ADDIS ABABA UNIVERSITY
COLLEGE OF COMPUTATIONAL AND NATURAL SCIENECE
SCHOOL OF EARTH SCIENCE

DISPERSIVE SOIL TREATMENT; A CASE STUDY ALONG MELKASA-SODERE-NURERA-METAHARA ROAD PROJECT, CENTRAL ETHIOPIA

A thesis submitted to
The school of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of Master of Science in Engineering Geology

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UNDERTAKING

I certify that this research work titled "Dispersive Soil Treatment; A case study along the Melkasa-Sodere-Nurera-Metahara Road Project, Central Ethiopia" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources, it has been properly acknowledged/referred.

Fetene Damtew

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ABSTRACT

Portland pozzolana cement (PPC) and Gypsum were used as a stabilizer to treat dispersive subgrade soil along the Melkasa-Sodere-Nurera-Metahara Road project. Experimental laboratory investigation were carried out on two subgrade soil samples to determine the engineering properties of stabilized soils. The untreated soil samples collected from two different locations show a dispersion potential of 69.9 and 99.1 percent, respectively evaluated on a double hydrometer test.

Treated soil samples were prepared by varying the amount of cement from 1.0 to 5.5 percent by weight of dry soil sample and gypsum from 2.0 to 8.0 percent by weight of dry soil. The treated samples were evaluated for dispersion potential by double hydrometer test and unconfined compressive strength. The result was evaluated based on the Decker and Sherard dispersive soil classification criteria.

The samples treated with cement had shown a huge improvement interms of dispersion potential and satify the non-dispersive soil classification based on the Decker and Sherard criteria at 1 and 2.5 percent for samples A and B respectively. These samples show a higher incement in compresssive strength too. The gypsum treated samples, even if shows a huge improvement in dispersion potenetial, they were failed to satisfy the non-dispersive soil classification based on the crieteria set by Decker and Sherard and it is not considered for treatment of the current subgrade soil. The strength development of soil samples treated with gypsum are lower as compared to cement treated samples.

Key Words: Portland Pozzolana Cement, Gypsum, Dispersive Soil, Soil Treatment.

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LIST OF ABBREVIATIONS

AASHTO - American Association of State Highway and Transportation Officials

ASTM - American standards for Testing Method

BBVC - Bericha Volcanic Complex Rift

BS - British Standard

CEC - Cations Exchane Capacity

DEM - Digital Elevation Model

ERA - Ethiopian Road Authority

ESP - Exchangeable Sodium Percentage (ESP)

HD – Highly Dispersive

LL - Liquid Limit

MD – Medium Dispersive

MDD - Maximum Dry Density

MER - Main Ethiopian Boset-

ND – Non Dispersive

OMC - Optimum Moisture Content

PI - Plasticity Index

PL - Plastic Limit

PPC - Portland pozzolana cement

PS - Percent Sodium

SAR - Sodium Adsorption Ratio

SD – Slightly Dispersive

SG - Specific Gravity

TDS - Total Dissolved Salt

UCS - Unconfined Compressive Strength

USCS - Unified Soil Classification System

WFB - Wonji Fault Belt

CHAPTER 1
INTRODUCTION

1.1 Background

Pavement design and construction requirres a detailed investigation of soil deposits, since all pavements are either built on soil foundation or built with soil and products from the ground. Characterization and evaluation of the engineering properties of soil is critical to the long term performance of pavement structures. The engineering properties like strength of the soil, modulus (or stiffness), and volumetric stability should be considered during investigation. The origin and type of soil, climate, location, and stress history should be considered in detail since these are the determining factors of the structure and characteristics of the soil. A detailed soil investigation should include the soil visual description, engineering classification using grain size analysis and consistency of soil, and to a graet extent should identify problematic soil which undergo volume instability in the presence of water like swelling, collapsing or dispersive nature.

Problematic soils were major causes of failure for road and other infrastructures due to which currently projects demanded more than 40,000 per year of soil improvement with cost exceeding US$6 billion/year are reported globally (DeJong, et al., 2010). Although the extent and range of distribution of these soils have not been studied and documented in detail in Ethiopia, some research papers showed its existence and effect in many parts. Among those studies on problematic soils much have been focused on expansive and collapsible soils. Studies on dispersive or sodic soil related to engineering infrastructures was barely exist but its existence was reported by many agricultural soil researchers. The impact of this soil on engineering infrastructures are evident especially in the rift valley as many roads are affected yearly.

Dispersive soils, which is the focus of this study are those soils where its particles disperse or deflocculate in the presence of relatively pure water and becomes highly susceptible to erosion and piping. This tendency for dispersive erosion in a given soil depends on mineralogy and chemistry of the soil, as well as dissolved salts in the water in soil pores and in the eroding water (Elges, 1985). Erosion of such soils usually initiated in a drying crack, settlement crack, hydraulic fracture crack, or other channel of high permeability in a soil mass. The common features observed on dispersive soils are thus internal and surface erosion, formation of erosion features such as rill and gully marks, channels, internal cavities and tunnels with in the soil mass.

Presence of dispersive soil was reported in the Melkassa-Sodere-Nuraera-Metahera road project, which is considered as the study area of this research. In dealing with this soil, I am convinced to apply a certain soil treatment as it would be appropriate and economical. To assess the effect of the treatment and determine the optimum stabilizer amount, laboratory experimental study was conducted using manufactured portland pozzolana cement and gypsum. Statistical studies was also carried out to correlate the dispersivity of the treated soils with laboratory unconfined compressive strength results.

1.2 Problem Statement

Construction of road requires huge resource, and hence the serviceability and safety should not be compromised throughout its design life. Most road failures before serving the design life time was due to various reasons including traffic (design), moisture ingress to foundation layers, subgrade performance, and construction quality (Adlinge and Gupta, 2013). Addressing failures due to subgrade performance are costly since it involves reclamation or reconstruction. In Ethiopia failure of road because of poor subgrade are reported mainly due to expansive soil (Yunus, 2015, Uba, 2016, 2017). Even if the occurrence and their extent of damage of other problematic soils are well known ERA (2013), not much have found in research and documents about dispersive soil. Considerations thus must be given for investigation of piping and internal erosion effects of dispersive soil.

Dispersive soils pose a problem for many engineering practices or structures. In appearance, these soils are like normal clays that are stable and somewhat resistant to erosion, but in reality they can be highly erosive and subject to severe damage or failure i.e. these soils are highly vulnerable to erosion by the segregation of individual particles. In Ethiopia not much has been studied about these soils and its consequences in the construction industry as compared to other problematic soils is not known. But its occurrence is heavily reported especially in the Main Ethiopian Rift. Internal erosion in subgrade foundation, embankment fills and gully formations along and across the road alignment caused very huge damage to pavement structures.

The current study area is located within the Main Ethiopian Rift valley which is topographically at low level and possibility of flood during high rainfall season is common. Due to this flooding risk the design of the road relatively demands a high earth fill and as a result large volume of fill materials are required. But the existing subgrade soil and available borrow materials at various locations along the road were found to be dispersive soil and are not suitable for use in its natural state. Thus, the aforementioned challenges involve considerations of capital-intensive nature of the project (road construction), the widely existence of dispersive problematic soil in the project area and the need for elevated embankment due to flooding risk.

The use of existing dispersive soil as a subgrade and embankment fills for the construction of the road warrants the economy. Modifying the engineering property of the soil using chemical stabilization method is thus considered the most suitable method by the author since it is economically feasible and environmentally sustainable. Therefore, conducting experimental researches to treat the existing dispersive soil in the current study area is vital.

1.3 Objectives

1.3.1 General objective

Laboratory experimental study of dispersive soil stabilization to improve the engineering property along the Melkassa-Sodere-Nurera-Metahara Road Project using Portland Pozzolana Cement (PPC) and Recycled Gypsum.

1.3.2 Specific objectives

- Identify the dispersion rate of virgin soil samples
- Determine the optimum mix proportion, and
- Develop a correlation between degree of dispersion and unconfined compressive strength (UCS) of treated soil.

1.4 Scope and Significance

1.4.1 Scope

The focus of the study is the dispersive problematic soil identified along the Melkassa-Sodere-Nurera-Metahara Road Project. The research work confined to laboratory experimental study on chemical treatments of the dispersive soil using Portland Pozzolana

Cement (PPC) and Gypsum. The Crumb and Double Hydrometer tests were the only tests used for identification of dispersivity, whereas the double hydrometer test was solely used to evaluate the dispersion rate of the stabilized soil.

1.4.2 Significance

Since the study focuses on dispersive soils as foundation material for pavement structures, it is expected to widen the knowledge on the properties of dispersive soil, associated problems and possible treatment for the wide community in the field of geotechnics. It can serve as a reference document for both governmental and other organizations involving in the policymaking, in design and construction of engineering structures. Furthermore, it serves as baseline data for any investigation in academics and it can be an added literature to existing knowledge.

1.5 Expected outcome

This research was conducted to experimentally investigate the treatment of dispersive soil within the laboratory using Portland pozzolana cement and recycled gypsum in order to use the existing soil as fill for embankment and subgrade material. The research is thus expected to determine the optimum mixture to be used for treatment, study the relationships of dispersivity and unconfined compressive strength (UCS) on treated soil and provide recommendations on the use of treatment methods for the study area.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Literature review are presented in this chapter; previous works in the area of dispersive soil and its stabilization have been discussed. Dispersive clay soil are defined first and followed by discussions of its nature and distribution. In orderly manner dispersive soil identification, problems caused by dispersive soils and mitigating mechanisms are discussed. Emphsis is given to the discussion on the nature of clay soils and the chemical process and mechanisms of treatment method. In the final section chemical stabilization technique using calcium-based stabilizers is discussed deeply and selected few recent researches conducted in the area of dispersive soil treatment are reviewed.

2.2 Dispersive Clay Soil

Dispersive soils are one of the problematic soils in engineering applications. They are also called by other names like sodic soils or erodible soils and cause a huge challenges not only to infrastructure construction but also for environmental management, and agricultural applications (H Abbaslou, et al., 2016). Dispersive soils shows a property, in which they deflocculate and rapidly eroded and carried away by waterflow. The dispersion in clay occurs when the repulsive forces between individual clay particles exceed the attractive forces (Vander Waals attraction) so that when the clay mass is even in contact with still water individual clay particles are progressively detached from the surface and go into suspension.

According to Elges (1985) erosion in dispersive soils are common due to factors like mineralogy and chemistry of the clay, the dissolved salts in both the soil water and the eroding water. Soils with clay fraction composed largely of smectitic clays, montmorillonite and some illites are highly dispersive; however, clays composed largely of kaolinites are resistant. The percentage of absorbed sodium cations on the surface of the clay particles relative to the quantities of other polyvalent cations (calcium, magnesium or aluminium) govers the dispersion. The total content of dissolved salts within the water have also affect the dispersion of the clay. Water having lower amount of dissolved salts have a greater effect in the dispersion of sodium saturated clay. These soils due to their chemical imbalances are highly vulnerable to tunneling and gully ersion (Umesh, et al., 2011, Singh, et al., 2018).

2.3 Distribution of Dispersive Soil

Earlier studies associated dispersive soils mainly with loess and alluvial deposits and their formation with arid and semi-arid climates (Decker and Sherard, 1977). But recent studies in the area shows that it can be formed in any weather and from any geologic sources. Dispersive soil can take any color; it can be either red, brown, gray, yellow, or various combinations of these colors (Knodel, 1991).

Dispersive soil existence is widely reported throughout the world. H Abbaslou, et al. (2016), refering the FAO/UNESCO soil map of the world (1976) and presented the estimated areal coverage of dispersive sodic soils worldwide. It covers globally around 434 million ha by comparison to that of saline soils which was 397 million ha (Table 2-1).

Table 2-1 : Frequency and spreading of dispersive soils in the world

Regions	Total Area	Sodic Soils		Saline Soils	
	(ha)	(ha)	(%)	(ha)	(%)
Africa	1899.1	33.5	1.8	38.7	2.0
Asia, the Pacific & Australia	3107.2	248.6	8.0	195.1	6.3
Europe	2010.8	72.7	3.6	6.7	0.3
Latin America	2038.6	50.9	2.5	60.5	3.0
Near East	1801.9	14.1	0.8	91.5	5.1
North America	1923.7	14.5	0.8	4.6	0.2
Total	12781.3	434.3	3.4%	397.1	3.1%

Ethiopian Road Authority ERA (2013) in its site investigation manual hints the existence of these soils in ethiopia in areas like the rift valley, the southern and eastern lowlands, in Afar, Somali and Tigray regions. They noted an isolated occurrences in various parts of the country as well. Dispersive soils are common in Ethiopia in areas where pyroclastic deposits and weak sedimentary rocks outcrop. Kefyalew Assefa (2016) documented that salt affected soils in Ethiopia have been reported to occur for the most part in the Rift Valley Zone and other areas that are characterized by higher evapotranspiration rate as compared to precipitation referring to previous studies. The study showed soil salinity and sodicity level have an influenec on infiltration rate (permeability). The low to moderate permeability of the soil in his study was correlated with high level of sodicity.

Normally, dispersive soils tend to develop in low-lying areas with gently rolling topography and relatively flat slopes. Their environment of formation is also characterized by an annual rainfall of less than 850mm, and have low natural fertility. Occurrence of erosion gullies and piping are highly indicative of the presence of dispersive soil (ERA, 2013).

2.4 Dispersion Mechanism in Clay

Dispersive soil has poor engineering properties hugely attributed to its porosity i.e its poor air and water movement. These properties can create problems with soil stability under infrastructures. When the dispersive clay comes in contact with water, the clay fraction behaves more like a single-grained particle with a minimum electrochemical attraction and does not adhere or bond with the other soil particles. The inter particle force of repulsion (Electrical surface forces) exceed those of attraction (Van der Waals attraction) (Singh, et al., 2018). The net dispersive charge of the soil determines the clay dispersion; clay disperses when its net dispersive charge is positive and does not disperse when it is zero or negative (Rengasamy, et al., 2016).

2.4.1 Clay Mineral Structure

The properties that determine the composition of a minerals are derived from its chemical foundation, geometric arrangement of atoms and ions, and the electrical forces that bind them together. The same way the engineering behaviors of a clay particles are best understood from the study of its microstructure. Clays are generally made up of two basic atomic sheets, the silica tetrahedral sheets and the aluminum octahedron sheets. The center positions in these sheets are occupied by Silica (Si^{4+}) and Aluminum (Al^{3+}) atom bonded strongly to the oxygen atom (O2-) and hydroxyl (OH-) respectively with combinations of ionic and covalent bond. These atomic bonds (primary bonds) are very strong and can never be broken by ordinary physical forces (Ishibashi and Hazarika, 2015). Figure 2-1 shows Silica tetrahedral sheet (Left) and Aluminum Octahedral sheet (Right) (Schulze, 2002).

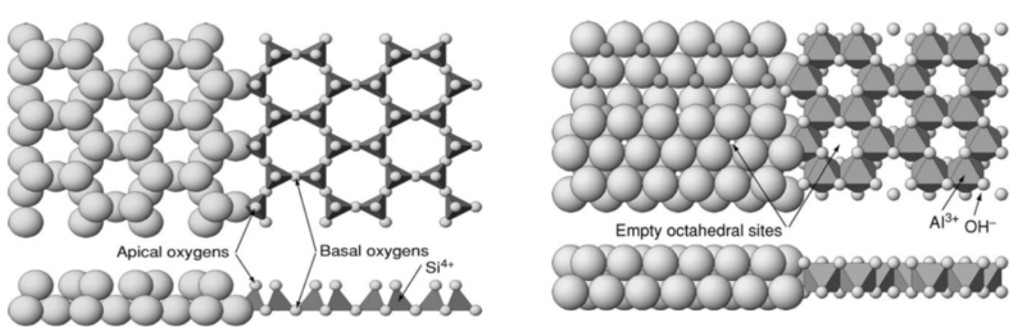

Figure 2-1 The basic structural components of clay minerals; Silica tetrahedral sheet (Left) and Aluminum Octahedral sheet (Right) (Schulze, 2002).

In the ocrahedral sheet, the cations exists in two states either divalent or trivalent. In the divalent stae where the ratio of divalent cations (Mg^{2+}, Fe^{2+}) to oxygens is 1:2, all three possible cation sites in the octahedron are occupied and electrical neutrality is maintained. This configuration and its respective sheet forms a tri-octahedral arrangement. Whereas in the trivalent state where the ratio of trivalent cations (Al^{3+}, Fe^{3+}) to oxygens is 1:3, the charge balance is maintained by leaving one of every three octahedral cation sites empty. This layer exhibits di-octahedral arrangement. A combination of tetrahedral and di- or tri-octahedral sheets bound by shared oxygen atoms forms aluminosilicate layers that comprise the basic structural units of phyllosilicates (Figure 2-2). Sheet arrangement within the aluminosilicate layers varies between clay mineral types resulting in variable physical and chemical properties that differentiate clay mineral classes (Barton, 2002, Schulze, 2002).

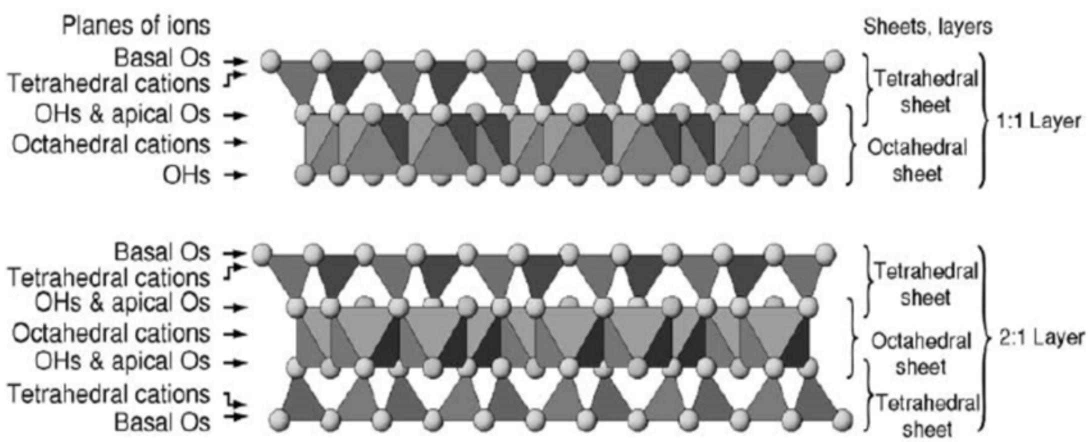

Figure 2-2 Structure of Clay Minerals 1:1 clay mineral consisting of one tetrahedral sheet bonded to an octahedral sheet; and b) 2:1 clay mineral consisting of an octahedral sheet bound between two tetrahedral sheets (Schulze, 2002).

2.4.2 Isomorphous Substitution

The elements structural arrangement forms the template for the silicate clay minerals, where its composition varies frequently due to substitution of ions within the mineral structure (Barton, 2002). The process of replacing one structural cation for another of similar size without any change in the crystal structure is referred to as isomorphous substitution. This replacement represents the primary source of both negative and positive charges in clay minerals. Some clay minerals exhibit substitutions that result in both positive and negative charges. In most soils, however, substitutions that result in net negative charge exceed those producing a positive charge.

Isomorphous substitution that brings about important properties of plasticity and compressibility to the clays in the presence of water, is one of the sources of permanent negative charge in soils. It is the primary source of a soil's ability to hold and exchange cations. This ability to hold and exchange cations is referred to as Cations Exchane Capacity (CEC).

The negatively charged clay particles due to the isomorphous substitution naturally repel each other since like charges repel. But adsorbed cations present in the clay tends to mask this negative charge (repulsion) to varying degrees, based on cation type. Small multi-charged cations (i.e., Al^{3+}, Ca^{2+}, Mg^{2+}) are strongly adsorbed by colloids because unlike charges attract each other, which greatly reduces the negative charge. When the negative charge of the colloid sufficiently reduced, flocculation will occurs. (Figure 2-3 a) on the other hand when the colloids are saturated with large weakly charged cations (i.e. $Na+$, $K+$), dispersion will occur. (Figure 2-3 b). The flocculation and dispersion reactions are the result of the cation exchange. In flocculated structure water moves through large pores whereas in dispersed clays, soil pores are plugged and impede water movement and soil drainage (Choudhary and Kharche, 2018, Singh, et al., 2018).

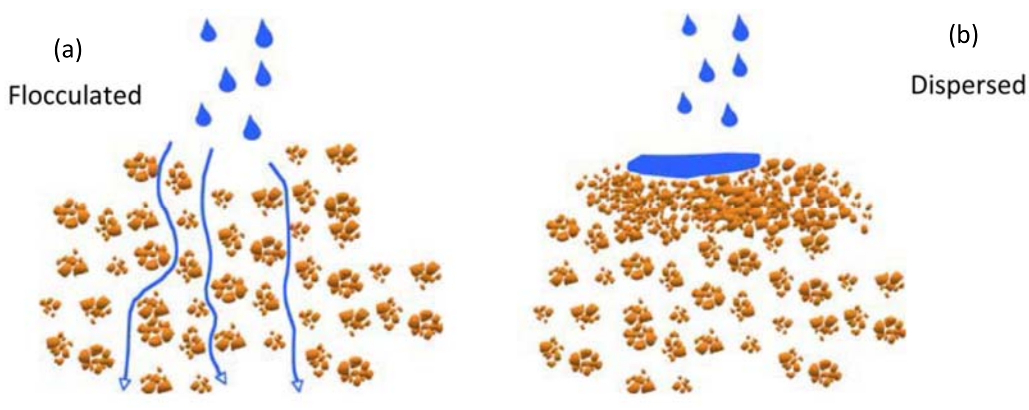

Figure 2-3 The difference between flocculated (aggregated) (a) and dispersed (b) soil structure (Choudhary and Kharche, 2018).

2.5 Identification of Dispersion of Soil

Dispersive soil identification is becoming crucial as it is one of the most common problematic soil all over the world that becomes a causes for failures of many earth dams, hydraulic and other infrastructures. The likes of road way embankments, Irrigation structures have suffered serious erosion problems and have failed due to the presence of the dispersive soils (Bhuvaneshwari, et al., 2007). Dispersive soil identification begins with field investigations using visual determination of the surface patterns. Standard laboratory index tests such as visual classification, grain size analysis, specific gravity do not provide a basis to identify dispersive clays. The conventional laboratory tests generally performed to identify dispersive clays are the crumb test, the double hydrometer test, the pinhole test, the chemical tests of dissolved salts in the pore water and the sodium absorption ratio (SAR) (Umesh, et al., 2011, Singh, et al., 2018).

The crumb test and double hydrometer tests are best suited to measure the dispersivity of the soil where as pinhole test is best to measuring the erodibility of the soil. The chemical tests measure the relative abundance of sodium cation relative to the other cations (Bell and Walker, 2000). No single test and even the use of a combination of methods are reliable for most part due to the actual testing procedures (Amrita Maharaj, 2011).

2.5.1 The Crumb Test

The crumb test was developed as a simple procedure to identify dispersive soil behavior in the field but is now often used in the laboratory as well. The test was first described by Emerson (1967) and he found the interaction of clay-sized particles in water to be a major determining factor in the stability of a soil (Emerson, 1967, Amrita Maharaj, 2011, Shoghi, et al., 2013). A cubical specimen of about 15 mm size is carefully placed in about 250 ml of distilled water. As the soil crumb begins to hydrate, the tendency for colloidal-sized particles to deflocculated and go into suspension is observed. According to Amrita Maharaj (2011) the soil sample can be at natural moisture content, air dried, oven dried or remoulded before being immersed in the beaker. After 5-10 minutes the soil crumb and the solution are analysed interms of suspended colloid quantity and four grades of reaction are discernible from no reaction to strong reaction (Table 2-2). The test was standardized by the American standards for Testing Method (D ASTM, D6572-00). and the British standards (BS-1377 British Standard, 2004).

The crumb test gives a good indication of the potential erodability of clay soils; however, a dispersive soil may sometimes give a non-dispersive reaction in the crumb test. If the crumb test indicates dispersion, likely the soil is most dispersive. Amrita Maharaj (2011) investigates basic problems associtaed with the test for lackof consistet results. She found out that lack of standard protocol regarding the variables are at the root of all. Which includes variables like immersion solution (dilute NaOH or distilled water), condition of crumb (moisture content and remoulding).

Table 2-2 A description of grades for a crumb test

Grade	Reaction	Description
1 (ND)	No reaction	Crumbs may slake, but no sign of cloudiness caused by colloids in suspension.
2 (SD)	Slight reaction	Bare hint of cloudiness in water at surface of crumb.
3 (MD)	Moderate reaction	Easily recognizable cloud of colloids in suspension, usually Spreading out in thin streaks on bottom of beaker.
4 (HD)	Strong reaction	Colloid cloud covers nearly the whole bottom of the beaker, Usually as a thick skin.

2.5.2 The Double Hydrometer Test

Double hydrometer test is one of a highly regarded test method for identifying the dispersion potential of soils. The test evaluates the dispersivity of soil by measuring the natural tendency of the clay fraction to go into suspension. The procedure involves the determination of the percentage of particles in the soil which are less than 0.005 mm in size by use of the standard hydrometer test. A parallel test is also carried out, in which no chemical dispersant is added and the solution is not mechanically agitated. The quantity of 0.005 mm sized particles in the parallel test is expressed as a percentage of the 0.005 mm sized particles in the standard test, which is defined as the dispersion ratio or dispersivity of the soil. The soil is then classified as being dispersive, moderately dispersive or non-dispersive based on the ratio obtained from the test (A Maharaj and Paige-Green, 2013, Shoghi, et al., 2013).

The test method is standardized by the American standards (ASTM Standard, D4221). and the British standards (BS-1377-2 British Standard, 2004). In this test the specimen tested should be at natural water content. The particle size distribution is first determined using the standard hydrometer test in which the soil specimen is dispersed in distilled water with strong mechanical agitation and a chemical dispersant. A parallel hydrometer test is then made on a duplicate soil specimen but without mechanical agitation and a chemical dispersant. Criteria for evaluating the degree of dispersion using results from the double hydrometer test is shown in Table 2-3.

Table 2-3 Degree of dispersion using results from double hydrometer test

Percent dispersion	Degree of dispersion
<30	Non-dispersive
30 to 50	Intermediate
>50	Dispersive

2.5.3 The Pinhole Test

The pinhole test originally developed by Decker and Sherard (1977) to directly measure the erodability of compacted fine-grained soils. A small hole (1.0mm diameter) drilled through a 34-mm-diameter cylindrical soil specimen that simulate a crack or concenterated leakage channel in natural soil, and water is made to flow through. Distilled water is used all the time to percolate through the pinhole under heads of 50, 180, and 380 mm. Flow rate and effluent turbidity are recorded. The test is done on soils under natural moisture content and a pass under 2-mm sieve (U.S. Standard No. 10) is used to remove larger size particles (Umesh, et al., 2011, Singh, et al., 2018). Dispesibility of the soil is judged by visual observation of presence and absenece of turbidity in the water emerging and measurement of flow rate and the hole diameter at end of test. Table 3 shows the clasification of dispersion under pinhole test. The test result at 50mm mm head is used as the principal means for separating the dispersive soil from the non dispersive. The test deemed completed if the watr is not substantially clear and rate of flow are increased to between 1.0 and 1.4 mL/s (Shoghi, et al., 2013). The test is standardized by the American standards (ASTM Standard, D4647). and the British standards (BS-1377 British Standard, 2004).

Table 2-4 Summary of Criteria for Evaluating Results (Decker and Sherard, 1977).

Classification	Head (mm)	Time (min)	Final Flow rate (ml/sec)	Effluent Color	Pinhole size after test
D1	50	5	>1.5	Very distinct	2x
D2	50	10	>1	Distinct to tight	2x
ND4	5	10	<0.8	Slight but easily visible	1.5x
ND3	180 – 380	5	>2.5	Slight but easily visible	2x
ND2	1020	5	>3.5	Clear to barely visible	2x
ND1	1020	5	<5	Crystal clear	No erosion

Table 2-5 Categories of pinhole test results (Decker and Sherard, 1977).

Classification of soil	Description of categories
D1 and D2	Dispersive – highly dispersive soils: Fail rapidly under 50mm head
ND4 and ND3	Intermediate soils: Erode slowly under 50mm or 180mm head
ND2 and ND1	Non-dispersive soils: No colloidal erosion under 380mm or 1020mm head

2.5.4 Chemical Tests

Soil sodicity (i.e. dispersion rate) is directly related with combined effects of salinity as measured by electrical conductivity of the soil, and soluble Na^+ concentration relative to soluble divalent cation concentration in soil solution. The later is measured with Sodium Adsorption Ratio (SAR), or Exchangeable Sodium Percentage (ESP) (Hanie Abbaslou, et al., 2020). Exchangeable Sodium Percent (ESP) is the most common analytical technique used to identify sodic or potentially dispersive soils. Criteria that have been used to classify dispersive clays using ESP data are shown in Table 2-6 and ESP value is calculated using the equation below.

$$\boldsymbol{ESP = \frac{Na^+}{Na^+ + Mg^{2+} + K^+ + Ca^{2+}} \times 100} \qquad \textbf{Equation 2.1}$$

Table 2-6 Degree of dispersion using ESP data

ESP	Degree of dispersion
<7	Non-dispersive
7 to 10	Intermediate
>10	Dispersive

The other parameter commonly used to evaluate and quantify the sodium concentration inorder to determine the dispersion when free salts are present is the SAR (sodium adsorption ratio). It is calculated using equation 2.2.

$$\boldsymbol{SAR = \frac{Na^+}{\sqrt{0.5(Ca^{2+} + Mg^{2+})}}} \qquad \textbf{Equation 2.2}$$

According to Hanie Abbaslou, et al. (2020) an ESP of 15 (~SAR 13) is generally taken to be the threshold, below which soils are classified as nonsodic, and above which soils are dispersive suffering from serious physical problems at the time of applying the water. The currently accepted method of evaluating the dispersion potential is from sherard diagram as shown in the figure below (Figure 2-4). The diagram is divided in to three zones based on the percent sodium (PS) and total dissolved salt (TDS) of the soil extract (Shoghi, et al., 2013).

$$PS = \frac{Na^{+}}{TDS} \times 100 \qquad \textbf{Equation 2.3}$$

$$TDS = Na^{+} + Ca^{2+} + Mg^{2+} + K^{+} \qquad \textbf{Equation 2.4}$$

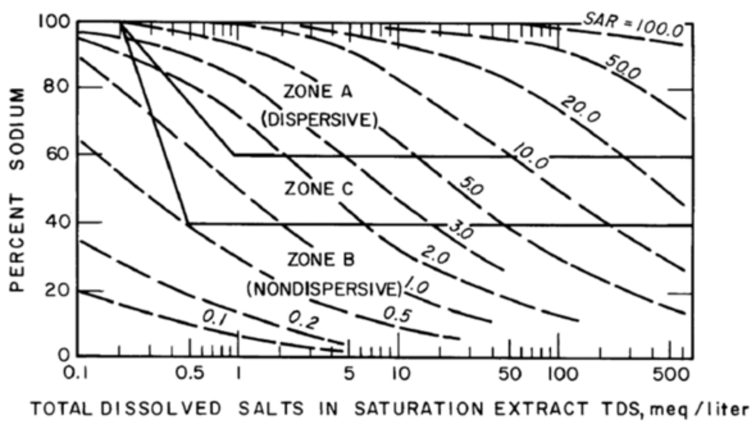

Figure 2-4 Determination of dispersive soil using chemical test.

In general, Amrita Maharaj, et al. (2015) gives some conclusive remark on the tests. The pinhole test was found to be a highly unreliable test, as the test method is ambiguous and its procedure is time-consuming with very little of the fundamental problems in dispersive soils being addressed. Whereas the double hydrometer test is a good indicator of dispersivity if done accurately and repeatedly. And the crumb test is also a good indicator if carried out accurately.

2.6 Problems of Dispersive Soil

Dispersive soil poses serious problem in construction, generally it is not suitable as foundation or fill material in engineering construction. These soils can cause serious engineering problems especially in hydraulic structures, embankment dams, or other structures like canals and roadway embankments. Structural failures due to dispersive soils like subsurface voids forming below highway infrastructure, along drainage routes (e.g., ditches, culverts, channels), and erosion of ditches and backslopes are commonly occur worldwide in many countries (Singh, et al., 2018).

Almost all failure of structures in dispersive soils were intiated through a concentrated leakage channels which might be either shrinkage cracks, differential settlements or construction deficiencies. Natural slope failures due to erosion of dispersive soil can be initiated due to the penetration of water throgh the cracks, plant roots or fissures. It thus becomes common to see erosion features on slopes, such as rill and gully marks, channels, internal cavities and tunnels. Generally, erosion in dispersive clays is not due to seepage through the pores of a clay mass as in cohesive soil (Umesh, et al., 2011). Thus it is clear that mechanism of failure in dispersive soil arises from either internal erosion and piping due to tunnel erosion or erosion of external soil slopes.

2.6.1 Internal Erosion and Piping Failure

Piping failure in cohesive soils usually occurs due to water flowing through the pores of the soil and when a concentrated leak emerges downstream of an embankment through a tunnel shaped passage which usually ends up in catastrophic damage. Whereas piping mechanism in dispersive clay is due to deflocculation process in which water travels through a concentrated leakage channel. Internal erosion in dispersive soil is thus the result of deflocculation rather than seepage through the pores of a clay mass as in other type of soils (Knodel, 1991). Decker and Sherard (1977) discussed for erosion to occur in dispersive soil, a concentrated leakage channel (even though it can be very small) must exist. For this reason, the damages due to dispersive soil erosion in construction generally occurs close to high crack potential areas like along conduits, in areas of large differences in compressibility of foundation materials, or in areas of desiccation (Decker and Sherard, 1977).

2.6.2 External Erosion of Dispersive Clay

Surface erosion potential of dispersive and nondispersive soil slopes have several important differences. Sheet or surface erosion occurs due to slaking of soil grains. The two causes of slaking related with dispersive erosion are replacement of entrapped air by water and internal shear stresses caused by swelling. The reaction between the surface of the soil mass with water results in soil crumbs, and slaking is the breakup of soil crumbs into discrete fragments when immersed in water. This breakup proceed to individual clay platelet size when the crumb particles are composed of dispersive clay (Knodel, 1991). Some dispersive soils may not exhibit rainfall erosion on either vegetated fill slopes or cut slopes which may be due to cracking potential, rate of swelling to close cracks, climatic conditions, or rate at which colloidal particles go into suspension (Sherard and Decker, 1977; Crouch, 1976).

2.7 Remedial Measures

When dispersive soils are found during exploration phase, decisions can be made to look for alternate materials or proceed with necessary engineering provisions to deal with the dispersive properties. Singh, et al. (2018) summarized three basic measures while dealing with dispersive soils, which are physical stabilization, chemical stabilization, design and construction measure.

2.7.1 Physical Stabilization

Physical stabilization is about changing the physical state of soil to make it stable. The methods in physical stabilization includes avoiding disturbance to areas with dispersive subsoil, minimizing excavation of dispersive soils, removing ponded water from the exposed soil surface, bury the dispersive soil under topsoil, careful control of compaction and water content during construction, cover the soil with vegetation and using sand filters and sand blocks.

2.7.2 Chemical Stabilization

Chemical stabilization or chemical amelioration involves a chemical process where the original structure of minerals breakdown to form a new stabilized mineralogical arrangement. Chemical stabilization of dispersive soil in construction industry using various chemicals such as lime, gypsum, alum, calcium chloride, sulfuric acid, fly ash, cement and pozzolan are common.

2.7.3 Design and Construction Measures

Design measures can be considered and incorporated while dealing with dispersive soil. The designer must base any special design features on the severity of the dispersive characteristics of the soil. It will include locating and use of non-dispersive borrow source for construction if available, excavate and replace dispersive soils or blanket it with non-dispersive soils to the lines and grades required on the construction plans, sand diaphragms design around conduits and chemical amendments may also be used to treat exposed dispersive soils on excavated slopes.

2.8 Soil Stabiliztion

Nicholson (2014) described ground improvement as a method that are used to address or solve ground conditions or problems inorder to improve the engineering properties of existing or available soil. Ground improvement can be used to increase the strength property like bearing capabilities, tensile strength, or it can be used to improve overall performance of in-situ subgrade or waste materials.

While building large infrastructures like road and dams greater emphasis is given to utilize effectively the available local material so as to minimize the cost of construction. Many researchers considered stabilization of local (existing) materials as the best way to construct economically feasible and environmentally suitable infrastuctures by improving the engineering properties. Among the various techniques of ground or soil improvement methods, the major ones are Mechanical stabilization, Hydraulic modification, Physical and Chemical stabilization, Bio stabilization, Electro-osmosis and Reinforcements. The choice among these stabilization techniques depends on factors like the soil type, location of treatment required, desired/required soil properties, availability of materials and availability of skills and local preferences (Nicholson, 2014).

Chemical stabilization technique which is the focus of this study is widely applied in road construction. It is the rendering or stabilizing of a soil using admixtures for making the soil less succeptible to fluctuations in engineering property like strength, volume or moisture content change. Variety of admixtures such as natural soils, chemical reagents, binders, polymers, industrial by-products (waste or recycled materials such as fly ash, slag, shredded rubber, crushed glass, etc.), salts, poly-fibers, and bitumen/tar are involved.

The use of chemicals stabilization in road construction is widely practiced since ancient times. Its efficiency and effectiveness was tested through times; the Romes Appian Way, which was built around 600AD using lime-soil mix and still functionong is a living example (Nicholson, 2014). The desired results is largely influenced by the chemical reactions between stabilizer (cementitious material) and soil minerals.

2.9 Chemical Treatment of Dispersive Soil

Treatment of soil using chemicals stabilizers have economical benefits as compared to other method like structural modification (e.g. increasing the thickness of layer), removal of existing subgrade material and replacing. The chemical stabilization techniques are recommended in many situations involving enhancement of strength properties, modifying the swelling and shrinkage characteristics and improving the dispersive nature of soils, thus offering improved foundation for the pavements and other infrastructure. Commonly used additives like cement, lime, and fly ash have been effective to improve the soil properties to requisite levels.

2.9.1 Mechanisms of Chemical Stabilization

The mechanism of clay soil stabilization using calcium-based stabilizers like cement and lime is discussed in this section. The basic mechanisms of soil modification involved are cation exchange, flocculation and agglomeration, hydration and pozzolanic reaction.

2.9.1.1 Cation Exchange

Due to isomorphous substitution the surface of clay minerals are negatively charged and naturally repel each other, and forms a diffuse "double layer." They attract cations and water molecules (H_2O) to neutralize the charge deficiency. When monovalent cation like sodium involves in the neutralization, the double layer become thicker and the soil gets more plastic. To reduce the plasticity of the soil by reducing the thickness of the double layer, the monovalent cations on the surface should be exchanged by a multivalent cation. And the process is called cation exchange (Figure 2-5a) and it happens rapidly under calcium-based stabilizers (Halsted, et al., 2008, Singh, et al., 2018).

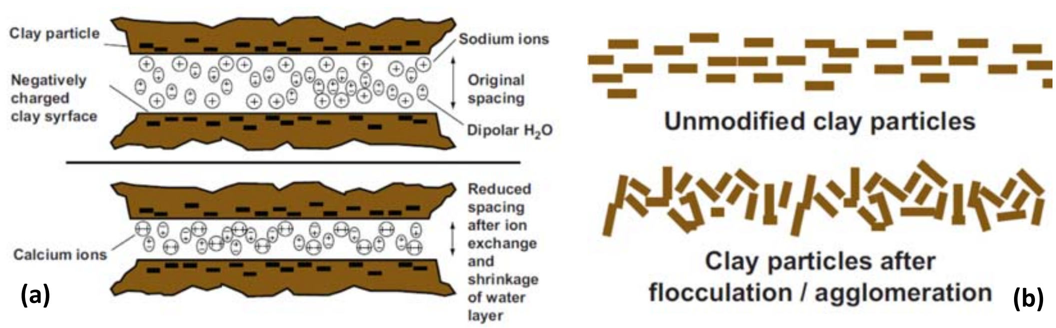

Figure 2-5 Cation exchange (a) and Particle restructuring (b) (Halsted, et al., 2008).

2.9.1.2 Particle Restructuring (Flocculation and Agglomeration)

Altering the arrangement of a flat and parallel structure to a more random edge-to-face orientation in clay particles is flocculation process (**Figure 2-5** b). Whereas agglomeration refers to the weak bonding at the edge-surface interfaces of the clay particles, which as a result form larger aggregates from finely divided clay particles and further improve the texture of the soil/aggregate (Halsted, et al., 2008). These process increased internal friction of clay particles and resulted in a reduction in plasticity, an increase in shear strength, and an improvement in texture. As with cation exchange, the particle restructuring process happens rapidly under calcium-based stabilizers.

2.9.1.3 Cementitious Hydration

Hydration is a process that ends up in products of calcium-silicate-hydrate (CSH) and calcium-aluminum-hydrate (CAH) and these products stabilize the flocculated clay particles by forming a bond which forms larger aggregates and improves the gradation of the clay (Figure 2-6 a). The process takes place after a day and stays for a month (Halsted, et al., 2008).

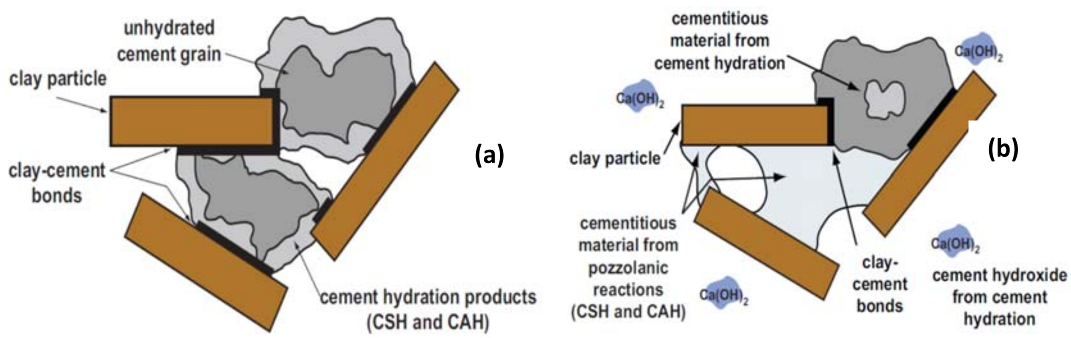

Figure 2-6 Cementitious hydration (a) and Pozzolanic reaction (b) (Halsted, et al., 2008).

2.9.1.4 Pozzolanic Reaction

A portion of the lime generated during the hydration process reacts with silica or alumina ions from the clay structure. The lime produced during hydration, enters a pozzolanic reaction. During this secondary soil modification process, the calcium ions supplied by the incorporation of stabilizer combines the silica and alumina dissolved from the clay structure to form additional CSH and CAH (Figure 2-6 b). It is a slow reaction and takes months or years and can further strengthen a modified soil/aggregate (Halsted, et al., 2008).

2.9.2 Cement Stabilization

Cement is the oldest binding agent and considered a primary stabilizing agent because it brings the required stabilizing action alone. Cement is used widely to treat different types of soil because the reaction of the cement with water is hugely responsible for stabilizing rather than the reaction with the soil mineral. The increase in strength, reduction in liquid limit, plastic limit and the potential for volume change achieved by cement stabilization is due to primary and secondary cementitious reactions in the soil cement matrix. The engineering properties of clay soil will be improved by cement stabilization due to chemicals and compounds present in cement that undergo four distinct mechanisms namely cation exchange, particle restructuring, cementitious hydration, and pozzolanic reaction (Halsted, et al., 2008, Umesha, et al., 2009).

1. Umesha, et al. (2009) has researched to improve the performance of dispersive soil in India using portland cement with intention to increase the strength properties. Ordinary Portland cement (grade 53) was used with 1, 2, 3 and 5 percent by dry weight of soil. The study found out that an increase in percent of cement content increases the unconfined compressive strength. The study concluded to use 3 percent optimum cement content for stabilizing the soil. Correlation of young's modulus with the compressive strength are also proposed by the author as:

   $$\boldsymbol{E_s = 0.9q_c + 330} \qquad \textbf{Equation 2.5}$$

   Where, Es - Young's modulus of the treated soil (kN/m2) and
   qc - unconfined compressive strength (kN/m2).

2. AH Vakili, et al. (2013b) have done extensive research on dispersive soil to improve its dipersivity and erosion properties. They attempted to use cement and natural pozzolana to treat the soil singly and simultaneously by varying the concentration. Initially they bring the soil to one hundred percent dispersion by mixing with 2.5 percent sodium hexametaphosphate. By varying the cement content from 1 to 4 percent, they found out all content of Portland cement could reduce dispersion potential to zero percent. Since the study was on improving the clay for best erosion resistance, the optimum cement content proposed by the study was 2 percent cement and 7 days of curing. The study did not consider in to account strength properties. They reporetd a 2 percent cement content decreases the dispersion problem with an increased electrical conductivity, decreased percent sodium, and brought about general improvement to the soil.

2.9.3 Fly Ash Stabilization

Fly ash is a fine textured alkaline (pH = 11-12) material, primarily composed of spherical non crystalline silicate, aluminum and iron oxides compounded with some microcrystalline material (Indraratna, et al., 1991). Generally fly ash is divided into class C and class F based on the type of coal burned. The principal difference between the two is the difference in pozzolanic and calcium contents (Nicholson, 2014). The low unit weight and compressibility, pozzolanic reactivity characteristic, cost-effectiveness, and energy saving benefit makes fly ash as one of the best waste materials that can be used extensively to improve the geotechnical properties of soil (Amiralian, et al., 2012).

1. Indraratna, et al. (1991) has researched to understand how a fly ash (pozzolanic) improve the performance of dispersive soil. The study was carried out using ASTM class 'C' fly ash from local thermal power plant on soils samples from Thailand, Khorat plateau. With an increase in fly ash content up to 3 percent, significant decrease in liquid and plastic limits were observed thereafter the decrease is marginal. Whereas in pinhole test a 5 to 8 percent fly ash shows a dramatic reduction in flow rate, but above 8 percent flow rate increases due to the lack of cohesion. The maximum dry density also increases with increase in fly ash content until 10 percent beyond that the change is negligible. The unconfined compressive strengths increase with curing time and fly ash content is attributable to the time-dependent pozzolanic activity. The study concluded that optimum proportion for the stability of this dispersive soil as 8 percent fly ash content by weight since the purpose was to control erosion. And they remarked a two weeks curing period as adequate to reach peak strength for all fly ash contents.

2. Faruk, et al. (investigates the influence of fly ash on the stabilization of dispersive soil. Soil samples from Faridpur District and the fly ash is a byproduct from Boropukuria coal powered thermal power plant both from Bangladesh. 3 to 9 percent of fly ash by weight were blended and the result was evaluated to investigate the dispersive characteristics. The blend with 9 percent have produced the highest maximum dry density, highest unconfined compressive strength (UCS) and non- dispersive in crumb test. The study concluded that an optimum of 9 percent of fly ash produce a better performance and found out the peak strength reached after three weeks. Thus, recommended three weeks curing period which is attributable to pozzolanic activity of fly ash.

2.9.4 Lime Stabilization

Lime is one of the oldest and most frequently used soil stabilizing agents known with a well-established technique for developing plastic properties and strength of cohesive soil. It is effectively used for permanent, long-term stabilization (especially for poor-quality, fine-grained soils) and in providing a rapid, short-term solution for enabling construction where wet soil conditions are present (Amiralian, et al., 2012, Nicholson, 2014). Lime stabilization can be achieved with 2 to 8 percent lime. If more lime is demanded to achieve the intended result, using another stabilizer like cement may be more economical. Stabilization of soil by lime is achieved through cation exchange, flocculation, agglomeration, lime carbonation and pozzolanic reaction (Umesha, et al., 2009, Amiralian, et al., 2012).

1. Umesha, et al. (2009) has researched to improve the performance of dispersive soil with lime stabilization with the aim of increasing the strength properties. Suddha soil from Karnataka India and pure lime obtained from standard manufacturers was used. Lime percentage of 1, 2 and 3 by dry weight of soil was mixed and observations were made. The study concluded that an increase in percent of lime content increases the unconfined compressive strength and recommended to use 3 percent optimum lime content for stabilizing this soil. Young's modulus was well correlated with compressive strength and the authors propose an equation (Equation 2.5).

2. A Vakili, et al. (2013a) have done extensive research on dispersive soil to improve its dipersivity and erosion properties. The soil used for the study was from Boordouzi, Iran and classified as highly dispersive. Lime with various percentages (1,2,3 and 4 percent) was studied to stabilize the soil. The study found out that a 4 percent lime and 1 day curing time or 3 percent lime and 7 days curing brings the dispersive soil to 0 percent dispersion. The treated sample under this condition indicates a significant increase in the compressive strength as well. The study recommended an optimum lime content of 2 to 3 percent lime with 7-14 days of curing.

3. Yilmaz and Civelekoglu (2009) had studied the effect Gypsum ($CaSO_2.2H_2O$) for improving the swelling behavior of natural bentonite clay (sodium based untreated material) soil by analyzing the Atterberg limits, free swell, and unconfined compressive strength tests. Percentages of gypsum used for the experiment were 2.5, 5.0, 7.5 and 10.

And bentonite-gypsum mix was compacted in optimum water content determined by standard compaction tests. The study found seven days of curing satisfactory; a remarkable decrease in liquid limit and plasticity index of the bentonite mixed with 5 percent gypsum were noted, which is attributed to replacement of monovalent sodium by calcium ions that reduce the diffuse double layer thickness. Swell percent decreases from 64.9 percent to 20.1 and improvement in unconfined compressive strength of 31.9 percent observed for 5 percent gypsum content. They concluded gypsum as a good stabilizer to improves the clay soils property significantly up on addition of 5 percent. Above this amount improvement being much less significant.

CHAPTER 3
THE STUDY AREA

3.1 Project Location and Accessibility

The Melkasa-Sodere-Nurera-Metahara Road Project have a total length of 94km and traverses through East Shewa and Arsi Zone of Oromiya Regional State at the central part of the Ethiopia. The road starts at Melkasa town at 110 km east of Addis Ababa and 17 km south of Adama at the junction with Adama-Asela road and ends at the outskirt of Metahara town at the junction with Addis-Mojo-Awash trunk road. The road follows a north-eastern direction traversing parallel to Awash River at close distance and is crossed by the river at two locations as it progresses to Metahara town.

The project is within the Middle Awash River Basin system where large mechanized farm investments are common because of its proximity to Awash River and hence plays its part to boost the economic growth of the country by providing standard access. The road passes through the ‘Nurera Farm’ station and is considered as the major link road of the region connecting East Shoa Zone of Fentale, Adama and Boset Woredas and North Arsi Zone of Jeju and Merti Woredas.

The geographical location of the project at the beginning and end points are:

- Start point of project (Melkasa town): UTM, N=928759; E=536919
- End point of project (Metahara town): UTM, N=985824; E=592689

A key map showing the centerline of the project road with respect to the the Awash River and the localities is shown in
Figure **3-1** overlain on a digital elevation model (DEM).

The access to the project site is through an existing road which starts from Melkasa town with an asphalt surfaced road of about 5 km until Sodere junction. It then continues to Bole town of Boset woreda for close to 54 km with a maintained gravel road. The next 20 km road from Bole to the entrance of ‘Metahara Sugar Farm’ is a heavily deteriorated gravel road and the remaining 14 km stretch of road section until Metahara town is molasses surfaced gravel road.

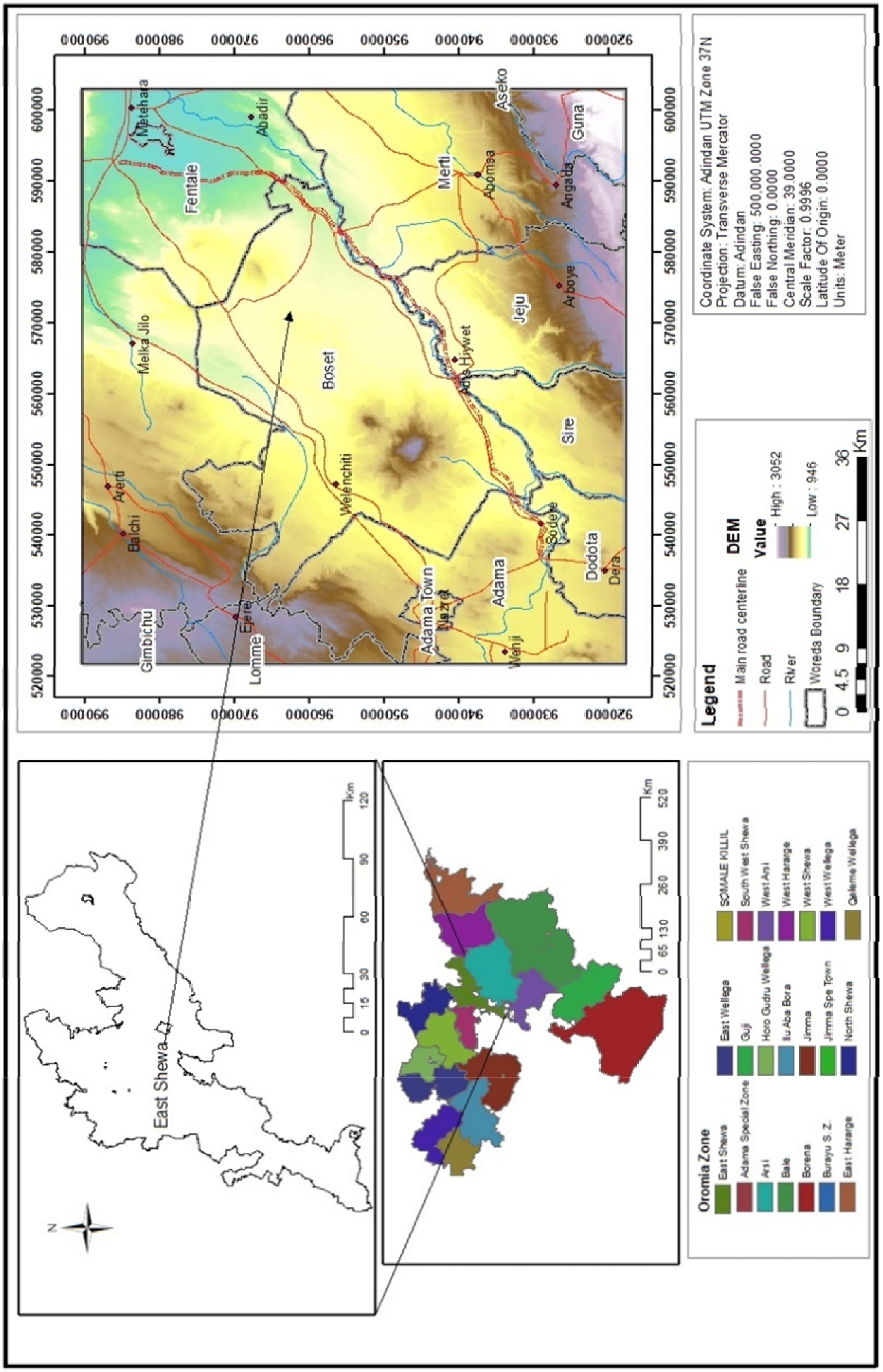

Figure 3-1: The Study Area, Project Road Centerline and Drainage Features

Since the project road is built within the depression area of the Main Ethiopian Rift valley (MER) and it is influenced by the Awash River (located within the Middle Awash River Basin) and the focus of the study is the subgrade soil, it is important to discuss the basic processes and factors that shaped it; climate, physiography and geomorphology, topography & slope characterstics, drainage, soil and erosion, geology and seismicity.

3.2 Climate

Ethiopia is located in the tropics and large climate variation from hot arid to cool temperate exists in the country. Based on climatic classifications of Ethiopia and National Atlas of Ethiopia & Meteorological Services Agency, the vicinity of the project area is grouped under hot semi arid climate (Kola) (Authority, 1988, Gonfa, 1996).

3.2.1 Rainfall

According to Russell-Smith (1984) settled dry weather due to north-east winds prevail between November and February and the period is known for little cloud, high diurnal temperatures and low relative humidity. Unsettled weather between March and May because of the convergence of moist south-east winds from the Indian Ocean with the north-east airstream results in a light rain. The main rain of the area however, come with the wet winds from the Indian and Atlantic oceans converging over the highlands between July to October, with intense rainfalls associated with convective thunderstorms frequently experienced at the beginning of this period (Russell-Smith, 1984). The same study shows the isohyet mean annual rainfall for the project site is between 600 and 700 mm. A similar isohytal map developed by JICA (2015) shows that the study area mean annual rainfall is between 500 and 800 mm. This study also shows the upstream area of the basin in northwestern part have higher annual rainfall than the downstream part. The historical trend of annual rainfall are shown in Figure 3-2.

3.2.2 Temperature

JICA (2015) have summarized the temperature record of the area and found out the maximum temperature occurs in the late small rainy season or in the beginning of the main rainy season, i.e., from March to June. In the main rainy season, although the maximum temperature reduces, the minimum temperature is still higher. The fluctuation of temperature is, therefore, small in the main rainy season. The maximum temperature reaches more than 36 °C at the stations of downstream regions such as Metehara. Russell-

Smith (1984) founds a reasonable correlation between temperature and altitude in the rift valley of ethiopia: on average a mean annual temperatures decrease by approximately 1.55°C for every 100 m increase in altitude. Russel have also found out the highest and lowest monthly temperatures in the area are correlated with the dry season. The maximum temperature occurs between November and March and the minimum temperatures recorded during the dry season when night skies are clear.

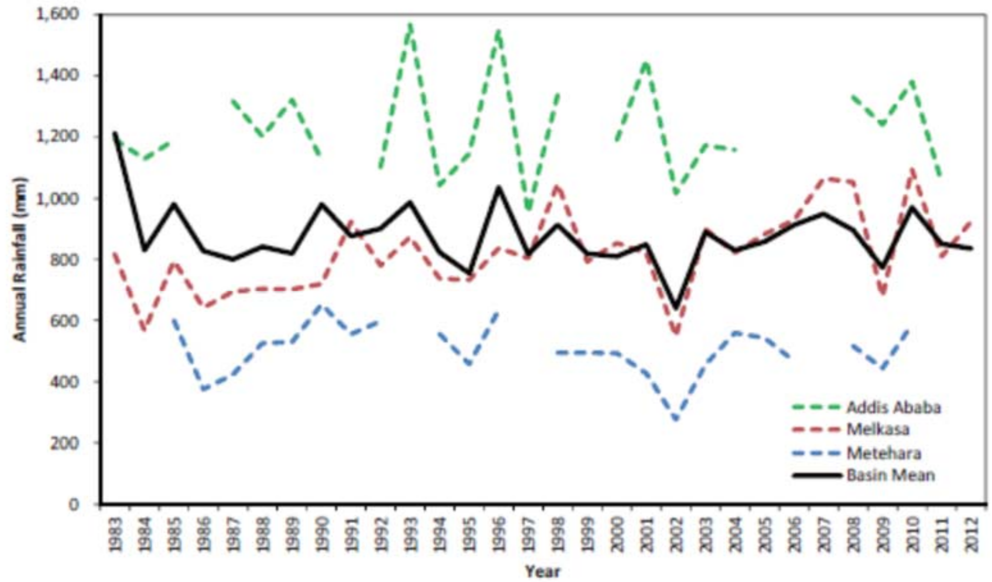

Figure 3-2: Historical Data of Annual Rainfall in Middle Awash River Basin (JICA, 2015).

3.3 Physiography and Geomorphology

The physiography of the study area is highly shaped by tectonic history which is responsible for creating the Main Ethiopian Rift (MER). The MER is a symmetrical graben with steep border faults dividing the thousand-kilometer-wide uplifted Ethiopian volcanic province asymmetrically into the northwest and southeast plateaus (Woldegabriel, et al., 1990). The MER is a magmatic rift that records all the different stages of rift evolution from rift initiation to break-up and incipient oceanic spreading (Corti, 2009).

The MER is one of the longest tectonic depressions in the world. Its geomorphology shows the central part is depressed while the margins are uplifted. The uplifted parts are mainly the plateau and the transition from this plateau to the depression is through two main escarpments that are usually subdivided by a series of minor escarpments associated with a staircase of faults having opposite down-throw. The huge landslides in the area is activated by tectonic and seismic movements along the escarpments. In general, the Rift floor elevation increases towards the south (Coltorti, et al., 2015).

The Boset-bericha mountain is an elevated place with a height of 2447 meters above sea level within the valley and becomes a distinctive feature north of the road project in Boset woreda. This mountain is a result of the largest stratovolcanoes in the MER, the Boset-Bericha Volcanic Complex (BBVC). It is formed by several large silicic explosive and effusive eruptions. It is characterized by pre- and post-caldera volcanic deposits with a remnant caldera rim in the western side and voluminous young post-caldera lavas on the eastern and southern side (Siegburg, et al., 2018).

3.4 Topography and Slope Characterstics

The road starts from Melkasa town at an elevation of 1560 meter above mean sea level and descends down towards the north east to Metahara town at an elevation of 960 meters above mean sea level. Generally the project road is traversing in a flat and rolling terrain from start to end. The road from Melkasa town on the junction of the Adama-Assella main road to Sodere resort for about 5 km before it turns south to join the gravel road is a rolling to mountainous terrain. After that the road traverses on a flat to rolling terrain to the end.

The area shows a maximum slope in the south-eastern and north-western part and the minimum in the central parts (Figure 3-3). Generally the the maximum slope in the area is 270 % from the south-eastern and north-western part and it is associated with the rift border wall of the MER. The observed minimum slope in the area is 0% and it was at the valley of the rift. The slope of the study area shows the SE and NW facing slope in the area is associated with the border faults of the MER. The steep slopes of the SE and NW escarpments will drain towards the center where the area is topographically low and drains towards NE through the Awash River.

3.5 Drainage

The project road is located within the middle Awash River Basin where the river Awash flows towards the northeast parallel to the road (
Figure **3-1**). The river is topographically at low level between the marginal faults of the rift valley at the edges. The area where the project road passes is characterized by a gentle relief and due to this the stream that cross the road are relatively slow flowing. All of these

streams that crossess the road are characterised by accumulation of large silt, sand and alluvial deposit at the bed due to its slow flowing behaviour and finally drain the area to the Awash River.

Frequent floods are observed in Awash River basin during the rainy season of August and September since it drains the highland and escarpment areas (Taddese, et al., 2003). The study desribes due to the numerous tributary rivers which drains the highlands area towards the east, the Awash River discharge increases and results in flooding of the lower Awash area especially along the river banks. The study indicates the major cause of flood as deforestation and serious environmental degradation due to overpopulation that directly affect soil and water run-off increase in the escarpment areas.

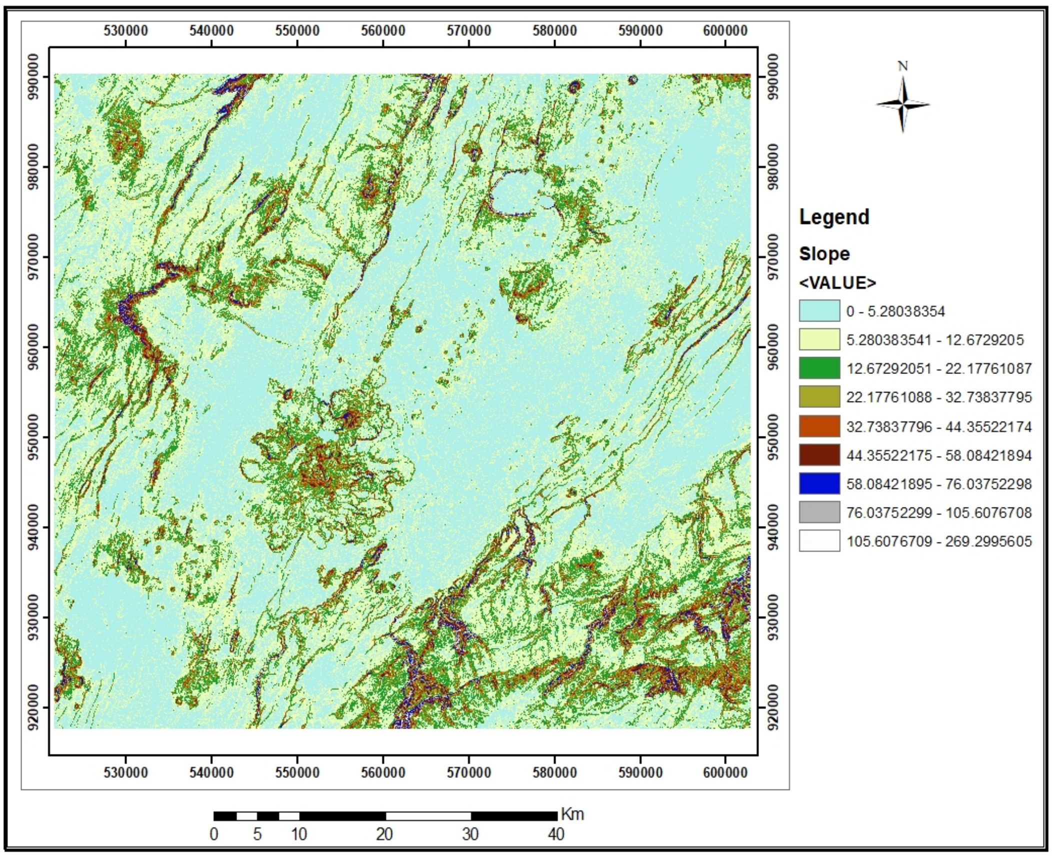

Figure 3-3: Slope Map of the Study Area.

3.6 Soils and Erosion

The distribution of soils in Ethiopia is a function of climate, regional landform, local topography and the underlying parent materials. Drainage is also an important factor in the formation of some soils (ERA, 2013). The ERA (2013) manual highlights the rift valley and lowland areas of the country as common places for the occurrence of dispersive soils. Dispersive or sodic soils are problematic soils for both engineering and agricultural activities. These soils covered a vast area in the middle Awash River Basin where the current project is located. In his review, Lemma 2019 showed a wide occurrence of a high level soil salinity and sodicity in the middle awash basin. He showed the extent and distribution of these soils in the middle awash area being higher as compared to lower and upper awash areas. The main causes reported are poor irrigation water quality, inappropriate irrigation practices, inadequate drainage, and the development of shallow ground water table (Lemma Mamo, 2019).

Generally dispersive or sodic soils go in to suspension when in contact with fresh water (rain) and result in tunnel and gully erosion. Occurence of erosion gullies and piping at unprotected road shoulders and cuts, drainage ditches, and other surfaces from which vegetation has been removed are main pointers for suspecting presence of dispersive soil as per ERA (2013) manual.

Figure 3-4: Gully Erosion and Piping Features in the Study Project Site.

Erosion is a common phenomenon in the project area. Gully erosion, especially along the road sides were observed throughout the existing road with varying degree as seen in Figure 3-4. These erosion gullies at places have affected the existing road services and have also affects the farm lands at some localities. Mukai (2017) explains his general observation of gully erosion as common especially within the semi-arid main Ethiopia Rift due to which road destruction and traffic disruption are reported.

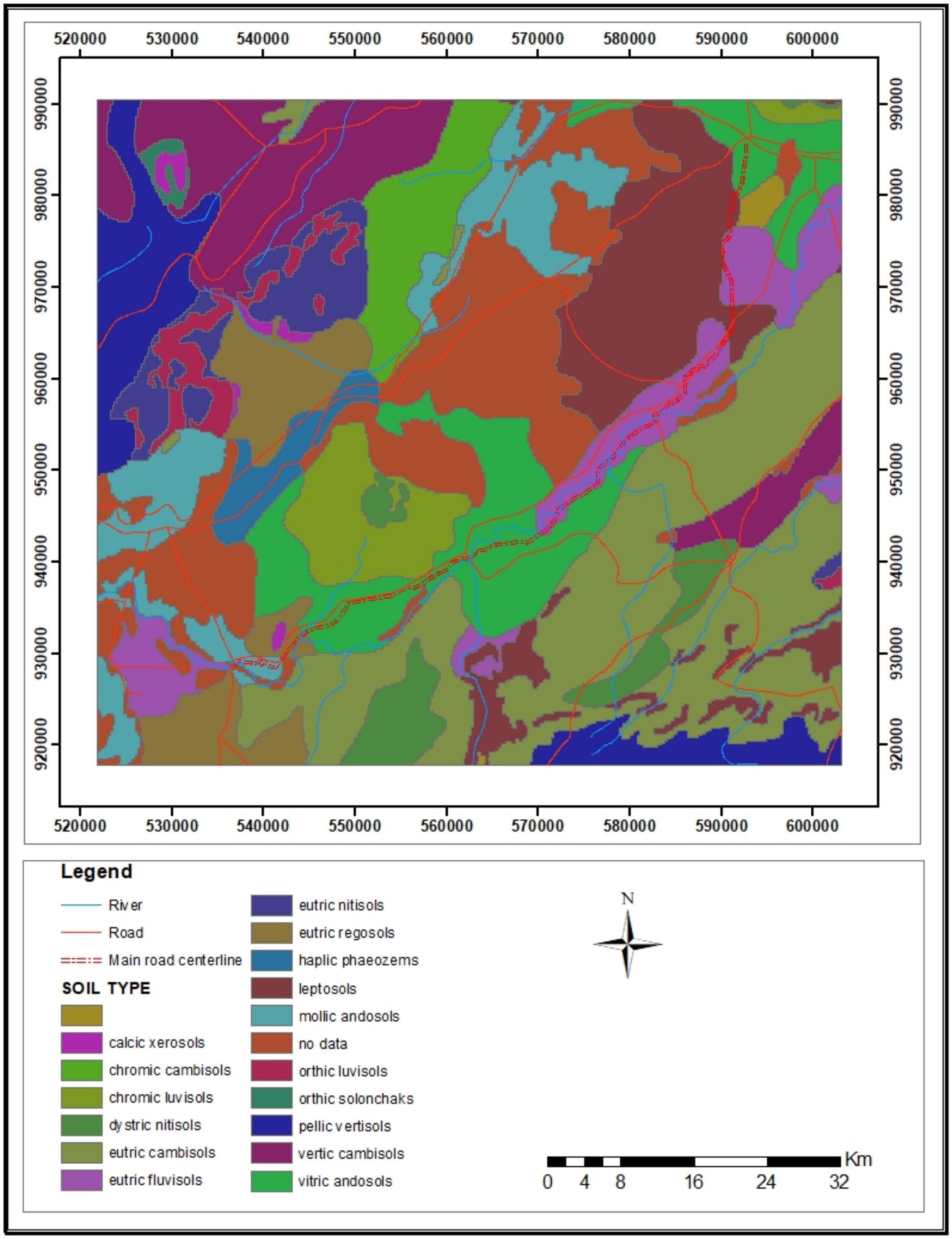

Figure 3-5: Soil Map of the Study Area.

The main agricultural soil types that cover the project study area are reviewed from the soil map of the region (Figure 3-5). According to the map along the road centerline, from Melkasa to Sodore the dominant soil types is Mollic Andosols and Sodore to Nurera is dominated by Vitric Andosols with small amount of Euteric Regosols. From Nuraera to

Metahara the major soil types is Eutric Fluvisols with small amount of Vetric Cambisols and Euteric Regosols.

3.7 Regional geology

The Main Ethiopian Rift (MER) is associated with huge volumes of volcanic products which were erupted since its birth. Volcanism started during the Miocene-Pliocene and it has been matching the tectonic evolution of the rift up to recent times (Abebe, et al., 1998). The pre-Cambrian rocks in the Ethiopian rift system are mostly covered by more recent Tertiary volcanic rocks and Mesozoic sediments. However, an older and extensive group of volcanic rocks of early and middle Tertiary age, normally called the Trap series, is well exposed on the southeastern and western plateaus. This group consists predominantly of alkaline basalt with interbedded pyroclastics and rare rhyolites erupted from the fissures. The rift floor is mainly covered by quaternary basaltic, trachytic and rhyolitic lavas, pyroclastic flows and fall deposits, and volcanoclastic sediments (Woldegabriel, et al., 1990).

Based on the Geological Map of Ethiopia, the geology of the project area comprises different types of units (Figure 3-6). The project road crosess through five geologic units from the beginning to the end. They are listed in the order of their coverage from lagrge to small as:

a) The Quaternary basaltic flows, spatter cones, and hyaloclastites and alkaline olivine basalts.
b) The Dino Formation: which comprises Ignimbrite, tuff, coarse pumice water lain pyroclastic rocks with rare intercalation of lacustrine sediments.
c) Quaternary Rhyolitic volcanic centers, obsidian pitchstone, pumice, ignimbrite, tuff, subordinate trachytic flows (predominantly peralkaline in composition).
d) Mursi and Bofa alkaline basalt
e) Nazreth Series (Nn): It comprises ignimbrites, un-welded tuff, ash flows, rhyolitic flows, domes and trachyte
f) Alluvial and lacustrine deposits containing the likes of sand, silt, clay, diatomite, and limestone and beach sand.

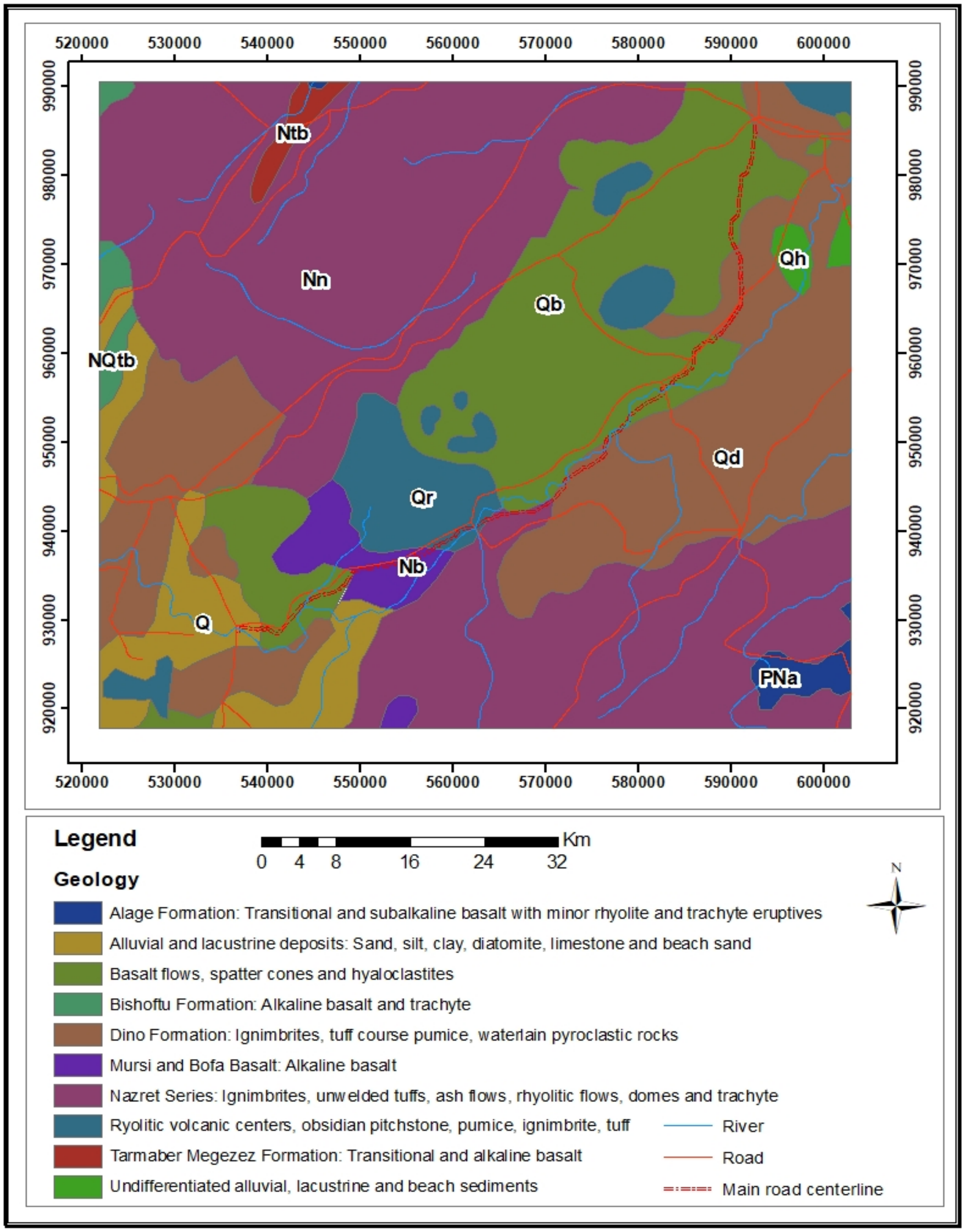

Figure 3-6 Geological Map of the Project Area.

3.8 Geology of the Route Corridor

The route corridor is mainly comprised of sandy silt soil derived from the volcanic ash, massive boulder and gravel scoria, basaltic rocks and ignimbrite & tuff.

The first 5 km is dominated by sandy silt soil with random occurrences of basaltic rocks in boulder forms. From the 5th to the 10th km it is totally rocky composed of scoria. From the

10th km forward up to the 31st km the soil is dominated by the sandy silt soil with random occurrences of basaltic rocks, tuff, and pumice. From the 31st km up to the 66th km, high soil development is observed and the big farms are situated in this section. The subgrade soil is mainly composed of the sandy clay and silty clay with frequent occurrences of small stretch of scoriaceous basaltic boulders. From the 66th km up the subgrade soil is dominated by scoriaceous basalt and tuffaceous rocks with minor occurrences of ignimbrites. In between rock sections, the areas are dominated by sandy gravelly silt soils.

3.9 Seismicity of the Area

Seismicity in the Main Ethiopian Rift (MER) is generally diffuse along the rift basin where earthquakes are typically of small to intermediate magnitudes (M <6), which is a commonly observed feature of continental rifting (Wilks, Ayele, et al., 2017). The project area is in Main Ethiopian Rift (MER) which is seismically active region that encompasses major active fault like the Wonji Fault Belt (WFB). The WFB trending NNE with a fresh steep fault scarp is an evidence of recent activity constituting a network of faults with a spacing of between 0.5 and 2 km. Most of the active strain along the WFB could be accommodated seismically in the MER floor by magma-induced faulting (Wilks, Kendall, et al., 2017).

According to Asrat Worku (2014) review and the seismic hazard map of Ethiopia for hundred years return period, the study area is located in zone 3 and 4 with bedrock acceleration value of 0.07 and 0.1g respectively, where g is acceleration due to gravity (MWUD, 1995).

3.10 Conclusion

As more and more infrastructures developed in areas with problematic soils, the risk associated with it grows. It is therefore important for future planning to be done based on informed decisions. Assessment of the Project area in terms of climate, physiography and geomorphology, topography & slope characteristics, drainage, erosion, geology and seismicity will serve to study and understand the where and why of dispersive soils origin and occurrence by association; and as a result it create awareness for public and government organizations to design future development in areas like this accordingly. And it also helps as a guide for future study and evaluations of similar areas in Ethiopia.

CHAPTER 4
EXPERIMENTAL METHODS

4.1 Introduction

This chapter deals with the approaches and methodologies used for sample collection, research design, sample preparation and test procedures needed to complete the experimental study. All non-treated and treated soil samples were subject to controlled laboratory testing which includes soil classification tests like particle size analysis, specific gravity, Atterberg limits, standard proctor (compaction), double hydrometer test and unconfined compressive strength (UCS).

4.2 Research Method

The focus of this study is to investigate the effect and efficiency of Portland pozzolana cement (PPC) and processed gypsum to treat a dispersive soil through an experimental program in the laboratory. Establishing the stabilizer content necessary to reduce the dispersion rate of the soil to an acceptable level based on the double hydrometer test result using Decker and Sherard (1977) criteria. The UCS results will be analyzed for strength development with change in stabilizer amount and curing period. The method followed were based primarily on the research objective set out and the limitations. Two soil samples from different locations of the study area (Melkasa-Sodere-Nurera-Metahara road project) were collected for this study. The cement and gypsum used were bought in bags from the market in Addis Ababa.

The major factors that determine the outcome in this experimental study includes the type of stabilizer used, the dosage of the stabilizer and curing period. The designed dosage of stabilizers proposed (i.e. the cement and gypsum) were selected solely based on literature review. The curing periods used for this study were 7 and 28 days. Double hydrometer and unconfined compressive strength tests were carried out on the treated samples to assess the dispersion rate and strength increase characteristics. The changes in dispersion rate based on Decker and Sherard (1977) were used to evaluate the efficiency of the stabilizer and determine the dosage to be used for treatment. A simplified flow-chart have been developed in Figure 4-1 to show the laboratory experimental work.

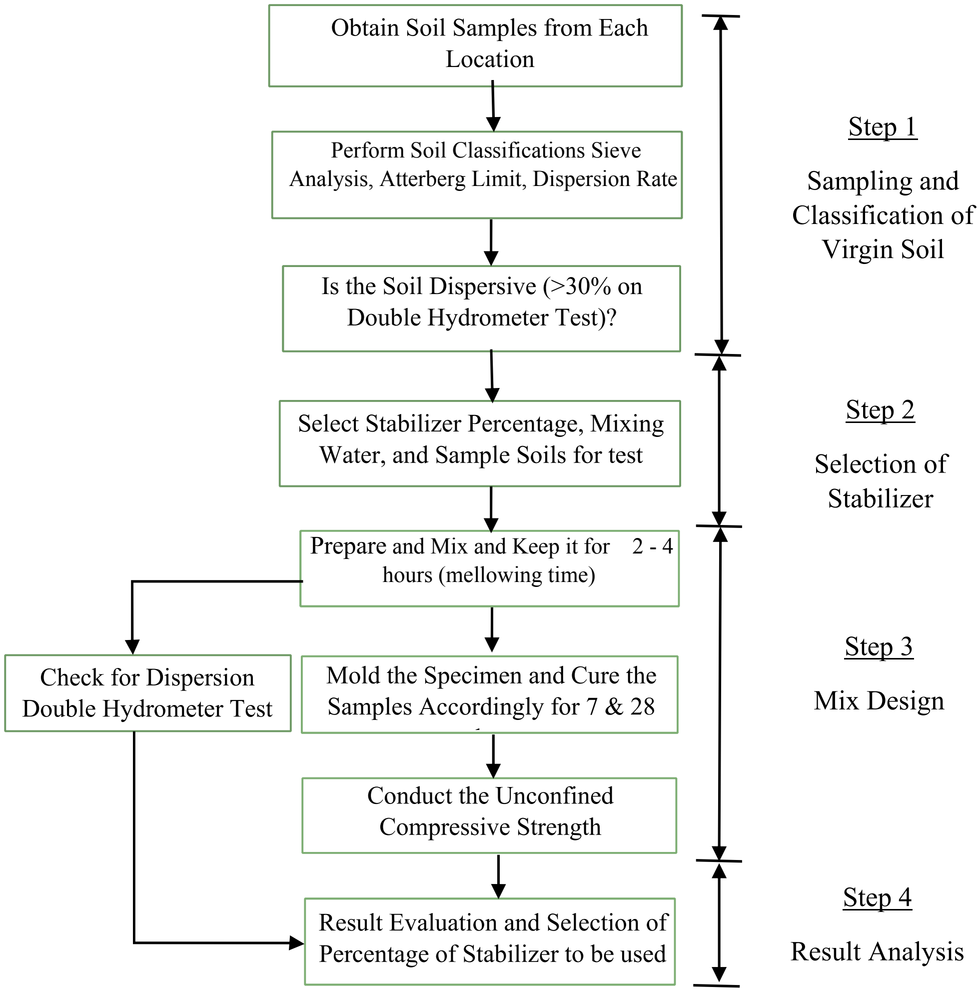

Figure 4-1 Flow chart for the experimental study

4.3 Materials

4.3.1 Soils

Two soil samples for this experimental study were collected from Ch. 10+400 and Ch. 17+750 along the Melkassa-Sodere-Nurera-Metahara Road project. These locations were selected based solely on previous geotechnical investigation works carried out during the construction period, where the double hydrometer tests result for dispersion rate are used as a guide.

The soil samples were collected during a survey of the area in December and January 2020, from areas showing a higher dispersion rate. The samples were collected by manually digging using picks and shovels from a depth of around 0.5m from naturally exposed surface by avoiding the upper part (Figure 4-2).

Soil Sample A (Ch. 17+750)	Soil Sample B (Ch. 10+400)
Brownish, Sandy Clayey silt (volcanic Ash deposit). Collected from the exposed gully at depth of 1.3m from the road surface on the right side of the existing gravel road.	**Light Brown to Gray, sandy silt (Pumiceous). Collected from the exposed gully at depth of 1.5m from the road surface on the left side of the existing gravel road.**

Figure 4-2 Soil sampling locations and visual description of the soil samples

The soil samples were tested to understand the engineering properties and the results are presented as a summary in Table 4-1 in order to have the general knowledge of the soil samples.

Table 4-1 Summary of Engineering Properties of Soil Samples

Engineering Properties	Soil sample A	Soil sample B	Standards followed
USCS Classification	SC	SMN*	ASTM D 2487
Particle size analysis			ASTM D 422 AASHTO T99
Passing #200 sieve (%)	19.4%	31%	
Specific gravity	2.59	2.47	BS-1377
Liquid limit, (%)	33.9	32.9	ASTM D4318 BS-1377
Plastic limit, (%)	16.7	-	
Plasticity index, (%)	17.2	NP	
Maximum dry density (g/cm3)	1.440	1.523	ASTM D698
Optimum water content, (%)	23.50	17.50	
Double Hydrometer Test	69.9%	99.1%	ASTM D4221
Crumb Test	MD to HD*	MD to HD**	ASTM D6572

* SMN - Non-plastic silty sands, sand-silt mixtures

** MD - Medium dispersive, and HD – Highly dispersive

4.3.2 Portland Pozzolana Cement (PPC)

Commercially available Portland Pozzolana Cement (PPC) was used for the experimental study. The PPC was identified and marked as 32.5R grade cement. Main constituents of PPC are calcium silicates, aluminates, ferro-aluminates, and sulfates. It contains gypsum and small amounts of sodium, potassium, and chromium compounds.

- Tricalcium silicate $3CaO.SiO_2$ 55-70%
- Dicalcium silicate $2CaO.SiO_2$ 5-20%
- Tricalcium aluminate $3CaO.Al_2O_3$ 2-10%
- Tetra calcium aluminoferrite $4CaO.Al2O_3.Fe_2O_3$ 5-15%
- Gypsum $CaSO_4.2H_2O$ 2-5%
- Calcium oxide CaO <1.5%

4.3.3 Gypsum

The gypsum used for this study was bought from the market in bag. It is a processed product fabricated for use in wall plastering. Generally, gypsum is a white or gray naturally occurring mineral, its chemical composition is a calcium sulfate de-hydrate ($CaSO_4.2H_2O$). Raw gypsum ore is processed into a variety of products such as a Portland cement additive, a soil conditioner, industrial and building plasters, and gypsum wallboard.

Both the cement and gypsum were bought in bag from the market in Addis Ababa. The samples were selected carefully so that it was not exposed to the air and its production date was not long.

4.4 Experimental Variables

The soil samples were treated with Portland Pozzolana Cement (PPC) and factory processed Gypsum. Double hydrometer and Unconfined compressive strength (UCS) tests were carried out for all the soil-Cement and soil-Gypsum mixtures (Table 4-3 and Table 4-4). The variables considered for the study thus includes the soil sample locations, stabilizers type used, the dosage of stabilizers used and the curing period. The dosage of stabilizer and the curing periods were adopted with modifications based on previous researches (Umesha, et al., 2009, Yilmaz and Civelekoglu, 2009, AH Vakili, et al., 2013b). Industry design standards like National Lime Association (2006) were also referred. Table 4-2 presents summary of the experimental variables (programmes).

Table 4-2 the Research Variables

No.	Parameter	Number of Variables	Variables Description
1	Sample Locations	2	Ch. 10+400 and Ch. 17+750
2	Stabilizer Type	2	PPC and Gypsum
3	Stabilizer dosage (in % of dry soil)	8	1%, 2.5%, 4.0%, 5.5% for PPC & 2%, 4%, 6%, & 8 % for Gypsum
4	Curing Duration	2	7 and 28 days of curing

4.5 Testing Program

Laboratory testing is the primary and essential component of the experimental investigation. It helps to offer sufficient data to complete an economical mix design. Laboratory tests were carried out at different stages of the study to achieve the desired result and to explain the objectives of the study in detail. The various soil tests performed on non-treated and treated soil samples were particle size analysis, Atterberg limits, specific gravity, standard proctor (compaction), double hydrometer test and Unconfined compressive strength (UCS) tests. The tests were conducted at Ethiopian Construction Design and Supervision Works Corporation (ECDSWCo) laboratory and ARCON Design-build laboratory facilities. The tests were performed as per the procedures outlined by the American Society for Testing Material (ASTM), American Association of State Highway and Transportation Officials (AASHTO) and British Standards (BS).

The laboratory activities were programmed as follows:

- Determine the engineering properties and classify the virgin soil samples.
- Assessment of the dispersion of virgin soil sample using double hydrometer test and crumb test.
- Establish the moisture density relationship of the virgin soils sample using standard proctor test.
- Determine the dispersion rate and compressive strength of stabilized soil using double hydrometer test and unconfined compressive strength test.

A detailed procedure of testing along with sample preparation for all stages are discussed in detail in this chapter. Unified Soil Classification System (USCS) was proposed for the soil classification using the versions standardized in ASTM D2487 and a modified version of the USCS for non-plastic soil by Prakash and Sridharan (ASTM, 2011, Prakash and Sridharan, 2012).

4.5.1 Grain Size Analysis (ASTM D442 and AASHTO T-88)

The grain size analysis was carried out to determine the relative proportions of different grain sizes which make up the soil sample. The data obtained from grain size distribution was intended for soil classification purpose. It was carried out using a stack of sieves, arranged in the order from 75.0mm (3 in) to 0.075mm (No. 200) size and the sample was separated into various fractions by sieving. The weight of soil retained on each sieve was recorded and the percentage cumulative passing was calculated. Finally, a graph was drawn between log sieve sizes versus percent pass (finer). The percentage of soil retained on each sieve was calculated based on the total weight of soil sample taken. The results of the grain size analysis of the virgin soil are presented in the next chapter.

4.5.2 Specific Gravity of Soil (BS 1377)

The specific gravity of soil is simply defined as the ratio of the unit weight of the soil mass with that of a distilled water at 4°C. The specific gravity (G) was determined using pycnometer based on the procedures according to BS 1377. Archimedes Principle "that a body submerged in a volume of water will displace a volume of water equal to the volume of the submerged body" applies to determine the volume of soil solid of known mass. The specific gravity was determined using the general formula:

$$G = \frac{W_0}{W_0 + (W_A - W_B)}$$

Where,

G = Specific gravity of soils

W_0 = weight of sample of oven-dry soil,

W_A = weight of pycnometer filled with water

W_B = weight of pycnometer filled with water and soil

Two tests were carried out for each sample and the average particle density obtained was reported as the specific gravity of the sample. Summary the specific gravity of soil samples was presented in Table 4-1.

4.5.3 Atterberg Limits (ASTM D4318, BS 1377)

The liquid limit (LL) was determined using Casagrande method and fall cone method. A thoroughly mixed sample of soil passing 425-micron sieve was mixed with water to form uniform paste. With a Casagrande method, the paste was placed in the cup of liquid limit apparatus and spread into portion with few strokes of spatula. Then it was trimmed to a depth of 1cm at the point of maximum thickness and been divided by the firm strokes of the grooving tool along the diameter through the center line. The number of blows required to cause the groove close for about 1 cm were recorded. And representative portion of soil was taken for water content determination. The test was repeated with three or four different moisture contents. Form the graph of water content versus number of blows, the moisture content corresponding to 25 blows was taken to represents liquid limit.

In the fall cone method, the test was carried out to determine the liquid limit based on penetration of a standard cone (shape and mass) into the soils. A cone with an apex angle of 30° and total mass of 80 grams is suspended above, but just in contact with the sample. The cone is permitted to fall freely for a period of 5 seconds. The water content corresponding to a cone penetration of 20 mm is taken as the liquid limit.

To determine the plastic limit (PL) a thoroughly mixed sample passing the 425-micron sieve close to the plastic state was rolled between fingers and glass plate with just enough pressure into a 3mm thread. By Kneading and re-rolling the process continued until it crumbled at the 3 mm diameter. The plastic limit was determined as the moisture content of the sample when the sample is crumbled at 3mm.

Finally, the plasticity index (PI) was calculated, which was used directly for soil classification purpose.

$$PI = LL - PL$$

Where: PI – is the plasticity Index
LL – is the liquid Limit
PL – is the plastic Limit

The Liquid Limit (LL), Plastic Limit (PL) and Plastic Index (PI) of virgin soil samples were presented in Table 4-1.

4.5.4 The Unified Soil Classification (ASTM D2487)

The Unified Soil Classification System (USCS) was proposed for classifying the soil for this study. It has an advantage that it can easily be extended to include more soil groups, giving a finer degree of classification. According to unified soil classification system, soils are broadly classified in to three groups as coarse-grained, fine-grained, and highly organic soils. These groups further classified/subdivided into 15 basic soil groups based on grain-size distribution, liquid limit, and plastic limit. For a non-plastic soil, it is recommended to classify the soils using a modified unified soil classification scheme proposed by Prakash and Sridharan (2012). They extended the USCS classification to include non-plastic soils in their work, the classification scheme for coarse-grained soil is presented below (Figure 4-3). The USCS classification of the virgin soil are summarized in Table 4-1.

4.5.5 The Crumb Tests (ASTM D6572)

Crumb test was developed as a simple and fast method of identifying soil for dispersive nature. It was carried out by putting a few cubical specimens of soil submerged in a glass of distilled water. Visual observation of the reaction follows the pattern: the shape of the sample, changes in the structure, color and turbidity of the water forming a colloidal "cloud" or clustering of colloidal particles. Depending on the reactions there are four classes of dispersion: 1) ND - non-dispersive soils, 2) SD - slight dispersive soils, 3) MD - medium dispersive soils and 4) HD - highly dispersive soils. The test results for dispersiveness of both soil samples by the crumb test indicate Medium to Highly Dispersive (Table 4-1).

4.5.6 Double Hydrometer Test (ASTM D4221)

The test provides an indication of the natural dispersive characteristics of soils. The grain size distribution of the specimen was determined with standard hydrometer test. The test was done with dispersing agent in one and without on the second specimen prepared with same soil. The percent dispersion is calculated as the ratio of the dry mass of particles smaller than 0.005 mm diameter of the test without dispersing agent to the test with dispersing agent expressed as a percentage. The double hydrometer test was done for a 2 mm passing soil samples. The results were evaluated based on the Sherard and Decker criteria (Sherard and Decker, 1977) for related soils Classification, i.e. soil with dispersive characteristics exhibited 30 percent or more dispersion when tested by this method. The degree of dispersion from the double hydrometer tests indicate that both virgin soil samples are highly dispersive (Table 4-1).

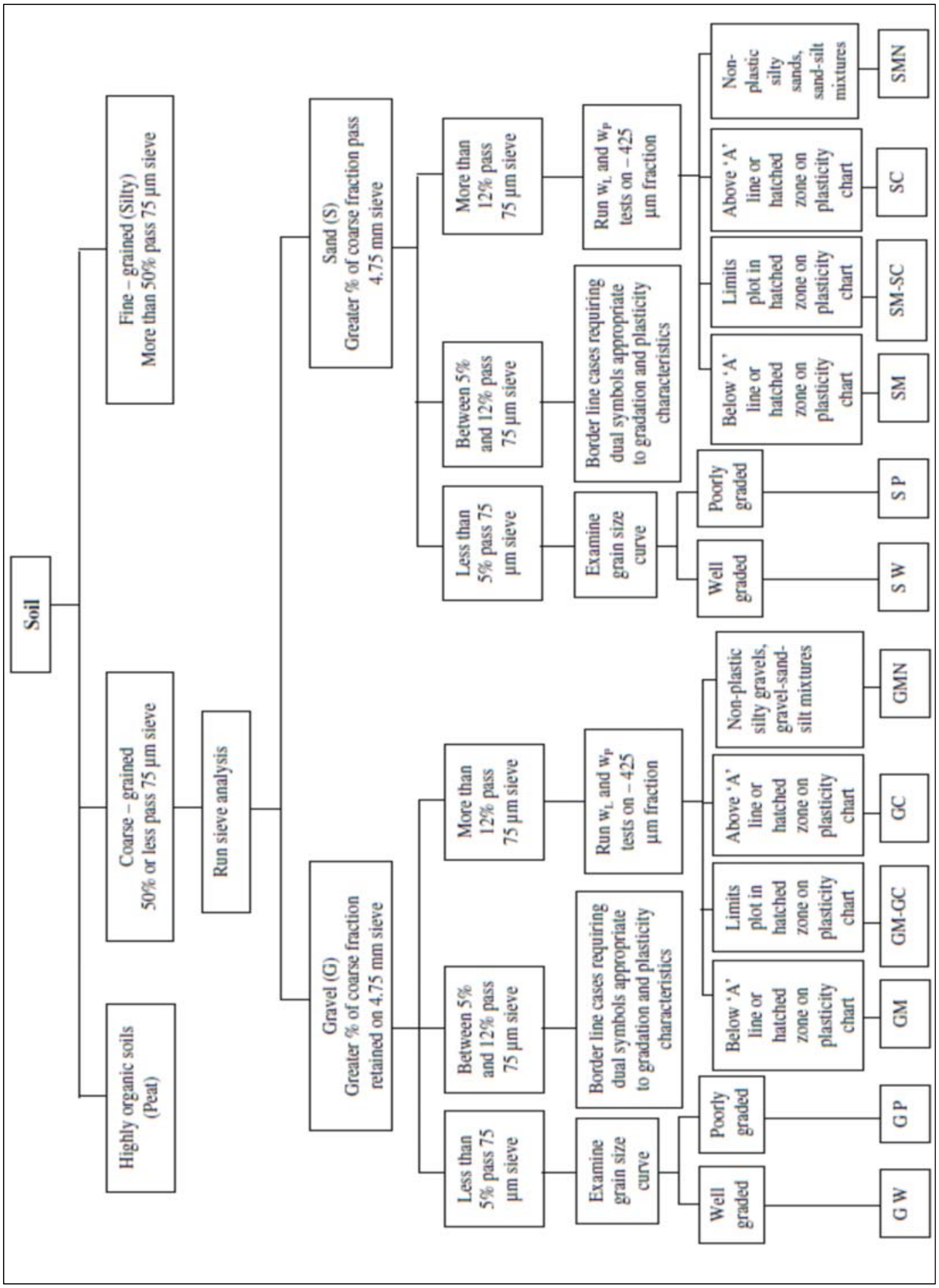

Figure 4-3 Classification scheme of coarse-grained soil (Prakash and Sridharan, 2012).

4.5.6.1 Specimen Preparation and Procedure for Double Hydrometer Test

Air-dried soil sample were sieved through 2.0mm sieve and mixed with stabilizer at pre-determined proportion. Table 4-3 presents the mixture proportion used for this study. The grain size distribution of the soil-stabilizer specimen was determined with standard hydrometer test. One test was done with mechanical mixer and chemical separator. Another hydrometer test was done without mixer and chemical separator on the second specimen prepared with same soil-stabilizer sample. The percent dispersion is then calculated as the ratio of the dry mass of particles smaller than 0.005 mm diameter of the test without dispersing agent to the test with dispersing agent expressed as a percentage.

Table 4-3 Sample preparation for Double Hydrometer Test of Soil-Stabilizer Mixture

Soil Sample A								
Double Hydrometer Test Mix Proportion								
Stabilizer Type	Pozzolana Cement (PPC)				Gypsum			
Stabilizer (%)	1.0%	2.5%	4.0%	5.5%	2.0%	4.0%	6.0%	8.0%
Weigh of Soil (gm)	49.50	48.78	48.08	47.39	49.02	48.08	47.17	46.30
Weight of Cement (gm)	0.50	1.22	1.92	2.61	0.98	1.92	2.83	3.70
Total Wt. (gm)	50	50	50	50	50	50	50	50
Test sample Name	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8

Soil Sample B								
Double Hydrometer Test Mix Proportion								
Stabilizer Type	Pozzolana Cement (PPC)				Gypsum			
Stabilizer (%)	1.0%	2.5%	4.0%	5.5%	2.0%	4.0%	6.0%	8.0%
Weigh of Soil (gm)	49.50	48.78	48.08	47.39	49.02	48.08	47.17	46.30
Weight of Cement (gm)	0.50	1.22	1.92	2.61	0.98	1.92	2.83	3.70
Total Wt. (gm)	50	50	50	50	50	50	50	50
Test sample Name	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8

4.5.7 Compaction Characteristics Using Standard Effort (ASTM D698)

Compaction characteristics using standard effort were performed for the soil samples to determine the maximum dry density and optimum moisture content. Enough amount of air-dried soil was pulverized in the mixing pan. The soil was then sieved through the No. 4 (4.75mm) sieve. Form the pass, four representative samples each about 3000gm were prepared for a single proctor test. Water was added to the soil to bring it to a predetermined moisture content percentage. Three layers of the soils then were compacted in a standard four-inch (101.6-mm) diameter mold using a standard Proctor hammer weighing 5.5 pounds (24.5 N) and a drop distance of 12 inches (305mm). Three to five runs were conducted by increasing water content from the initial run. The moisture density relationship was plotted, and the maximum dry density (MDD) and optimum moisture content (OMC) was determined. The test results for the virgin soil samples were summarized in Table 4-1 and it was used for remolding the disturbed sample for uniaxial compressive strength test.

4.5.8 Unconfined Compression Strength Test (ASTM D2166)

The unconfined compression strength (UCS) test is carried out on the stabilized soil sample. It is a widely used test in soil stabilization process. The UCS helps to determine the undrained cohesion (cu) of clay soils. The test was carried out on the prepared cylindrical specimen under an axial load without confining pressure. The unconfined compressive strength (qu) is the stress at failure. The undrained cohesion, cu is half the unconfined compressive strength (qu). The largest grain size should be smaller than 1/6 the mold diameter (ASTM D2166) and accordingly a soil passing #4 sieve (4.75mm opening) were used for remolding the sample for this study. Cement and gypsum treated soils were subjected to unconfined compressive strength tests, with axial load increment applied at a rate of 1% strain per minute. The results are presented and analyzed in the next chapter.

4.5.8.1 Specimen Preparation and Procedure for UCS

Specimens for UCS were prepared by thoroughly mixing the oven dried soil sample and a predetermined quantity of stabilizer with water until uniform color was observed. The molding water content was calculated by summing the optimum water content (OMC) and water required for hydration of the stabilizer involved. The OMC is determined from the compaction characteristics as discussed above. The water required for hydration is taken from literatures and for the cement it is 38% by weigh refer Shetty (2005) and for hydration of gypsum an average additional water of 47% by weight is required (Yu, et al., 2009).

The dosage of stabilizer i.e. weight (grams) was calculated from the percentage of stabilizer proposed for mixing by using simple calculations as presented below. And mix proportions for different stabilizer percent was prepared in Table 4-4 for laboratory use.

$$M_{st}(gm) = P(\%)x\ M_s$$

$$W_m = OMCxM_s + P_h(\%)xM_{st}$$

Where: Mst - Weight of stabilizer required for the mix in grams
P (%) - Percentage of stabilizer proposed
Ms - Weight of oven-dried soil sample in grams
Wm - Molding Water required in milliliter
Ph (%) - Percentage of water for hydration (38% for Cement and 47% for Gypsum)
OMC - Optimum Moisture Content from density moisture relationship test

Table 4-4 Mixture Proportion for UCS Specimen Preparation

Soil Sample B								
Stabilizer Type	Cement				Gypsum			
Stabilizer (%)	1.0	2.5	4.0	5.5	2.0	4.0	6.0	8.0
MDD (gm/cm3)	1.520	1.520	1.520	1.520	1.520	1.520	1.520	1.520
OMC (%)	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Water Req. for hydration (%)	38	38	38	38	47	47	47	47
Mold Diameter (cm)	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Mold Height (cm)	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Vol. Remolded Sample (cm3)	85.1	85.1	85.1	85.1	85.1	85.1	85.1	85.1
Weight of remolded Sample (gm)	129.3	129.3	129.3	129.3	129.3	129.3	129.3	129.3
Weight of Oven-Dry Soil (gm)	128.0	126.1	124.3	122.5	126.8	124.3	122.0	119.7
Weight of Cement (gm)	1.3	3.2	5.0	6.7	2.5	5.0	7.3	9.6
Water Required (ml)	22.9	23.3	23.6	24.0	23.4	24.1	24.8	25.5
Single Sample Weight (gm)	152.2	152.6	152.9	153.3	152.7	153.4	154.1	154.7

The procedure for molding and testing follows a sequence

- For the desired water content and dry density, calculate the weight of the dry soil Ms required for preparing a specimen of 3.8 cm diameter and 7.5 cm long.
- Add required quantity of water Wm to this soil.
- Mix the soil and stabilizer and add the water and mix thoroughly until uniform color

- Place the wet soil in an air-tight waterproof (polyethylene) bag in a humid chamber for a mellowing period of 2 - 4 hours.
- Take out the mix from the humidity chamber and compact in a constant volume mould of internal height of 7.5 cm and diameter of 3.8 cm.
- Extract the specimen from the constant volume mould. And record the correct height, weight, and diameter of the specimen.
- Wrap the specimens in plastic and seal in an airtight, moisture proof container for 7 and 28 days at normal room temperature.
- Determine the UCS after 4-hour capillary soak of a cured and moisture conditioned specimens. The UCS is the average of results from two specimens. (ASTM D 5102)

Record Soil description, Specific gravity (GS), Bulk density, Water content, Degree of saturation, Diameter (Do) of the sample and Area of cross-section.

All the tests discussed in this chapter were carried out strictly following the procedures and standards outlined. And the results of all the tests are discussed in detail in the coming chapter, ‘Results and Discussion’.

CHAPTER 5
RESULT AND DISCUSSIONS

5.1 Introduction

This chapter presents the laboratory test results with detailed analysis and discussions. Analysis of test results was carried out within the boundaries of standards, literatures and books reviewed and it is also confined to the framework of the study objective which is experimental investiagtion of the treatment of the dispersive soil found in the Melkasa-Sodere-Nurera-Metahara road project.

The first part of the chapter focuses on the discussion and analysis of test results regarding the engineering properties of the subgrade soil. The test results were analyzed in detail to identify the basic characteristics of the soil and classify the soil group in terms of USCS classification and explore the relationships of the soil with the physical features observed on site. The data used for the analysis of this part comes from two sources. The primary data from the laboratory test results aimed to characterize the soil sample collected for the experimental work and the secondary sources of previously done laboratory tests in the project road.

The second part of the chapter presents and analyses the experimental investigation work which is the core of the present study. This part of the chapter attempted to investigate the treatment of soil identified as dispersive subgrade soil. As discussed in the chapter before a sample subgrade soil from two locations identified as dispersive were collected for this experimental work. The samples were treated with cement and gypsum, and the effect and efficiency of the treatments were studied by undergoing double hydrometer and unconfined compressive strength (UCS) tests. Analysis and discussion of this part of the chapter will answer the research question and helps to reach a conclusion.

The experimental work as discussed in chapter four involves analysis of UCS and double hydrometer tests. The two soil samples were treated with cement and gypsum by increasing the percent by weight in four stages. The 7-day UCS result is used to evaluate the efficiency of the stabilizer together with the double hydrometer test result. To further study the effect of the cement and gypsum on strength gain of the treated sample with age, one of the sample was cured for 28 days. Overall a pair of 16 UCS samples cured for 7-days, 8 UCS samples cured for 28-days and 16 double hydrometer tests were carried out for the experimental work.

5.2 Engineerin Properties of Soil Samples

In this section the engineering properties of the soil samples were studied. Laboratory test results of the virgin soil samples collected from the project road for the experimental investigation were presented followed by discussions with respect to its importance with the objectives of the study. The tests include, grain size analysis, Atterberg limits, compaction characteristics, crumb test and double hydrometer test.

5.2.1 Grain Size Analysis

The grain size analysis was carried out on virgin soil samples and the results are plotted in Figure 5-1. Wet sieving and hydrometer analysis was used to detrmine the grain size distribution. From the graph plotted, it is seen that the percent pass 75 µm sieve is less than 50% that revealed both soil samples collected for the experimental work were coarse-grained. Table 5-1 summarizes the various particle sizes and it shows soil sample A consist of 36.3% gravel, 44.3% sand and 19.0% of fines; and sample B consist of 26.4% gravel, 43.2% sand and 30.4% of fines. This revealed that both samples are sandy soils.

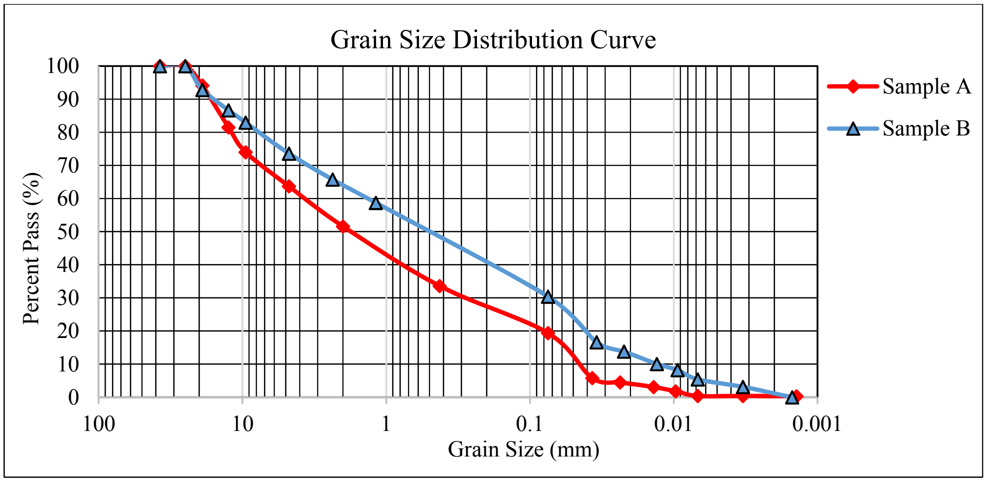

Figure 5-1: Figure. 1 Grain Size Analysis Chart for Virgin Soil Samples

Table 5-1: Proportion of Various Sizes of the Soil Samples

Soil Samples	% Gravel	% Sand	% Fines	% Silt	% Clay
Soil sample A	36.3	44.3	19.4	19.0	0.4
Soil sample B	26.4	43.2	30.4	26.1	4.3

5.2.2 Atterberg Limits

Atterberg limits test was performed on virgin soil sample using Casagrande method on sample A and fall cone method for sample B. The results are presented in Table 5-2, and this result are used to further classify the soil in unified soil classification system (USCS).

Table 5-2: Atterberg Limits of the Soil Samples

Atterberg Limits	Liquid Limit LL (%)	Plastic Limit PL (%)	Plasticity Index PI
Soil sample A	33.9	16.7	17.2
Soil sample B	32.9	NP	NP

5.2.3 Specific Gravity

The specific gravity of the soil solids determined using pycnometer shows a value of 2.59 for sample A and 2.47 for sample B.

5.2.4 Soil Classification

In general soil classification helps to get insight about the engineering behavior based on previous experience of similar soils. The Unified Soil Classification System (USCS) are employed for classifying the soil samples using the results of sieve analysis and Atterberg limits. Based on the USCS soil sample A is classified as SC (Clayey sands) and using the modified USCS classification by Prakash and Sridharan (2012) soil sample B is classified as SMN (Non-plastic silty sands mixtures).

5.2.5 Compaction Characteristics Soil Samples

Soil samples were compacted using the standard Proctor specifications as discussed in chapter four in a cylindrical mould. The standard compaction curves were established for both soil samples A and B. The optimum moisture content (OMC) and the maximum dry density (MDD) of sample A and B were then determined from the graph in Figure 5-2. The results from the graph are 23.50 percent and 1.440 g/cm3 for sample A and 17.50 percent and 1.523 g/cm3 for soil sample B respectively. The results from this test were used for moulding the UCS samples of treated soil.

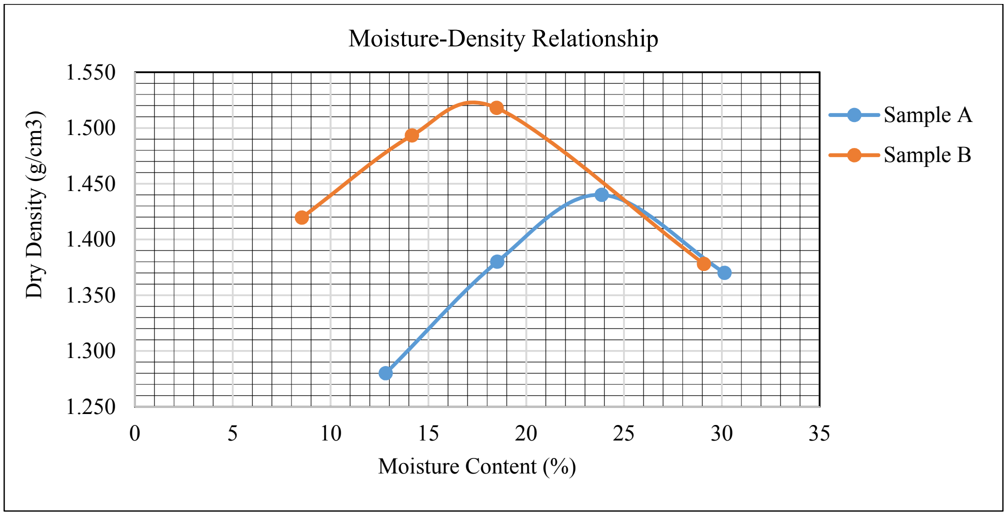

Figure 5-2: Moisture Density Relationship of the Soil Samples

5.2.6 The Crumb Tests

The crumb test was developed as a simple, fast method of identifying soil for dispersive nature. As discussed in the previous chapter, a few soil crumbs having a size of 15mm was immersed in a beaker of distilled water and the subsequent reaction was observed. As a preliminary test to affirm dispersive nature of the soil both samples were tested in the field and they were found Medium to highly dispersive (MD to HD).

5.2.7 Double Hydrometer Test

The double hydrometer test to evaluate the dispersion rate was carried out for soil samples A and B and it was found 69.9 and 99.1 percent respectively. These results were evaluated based on the Decker and Sherard criteria for dispersive soils classification and both samples found to be highly dispersive exhibiting more than 50 percent dispersion (Decker and Sherard, 1977). The result are summarized and presented in Table 5-3, Figure 5-3 and Figure 5-4.

Table 5-3: Summary of the Double Hydrometer Test result

Soil Sample	Percent finer than 0.005mm		% Dispersion
	With Solution (a)	Without Solution (b)	[= b/a x 100]
A	0.59	0.41	69.9
B	4.28	4.24	99.2

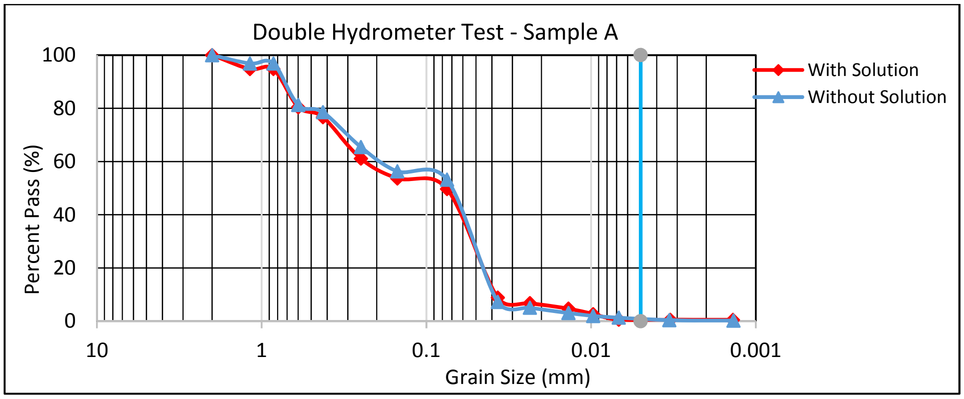

Figure 5-3: Double hydrometer test for Sample A

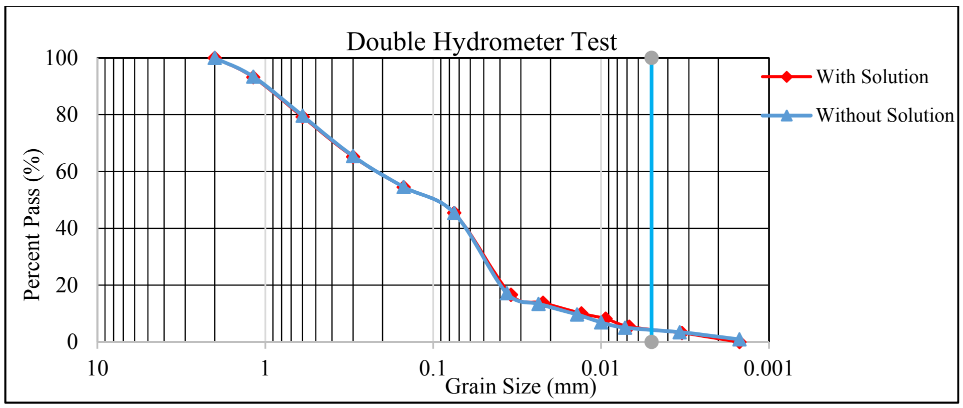

Figure 5-4: Double hydrometer test for Sample B

5.2.8 Previous Study in The Project

Study of soil behavior was carried out during the detailed site investigation under the consulting engineer Transport Construction Design Share Company (TCD). The result is presented in Table 5-4 and these result from previous investigation were evaluated based on the Decker and Sherard criteria for dispersive soil classification and both samples found to be highly dispersive exhibiting more than 50 percent dispersion (Decker and Sherard, 1977) and initiated this current study. The findings from the previous result are discussed here to see how the engineering property of the current sample will fit in.

From the summary of the investigation in Table 5-4, half of the samples tested are found coarse grained soils (i.e. the percent passing the 0.075mm sieve are less than 50 percent), which is in agreement to the current samples used for the study. The Atterberg limits test results shows low plasticity which is in congruence with sample A of the current study whereas sample B was non-plastic. The higher percentage of fines observed in the tests (>37 percent), make the classification of the samples in the AASHTO classification as silty clay materials from group A-4 to A-7. Whereas the current samples collected for the study are classified as silty or clayey sand of the AASHTO group A-2-4 and A-2-6. This minor difference probably been seen due to sampling and test procedures followed.

The AASHTO classification indicates the soil samples of the current study as fair (A-2 group) and those found during this investigation (A-6 and A-7) as poor to use naturally as a subgrade soil.

Table 5-4: Summary of Engineering Properties of Soil from Previous Investigation

Sampling Stretch	% Passing	Atterberg Limits			Soil Classification	Group Index
	0.075mm	LL (%)	PL (%)	PI (%)		
10+000 - 10+500	71.5	52.9	36	17	A-7-5	14
13+000 - 13+500	42.5	38	23.9	14	A-6	3
15+000 - 15+500	44.6	33	21.1	12	A-6	2
17+500 - 18+000	45.4	32.3	18.8	13.5	A-6	3
30+000 - 30+500	58.6	37.7	25.5	12.2	A-6	5
57+500 - 58+000	76.5	48.3	32.9	15	A-7-5	13

Table 5-5: Summary of Engineering Properties of Soil from Previous

Sampling Stretch	Compaction Characteristics		Double Hydrometer-Dispersion (%)	Dispersiveness Potential
	MDD (gm/cc)	OMC (%)		
10+000 - 10+500	1.335	29.5	85.7	Highly Dispersive
13+000 - 13+500	1.283	18.7	71.4	Highly Dispersive
15+000 - 15+500	1.477	24.6	73.3	Highly Dispersive
17+500 - 18+000	1.520	17.0	76.9	Highly Dispersive
30+000 - 30+500	1.414	21.4	90.0	Highly Dispersive
57+500 - 58+000	1.477	25.6	61.1	Highly Dispersive

Other engineering characters of the soil were investigated, and the results are summarized in Table 5-5 below. The results for the standard compaction effort moisture-density relationship showed a similar characteristic with the samples collected for the current study.

The double hydrometer dispersion rate results showed a high dispersion potential, which was confirmed with the test results of the current study samples. The results of the double hydrometer test is also once more confirm the necessity of the current study, i.e. dispersive soil treatment.

5.3 Test Results of Treated Soil Samples

Double hydrometer and UCS tests were carried out for all the treated soil samples in order to evaluate the efficiency of the stabilizer and determine the optimum content of stabilizer to be used for treating the natural dispersive soil. The optimum stabilizer (the minimum content) required for soil-cement and soil-gypsum mixture was determined from the results of the double hydrometer test by evaluating it against the Decker and Sherard criteria (Decker and Sherard, 1977).

Table 5-6 Degree of Dispersion using Double Hydrometer Test (Decker and Sherard, 1977)

Percent dispersion	Degree of dispersion
<30	Non-dispersive
30 to 50	Intermediate
>50	Dispersive

5.3.1 Double Hydrometer Test Results for Treated Soils

The double hydrometer tests are used to measure the dispersion percent of treated soil samples and evaluate the modifications in dispersiveness of the soil samples.

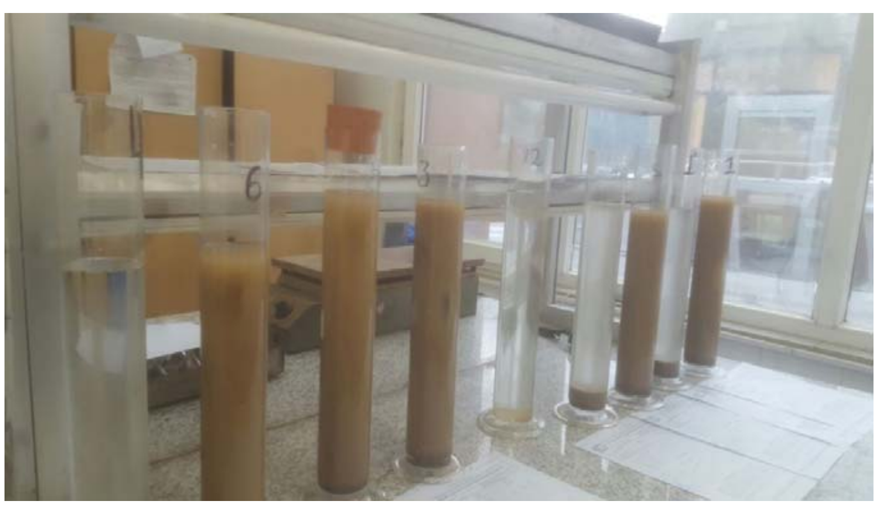

Figure 5-5 Double Hydrometer Tests (ECDSWCo laboratory)

5.3.1.1 Cement Treated Samples

The percent dispersion of the cement treated soil samples are presented in Figure 5-6 and it shows the addition of a 1 percent cement content by weight on the virgin soil sample reduces the dispersion rate by more than 50 percent on both samples. AH Vakili, et al. (2013b) has proved a similar result, with the addition of a 1 percent cement content a dispersive soil turns non-dispersive. This result indicates that both soil samples reacts well for cement treatment. Soil sample A with an initial dispersion rate of 69.9 percent becomes non-dispersive on a Decker and Sherard criteria with addition of 1 percent cement content by weight. The dispersion rate at 1 percent cement content becomes 14.5 percent and it is well below the 30 percent mark. Whereas Sample B naturally at 99.1 percent dispersive rate becomes non-dispersive at a cement content of 2.5 percent by weight and its dispersion rate at this cement content is 25.62 percent that satisfies the criteria of Decker and Sherard for dispersion. The dispersion rate converges to zero with subsequent addition of cement. The result shows similarity with the findings of AH Vakili, et al. (2013b) where the study indicates dispersion potential of the treated samples converges down to zero percent and the fully nondispersive status was achieved.

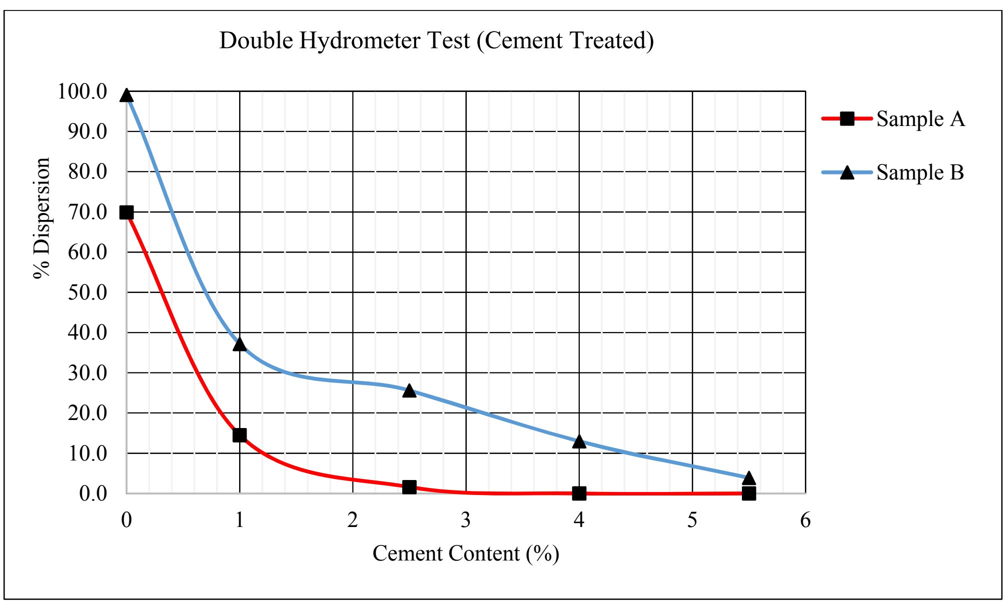

Figure 5-6: Double Hydrometer Test Results for Cement Treated Soil

As it is seen in the graph the cement content required to treat the soils against dispersion based on the Decker and Sherard criteria is different for soil sample A and B and this is due to the degree of dispersiveness of the soil samples before the treatment. This result indicates a soil having different dispersion rate requires a different degree of cement content to treat. Singh, et al. (2018) also discusses in his recommendation for treatment of dispersive soil using cement and he mentioned the reason as existence of lime in most cements. When cement is used for the treatment of dispersive clays, Singh recommended a 2-4% of cement by weight as ideal. The optimum cement content for this study is between 1 and 2.5 percent with 2 percent as ideal, above that the dispersion rate decreases with a decreased rate.

5.3.1.2 Gypsum Treated Samples

Gypsum treated samples double hydrometer test result for dispersion are presented in Figure 5-7 for a gypsum content 2, 4, 6 and 8 percent by weight. The graph indicates an early good reaction to both samples with the addition of gypsum. A large decrease in the dispersion rate at 2 percent of gypsum content by weight were observed. But the consecutive increment in gypsum content brings a minor modification in the dispersion rate. Singh, et al. (2018) also recommended gypsum as an effective treatment chemical and its effectiveness as higher than lime as it increases the electrolyte concentration in the soil solution as well as displacing sodium with calcium within the clay structure.

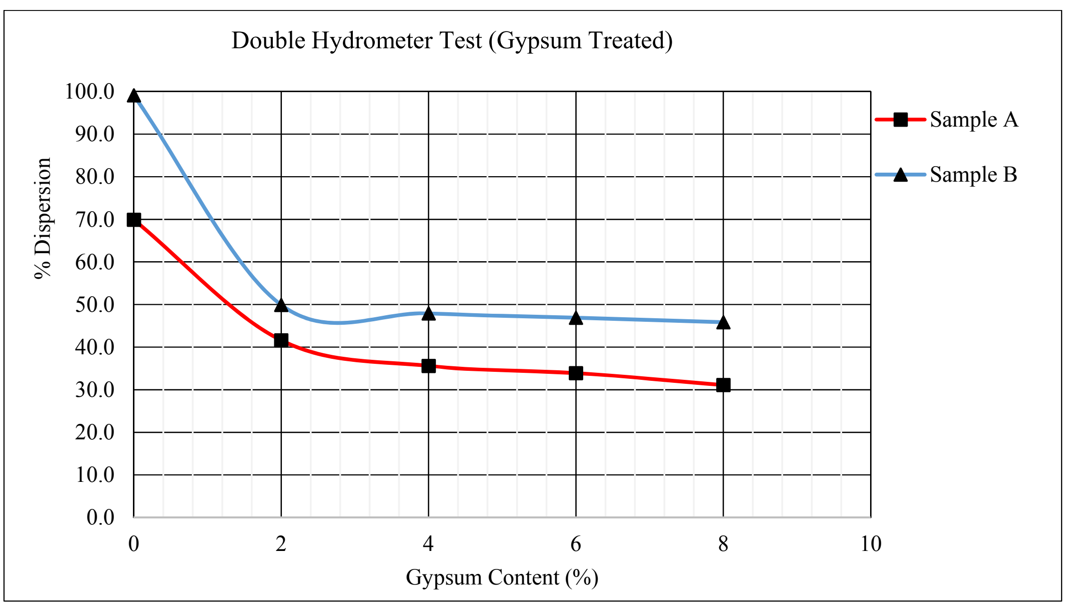

Figure 5-7: Double Hydrometer Test Results for Gypsum Treated Soil

But the result of dispersiveness of the soil samples with the final 10 percent by weight of gypsum becomes 31.1 and 45.9 for soil samples A and B respectively, which according to Decker and Sherard are an intermediate dispersion. Since the result is not below 30 percent, it does not satisfy the requirement as non-dispersive. Singh, et al. (2018) recommends a minimum of 2% by mass of gypsum as treatment for dispersion but usually according to him gypsum is less commonly used and the reason is due to its lower solubility, and higher cost. Umesh, et al. (2011) by using lime found out the optimum lime content of about 3 percent and he also showed with whatever amount of lime, the dispersiveness of the soil does not reduced below 30 percent in his study.

The optimum gypsum content from the graph in Figure 5-7 is between 2 and 4 percent and taking 3 percent is a conservative value. Increasing the gypsum content above 3 percent produces a negligible effect in the dispersion rate.

5.3.2 The Unconfined Compressive Strength Test Results of Treated Soils

Samples of UCS are prepared at optimum moisture content as detailed in chapter four and cured in moisture proof plastic bags as in the picture in Figure 5-8.

Figure 5-8 UCS samples compacted and cured in moisture proof bags for 7 and 28 days

5.3.2.1 Cement Treated Samples

The unconfined compressive strength (UCS) results of cement treated samples cured for 7 days are presented in Figure 5-9. The graph shows the UCS result in relation with the cement content. It showed the increase in cement content brings about an increase in the compressive strength of the treated sample. The results are in congruence with the experimental findings by other researches like (Umesha, et al., 2009, Pongsivasathit, et al., 2019). Both this studies indicated that the soil-cement continues to increase in strength with increasing cement content. The study by Pongsivasathit et al. shows this result by increasing the cement content up to 11 percent by weight.

The graph in Figure 5-9 shows the compressive strength of cement treated sample A is higher as compared to that of sample B for a cement content of similar amount. The Presence of higher proportion of coarse-grained material in sample A as compared to B may have brought an effect for the higher strength gain in sample A. Pongsivasathit, et al. (2019) have showed similar findings in that the compressive strength values of cement treated sandy soil becomes highest compared to that of the other cement treated clay soils in the study, and it concluded that the possible reason as the largest specific surface of sand which facilitate the cement hydration (The Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH) by the cement hydration can interlock effortlessly with the particles of sand).

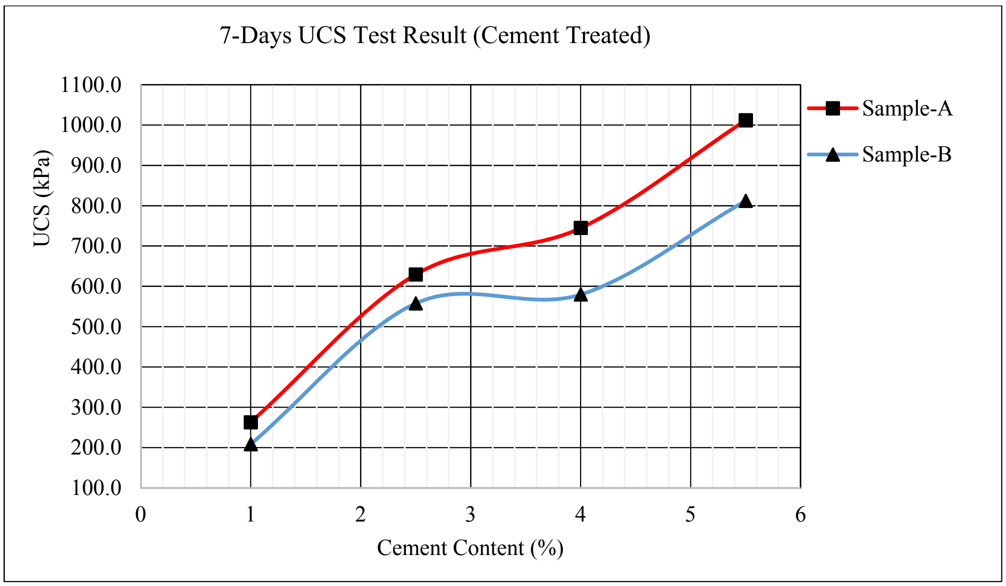

Figure 5-9: Unconfined Compressive Strength Test Results for Cement Treated Soil

The early strength gain within the 7-days of the cement treated soil sample is related to the cation exchange and hydration of the cement. Halsted, et al. (2008) indicates that cementitious materials get an early strength due to the cation exchange and hydration reaction and it also indicates the hydration reaction will continue its effect for a month. Pongsivasathit, et al. (2019) also describes the increase of early UCS value are highly related with the cement hydration by providing the Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH).

5.3.2.2 Gypsum Treated Samples

The unconfined compressive strength (UCS) of samples cured for 7-days for gypsum treated soil in relation with the percentage of gypsum by weight are presented in Figure 5-10. From the graph of UCS versus gypsum content, it is seen that the compressive strength steadily increased with increase in gypsum content but the rate of increment decreases with increase in gypsum content (see Table 5-7). Yilmaz and Civelekoglu (2009) have found a similar result that with increasing the gypsum content the rate of increment in strength decreases and their finding indicates with a gypsum content of above 7.5 percent the increment in strength becomes negligible.

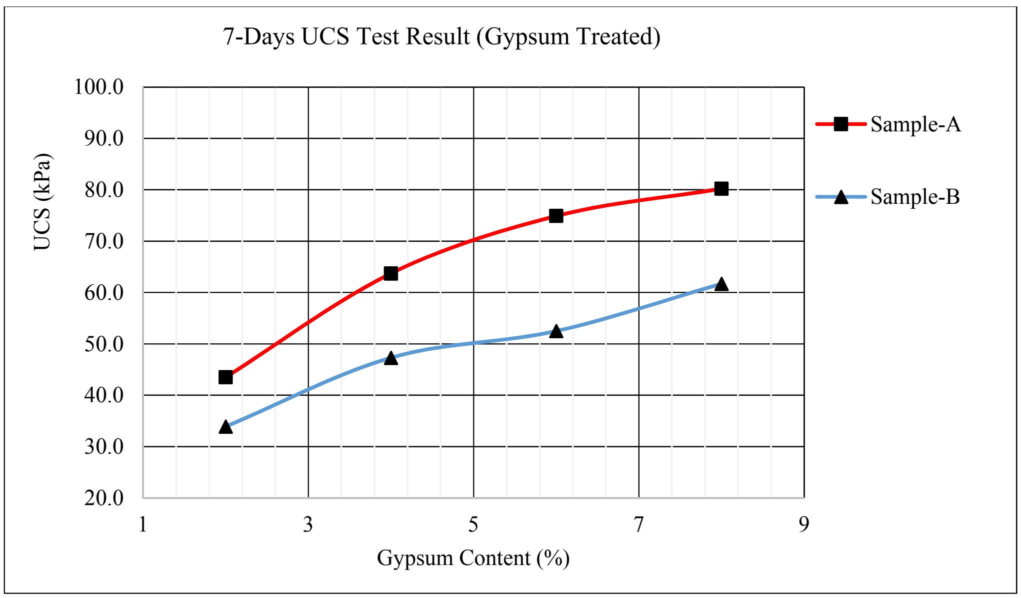

Figure 5-10: Unconfined Compressive Strength Test Results for Gypsum Treated Soil

Table 5-7: The UCS Test Results and Increment with Increase in Gypsum Content

Gypsum Content	UCS			
	Sample A	Increment	Sample B	Increment
2	43.5		33.9	
4	63.7	20.2	47.3	13.4
6	74.9	11.2	52.5	5.2
8	80.2	5.3	61.7	9.2

5.3.3 Compressive Strength and Curing Period of Treated Sample

The 28 days unconfined compressive strength (UCS) of cement and gypsum treated soil sample B were carried out and the result are plotted in the graph Figure 5-11 and Figure 5-12 respectively together with the 7 day UCS value for comparison and study of the strength development with age. Study of increase in UCS with time is important because this property determines the long-term durability and service of the structure built on these soils.

The cement treated soil sample indicates an increase in UCS result with increase in curing period for similar cement content except for the cement content of 5.5 percent. An increase in strength with curing period for cement treated samples was observed by many researchers like Ashraf, et al. (2018) and Umesha, et al. (2009). According to these studies the time–strength development of soils treated with cement stabilizer is due to continuing hydration and pozzolanic reactions. Umesh further found out at any given curing period, the strength gain is more with increase in cement percent. The exceptional 28 days strength reduction in the 5.5 percent cement content in this study may be is related to personal error during sample preparation.

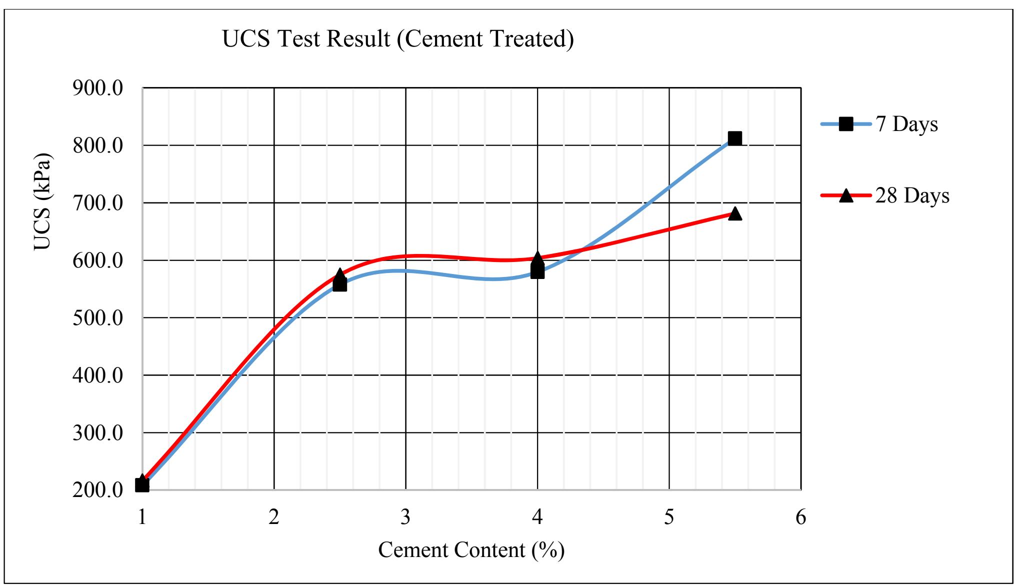

Figure 5-11: Figure Compressive Strength of Cement Treated soil Sample B with Age

The gypsum treated samples UCS result for 28-days are presented in the Figure 5-12 together with the 7-day UCS result. It shows the effect of curing period that an increase in strength brought about due to additional curing period. The 28-days strength is higher for each cement content as compared to the 7-days strength result. Umesha, et al. (2009) found in a lime treated soil a similar increase in strength with curing period. He showed also at any given curing period, the strength gain is more with increased lime content.

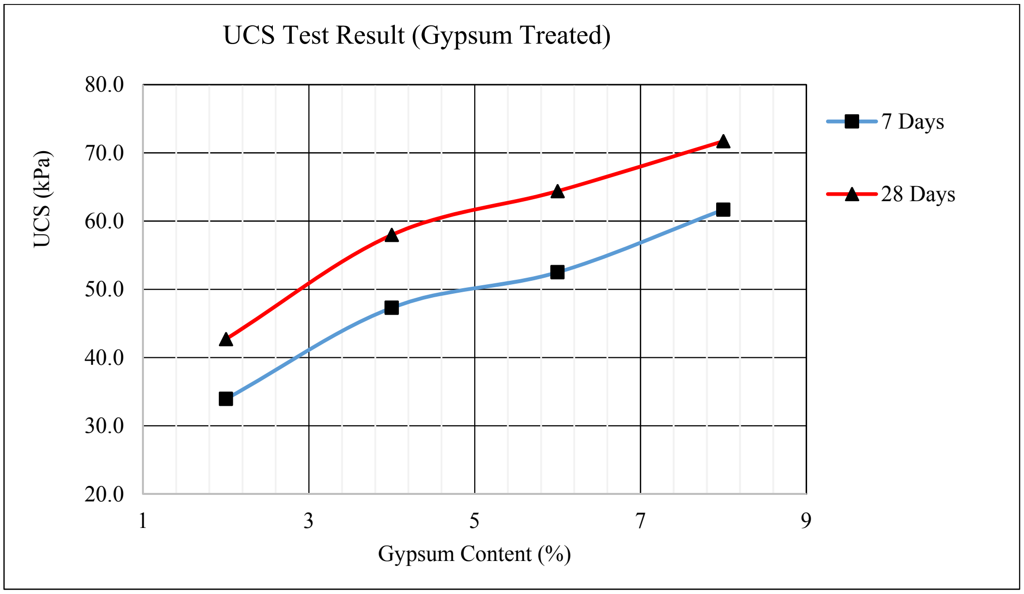

Figure 5-12: Compressive Strength of Gypsum Treated soil Sample B with Age

5.4 Relationship between Stabilizer, Dispersion Rate and UCS

It is important to assess the influence of the cement and gypsum on the dispersion rate and UCS results. In the previous sections it was investigated that an increase in the stabilizers amount affects the UCS and dispersion rate of the treated sample. In here it is intended to show the effect of the stabilizer on the treated sample by correlating the double hydrometer results and UCS results. But to build a correlation formula from this few results have prompted a very bad output and it is found inconclusive with this study to put a correlation formula.

But in general, the addition of cement reduces the dispersion rate and increases the UCS value for both soil samples. It is shown in the Figure 5-13 the effect of adding a cement on both soil samples summarized in a single graph for comparison.

Figure 5-14 presents the effect of adding a gypsum in the UCS value and dispersion rate, the summary of both samples was shown in the same graph. The addition of gypsum reduces the dispersion rate and increases the UCS that shows a similar pattern to the cement treated sample.

In general, the addition of cement-based materials to a soil brings an increase in strength Halsted, et al. (2008) detailed about cation exchange, hydration reaction, grain structuring and pozzolanic reaction as responsible for bringing increase in strength. And increase in cement-based stabilizers have an effect in reducing the dispersion rate (Umesh, et al., 2011).

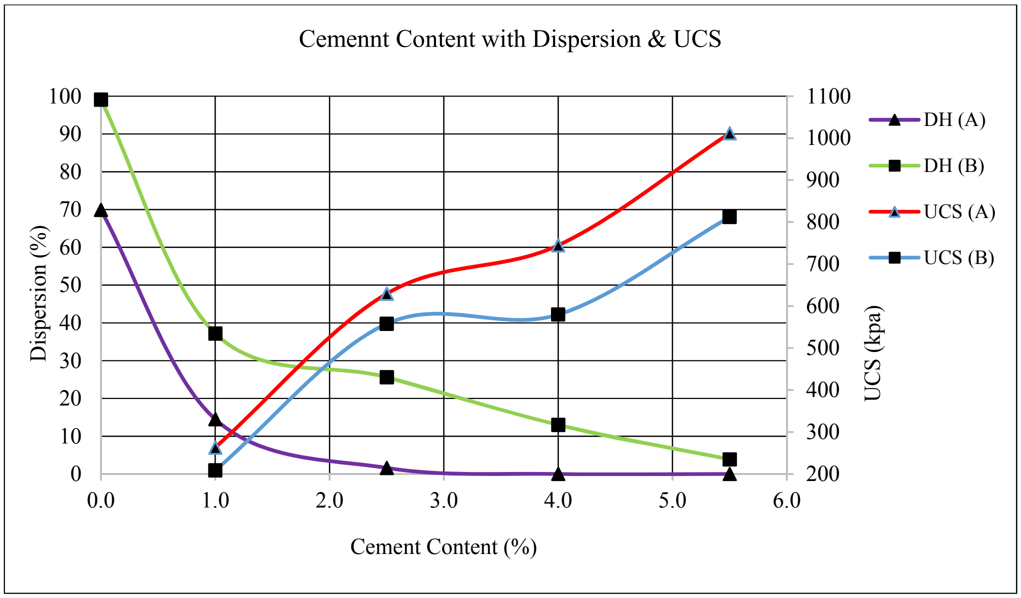

Figure 5-13: Effect of Cement Stabilizer on UCS and Dispersion Rate

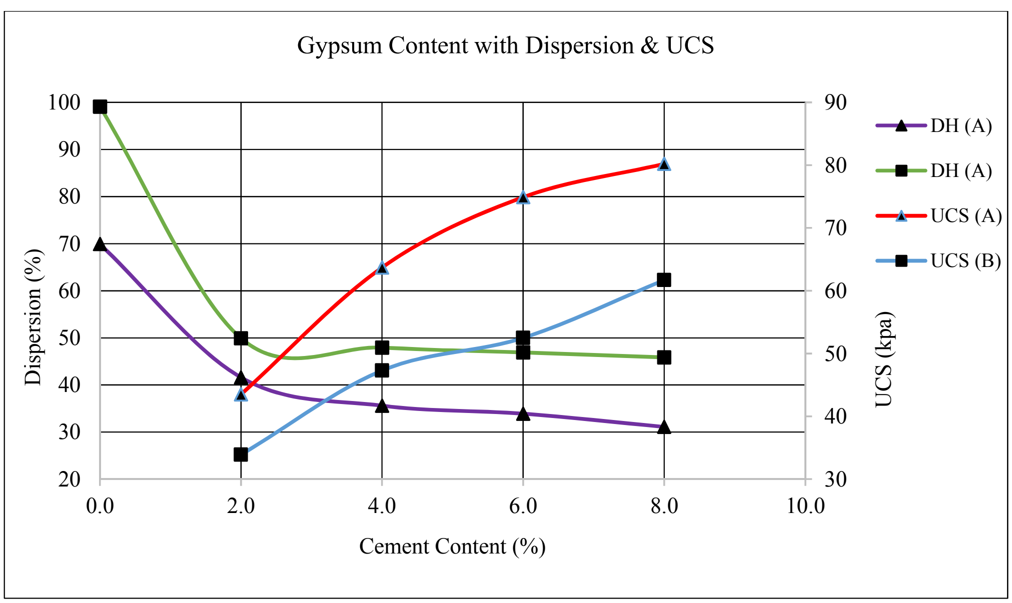

Figure 5-14: Effect of Gypsum Stabilizer on UCS and Dispersion Rate

CHAPTER 6
SUMMARY, CONCLUSION AND RECOMENDATIONS

6.1 Introduction

This chapter presents the summary of the findings, conclusions and recommendations based on the the laboratory test results presented and analysed in the preceding chapters. The treatment of dispersive soil using cement and gypsum were studied experimentally in the laboratory. The effectiveness of the stabilizers were researched and finally the chapter determines the extent the research objectives were attained.

6.2 Smmary of the results

The focus of this study was to determine the effectiveness of cement and gypsum additives to controle the dispersiveness of soil. The objectives of the study were:

- Identify the dispersion rate of virgin soil samples
- Determine the optimum mix proportion, and
- Develop a correlation between degree of dispersion and unconfined compressive strength (UCS) of treated soil.

The research followed the methodologies developed within the framework of the objectives in chapter four to establish the outcomes. The important findings from this research may be summarized as follows:

- The engineering properties of the virgin soil samples collected from the project road have shown a high degree of dispersivity and it is not recommended to use such soils both as subgrade and embankment fills without improving their engineering properties.

- The soils treated with cement showed a great improvement interms of dispersivity as well as in compressive strength. The soil sample A becomes non-dispersive at a cement content of only 1 percent by weight, its dispersiveness decreases from 69.9 percent to 14.5 percent. And with the addition of 4 percent cement by weight, the soil becomes completely non-dispersive i.e. the soil showing zero percent dispersion. Whereas the sample B with initial dispesion of 99.1 percent becomes non-dispersive at a cement content of 2.5 percent by reaching a dispersion of 25.62 percent. Therefore the two subgrade soils satisfy the Decker and Sherard criteria for dispersivity at 1 and 2.5 percent cement contents.

- A similar soil samples treated with gypsum showed a decrease in dispersion rate but the final result does not satisfy the Decker and Sherard criteria for dispersivity. With the addition of the maximum dosage for this study 8 percent by weight of gypsum sample A reaches a dispersion rate of 31.1 and sample B to 45.86 percent, which is an intermediate dispersive value.

- The unconfined compressive strengths (UCS) results of both cement and gypsum treated soils increase with the increase in content of the stabilizers. The cement treated samples shows a higher UCS value than the gypsum treated samples.

- The unconfined compressive strength also increases with curing period. The samples cured for 28-days shows a higher strength than those samples cured for 7-days for a similar stabilizer content for both cement and gypsum. Exception was found for a cement content of 5.5 percent the UCS value for 28-days is lesser than the 7-days result.

6.3 Conclusions

The following concluding remarks are drawn from the research:

- Both soils of the study react well for the cement and gypsum addition and this is due to the cation exchanges reaction. This cation exchange took place between the $Ca2^{+}$ and Al^{3+} ions of the cement and gypsum and the Na^{+} ion of the dispersive soil, as a result the dispersion potential decreases.

- The optimum cement content for treatment of the soil against dispersion was determined to be 2 percent and for that of the gypsum the optimum content was 3 percent.

- Evenif the the use of optimum gypsum content brought abought huge improvement in dispersion, it does not passed the Decker and Sherard criteria. It was also not recommended for use as a treatment based on this study.

- The cement treatnment shows an improvement that satisfies the Decker and Sherard criteria. It was thus recommended to use the cement treatment with the optimum cement content of 2 percent.

- The unconfined compressive strengths of of both gypsum and cement treatment showed improvement and it is due to the hydration and pozzolanic reactions which is common in cement-based treatments.

- It was not successful this time to developing a correlation between the degree of dispersion and unconfined compressive strength (UCS) of treated soil because of very few results available and it was not convincing.

Although the gypsum treatment brings about a huge improvement in dispersion the final result still be in a dispersive rannge according to Decker and Sherard Criteria and use of gypsum for treating the dispersive soil in question was found unsuccessful. Whereas the cement treatment with the optimum content of 2 percent was found to be effective in keeping the sub-grade soil below the requred dispersion limit.

6.4 Recommendations

Future research in the area of dispersive soil treatment are necessary since not much have done in this area. There are much recommendations for further investigation in the area on different aspects of stablization which were not covered fully in this research. These may be listed as below:

- The current research is experimental study in the laboratory, it lacks addessing a field trial experiment. With a similar design further research can be carried out on site, to confirm the result.

- Only two soil samples were investigated and it is considered few as compared to the variability the site soil had, it is thus suggested to carryout a further investigation with a similar setup of the current study.

- The current investigation as indicated in the study uses double hydrometer (dispersion rate) and strength (UCS) results as a basis for evaluating the effectiveness of the stabilizer. Because of the nature of the soil using this tests alone can be misleading and it is suggested to make a similar study by adding other test methods for evaluation.

- This study showed that cement is the best treatment out of the two researched stabilizers for dispersion and the research focused only to study them as a separate additive. It is thus recommended to make a research using cement-gypsum mix to produce an economical treatment. And it is further recommended to use a quarry gypsum rather than factory processed to address a more economical way.

- Developing a correlation between UCS and disperssion can be done as more and more samples were tested, and such relationship can be useful for field controle.

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Appendices

Laboratory Test Results