be satisfactorily stabilized with about 7% addition of lime. He mentioned that MDD decreased with addition of lime and unconfined compression strength increased by nearly five times at 7% lime and 30days curing.

Khemissa and Mahamedi 2014 studied expansive clay by adding mixture of lime and cement. They presented that combination of both stabilizer decrease plasticity index. They presented that CBR was also increased and bearing capacity of soil was improved. It was reported that best results were obtained with addition of 2% cement+10% lime and 8% Cement + 4% lime for soaked and unsoaked CBR respectivly.

Asgari, Dezfuli et al. 2015 carried out experimental study of low plastic clay soil stabilized with lime and cement.. He observed that lime and cement both significantly increase strength of soil. He concluded that lime has more effect on OMC and MDD as compared to cement.

Zukri and Ghani 2015 studied effect of lime on clay soil. From the results he concluded that addition of lime increases OMC and MDD with increase in lime content. UCS test results show that highest improvement in strength was obtained using 9% lime. It was found that compressive strength rise with higher lime content and longer curing period.

Dang, Hasan et al. 2015 carried out experimental study of soil stabilized with lime and bagasse ash. Improvement in CBR of soil is observed with addition of both stabilizers. Reduction in swell as compared to unstabilized soil was observed with addition of lime and bagasse ash.

Kiliç, Küçükali et al. 2016 proved lime as an effective additive for expansive soil. He concluded that to overcome swelling, settelment and bearing capacity problems in high plastic clays 6% lime would be enough

El Shinawi 2017 performed lime stabilization of subgrade soil in Egypt. He concluded that lime increase OMC and decrease MDD. He also concluded that compressive strength and CBR both increase with addition of lime. It was mentioned that lime has potential to improve geotechnical properties of soil.

Numerous other studies on soil and subgrade stabilization has been conducted by using pozzolanic and non pozzolanic materials that proved beneficial. Studies on fly-ash, rice husk ash, lime, cement, gypsum, coal waste etc. (Eads and Grim 1960; Lazaro and Moh, 1970; Mitchell 1981; Nelson and Miller 1992; Bell 1996; Petry and Little 2002; Jung et al 2008; Seco et al 2011; Sabat 2012; Consoli et al 2011; Negawo et al 2017).

2.7 Summary

This chapter presents literature review of subgrade, clay soil its structure and stabilizers used in this research. Different types and methods of soil stabilization techniques are discussed. Effect of lime and natural pozzolans 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 and Wheat Straw Ash. 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 at different WSA content. Finally fourth phase different properties of treated subgrade soil were evaluated. Phase five was to determine benefits of research by performing economic analysis and comparison of untreated and treated soils.

All the experiments were performed by following ASTM standards. NLA approach was used for soil stabilization using Lime. Chemical composition test XRF for all the materials was conducted in Analytical Testing Laboratory in IESE NUST. Further detailed methodology is discussed in sections below.

3.2 Materials

Details about material i.e. subgrade soil, lime and wheat straw ash 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.

3.2.3 Wheat Straw Ash

Wheat Straw was collected from open source market. Ash was produced manually by burning Wheat Straw in open air and then grinding ash into fine powder using Los Angeles Abrasion machine. 5kg oven dried ash was placed in machine and 2500 revolutions were applied. Grounded ash passing through sieve#100 was used. Ash was preserved in an air tight polyethylene bags.

Figure 3-1 (a,b,c) WSA Burning Process

Figure 3-2 (a) WSA after Burning **Figure 3-2 (b)** WSA after Grinding

3.3 Methodology

Research methodology consists of five phases. Material testing was carried out in four phases and economic analysis in fifth phase was performed.

Phase I: Properties of Natural/ Untreated soil sample

Phase II: Optimization of Lime content

Phase III: Optimization of Wheat Straw Ash content

Phase IV: Properties of treated soil

Phase V: Cost Analysis

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 UCS. 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.

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.

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.

3.3.1.4 Specific Gravity of Soil

Specific gravity of soil was determined by following ASTM D 854. Soil passing through sieve#4 was used as per ASTM.

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 8cm and diameter 4cm. Soaked and unsoaked unconfined compressive tests were performed. Samples were made at optimum moisture content and maximum dry density taken from modified proctor test.

For soaked UCS sample were wrapped in absorption fabric and were placed over a porous stone inside a container. Samples were subjected to capillary soak for 24 hours. Direct contact of sample with the water was avoided. After curing samples were tested in UCS machine. Two samples were prepared for each test. Average strength of samples was reported.

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

Figure 3-4 (a,b) Soaking of UCS Samples

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 65 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 3-5 Soaking and Swell Measurement of CBR Sample

Figure 3-6 (a,b) CBR Testing

3.3.1.8 Chemical Analysis of Soil

Chemical analysis of soil to find its chemical composition was done using XRF. XRF was conducted at Analytical Testing Laboratory IESE, NUST Islamabad. Small pallets were prepared and tested for all the constituents as shown in figure 3-7 (c).

Figure 3-7 (a,b,c,d) Chemical Testing of Material Using XRF

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% and 8% lime content.

3.3.2.1 Chemical Properties of Lime

Before using lime as stabilizing agent its chemical properties were determined. Chemical constituents of lime were derived by performing X-Ray Fluorescence test. Test was performed in IESE, NUST Islamabad.

3.3.2.2 Eads and Grim Test

Test was carried out accordance with ASTM D 6276 to. Six air tight bottles were filled with 25 gram of soil sample with 2%, 4%, 6% and 8% lime content respectively. pH meter was used to find pH of soil-lime mixture. Lime content with pH 12.4 was taken as optimum lime content. Eads and Grim pH test gives approximate quantity of lime for stabilization.

3.3.2.3 Moisture Density Relationship at Various Lime Content

Different samples were prepared by adding 2, 4, 6 and 8% lime. OMC and MDD were found for each sample using modified proctor tests. All experiments were carried out as per ASTM D 1557.

3.3.2.4 Unconfined Compressive Strength at Various Lime Content

Approximate optimum lime content was determined using Eads and Grim test but UCS test was performed on samples with different lime contents within the range of lime content obtained from Eads and Grim pH test.

Unconfined compressive strength test samples were prepared at for 2%, 4%, 6% and 8% 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.

Figure 3-8 (a,b,c,d) UCS Testing Soil Lime Mix

3.3.2.5 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: Optimization of Wheat Straw Ash content

Third phase of this research was intended for the determination of optimum Wheat Straw Ash content for subgrade soil under study. Optimum wheat straw ash content was determined by adding optimum lime content and different percentages of Wheat straw ash. Average values of the results were taken for all tests.

3.3.3.1 Chemical Properties of Wheat Straw Ash

It was important to determine chemical properties of WSA before using as stabilizing agent for soil. XRF test was performed and its suitability as Pozzolanic material was checked as per ASTM.Test was conducted in IESE, NUST Islamabad. Small pallets were prepared and tested using XRF machine as shown in figure 3-7.

3.3.3.2 Moisture Density Relationship at Various WSA content

Different soil samples were prepared at optimum lime and 5%, 10%, 15%, 20% and 25% WSA. OMC and MDD were determined using modified proctor test. Soil was compacted in five layers and 25 blows applied to each layer with 10-lb hammer and hammer drop height was 18 inch. All tests were performed according to ASTM D 1557.

3.3.3.3 Unconfined Compressive Strength at Various WSA content

Unconfined compressive strength test samples of height to diameter ratio 2:1 were prepared at optimum lime and 5%, 10%, 15%, 20% and 25% wheat straw ash content. Same mold as used for determining UCS of lime was used for UCS of samples at various WSA content. All the samples were made at optimum moisture content and maximum dry density already deduced from modified proctor test. Maximum change due to addition of wheat straw ash 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 wheat straw ash percentage resulting in the highest improvement in UCS was selected as optimum WSA content.

Figure 3-9 (a,b) UCS Testing Soil-Lime-WSA Mix

3.3.4 Phase IV: Properties of Treated Soil

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

3.3.4.1 Grain Size Distribution of Treated Soils

Soil-stabilizer mixture was kept for 7 days and percent passing through and retaining on sieve#200 was determined.

3.3.4.2 Atterberg's Limits of Treated Soil

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

3.3.4.3 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 both optimum lime and optimum lime and optimum WSA content.

3.3.4.4 Unconfined Compressive Strength of Treated Soil

UCS tests were performed on samples with optimum lime content and samples with optimum lime and WSA content after 7 and 28 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 40^{o}C for the respected curing period.

3.3.4.5 California Bearing Ratio and Swell Potential of Treated Soil

California bearing ratio (CBR) and swell potential of the soil were determined for soil treated with lime and wheat straw ash. ASTM D 1883 was followed throughout the test procedure. CBR samples were made at OMC already determined from moisture density relationship and compacted in five layers with 65 blows applied for the compaction of each layer. Samples were soaked for 96 hours and CBR test was performed for soaked condition. Swell potential of the soil was also determined.

3.3.5 Phase V: Cost Analysis

In order to examine importance of studies cost comparison was done for subgrade soil with and without stabilization. A pavement with natural soil CBR was designed using AASHTO design procedure and layer thickness was determined for each layer. Removal of weak subgrade soil, its excavation, disposal, replacement with new material was considered. Cost for each layer including subgrade layer of assumed depth was calculated.

Same procedure was adopted for soil treated with optimum lime content and optimum lime and optimum WSA content. Reduction in layers thickness due to soil stabilization was determined. Preparation of subgrade, mixing of stabilizers, cost and quantity of stabilizer and cost of each item was determined. Overall unit cost of road construction was calculated with and without stabilizers. Unit costs of materials and all work items were obtained from Composite Schedule of Rates (2014) and Market Rates System (2018).

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 and WSA 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 and WSA as stabilizers for weak subgrade soil. Two samples were prepared for each test and their average value was reported. Detail result analysis is presented below

4.2 Phase I: Properties of Natural/ Untreated soil sample

4.2.1 Chemical Analysis

Chemical analysis of soil using XRF was used. Soil composition in form of oxides is given below:

Table 4-1 Chemical Composition of Soil

Composition	Percentage
SiO_2	56.12
K_2O	3.16
CaO	7.43
TiO_2	1.44
Fe_2O_3	6.57
MgO	4.18
Al_2O_3	18.03
Na_2O_3	3.04
Others	0.03

4.2.2 Grain Size Distribution

Grain size distribution was carried out using wash method to determine percent passing through sieve#200. 80.85% was passing through sieve#200. According to minimum percent passing through sieve #200 for soil to be suitable for lime stabilization is 25%.

4.2.3 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 to be suitable for lime stabilization should have Plasticity Index >10. Liquid limit of this subgrade soil determined was 33.33% and Plastic limit was 17%. Plasticity index i.e. LL-PL came out to be 16.33.

Soil was classified based on GSD and Atterberg's limits. It is classified as CL as per USCS system and A-6 as per AASHTO classification system as given in figure 4-1 and figure 4-2 below.

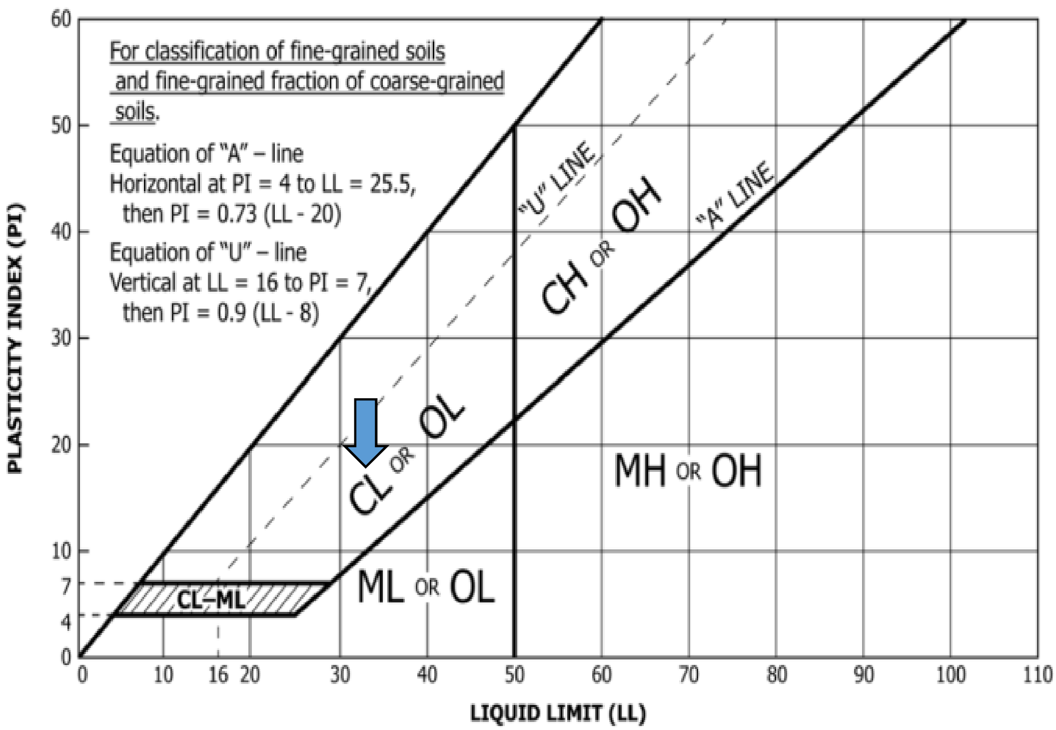
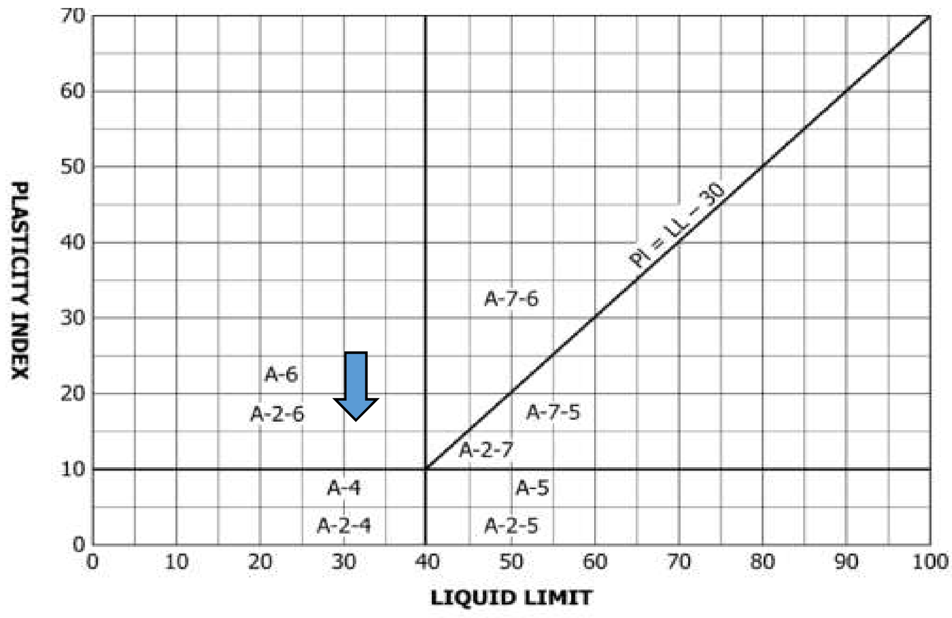


Figure 4-1 Soil Classification (ASTM D2487)



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

Figure 4-2 Soil Classification (ASTM D3282)

4.2.4 Specific Gravity of Soil

Specific gravity of subgrade soil was found using ASTM D 854 standard. Specific gravity came out to be 2.67.

4.2.5 Moisture Density Relationship of Soil

MDD and OMC for natural subgrade soil determined were 1.96 g/cm3 and 11.11% respectively. Compaction curve is shown below in figure 4-3:

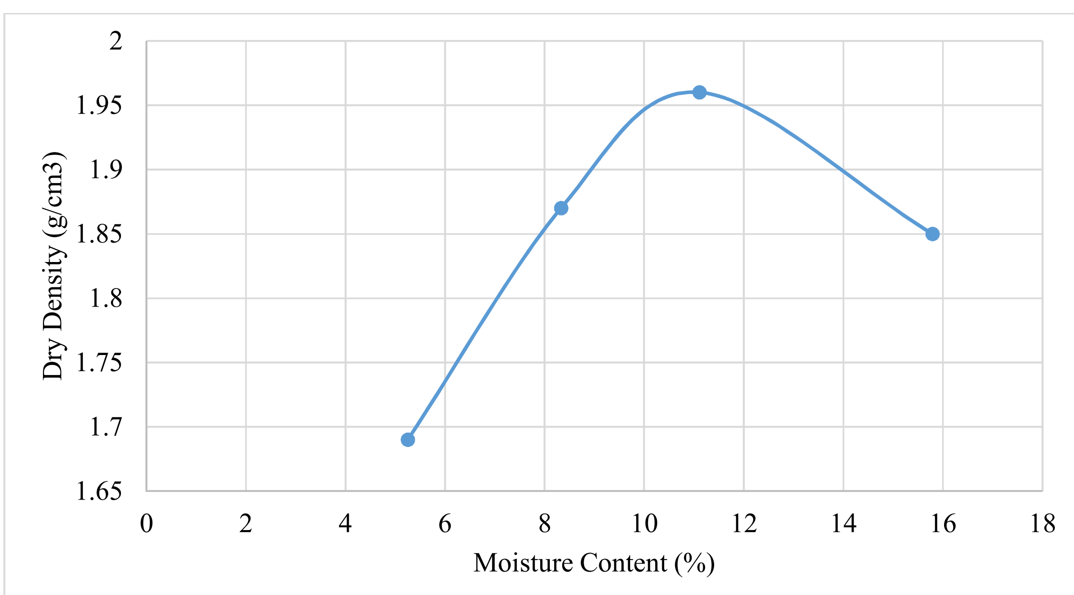


Figure 4-3 M-D Relationship Natural Soil

4.2.6 Unconfined Compressive Strength of Natural/Untreated Soil

Samples to find UCS were made for both soaked and unsoaked condition and testing was carried out.

Subgrade soil had an unsoaked UCS strength of 46.08 psi and unsoaked UCS strength of 4.62 psi. Almost 90% strength was lost when soil was subjected to capillary soak of 24 hours. Soil strength was highly effected due to capillary soak.

4.2.7 California Bearing Ratio and Swell Potential of Soil

Soaked and Unsoaked CBR both were performed for natural/untreated soil as per ASTM standards. Soil had high strength in unsoaked condition i.e. its CBR was 23.79%. With soaked CBR soil strength dropped up to 77% and soaked CBR was 5.47%. And the swell potential was 2.7%. Based on CBR soil material is classified as weak subgrade material.

4.2.8 Brief Summary

A brief summary of the natural subgrade soil properties are given below:

Table 4-2 Natural Soil Properties

Properties	Values
% Passing Sieve#200	80.85
Liquid Limit	33.33
Plastic Limit	17
Plasticity Index	16.33
Soil Type USCS	CL
Soil Type AASHTO	A-6
Moisture Content	11.11 %
Maximum Dry Density	1.96 g/cm3
Specific Gravity	2.67
UCS Unsoaked	46.08 psi
UCS Soaked	4.62 psi
CBR Soaked	5.47 %
CBR UnSoaked	23.79 %
Swell Potential	2.7 %

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 Chemical Analysis

Below Table 4-3 gives chemical composition of lime done using XRF.

Table 4-3 Chemical Composition of Lime

Composition	Percentage
SiO_2	4.32
CaO	88.92
Fe_2O_3	3.32
SrO	3.42

4.3.2 Eads and Grim pH Test

pH was measured for every content of lime added to the soil. pH and lime relation is shown below in graph. At 6% lime content lime soil mixture achieves pH of 12.4 as shown in figure 4-4.

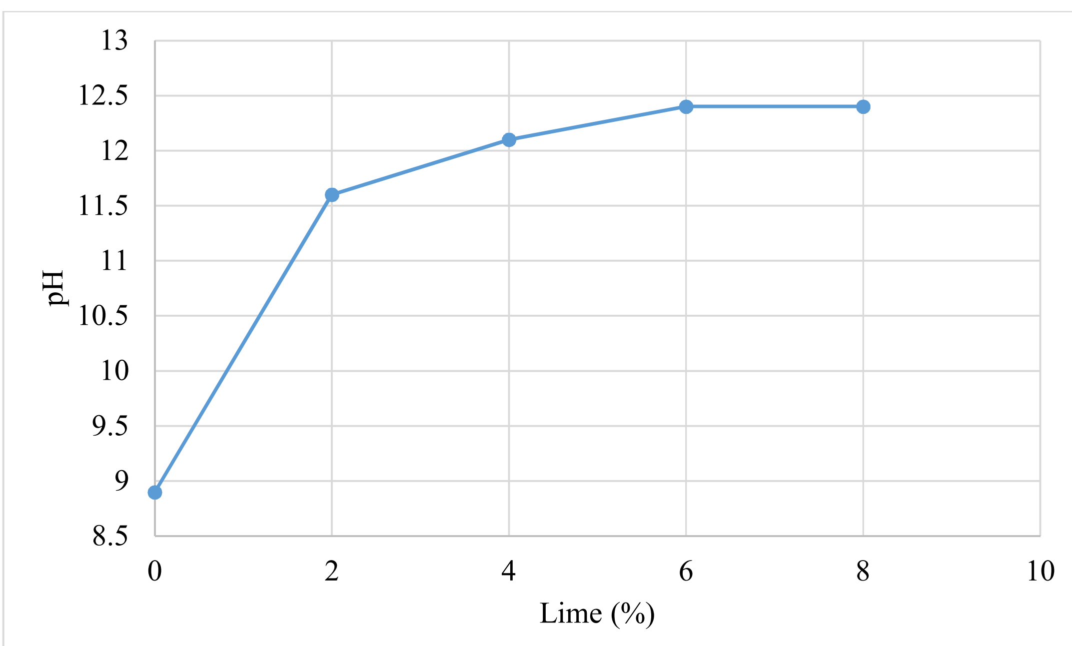


Figure 4-4 Eads and Grim pH Test

4.3.3 Moisture Density Relationship at Various Lime Content

MD relationship was established for various lime content. Sample were prepared by adding lime 2%, 4%, 6% and 8%. OMC and MDD was determined for each soil sample Figure 4-5 (a,b,c) presents the moisture-density behaviour of the soil.

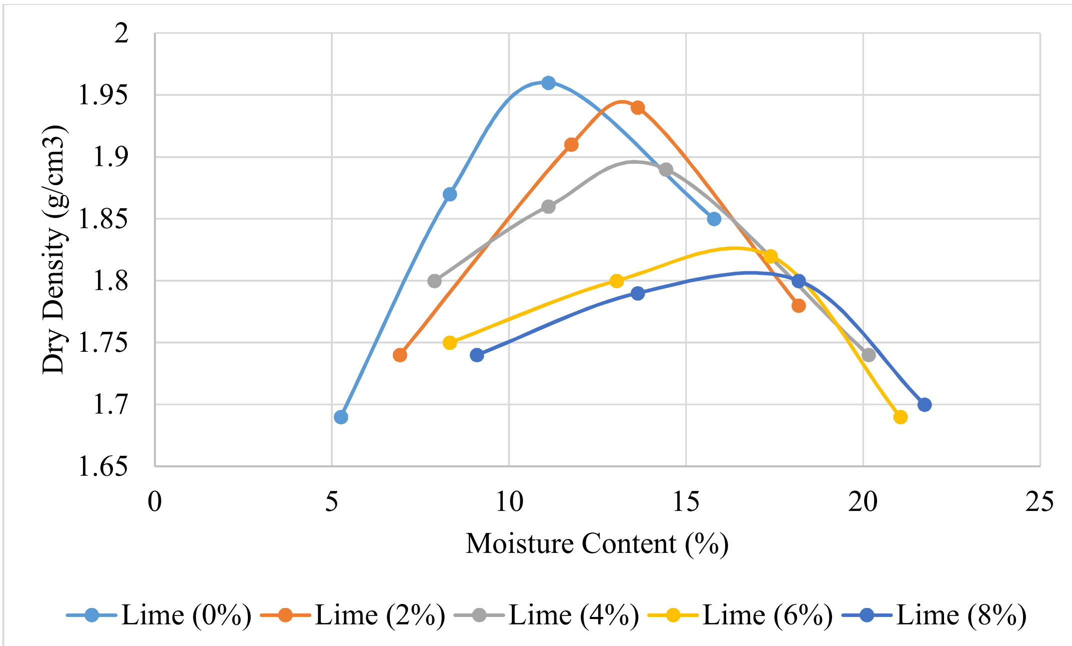


Figure 4-5 (a) Moisture Density Relationship Soil-Lime Mix

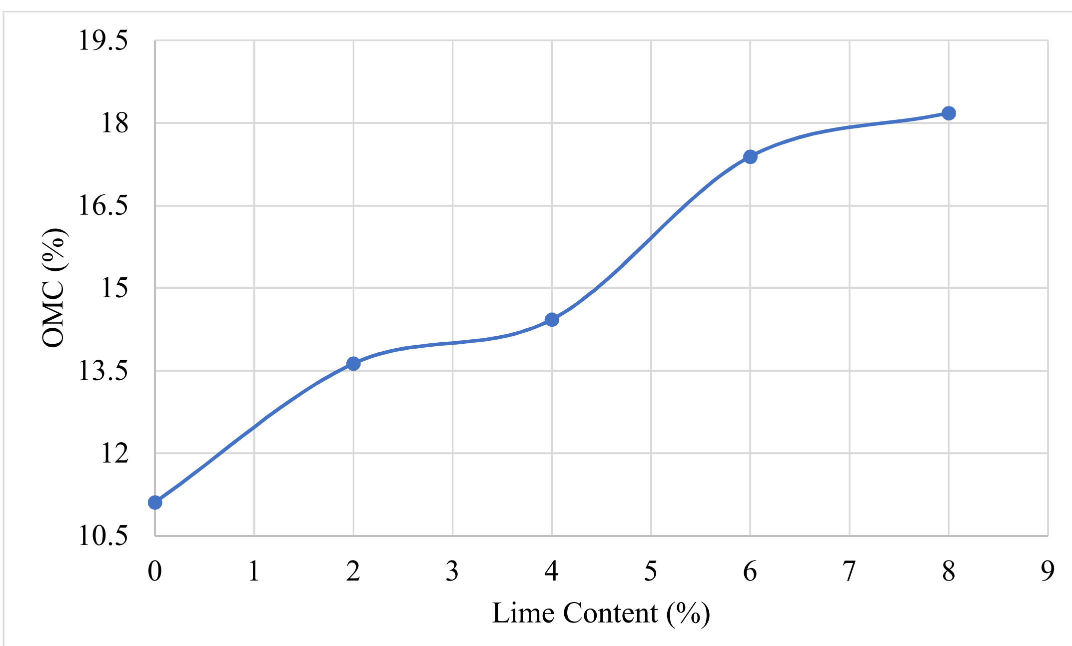


Figure 4-5 (b) OMC at Various Lime Content

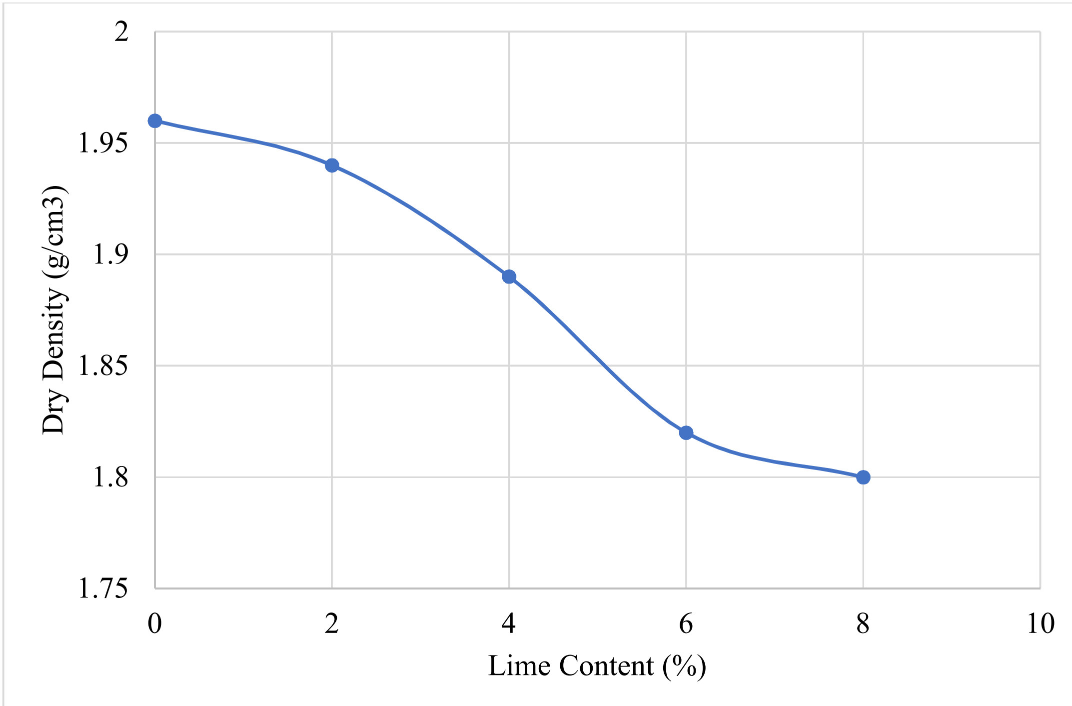


Figure 4-5 (c) MDD at Various Lime Content

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.

4.3.4 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 7 days for curing and at 40^{o}C in oven and then tested. Lime percentage giving maximum unconfined compressive strength is optimum lime content. UCS test indicate that soil sample with 6 % lime content possess maximum strength.

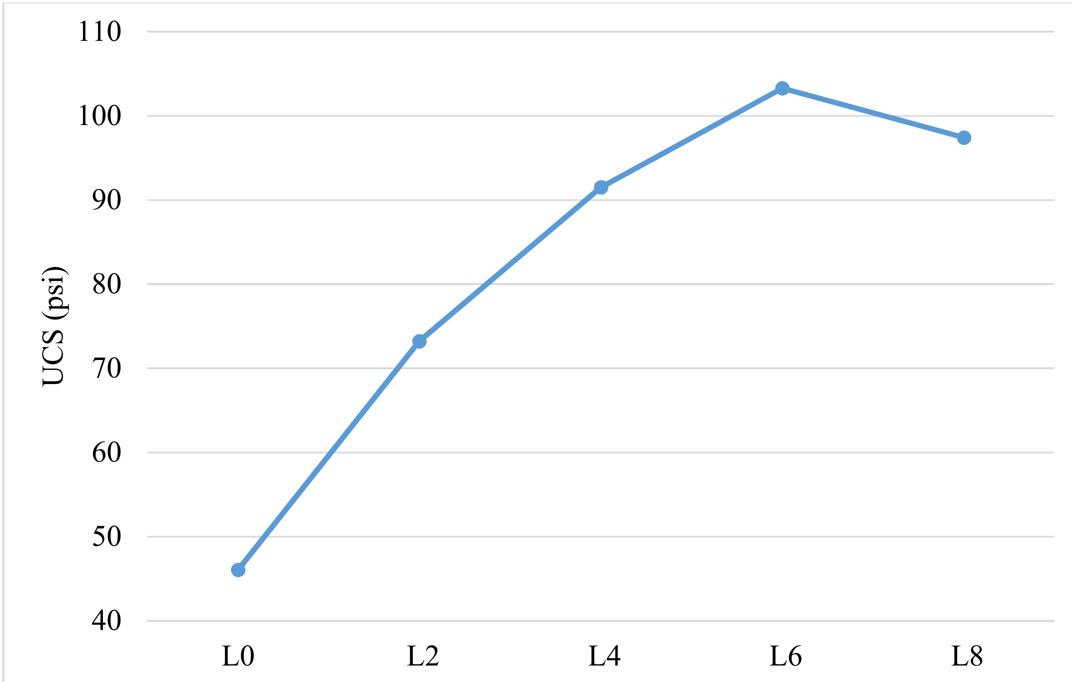


Figure 4-6 Unconfined Compressive Strength of Soil Lime Mixes

4.4 Phase III: Optimization of Wheat Straw Ash

The main criteria to determine wheat straw ash optimum content was same as for optimum lime content i.e. wheat straw ash content giving highest unconfined compressive strength is selected as optimum wheat straw ash.

4.4.1 Chemical Composition

Chemical composition of WSA obtained using XRF is shown below in table 4-4

Table 4-4 Chemical composition of WSA

Composition	Percentage
SiO_2	57.41
K_2O	3.79
CaO	2.93
Fe_2O_3	20.24
MgO	0.78
Al_2O_3	0.89
SrO	4.04
SO_3	1.26

4.4.2 Moisture Density Relationship at Various Wheat Straw Content

Modified proctor test was performed to develop moisture density relationship at wheat straw ash content of 5%, 10%, 15%, 20% and 25%. Samples were prepared at optimum lime content determined from Phase-II i.e. 6% lime and different wheat straw ash content. OMC and MDD was determined for each soil sample. Figure 4-7 (a,b,c) show the moisture-density relationship. Figure 4-7 indicate that 15% wheat straw ash along with 6% lime has maximum effect on compaction characteristics.

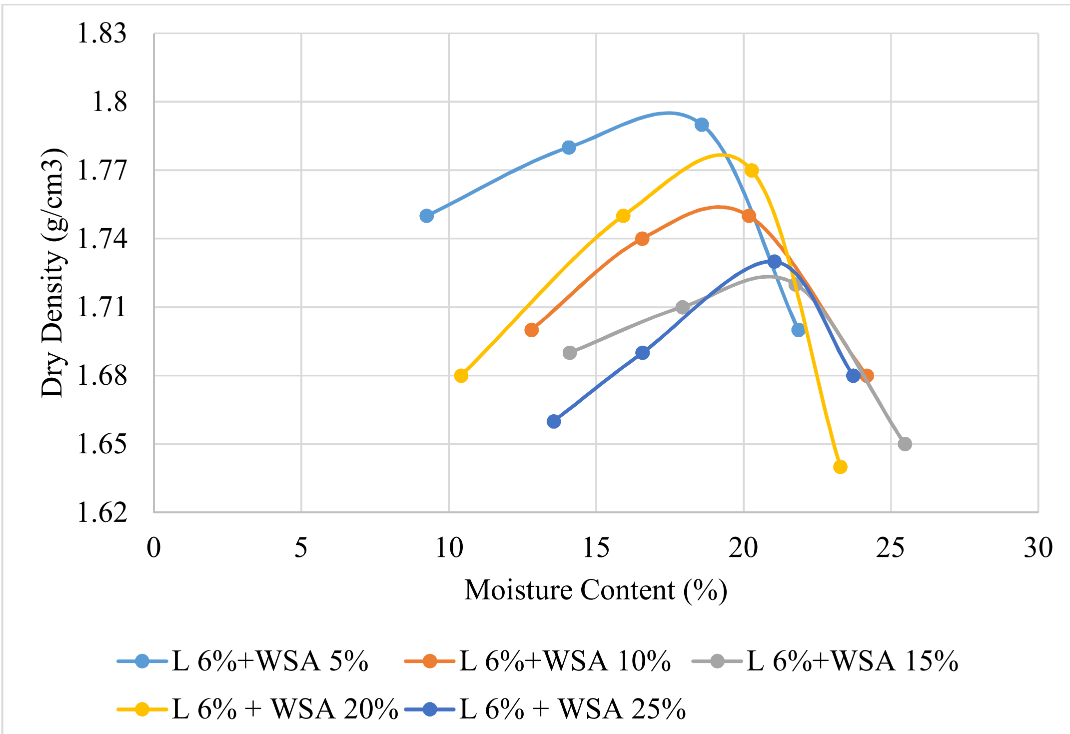


Figure 4-7 (a) Moisture Density Curve at Various WSA Content

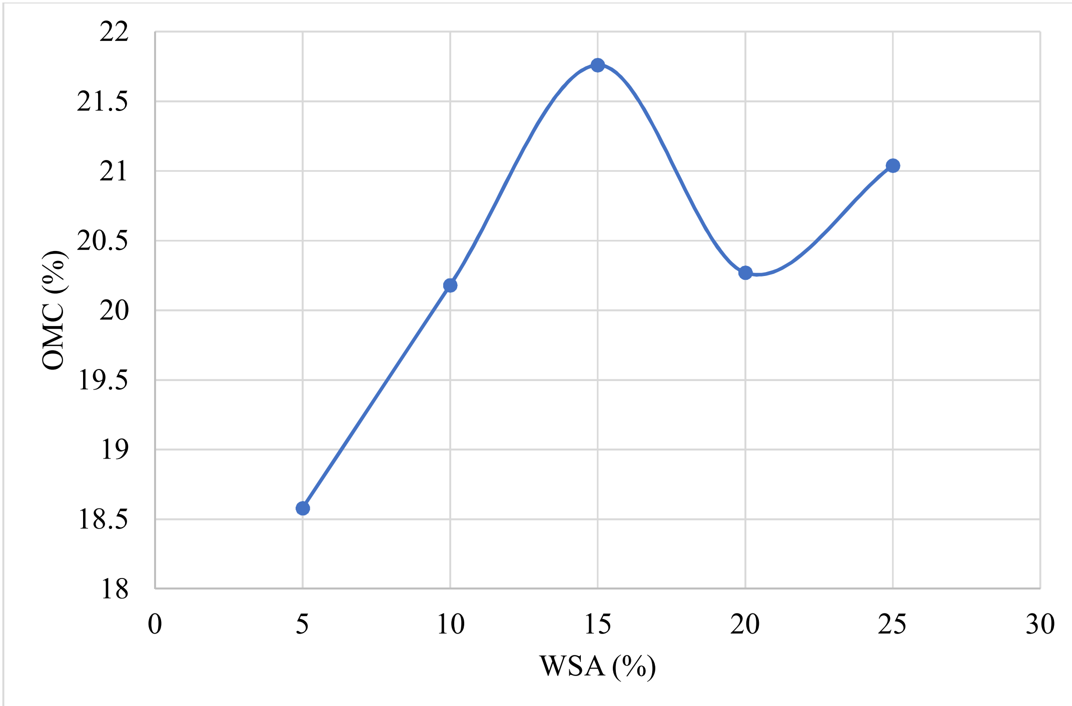


Figure 4-7 (b) OMC at Various WSA Content

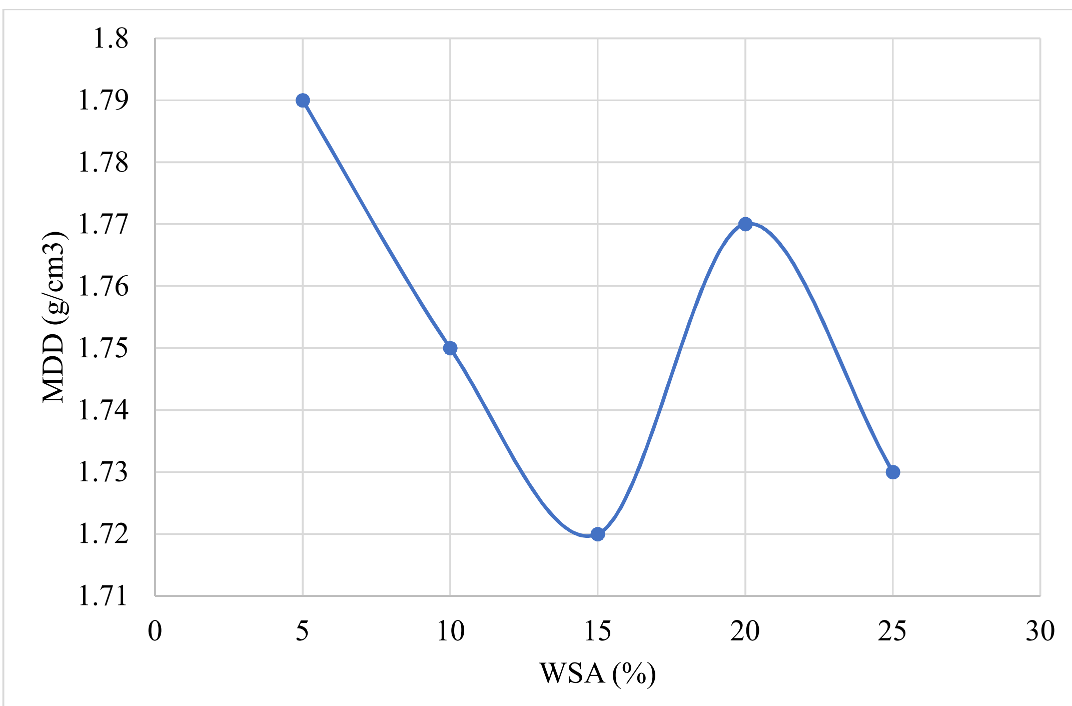


Figure 4-7 (c) MDD at Various WSA Content

Compaction test on soil indicate a gradual decrease in max dry density and increase in OMC up till 15% WSA. The reduction in density is due to flocculation and agglomeration of fine grained soil particles. These flocculated particles occupy larger spaces which reduce the dry density of soil. An increase in optimum moisture content is observed with increase in WSA content. This is due to the reason that lime and WSA are finer than soil. The finer the material is larger will be its surface area and more water will be required for the lubrication of these particles. The increase in moisture content is also attributed to the pozzolanic activity between lime, WSA and soil particles

4.4.3 Unconfined Compressive Strength at Various Wheat Straw Ash Content

Unconfined compressive strength samples were made at optimum lime content and various wheat straw ash content. Samples were made at their optimum moisture content. Samples were cured for 7days and then tested. Height to diameter ratio was 2:1 as per ASTM standards. Wheat straw ash content giving the highest UCS strength is optimum WSA content. Optimum WSA content came out to be 15%.

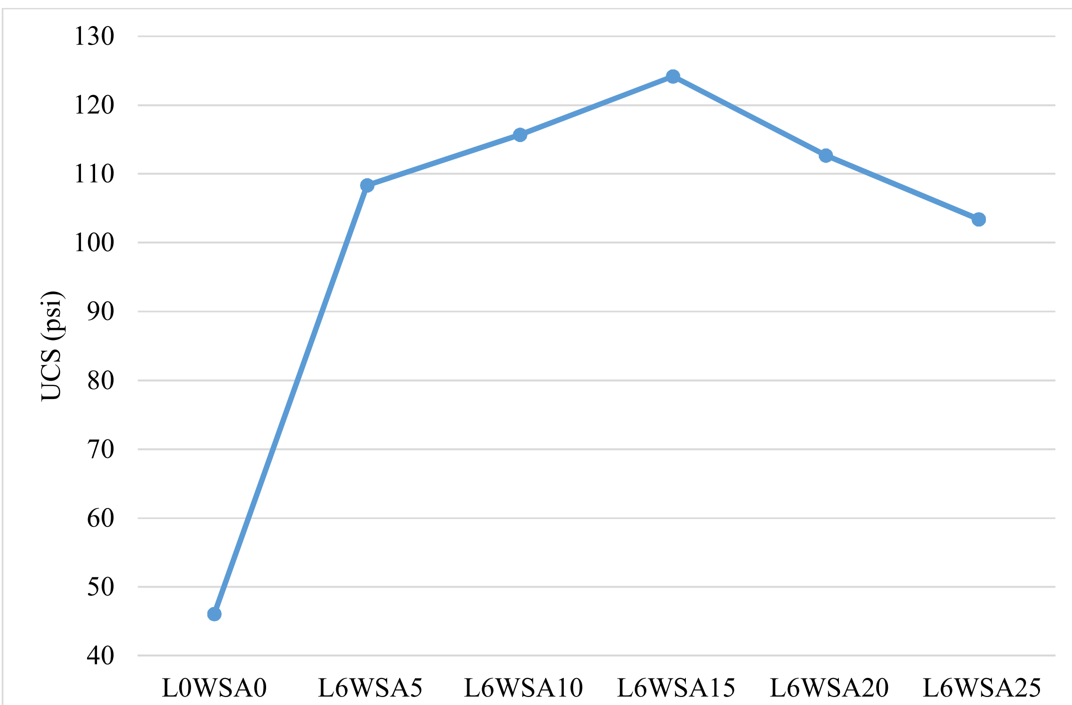


Figure 4-8 Unconfined Compressive Strength at Various WSA Content

4.5 Phase IV: 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 and WSA on weak subgrade soil.

4.5.1 GSD and Atterberg's Limit of Treated Soil

Effect of lime on GSD shows that after 7 days of soil lime mixture percent passing sieve#200 reduced by 12.88%. And in case of soil-lime-WSA mixture after 7 days percent passing #200 further reduced by 9.38%. Figure 4-9 below shows percent passing through sieve#200.

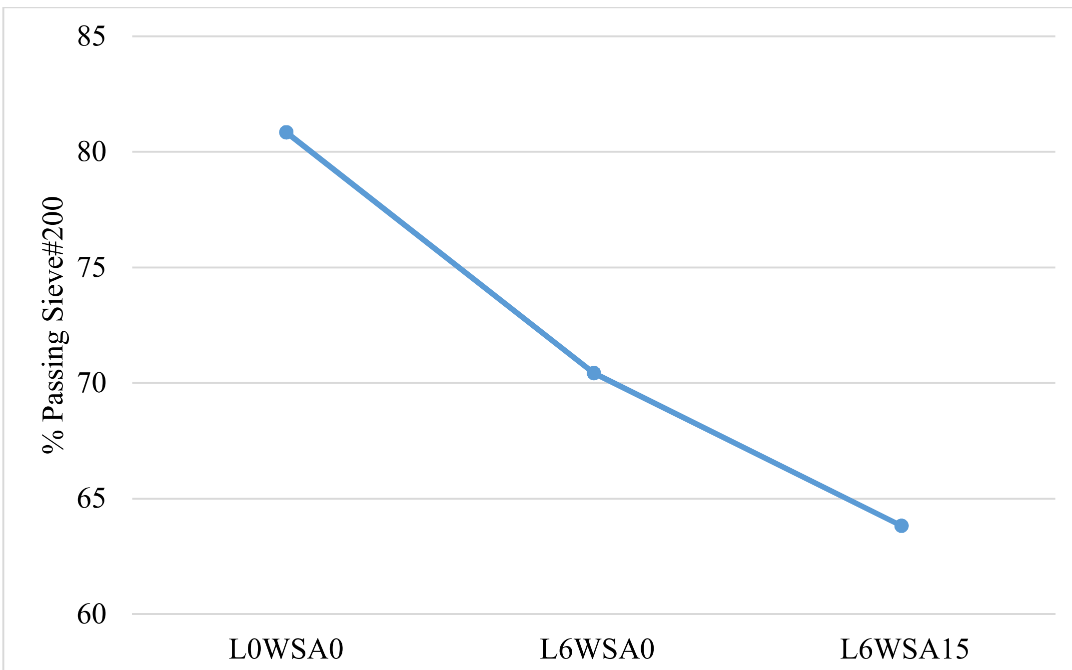


Figure 4-9 Percent Passing Sieve#200 at Various Stabilizer Content

Plasticity index of soil-lime-WSA mixture dropped to 4.88 after 7 days. And Plasticity index in case of soil-lime-WSA mixture further dropped by 78% after 7 days. Soil classification changed from A-6 to A-4 as per AASHTO classification. Figure 4-10 below shows liquid limit and plasticity index of treated soil.

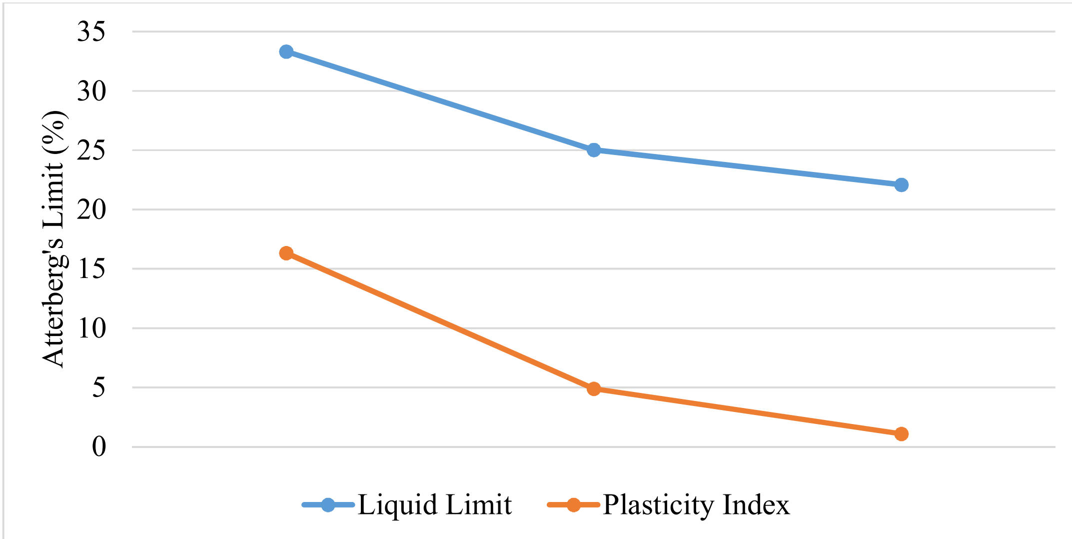


Figure 4-10 LL and PI at Various Stabilizer Content

4.5.2 Moisture Density Relationship of Treated Soil

The variation of OMC and MDD are shown in figures 4-5 and figure 4-7. With optimum lime content addition and WSA content addition MDD decreased and OMC increased. Increase in moisture content is due to hydration process of lime and pozzolanic properties of lime and WSA. OMC also increased due to fineness of lime and WSA i.e. finer the material larger will be its surface area so higher amount of water is needed for lubrication. While reduction in dry density is due to flocculation-agglomeration reaction. Flocculated particles occupy larger space which reduces maximum dry density of soil.

4.5.3 Unconfined Compressive Strength of Treated Soil

Unconfined compressive strength tests in both soaked and unsoaked condition were carried out on samples after 7 and 28 days curing. Soaked testing was done to assess the behavior of soil in moist condition. Unsoaked unconfined compressive strength tests result for untreated and treated soil at optimum lime and optimum lime and optimum WSA content are shown below in Figure 4-11 and Figure 4-12 shows compressive strength in soaked condition.

These results indicate that there is a gradual increase in UCS of soil in treated form as the curing period increases. Figure 4-11 shows that the UCS of natural soil increased by 211% after 28 days of curing when treated with 6% lime. Improvement observed was even more when 15% wheat straw ash was used in conjunction with 6 % lime. There was almost 276% increase in unsoaked UCS after 28days of soil when treated with lime and wheat straw ash.

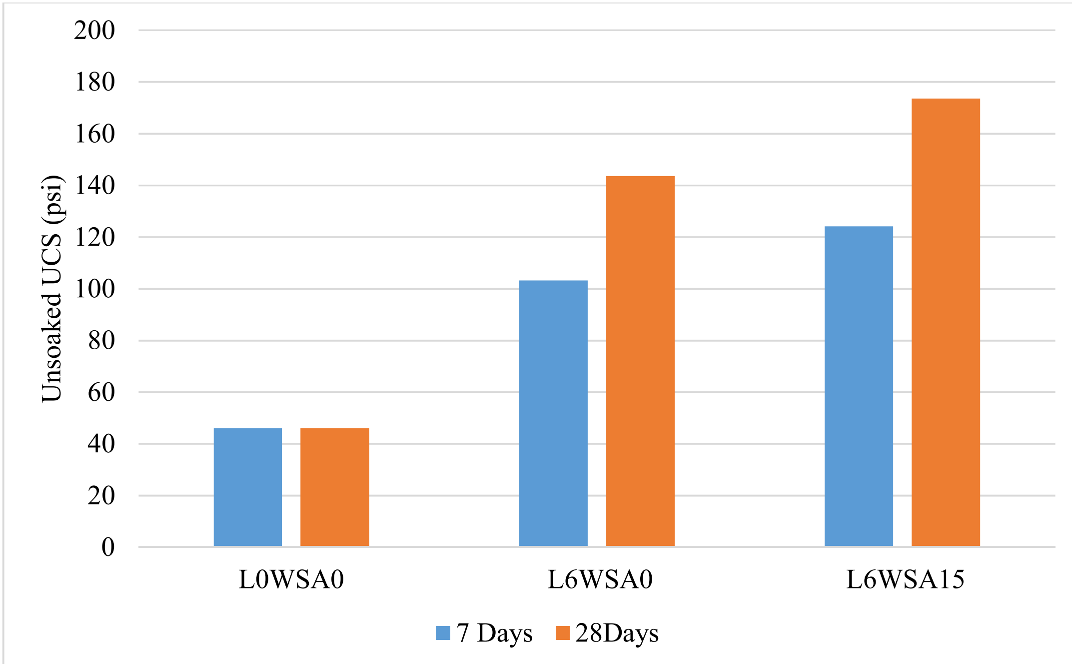


Figure 4-11 Unsoaked UCS Treated and Untreated Soil

There was also and significant improvement in soaked UCS of treated soil. Figure 4-12 shows that soaked UCS of treated soil cured for 28days increased approximately 16 times with 6% lime and 22 times when wheat straw ash was also used.

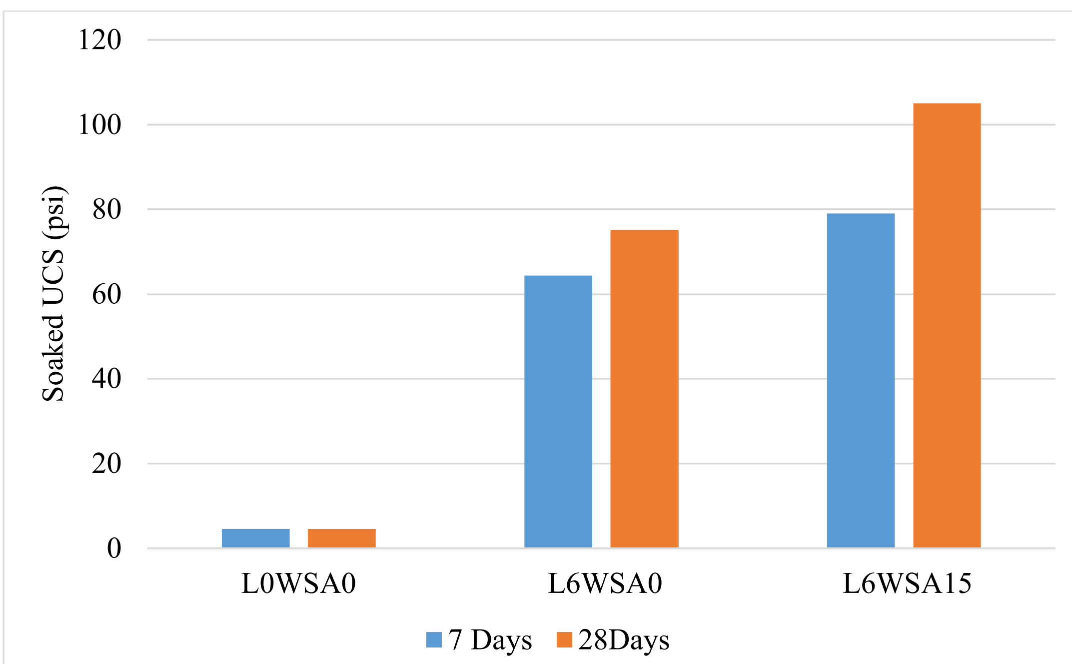


Figure 4-12 Soaked UCS Treated and Untreated Soil

4.5.4 California Bearing Ratio and Swell Potential of Treated Soil

Soaked CBR was performed to assess optimum lime and WSA content potential. Figure 4-13 below shows effect of stabilizer on soaked CBR. Results show that CBR of lime treated soil increased approximately 2 times and CBR of soil treated with optimum lime and optimum WSA increased approximately 3 times. Swell of soil reduced to approximately zero for soil treated with optimum lime and soil treated with optimum lime and optimum wheat straw ash.

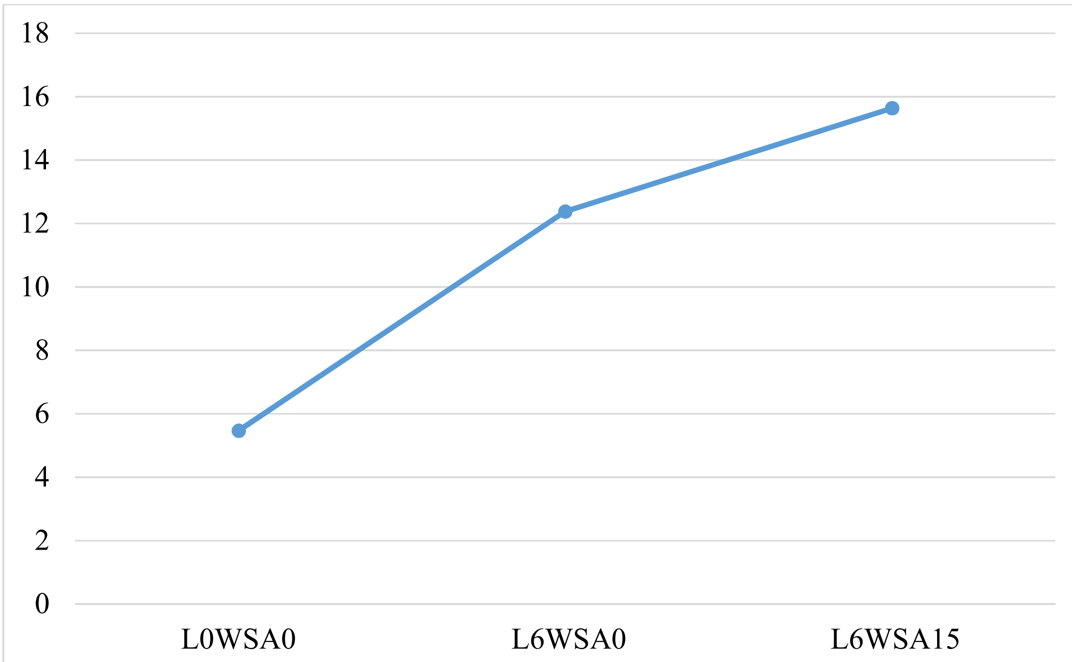


Figure 4-13 CBR of Treated and Untreated Soil

4.6 Phase V: Design and Cost Analysis

After laboratory testing of natural and stabilized soil design and cost analysis was conducted to check practical implications of stabilizers. AASHTO design procedure was adopted. Single lane 1km road of 3.6m width was designed with $1*10^6$ ESALs. Resilient modulus (M_r) of subgrade was calculated using CBR obtained from laboratory testing. Reliability (R) was taken 80% and standard deviation (S_o) 0.35 while initial serviceability (p_i) and terminal serviceability (p_t) were taken as 4.2 and 2.5 respectively. Structural number (SN) for each layer i.e. base, sub-base and asphaltic layers was computed using AASHTO design. Thickness of each layer for natural soil, lime treated soil and lime-WSA treated soil based on structural number was determined.

Reduction in layer thickness was observed for lime treated soil and also lime-WSA treated soil. 3-inch reduction in base layer and 5-inch reduction in sub-base layer was obtained. With addition of WSA with lime and natural soil further 2-inch sub-base layer thickness was reduced. Reduction in layer thickness was due to increase in strength which results in reduction in SN. Below table shows comparison of layer thickness for natural and stabilized soil however detailed calculations are presented in Appendix A.

Table 4-5 Layers Thickness Comparison

Layers	**Thickness (inches)**		
	Natural Soil	**Soil + Lime**	**Soil + Lime + WSA**
HMA	2	2	2
Base	7	4	4
Sub-Base	14	9	7
Total	23	15	13

After design cost analysis was conducted. Market Rate System provided by Punjab Government and Composite Schedule of Rates provided by NHA was used. Open market rates were used for lime and wheat straw. To find quantity of stabilizers depth of subgrade was assumed as 4.5-inches.

Approximately 24.5 lac PKR can be saved by using lime alone while using WSA there was negligible or very less difference in cost of about 3.00 lac PKR but WSA gives more strength and less layer thickness. Reduction in layer thickness was the primary reason resulting in cost saving. Cost comparison is shown below in figure 4-14 while detailed cost analysis is presented in Appendix B.

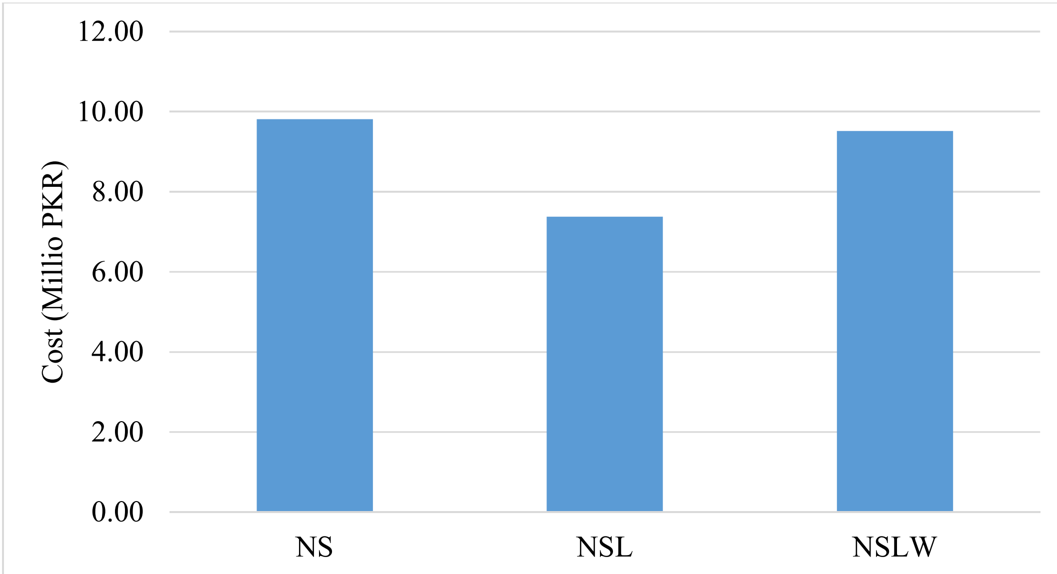


Figure 4-14 Cost Comparison

4.7 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 and WSA on clay soil are discussed. In the end the stabilizers efficiency was checked by using pavement design and cost analysis. In the next chapter, the conclusions and recommendations are made based on results of lab experiments and results analysis.

CHAPTER 5

CONCLUSION AND RECCOMENDATIONS

5.1 Summary

This study was performed to check suitability of lime and wheat straw ash as a stabilizers for weak subgrade soil. Optimization of lime and wheat straw ash was carried out. Grain Size Distribution, Atterberg's Limits, Specific Gravity, Modified Proctor, Unconfined Compressive Strength and California Bearing Ratio tests were performed on treated and untreated soils. Based on these results following conclusions are drawn. In later section reccomendations are enlisted based on conclusion drawn from results and analysis.

5.2 Conclusions

Atterberg's limit tests were performed for both treated and untreated soils. Results show a significant decrease in liquid limit and plasticity index of soil by the use of lime alone as well as for the combination of lime and wheat straw ash. The improvement in Atterberg's Limits was more significant when a combination of lime and Wheat straw ash was used as compared to individual effect of 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 is decreased by the use of lime and wheat straw ash while rise in value of OMC of subgrade soil is observed. Decrease in dry density is due to flocculation of soil particles. While the rise in optimum moisture content is due to fineness of lime and wheat straw ash.

Significant improvement of UCCS of soil in soaked and unsoaked condition with the use of lime and wheat straw ash. There was almost 211% increase in unsoaked UCS treated with lime and 276% increase in unsoaked UCS of soil-lime-WSA mix for 28 days curing. For soaked UCS soil strength increased 16 times with lime while 22 time when WSA was also used. This improvement in unconfined compressive strength is due to cat-ionic exchange, flocculation agglomeration and pozzolanic reactions between soil-lime and soil-lime-WSA mix.

California Bearing Ratio of the soil was improved greater than 2 times for subgrade soil stabilized with lime and 3 times for soil treated with lime and wheat straw ash. Whereas swell potential was reduced to less than 1% for soil lime and approximately zero for soil stabilized with lime and wheat straw ash.

Pavement design of road with stabilized subgrade significantly reduces layer thickness and as compared to pavement design of road with untreated subgrade. Decrease in cost was mainly due to reduction in thickness. Only lime can save more cost as compared to using lime and WSA combine in subgrade. However, if WSA is taken from rural areas of Pakistan where farmers/villagers burn WS in open fields to get rid of it then it will be economical.

In the light of the results obtained, it can be concluded that lime and WSA can be efficiently used for the stabilization and improvement of weak subgrade clayey soils.

5.3 Recommendations

Clayey soil was used for stabilization with lime and wheat straw ash. It is recommended to use different type of soils with varying clay content.

Lime was used along with wheat straw ash in this research. It is recommended to use different types of stabilizers along with wheat straw ash.

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 and dry densities.

The composition of agro-based waste products varies with soil (due to the silica available in soil). Effort should be made to prepare wheat straw ash at different temperature for better pozzolanic properties of soil.

Field investigations should be carried out to implement the findings of research. Trial sections can be planned in coordination with NHA.

WSA was prepared manually by burning WS which incurs high cost. If waste WSA is taken from rural areas where farmers burn WS to get rid of it then this can be economical.

REFERENCES

Al-Rawas, A. A., et al. (2005). "Effect of lime, cement and Sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman." Building and Environment 40(5): 681-687.

Asgari, M., et al. (2015). "Experimental study on stabilization of a low plasticity clayey soil with cement/lime." Arabian Journal of Geosciences 8(3): 1439-1452.

Beeghly, J. H. (2003). Recent experiences with lime-fly ash stabilization of pavement subgrade soils, base and recycled asphalt. Proceedings of the International Ash Utilization Symposium, University of Kentucky, Lexingston, USA, Oct.

Bell, F. (1993). Engineering treatment of soils, E&FN; Spon.

Bell, F. (1996). "Lime stabilization of clay minerals and soils." Engineering geology 42(4): 223-237.

Biricik, H., et al. (1999). "Study of pozzolanic properties of wheat straw ash." Cement and concrete research 29(5): 637-643.

Brooks, R. M. (2009). "Soil stabilization with fly ash and rice husk ash." International Journal of Research and Reviews in Applied Sciences 1(3): 209-217.

Carmeuse (2002). "Lime for Soil Stabilization and Soil Modification. A Proven Solution." Technical Bulletin, Pittsburg. PA15222.

Choobbasti, A., et al. (2010). "Influence of using rice husk ash in soil stabilization method with lime." Frontiers of Earth Science in China 4(4): 471-480.

Dahale, P., et al. (2016). "EFFECT OF FLYASH AND LIME ON STABILIZATION OF EXPANSIVE SOIL." i-Manager's Journal on Civil Engineering 6(2): 8.

Dang, L., et al. (2015). "Influence of bagasse ash and hydrated lime on strength and mechanical behaviour of stabilised expansive soil." GEOQuébec 2015.

Eisazadeh, A., et al. (2012). "Solid-state NMR and FTIR studies of lime stabilized montmorillonitic and lateritic clays." Applied Clay Science 67: 5-10.

El Shinawi, A. (2017). "Instability improvement of the subgrade soils by lime addition at Borg El-Arab, Alexandria, Egypt." Journal of African Earth Sciences 130: 195-201.

George, S., et al. (1992). "Effect of temperature on lime-soil stabilization." Construction and Building Materials 6(4): 247-252.

Ghobadi, M., et al. (2014). "Stabilization of clay soils using lime and effect of pH variations on shear strength parameters." Bulletin of Engineering Geology and the Environment 73(2): 611-619.

Grim, R. E. (1959). "Physico-chemical properties of soils: clay mineral." Journal of the Soil Mechanics and Foundations Division 85(2): 1-18.

Harichane, K., et al. (2011). "Use of natural pozzolana and lime for stabilization of cohesive soils." Geotechnical and geological engineering 29(5): 759-769.

Hausmann, M. R. (1990). Engineering principles of ground modification, McGraw-Hill New York.

Holeman, J. N. (1965). Clay minerals, US Department of Agriculture, Soil Conservation Service, Engineering Division.

Ingles, O. G. and J. B. Metcalf (1972). Soil stabilization principles and practice.

Jan, M. A. and R. D. Walker (1963). "Effect of lime, moisture and compaction on a clay soil." Highway Research Record(29).

Khemissa, M. and A. Mahamedi (2014). "Cement and lime mixture stabilization of an expansive overconsolidated clay." Applied Clay Science 95: 104-110.

Kiliç, R., et al. (2016). "Stabilization of high plasticity clay with lime and gypsum (Ankara, Turkey)." Bulletin of Engineering Geology and the Environment 75(2): 735-744.

Little, D. N. (1998). Evaluation of structural properties of lime stabilized soils and aggregates, National Lime Association.

Little, D. N. (2000). "Evaluation of Structural Properties of Lime Stabilized Soils and Aggregates, Volume 3: Mixture Design and Testing Protocol for Lime Stabilized Soils." National Lime Association, http://www. lime. org/SOIL3. PDF, accessed February 13: 2013.

Little, D. N. and S. Nair (2009). "Recommended practice for stabilization of subgrade soils and base materials."

Little, D. N., et al. (1987). Soil stabilization for roadways and airfields, LITTLE (DALLAS N) AND ASSOCIATES BRYAN TX.

Lund, O. and W. J. Ramsey (1959). "Experimental lime stabilization in Nebraska." Highway Research Board Bulletin(231).

Mallela, J., et al. (2004). "Consideration of lime-stabilized layers in mechanistic-empirical pavement design." The National Lime Association 200.

McDowell, C. (1959). "Stabilization of soils with lime, lime-fly ash and other lime reactive materials." Highway Research Board Bulletin 231: 60-66.

Mitchell, J. (1993). "1993, Fundamentals of Soil Behavior, John Wiley and Sons, Inc., New York."

Muhmed, A. and D. Wanatowski (2013). "Effect of Lime Stabilisation on the Strength and Microstructure of Clay IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) ISSN: 2320-334X." Volume6, Issue3.

Murthy, V. (2002). Geotechnical engineering: principles and practices of soil mechanics and foundation engineering, CRC press.

Osinubi, K., et al. (2009). Bagasse ash stabilization of lateritic soil. Appropriate Technologies for Environmental Protection in the Developing World, Springer: 271-280.

Pakistan, M. (2017). Pakistan Economic Survey 2017-2018, Islamabad. Available at: http://www. finance. gov. pk/survey/chapters_18/02-Agriculture.pdf

Prusinski, J. and S. Bhattacharja (1999). "Effectiveness of Portland cement and lime in stabilizing clay soils." Transportation Research Record: Journal of the Transportation Research Board(1652): 215-227.

Rogers, C., et al. (1997). Lime modification of clay soils for construction expediency. Proceedings of the Institution of Civil Engineers: Geotechnical Engineering.

Tuncer, E. R. and A. A. Basma (1991). "Strength and stress-strain characteristics of a lime-treated cohesive soil." Transportation Research Record(1295).

Winterkorn, H. F. and H.-Y. Fang (1991). Soil technology and engineering properties of soils. Foundation engineering handbook, Springer: 88-143.

Zukri, A. and N. A. A. A. Ghani (2015). A study of soil stabilization by hydrated lime at Kampung Kedaik Asal, Rompin, Pahang, Malaysia. Applied Mechanics and Materials, Trans Tech Publ.

APPENDICES

APPENDIX A: Pavement Design

AASHTO FLEXIBLE PAVEMENT DESIGN				
SN Determination				
Design Inputs				
W18 =	1,000,000		*ESALs Applications Over Design Period*	Typ. Range 0.1 to 80 million
R =	80	%	*Reliability*	Typ. Range 80 to 95%
So =	0.35		*Standard Deviation*	Typ. Range 0.3 to 0.5
MR =	7,500	psi	*Subgrade Resilient Modulus*	Typ. Range 3000 to 9000 psi
Pi =	4.2		*Initial Serviceability*	Typ. Range 4.4 to 4.8
Pt =	2.5		*Terminal Serviceability*	Typ. Range 2.0 to 3.0
DESIGN SN =	**3.12**			

Design SN of NS

AASHTO FLEXIBLE PAVEMENT DESIGN
Layer Thickness Determination

	Layer No.	Description	Layer Coefficient, a_i	Drainage Coefficient, m_i	Layer Thickness, in	SN
(topmost)	Layer 1	AC Wearing	0.42	1.00	2.00	0.84
	Layer 2	Gran. Base A	0.44	1.00	0.00	0.00
	Layer 3	Gran. Base B	0.16	0.80	7.00	0.90
	Layer 4	Gran. Subbase	0.13	0.80	14.00	1.46
	Layer 5					0.00
	Layer 6					0.00
	Layer 7					0.00
(bottommost)	Layer 8					0.00
	Subgrade	Subgrade	N/A	N/A	N/A	N/A
					Calculated SN	3.19
					Design SN to Match	3.12
					Design is sufficient	

Layer Thickness of NS

AASHTO FLEXIBLE PAVEMENT DESIGN				
SN Determination				
Design Inputs				
W18 =	1,000,000		*ESALs Applications Over Design Period*	Typ. Range 0.1 to 80 million
R =	80	%	*Reliability*	Typ. Range 80 to 95%
So =	0.35		*Standard Deviation*	Typ. Range 0.3 to 0.5
MR =	18,000	psi	*Subgrade Resilient Modulus*	Typ. Range 3000 to 9000 psi
Pi =	4.2		*Initial Serviceability*	Typ. Range 4.4 to 4.8
Pt =	2.5		*Terminal Serviceability*	Typ. Range 2.0 to 3.0
DESIGN SN =	2.23			

Design SN of NSL Mix

AASHTO FLEXIBLE PAVEMENT DESIGN
Layer Thickness Determination

	Layer No.	Description	Layer Coefficient, a_i	Drainage Coefficient, m_i	Layer Thickness, in	SN
(topmost)	Layer 1	AC Wearing	0.42	1.00	2.00	0.84
	Layer 2	Gran. Base A	0.44	1.00	0.00	0.00
	Layer 3	Gran. Base B	0.16	0.80	4.00	0.51
	Layer 4	Gran. Subbase	0.13	0.80	9.00	0.94
	Layer 5					0.00
	Layer 6					0.00
	Layer 7					0.00
(bottommost)	Layer 8					0.00
	Subgrade	Subgrade	N/A	N/A	N/A	N/A

Calculated SN 2.29

Design SN to Match 2.23

Design is sufficient

Layer Thickness of NSL Mix

AASHTO FLEXIBLE PAVEMENT DESIGN

SN Determination

Design Inputs

W18 =	1,000,000	*ESALs Applications Over Design Period*	Typ. Range 0.1 to 80 million
R =	80 %	*Reliability*	Typ. Range 80 to 95%
So =	0.35	*Standard Deviation*	Typ. Range 0.3 to 0.5
MR =	22,500 psi	*Subgrade Resilient Modulus*	Typ. Range 3000 to 9000 psi
Pi =	4.2	*Initial Serviceability*	Typ. Range 4.4 to 4.8
Pt =	2.5	*Terminal Serviceability*	Typ. Range 2.0 to 3.0

DESIGN SN = 2.04

Design SN of NSLW Mix

AASHTO FLEXIBLE PAVEMENT DESIGN
Layer Thickness Determination

	Layer No.	Description	Layer Coefficient, a_i	Drainage Coefficient, m_i	Layer Thickness, in	SN
(topmost)	Layer 1	AC Wearing	0.42	1.00	2.00	0.84
	Layer 2	Gran. Base A	0.44	1.00	0.00	0.00
	Layer 3	Gran. Base B	0.16	0.80	4.00	0.51
	Layer 4	Gran. Subbase	0.13	0.80	7.00	0.73
	Layer 5					0.00
	Layer 6					0.00
	Layer 7					0.00
(bottommost)	Layer 8					0.00
	Subgrade	Subgrade	N/A	N/A	N/A	N/A

Calculated SN 2.08

Design SN to Match 2.04

Design is sufficient

Layer Thickness of NSLW Mix

APPENDIX B: Cost Analysis

Layer	L	W	D			Volume/ Area/ Weight	Unit	Unit Price	Total Price	Reference Rawalpindi	
	m	m	in	cm	m						
HMA	1000	3.60	2	5.08	0.05	3600	sq.m				
Carpet 5% Bitumen						3600	sq.m	931.10	3351960	MRS/P110	10-a-v
Carriage Aggregates						173.74	cu.m	68.52	11903.68	MRS/P3	1
Carriage Bitumen						21.58	tonn	1256.80	27121.54	MRS/P18	a
Loading and Unloading						21.58	tonn	369.80	7980.22	MRS/P2	25
Base	1000	3.60	7	17.78	0.18	640.08	cu.m				
Crushed Stone Aggregate						640.08	cu.m	2742.15	1755195.37	MRS/P108	4-a
Carriage						640.08	cu.m	68.52	43855.66	MRS/P3	1
Loading/Unloading						640.08	cu.m	442.40	283171.39	MRS/P2	1
Subbase	1000	3.60	14	35.56	0.36	1280.16	cu.m				
Crushed Stone Aggregate						1280.16	cu.m	1970.60	2522683.30	MRS/P107	3-a-ii
Carriage						1280.16	cu.m	68.52	87711.31	MRS/P3	1
Loading and Unloading						1280.16	cu.m	442.40	566342.78	MRS/P2	1
Subgrade	1000	3.60	4.5	11.43	0.11	411.48	cu.m			MRS/P3	8-i
Replacement Material						411.48	cu.m	1538.25	632959.11	MRS/P107	2
Carriage						411.48	cu.m	68.52	28192.92	MRS/P3	1
Loading and Unloading						411.48	cu.m	442.40	182038.75	MRS/P2	1
Excavation						411.48	cu.m	211.05	86842.85	MRS/P3	8i
Transportation						411.48	cu.m	104	42793.92	MRS/P3	17i
Loading and Unloading						411.48	cu.m	442.40	182038.75	MRS/P2	1
Total Price									9812791.57		

Cost Determination NS

Layer	L	W	D			Volume/ Area/ Weight	Unit	Unit Price	Total Price	Reference Rawalpindi	
	m	m	in	cm	m						
HMA	1000	3.60	2	5.08	0.05	3600	sq.m				
Carpet 5% Bitumen						3600	sq.m	931.10	3351960	MRS/P110	10-a-v
Carriage Aggregates						173.74	cu.m	68.52	11903.68	MRS/P3	1
Carriage Bitumen						21.58	tonn	1256.80	27121.54	MRS/P18	a
Loading and Unloading						21.58	tonn	369.80	7980.22	MRS/P2	25
Base	1000	3.60	4	10.16	0.10	365.76	cu.m				
Crushed Stone Aggregate						365.76	cu.m	2742.15	1002968.78	MRS/P108	4-a
Carriage						365.76	cu.m	68.52	25060.38	MRS/P3	1
Loading/Unloading						365.76	cu.m	442.40	161812.22	MRS/P2	1
Subbase	1000	3.60	9	22.86	0.23	822.96	cu.m				
Crushed Stone Aggregate						822.96	cu.m	1970.60	1621724.98	MRS/P107	3-a-ii
Carriage						822.96	cu.m	68.52	56385.85	MRS/P3	1
Loading and Unloading						822.96	cu.m	442.40	364077.50	MRS/P2	1
Subgrade	1000	3.60	4.5	11.43	0.11	411.48	cu.m			MRS/P3	8-i
Lime				24.69	cu.m	27.16	tonn	20000	543153.60		
Carriage (10T/Truck)						2.72	trucks	3000	8147.30		
Loading and Unloading						24.69	cu.m	442.40	10922.33	MRS/P2	1
Subgrade Preparation						3600	sq.m	51.76	186336	CSR/P323	109bi
Total Price									7379554.38		

Cost Determination NSL Mix

Layer	L	W	D			Volume/ Area/ Weight	Unit	Unit Price	Total Price	Reference Rawalpindi	
	m	m	in	cm	m						
HMA	1000	3.60	2	5.08	0.05	3600	sq.m				
Carpet 5% Bitumen						3600	sq.m	931.10	3351960	MRS/P110	10-a-v
Carriage Aggregates						173.74	cu.m	68.52	11903.68	MRS/P3	1
Carriage Bitumen						21.58	tonn	1256.80	27121.54	MRS/P18	a
Loading and Unloading						21.58	tonn	369.80	7980.22	MRS/P2	25
Base	1000	3.60	4	10.16	0.10	365.76	cu.m				
Crushed Stone Aggregate						365.76	cu.m	2742.15	1002968.78	MRS/P108	4-a
Carriage						365.76	cu.m	68.52	25060.38	MRS/P3	1
Loading/Unloading						365.76	cu.m	442.40	161812.22	MRS/P2	1
Subbase	1000	3.60	7	17.78	0.18	640.08	cu.m				
Crushed Stone Aggregate						640.08	cu.m	1970.60	1261341.65	MRS/P107	3-a-ii
Carriage						640.08	cu.m	68.52	43855.66	MRS/P3	1
Loading and Unloading						640.08	cu.m	442.40	283171.39	MRS/P2	1
Subgrade	1000	3.60	4.5	11.43	0.11	411.48	cu.m			MRS/P3	8-i
Lime				24.69	cu.m	27.16	tonn	20000	543153.60		
WSA				58.02	cu.m	23.21	tonn				
WS						154.79	tonn	16250	2515399.87		
Carriage (10T/Truck)						18.20	trucks	3000	54585.46		
Loading and Unloading						82.71	cu.m	442.40	36589.79	MRS/P2	1
Subgrade Preparation						3600	sq.m	51.76	186336	CSR/P323	109bi
Total Price									9513240.24		

Cost Determination NSLW Mix