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ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL
ENGINEERING**



**Application of Dispersive Soils as a Sub Grade and
Embankment Materials**

(Case Study on Adama – Awash Railway Section)

A Thesis in Civil Engineering (Railway Engineering)

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A Thesis

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ABSTRACT

Dispersive soils are prevalent in many areas of Ethiopia (especially in the rift valley). The use of dispersive soils in embankment structure can lead to serious engineering problems if the soil is not accurately identified before use and appropriate mitigation measures are not taken. The current tests used for identification include pinhole, double hydrometer, crumb and chemical tests.

The main objective of this research is to use dispersive soil as an alternative embankment construction material. The light greyish sub grade soil of the pilot – study area (Adama – Welenchity section) have been tested with all identification tests of dispersive soil to check the extent of dispresivity of the soil. According to the result, the sub grade soil is dispersive with Pinhole test D2 (dispersive soil category 2), double hydrometer percent dispersion value TP1=87.17% and TP2=83.24%, crumb test result of grade 3 and Chemical analysis exchangeable sodium percentage of 31.93%.

Treatments to dispersive clay using gypsum was carried out in this study. The optimum amount of gypsum required to treat a dispersive clay sample was 5%. The identification test results obtained by stabilizing with 5% recycled gypsum are: - double hydrometer percent dispersion value 24.72%, pinhole test ND1 (non-dispersive soil 1) and chemical analysis exchangeable sodium percentage of 6.54%. The engineering index tests of the dispersive soil have also been checked and found that the dispersive soil qualifies the specification requirement of embankment construction materials. After being treated with 5% recycled gypsum the dispersive soil can be used for embankment construction.

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TABLE OF CONTENTS

ABSTRACT.....	IV
ACKNOWLEDGMENTS.....	V
TABLE OF CONTENTS.....	VI
LIST OF TABLES.....	VIII
LIST OF FIGURES.....	IX
CHAPTER 1 INTRODUCTION.....	1
1.1 Background.....	1
1.2 Objectives.....	2
1.3 Methodology.....	3
CHAPTER 2 LITERATURE REVIEW.....	4
2.1 Properties of Dispersive Soils.....	4
2.2 Clay Mineral Chemistry and Dispersivity.....	4
2.2.1 Crystal structure.....	4
2.2.2 The Diffuse Double Layer.....	6
2.2.3 The effect of the DDL on dispersion.....	8
2.3 Experiences with Dispersive Clay Soil.....	9
2.4 Identification of Dispersive Soils.....	10
2.5 Laboratory Tests.....	11
2.5.1 The Crumb Test.....	11
2.5.2 The Double Hydrometer Test.....	12
2.5.3 The Pinhole Test.....	13
2.5.4 Chemical Tests.....	16
2.6 Using dispersive soils for railway embankment.....	17
2.7 Recycled Gypsum.....	19
CHAPTER 3 DATA COLLECTION AND SAMPLING AREA DESCRIPTION.....	21
3.1 Topography and Climate.....	21
3.2 Soil and Geology.....	22
3.3 Soil sampling.....	23

CHAPTER 4	DISCUSSION AND ANALYSIS OF LABORATORY TEST RESULT ...	25
4.1	General	25
4.2	Evaluation of Dispersiveness of the Soil before Stabilization	25
4.2.1	Pinhole test.....	26
4.2.2	Double Hydrometer Test	29
4.2.3	Crumb test.....	32
4.2.4	Chemical Test Analyses	33
4.2.5	Summary	35
4.3	Stabilization of Dispersive Soil.....	36
4.3.1	Mixing Dispersive Soil with Gypsum	37
4.4	Evaluation of Dispersiveness of the Soil after Stabilization.....	37
4.4.1	Double Hydrometer test.....	38
4.4.2	Pinhole test.....	39
4.4.3	Chemical test	40
4.5	Index and Strength Properties of Adama – Welenchity Dispersive Soil	42
4.5.1	General.....	42
4.5.2	Plasticity Index of Soils	42
4.5.3	Classification Grading	46
4.5.4	Sub Grade Strength.....	46
CHAPTER 5	CONCLUSIONS AND RECOMMENDATIONS.....	51
5.1	Conclusions	51
5.2	Recommendations	53
REFERENCES	54
APPENDIX A		56

LIST OF TABLES

Table 2-1: Summary of Criteria for Evaluating Results (Adapted from Sherard et al., 1976a)	14
Table 2-2: categories of pinhole test results (Adapted from Sherard et al., 1976a) .	15
Table 3-1: Annual Temperature for Nazret year 1981 - 2013	21
Table 3-2: Annual Rainfall for Nazret year 1981 - 2013	21
Table 3-3: Annual Rainfall for Welenchity year 1981 – 2013	22
Table 4-1: pinhole test result	27
Table 4-2: double hydrometer test result	31
Table 4-3: interface between clay mineralogy and CEC/ (Bolt and Bruggenwert, 1978)	34
Table 4-4: pinhole test result after stabilization with 5% gypsum (TP-1)	39
Table 4-5: properties of the CL soil group (Arora, 2000)	45

LIST OF FIGURES

Figure 2-1:diagrammatic sketch showing (a) single octahedral unit and (b) the sheet structure of the octahedral units (from Grim, 1962).....	5
Figure 2-2:diagrammatic sketch showing (a) single silica tetrahedron and (b) the sheet structure of silica tetrahedrons arranged hexagonal network (from Grim, 1962).	5
Figure 2-3: distribution of counter ions around DDL.....	7
Figure 2-4: Percent dispersion as determined from the double hydrometer (from Sherard and Decker, 1977).	13
Figure 2-5: Schematic drawing of the pinhole test equipment (adapted from Sherard et al, 1776a).....	14
Figure 2-6: dispersive grade Vs flow rate (Adapted from ASTM D-4847)	15
Figure 2-7: Dispersive potential evaluated from analysis of dissolved salts in pore water (Adapted from Harmse, 1980)	17
Figure 3-1: Geological and Soil Map of the Area Pilot Study Area.....	22
Figure 3-2: erosion gullies on Adama – Welenchity route sections.....	24
Figure 4-2: effluent color after 30 minute	28
Figure 4-1: Diameter of the hole after the test	28
Figure 4-3: leached soil at the front face	28
Figure 4-4: double hydrometer test result of TP-1	30
Figure 4-5: double hydrometer test result of TP-4.....	31
Figure 4-6: mixing dispersive soil with gypsum.....	37
Figure 4-7: natural soil sample before mixing	37
Figure 4-8: dispersion potential Vs % of gypsum.....	38
Figure 4-9: dispersion potential determination with different percentage of gypsum	39
Figure 4-10: pinhole test result before and after stabilization with 5% gypsum.....	40
Figure 4-11: Chemical analysis test result before and after stabilization with 5% gypsum (TP-1).....	41
Figure 4-12: Plasticity Index and Liquid Limit Values on dispersive soils of Adama - Welenchity	43
Figure 4-13: Weighted Plasticity Index Values on dispersive soil of Adama - Welenchity	44
Figure 4-14: Plasticity Chart of the Subgrade.....	45

Figure 4-15: Particle Size Distribution of Sub grade Soils along the road alignment	46
Figure 4-16: Variation of Maximum Dry Density along the route (T180 Compaction)	47
Figure 4-17: Variation of Optimum Moisture Content (T180) along the road	48
Figure 4-18: Variation of CBR swell along the alignment	49
Figure 4-19: Variation of CBR along the alignment	50

CHAPTER 1 INTRODUCTION

1.1 Background

A railway line is constructed which connects Addis Ababa with the port of Djibouti. This railway line in its way to Djibouti traverses through Adama – Awash section which have erosive sub grade material which exist between the town of Adama and Welenchity and on some stretches between Welenchity and Awash.

Adama – Awash section road embankments have suffered serious erosion problems and have failed due to the soil erosion. Since, the new railway line of Addis - Djibouti Traverses adjacent to the road, this dispersive sub grade material will affect the future performance of Adama – Welenchity railway track.

As visually seen from the old railway line, the toe of the embankment and in some sections the sub grade have been highly affected by erosion. Many road and railway embankments have suffered serious erosion problems and have failed due to the presence of the dispersive soils. As the scope and magnitude of the problem which can result from construction in this dispersive soil region is very high, preventing the failures caused by the dispersibility of the soils has become one of the major concerns.

Erosion through internal cracks leading to piping and surface erosion are the most common erosion modes, which cause failures of embankments. Hence, it is very important to improve the erosion resistance of soils using appropriate and cost effective techniques. Use of chemical stabilizers is one way of increasing the erosion resistance of soils. To tackle Adama – Welenchity railway track from erosive nature of the sub grade the contractor had covered the whole section embankment with masonry.

When dispersive clay comes in contact with water, the clay fraction behaves more like a single-grained particle with a minimum electrochemical attraction and there by 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) and as such when the water flows, the detached clay particles are carried away and piping occurs. Dispersiveness of soil is mainly a function of the concentration of sodium ion with in the soil particle. (Sherard and Decker, 1977).

Dispersive soils have a very low permeability, therefore as the water flows, the velocity is insufficient to move the particles but however when a crack or opening occurs the clay particles get into suspension and easily carried away by water forming a large opening there by enlarging it. Generally soil replacement is considered as a remedy but in most of the cases it becomes expensive (like in Adama-Welenchity section). Therefore alternative solution such as chemical treatment is usually adopted. The common additives used are lime, gypsum, cement, fly ash etc.

Understanding the degree of dispersion of Adama – Welenchity sub grade is important because it helps to identify the best treatment option. In this research, based up on the natural sub grade soil test result it will be mixed with stabilizers and we will evaluate the effectiveness of chemical treatment on the erosion behavior of the soil. If wrong treatment option is chosen then the erosion could simply start over again, even after significant time and money has been spent stabilizing the original soil.

1.2 Objectives

General Objectives

To examine the treatment option for the erosive sub grade soil of Adama – Welenchity.

Specific objectives

Specifically the research have the following objectives: -

- Determining the potential to erosion of the sub grade in the study area,
- Determining the decrease in dispersion of the soil with stabilizers,
- Suggesting the percentage amount of the stabilizer to minimize erosive nature of the soil so that the soil will be used as a construction material for the railway and road embankment.

1.3 Methodology

The main source of data which will be used to evaluate the level of dispersiveness of the sub grade and its effect on the railway track is obtained from field investigation on the Adama – Welenchity sub grade material.

For this research it has been tried to get data from Addis – Meiso railway line contractor and Ethiopian road construction corporation Adama – Welenchity road maintenance team. Based upon the data from those organizations, it has been tried to find a solution for the existing problems. Various literatures written on this area and on similar kinds of problems were assessed for the purpose of comparison.

By visiting the site, the performance of existing transportation infrastructures were assessed. To know property of the sub grade soil, samples were taken from representative places for undertaking necessary laboratory tests. Field and laboratory tests were undertaken such as strength (CBR) test, grain size analysis test, Atterberg limit test, compaction, crumble, pinhole, double hydrometer and chemical tests.

The tests stated above were undertaken on the natural sub grade soil before chemical stabilization and after the chemical treatment on the sub grade soil sample. The change in properties of the dispersive sub grade resulting from the treatment were registered and compared with the untreated sub grade sample test result.

CHAPTER 2 LITERATURE REVIEW

2.1 Properties of Dispersive Soils

Dispersive clays differ from ordinary erosion resistant clays because they have a higher relative content of dissolved sodium in the pore water. Ordinary clays have a preponderance of calcium and magnesium dissolved in the pore water. Ordinary clays have a flocculated or aggregated structure because of the electrochemical attraction of the particles to each other and to water. This accounts for these soils' non-erosive behavior.

Dispersive clays have an imbalance in the electrochemical forces between particles. This imbalance causes the minute soil particles in dispersive clay to be repulsed rather than attracted to one another. Consequently, dispersive clay particles tend to react as single-grained particles and not as an aggregated mass of particles.

2.2 Clay Mineral Chemistry and Dispersivity

2.2.1 Crystal structure

The crystal structure of a clay minerals is the principal factor which determines their physical and chemical properties and their attraction to water. In order to identify with the concept and process of dispersion, these properties of clay particles need to be examined and understood.

The atomic lattices of clay minerals comprises two structural elements. The first element consists of sheets of octahedrons made up of oxygen atoms or hydroxyl groups, with 8-coordinated aluminum, iron or magnesium atoms occurring in the interstices at equal distance from the oxygen atoms (figure below). When aluminum is present, only two-thirds of possible positions are filled to balance the structure, which is the gibbsite structure and formula is $Al_2(OH)_6$ when magnesium is present, all the positions are filled to balance the structure, which is the brucite structure with the formula $Mg_3(OH)_6$ (Grim 1962; Ovcharenko et al. 1967).

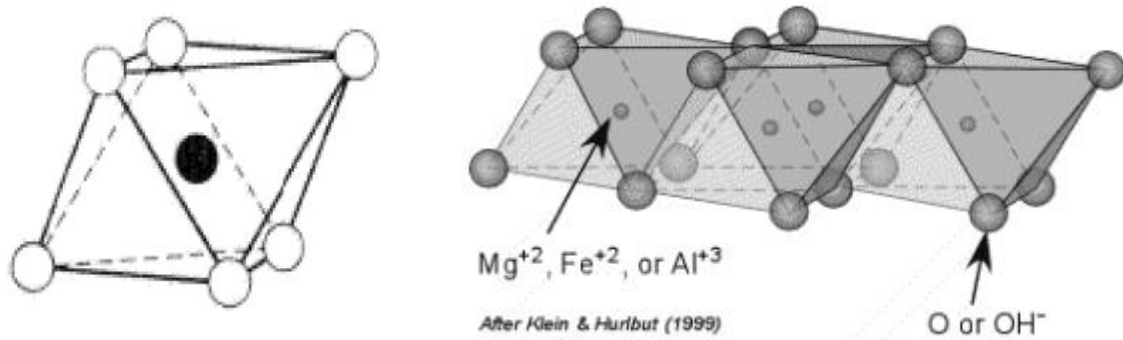


Figure 2-1:diagrammatic sketch showing (a) single octahedral unit and (b) the sheet structure of the octahedral units (from Grim, 1962).

The second element comprises of silicon-oxygen tetrahedral, where the silicon atom is equidistant from the four oxygen atoms in each tetrahedron (figure below). This is necessary to ensure lattice equilibrium. The tetrahedral silicon-oxygen groups are arranged in an infinitely repeating hexagonal lattice with sheets of composition Si_4O_6 (in some cases hydroxyl ions can replace oxygen ions). The tetrahedrons are arranged so that the tips of all of them point in the same direction, and the bases are on the same plane (Grim 1962; Ovcharenko et al. 1967).

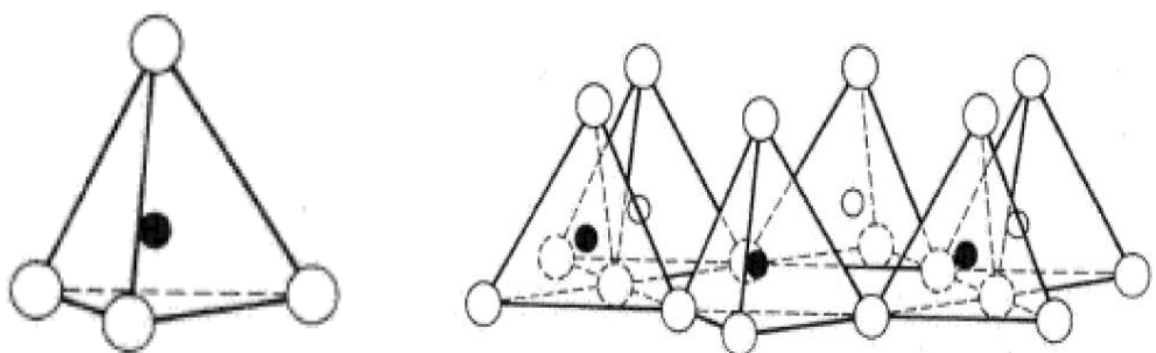


Figure 2-2:diagrammatic sketch showing (a) single silica tetrahedron and (b) the sheet structure of silica tetrahedrons arranged hexagonal network (from Grim, 1962).

Although the aluminum-oxygen and silicon-oxygen sheet are electrically neutral, the electric fields of the two molecular sheets are adjusted such that the resulting lattice displays minimum potential energy. The ions inside the layers are bonded by electrostatic forces and the layers are held together by van der Waals forces (Ovcharenko et al. 1967).

The chemical classification of clay minerals is based on the lattice types. The first type is a layer structure of alternating silicon-oxygen tetrahedral and aluminum-oxygen octahedral with the ratio of 1:1. Kaolinite, imperfect kaolinite and hallo site belong to this group. The second structure comprises the same elements, but with a ratio of 2:1, examples of there are montmorillonite and illite.

The layered structure of kaolinite is made of alternating sheets of silicon-oxygen and aluminum-oxygen joined to form a single electrically neutral unit cell, with a structural formula of $(\text{OH})_8\text{Si}_4\text{Al}_4\text{O}_{10}$. The strong bonding between the different sheets prevents hydration and adsorption from occurring in the interstices. The montmorillonite unit cell on the other hand comprises two external silicon-oxygen sheets and one intermediate aluminum-oxygen sheet. The theoretical formula of the structure is $(\text{OH})_4\text{Si}_8\text{Al}_4\text{O}_{20} \cdot n\text{H}_2\text{O}$. Each unit cell is surrounded by a layers of oxygen atoms and the adjoining unit cells are held together by van der Waals bonds, which is easily broken when polar molecules infiltrate the interstices. The polar molecules cause substantial swelling of the lattice until the individual layers are entirely separated (Ovcharenko et al. 1967).

2.2.2 The Diffuse Double Layer

The internal structure of a clay mineral can have an imbalance of charges due to substitution of Si^{4+} and Al^{3+} ions by other cations of lower valence. The electro neutrality of the clay particle is then provided for by the presence of certain cations (Na^+ , Ca^{2+} , K^+ , Mg^{2+} , etc) on the exterior surface of the clay. These are generally referred to as 'counter' ions. The exterior cations (which are not really a part of the crystal lattice) can dissociate completely from the surface if it is in contact with water. A partial dissociation of surface ions usually takes place in an aqueous solution, imparting an electrical charge to the surface of the solid phase. In contrast to other molecular environments, the ions that detach themselves from the solid surface tend to remain in the surrounding area of the charged surface. The cause of this trend is the fixation of the surface charges to the solid phase which prevents them from spreading throughout the system. Depending on the proximity of the charges on the surface, the electric fields of the individual charges reinforce each

other, giving rise to a combined electric field in the individual charges reinforce each other, giving rise to a combined electric field in the liquid layer bordering the solid surface. This field will attract any dissociated ions which will then accumulate close to the charged surface. The resulting distribution of charges (i.e. negatively charged surface with accumulation of positively charged ions close to it) is known as the “electric double layer” (Bolt and Bruggenwert 1978).

Since the accumulated counter ions can move freely through the solution phase, this indicates that they are subject to two opposing tendencies. They are attracted towards the clay surface by the electric field (adsorption tendency) and they have a propensity to distribute themselves uniformly throughout the solution phase by diffusion (diffusion tendency). In general, the distribution is said to endeavor towards minimum energy but also in the direction of maximum entropy of the system. The resulting (equilibrium) distribution corresponds to a minimum of the ‘free energy’ of the system and amounts to a ‘diffuse’ accumulation zone. These conditions are illustrated in figure 2-3 (Bolt and Bruggenwert, 1978).

The resulting arrangement of charges is defined as the diffuse (electric) double layer (DDL).

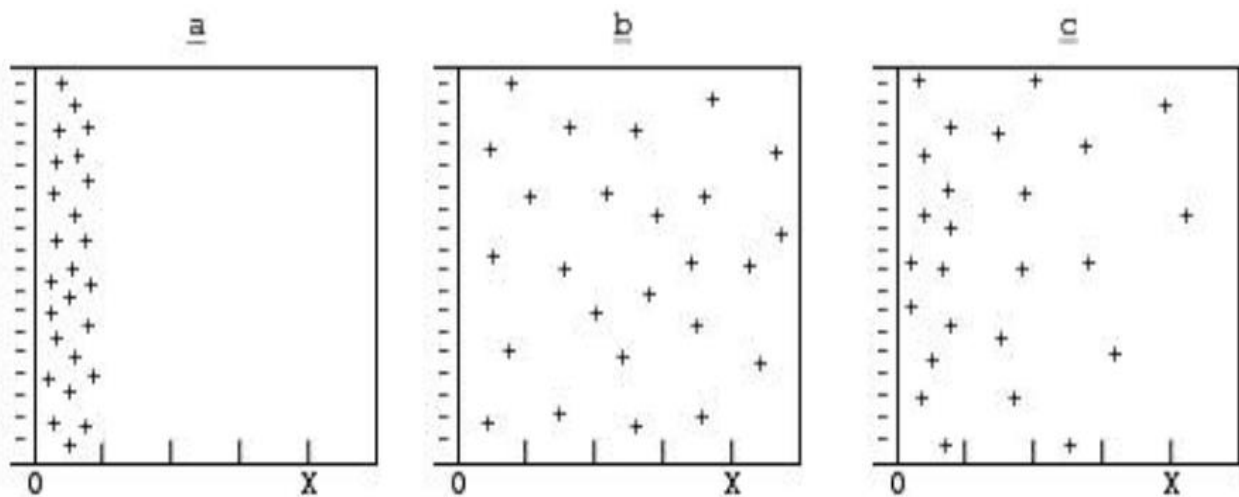


Figure 2-3: distribution of counter ions around DDL

A: condition of minimum energy; b: condition of maximum entropy; c: condition of minimum free energy, i.e. actual distribution (Bolt and Bruggenwert, 1976).

The equivalent concentration (C) distribution is shown in figure 2.3, in which the extent, x , of the DDL can be recognized. The extent of the DDL (x) is defined as the width of the region in which the electric field of the charged surface is still distinguishable, or where an obvious accumulation of electric field of the charged surface is still distinguishable, or where an obvious accumulation of counter ions is situated. According to Bolt and Bruggenwert (1978), the extent of the DDL is influenced by two main factors. These factors are the valence of the counter ions and the concentration of ions in the pore water. Divalent cations (Ca^{2+}) are attracted more strongly than monovalent cations. Therefore, the extent of the DDL will decrease with increasing valence of the counter ions. The addition of salts to the pore water inhibits the inclination of the counter ions to diffuse away from the accumulation zone and thus decreases the extent of the DDL (Bolt and Bruggenwert 1978).

2.2.3 The effect of the DDL on dispersion

The two forces that act between clay particles affecting dispersion are van der Waal's attraction forces and the repulsive forces resulting from positively charged cations surrounding each particle. It should be noted that the influence of van der Waal's forces is only effective over a small area, whereas repulsive forces may extend over a greater distance. The excessive amounts of sodium as opposed to calcium and potassium in dispersive soils have the effect of pushing clay particles away from each other causing the forces of repulsion to act on the clays. Ballantine and Rossouw (1989), state that the sodium cation is highly problematic in clays since it can hold 79 molecules of water, pushing the individual clay particles further away from each other. Calcium on the other hand, only holds 2 molecules of water, which keeps the clay particles close enough for van der Waal's forces to take effect.

Attractive and repulsive forces acting on clay particles depend on the closeness of the particles to one another. If the clay particles are in close proximity, attractive forces (van der Waal's) will be the governing forces between the particles, and if they are further apart, they will repel each other. The major factor influencing the distance between clay particles is the thickness of the DDL. If the thickness of the DDL is small, clay particles may be close enough for van der Waal's forces to prevail. The clay particles would therefore be attracted to one another and remain flocculated. When the DDL is large, repulsive forces

predominate and the clay particles repel one another and disperse (Bolt and Bruggenwert 1978; walker 1997).

2.3 Experiences with Dispersive Clay Soil

Because general recognition of dispersive clays in civil engineering practice is so recent, only a few structures have been built on dispersive soil since engineers have become aware of the problem. Experience with thousands of road and railway embankments built according to current accepted practice has shown very few failures or problems from piping, and surface erosion on the embankments. Most of these failures/problems were attributable to some condition unforeseen by the designer, such as inadequate construction quality control or a dispersive soil not discovered during explorations. (Sherard and Decker, 1977).

Most of the problems reported with dispersive clays occurred in existing embankment built before current identification methods and accepted design practices were in place. Problems that resulted were internal erosion or piping, tunneling, surface erosion, and jugging (formation of the vertical portion of an underground erosion tunnel where the base is larger than the top, resembling a jug at the toe of the embankment).

Most studies cited in the literatures have shown that failures of structures/ (embankments and sub grade soil) built of dispersive clay soils occurred on first wetting. These included cases on swampy areas where the water level was raised after having been at a given elevation for a period of time. All failures were associated with the presence of water and cracking by shrinkage, differential settlement, or construction deficiencies (Sherard and Decker, 1977).

Cracking has been determined to be a contributing factor since all structures that failed by internal erosion failed during first filling, and tunneling and jugging were often present without surface (sheet) erosion. Another condition for failure is that there must be a significant amount of material of a size which the initial flow of water could move to start the enlarging process. It has also been observed that vertical cracks in dispersive clay soils could enlarge by sloughing the upper walls into the lower reaches when water enters the crack, even though there was no flow through the crack (Steele, 1976).

Knowing now that dispersive clays are found in widespread geographic areas in our country, we can conclude that many small embankments were constructed of dispersive clays because at they were considered good clay soils for construction. The current practice for designing and building embankment and other structures, including the use of well-designed features and careful construction control are provided while working with dispersive soils. However, the successful use of dispersive clays requires their recognition and identification and, when used in embankments, appropriate engineering measures must be taken.

2.4 Identification of Dispersive Soils

In Ethiopia, dispersive soils exist in the rift valley, the southern and eastern lowlands, and Afar, Somali and Tigray regions. Isolated occurrences of these soils can also be found in other parts of the country. They are common in areas where pyroclastic deposits and weak sedimentary rocks outcrop. 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 annual rainfall of less than 850mm. dispersive soils have low natural fertility. Suspicion of their presence is indicated by the occurrence of erosion gullies and piping. (ERA manual, 2013).

Identification of dispersive soils should start with field reconnaissance investigations to determine if there are any surface indications such as unusual erosion patterns with tunnels and deep gullies, concurrent with excessive turbidity in any storage water. Although surface evidence can give a strong indication of dispersive soils, lack of such evidence does not in itself preclude the presence of dispersive clay at depth and further explorations should proceed. Dispersive clays cannot be identified by the standard laboratory index tests such as visual classification, grain size analysis, specific gravity or Atterberg limits and therefore other laboratory tests have been devised for this purpose. (ERA manual, 2013). Clay soils should be routinely tested for dispersive characteristics during the construction of structures where clay may be subjected to potential erosion and piping.

2.5 Laboratory Tests

The four laboratory tests most generally performed to identify dispersive clays are the crumb test, the double hydrometer test, the pinhole test, and the ESP (exchangeable sodium percentage) tests. The tests are most commonly used in the United States, Australia and South Africa. It is important that all soil specimens be maintained and tested at their natural water content since drying, especially oven drying, may alter dispersive characteristics (1976a; Sherard and Decker, 1977). To check dispersivity characteristic of soil it is prudent to perform all four tests on each soil sample.

2.5.1 The Crumb Test

The Emerson Crumb Test (Emerson, 1967) 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 consists of either preparing a cubical specimen of about 15 mm at natural water content or selecting a soil crumb at natural water content of about equal volume. The specimen 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. Results are interpreted at timed intervals and four grades of reaction are discernible: 1 - no reaction; 2 - slight reaction; 3 - moderate reaction; and 4 – strong reaction (colloidal cloud covering the entire bottom of the container). The following interpretive guide may be used to assess dispersive potential:

- No reaction: The crumb may slake and run out on the bottom of the beaker in a flat pile but there is no sign of cloudy water caused by colloids in suspension.
- Slight to moderate reaction: There is a bare hint to easily recognizable cloud of colloids in suspension. The colloids may be just at the surface of the crumb or spreading out in thin streaks on the bottom of the beaker.
- Strong reaction: The colloid cloud covers nearly the entire bottom of the beaker, usually in a very thin layer. In extreme cases, all the water in the beaker becomes cloudy.

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, the soil is most likely dispersive. The test procedure is

fully described in USBR 5400 and ASTM D-6572, Procedure for Determining Dispensability of Clayey Soils by the Crumb Test Method (Bureau of Reclamation, 1990).

2.5.2 The Double Hydrometer Test

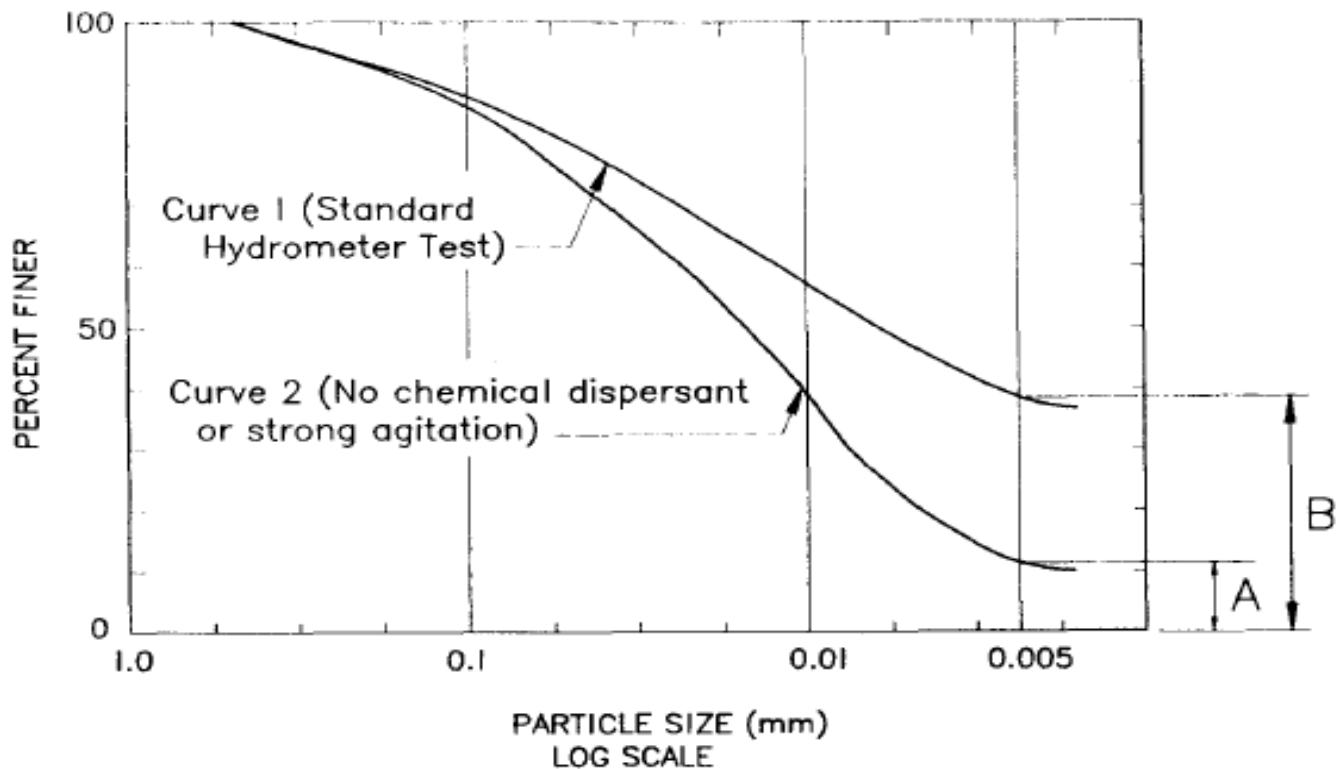
The SCS (Soil Conservation Service) laboratory dispersion test, also known as the double hydrometer test, is one of the first methods developed to assess dispersion of clay soils. The current test method was developed in 1937 from a procedure proposed by Volk (1937).

The sample will be transported to the laboratory in an airtight container to prevent moisture loss. Testing is performed on specimens 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 without a chemical dispersant. The "percent dispersion" is the ratio of the dry mass of particles smaller than 0.005-mm diameter of the second test to the first expressed as a percentage as shown on figure below. Procedures for performing the test are outlined in USBR 5405 and ASTM D-4221, Determining Dispensability of Clayey Soils by the Double Hydrometer Test Method (Bureau of Reclamation, 1990; Kinney, 1979).

Criteria for evaluating degree of dispersion using results from the double hydrometer test are:

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

Test results show that a dispersive soil will exhibit percent dispersion value of 30 percent and above when tested by this method (Sherard and Decker, 1977).



$$\text{DEFINITION: PERCENT DISPERSION} = \frac{A}{B} (100)$$

Figure 2-4: Percent dispersion as determined from the double hydrometer (from Sherard and Decker, 1977).

2.5.3 The Pinhole Test

The pinhole test was developed to directly measure disperseability of compacted fine-grained soils in which water is made to flow through a small hole in a soil specimen, where water flow through the pinhole simulates water flow through a crack or other concentrated leakage channel in the impervious core of soil mass. A 1.0-mm-diameter hole is punched or drilled through a 34-mm-diameter cylindrical soil specimen. Distilled water is percolated through the pinhole under heads of 50, 180, and 380 mm and the flow rate and effluent turbidity are recorded. The test was developed by Sherard et al. (1976a) and in the past few years it become a widely used physical test. It is important that the test be made on soil at its natural water content because drying may affect test results for some soils. If the material contains coarse sand or gravel particles, these should be removed by working the sample through a 2-mm sieve (U.S. Standard No. 10). The natural water content should be determined and the desired water content for compaction achieved by adding the

required amount of water (or by gradually air-drying, if too wet). All water added should be distilled water. Detailed test procedures are outlined in USBR 5410 and ASTM D-4647. Determining Dispersibility of Clayey Soils by the Pinhole Test Method (Bureau of Reclamation, 1990).

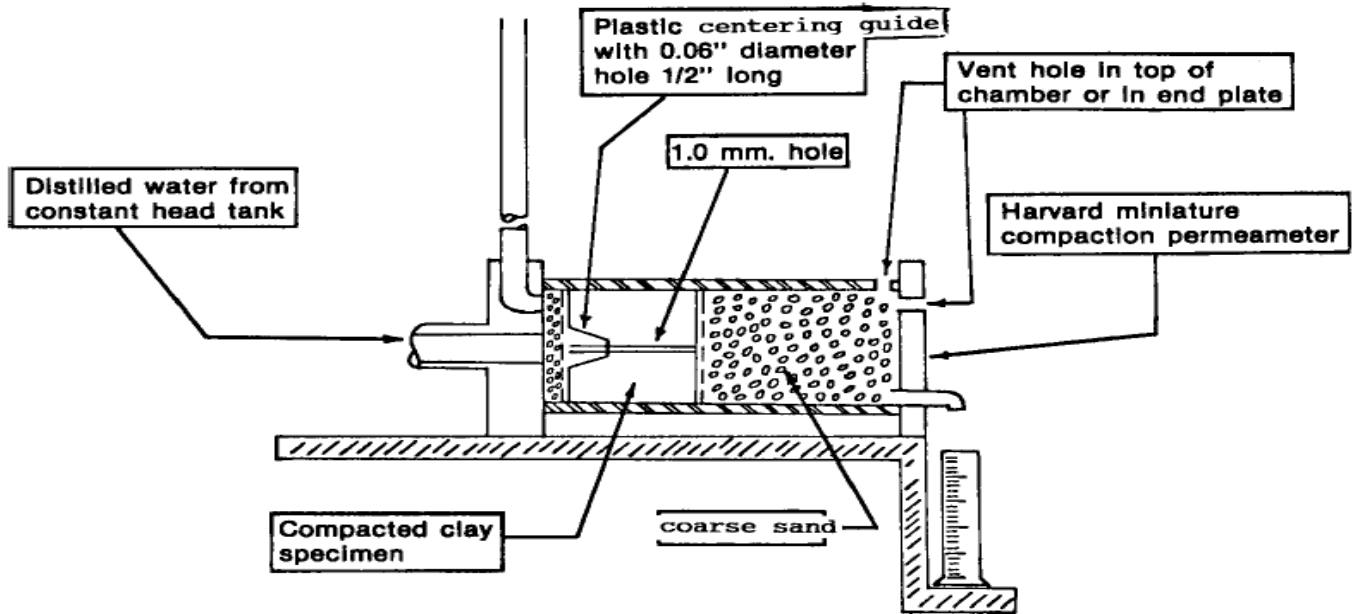


Figure 2-5: Schematic drawing of the pinhole test equipment (adapted from Sherard et al, 1776a)

Table 2-1: Summary of Criteria for Evaluating Results (Adapted from Sherard et al., 1976a)

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 slight	2x
ND4	50	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 2-2: categories of pinhole test results (Adapted from Sherard et al., 1976a)

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

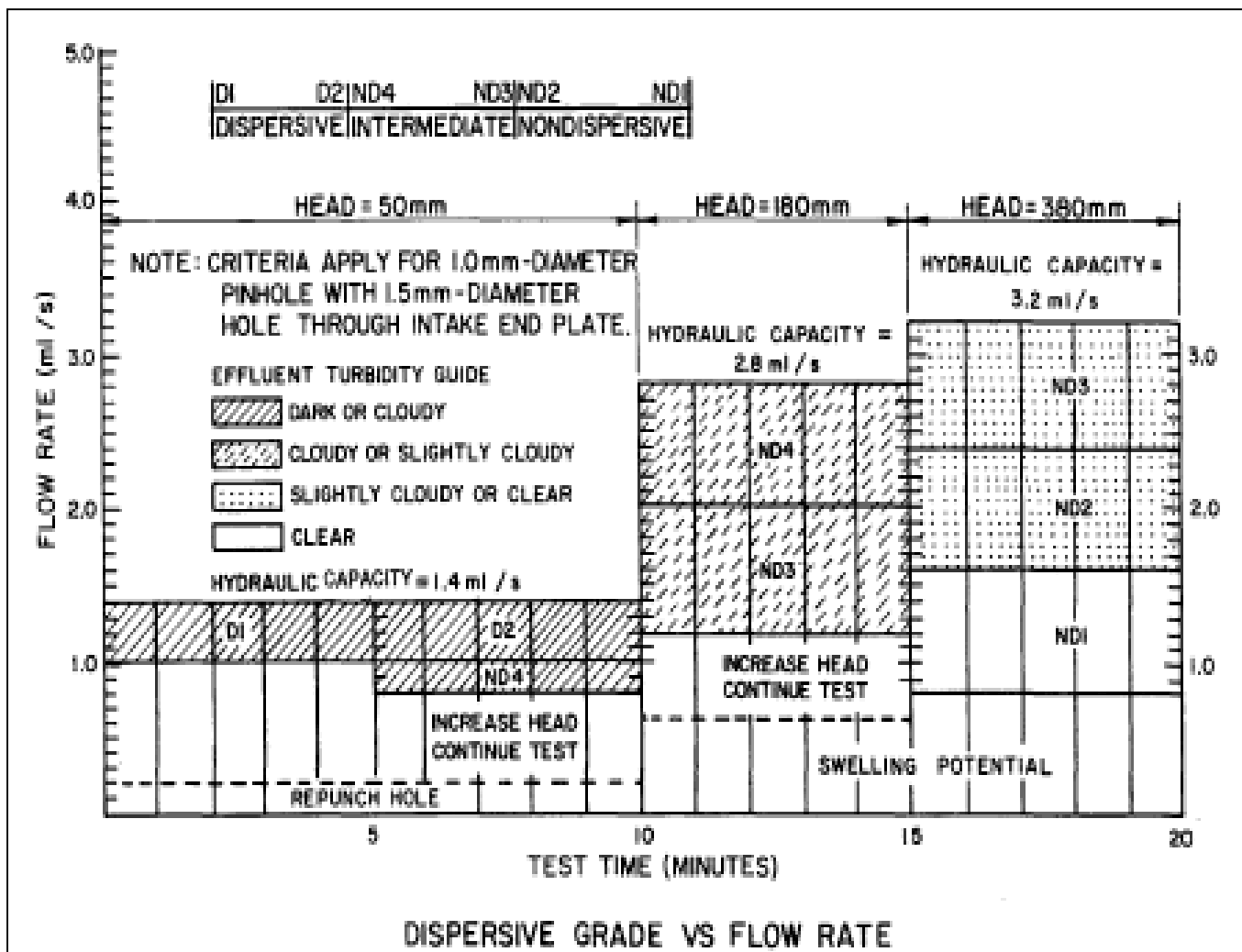


Figure 2-6: dispersive grade Vs flow rate (Adapted from ASTM D-4847)

Other indirect tests such as the crumb test, double hydrometer, and exchangeable sodium percentage are also used to help identify dispersive clays. However, results from the pinhole test is considered the most reliable since it is a direct physical test. It is emphasized

that all of the tests should be performed on each soil sample for the most complete information and most reliable identification.

2.5.4 Chemical Tests

Chemical analysis are carried out to determine the amount of sodium relative to other cations (calcium, magnesium, potassium) present in the soil sample and the pore water. Tests are run to determine the exchangeable cations on the clays as well as the cations in the saturation extract. From the laboratory results, the exchangeable sodium percentage (ESP) and cation exchange capacity (CEC) can be determined.

The presence of exchangeable sodium is main contributing chemical factor to dispersive clay behavior. The basic parameter to quantify this effect is ESP (exchangeable sodium percentage), where:

$$ESP = \frac{\text{Exchangable sodium}}{CEC (\text{cation exchange capacity})} * 100$$

Soils with ESP of 10 or above which are subject to having free salts leached by seepage or relatively pure water are classified as dispersive. Criteria which have been used to classify dispersive clays using ESP data are:

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

Elges (1985) identified the exchangeable sodium percentage (ESP) as the most reliable method of identifying dispersive clays based on work carried out by Harmse (1980) in which a combination of PH, conductivity, sodium Adsorption ratio (SAR), ESP and exchangeable magnesium percentage (EMgP) are employed (figure 2.7). This has been generally implemented in South Africa together with the pinhole test to classify dispersive soils.

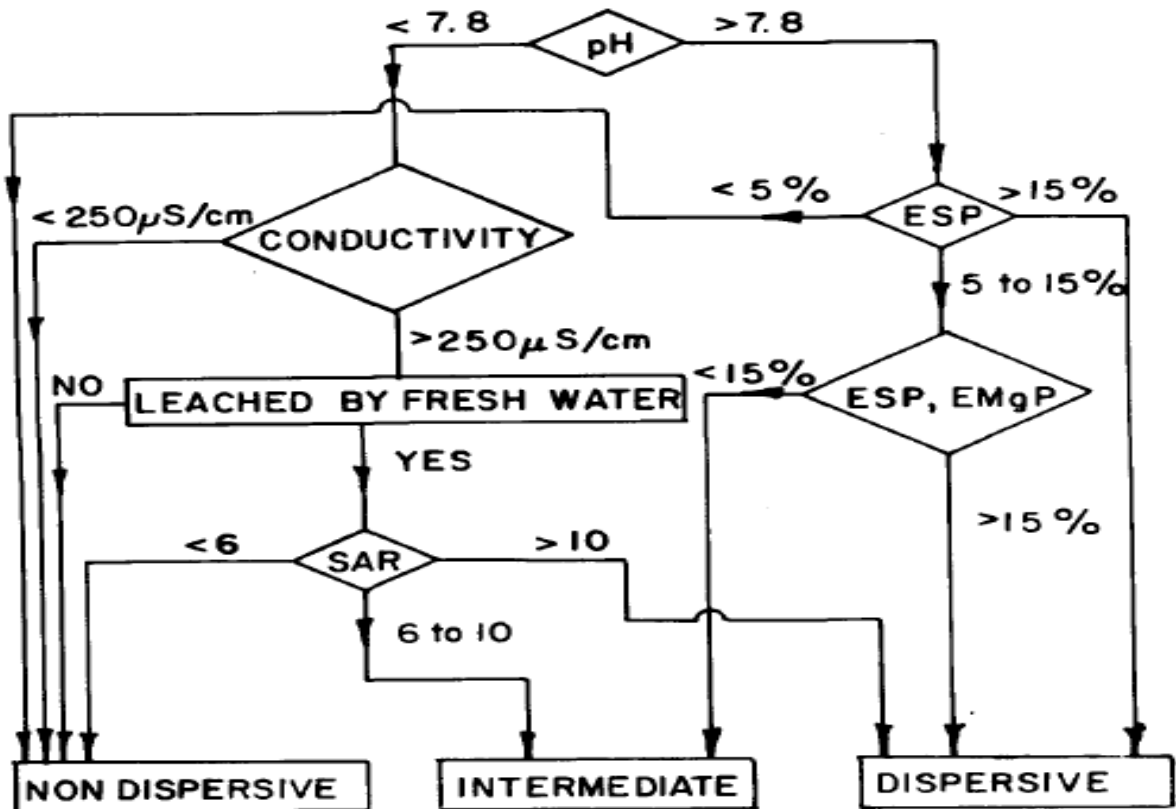


Figure 2-7: Dispersive potential evaluated from analysis of dissolved salts in pore water (Adapted from Harmse, 1980)

2.6 Using dispersive soils for railway embankment

As seen from different scholarly papers on dispersive soil road and railway embankments can be built with dispersive clay soil if certain precautions are taken. Several solutions have been suggested in order to lower the soil sensitivity to dispersion, or even prevent the internal erosion by the use of chemical stabilizers.

The presence of dispersive soils poses a risk to the stability of structures. In most construction works dispersive soils are not used for embankment constructions due to the fear that they will be eroded by water, and this made the work more difficult and expensive.

Most studies clearly show that dispersive soil will not be used in the construction of embankments due to their low resistance to water erosion. Dispersive soils were treated in the laboratory in order to improve their dispersion characteristics and increase their shear strength. Recycled gypsum was chosen as an additive in this research because it's locally

available and it is produced from demolished ceiling. There is an optimum content of recycled gypsum that gives a treated soil more resistant to dispersion.

In most failure of structures involving dispersive soils, failure of the embankment is usually the first indication of the presence of dispersive soils in the area. This illustrates the importance of early recognition and identification of dispersive soils. The problem caused by these soils can result in rapid, irreversible catastrophic failure of structures and topography. To avoid these problems, as well as the appropriate utilization of available construction materials, the possible presence of dispersive soils should be considered during the early stages of investigation. This is especially important if geological and surface evidence of possible dispersive soils exists. If the presence of dispersive soils is confirmed during the site investigation phase, decisions can be made regarding the use of alternative materials or treatment/stabilization of the dispersive soils if no other materials is available with a reasonable cost.

Although dispersive soils require special treatment when used in embankment construction, they may still constitute the most economic options for a specific situation. Sand filters can often seal and control leaks in dispersive clays. Sand filters act to prevent silt-sized particles from being carried along with the flow of water, which are then retained in the leakage channel and will subsequently seal off the leak. These filters, however, cannot prevent colloidal clay particles in suspension from passing through them.

Dispersive soils can be completely converted into non-dispersive soils by the addition of chemical modifiers such as hydrated lime (calcium hydroxide), gypsum (calcium sulfate) and alum (aluminum sulfate). These chemical are used as a calcium (or aluminum) source to replace sodium in the cation exchange complex reducing the distance between the clays considerably. The application of lime, gypsum or alum increases both the soil solution electrolyte concentration and the levels of exchangeable calcium in the soil. This, in turn reduces the inter-particle swelling pressures and hence the potential for dispersion. Lime is the most commonly used chemical modifier because it is more soluble and cost effective. Gypsum is generally more effective in reducing dispersive qualities of a soil due to higher electrolyte content. Elges (1985) states that in a laboratory, 0.2% of lime or gypsum by mass of clay is usually adequate. However, in construction a minimum of 2% is generally used in order to improve mixing and allow proper/uniform distribution through the soil.

When considering the construction of embankment in swampy areas with dispersive soils, four options of treatment should be studied. The first option is relocation from such area, which is not always the most practical alternative. The second option is lining protection, with the use of masonry. The third option is excavation and replacement with non-dispersive material and the last one is stabilization of the dispersive soil.

With regards to cuts and fills, if dispersive soils are exposed in cuts, the material would either need to be treated or removed so as to avoid erosion of the face. The soils can also be covered (Paige-Green, 2010).

For this research to cure the erosive nature of the sub grade soil and for using this soil for embankment construction stabilization of the soil with chemical stabilizer is used. Laboratory test results on the effect of addition of recycled gypsum to the soils are reported. This can easily be carried out in practice and responds positively and equally for both new and old constructions. The treatment results are shown using erosion tests: crumble test, pinhole test, double hydrometer and chemical tests. Adding a small percentage of gypsum slightly increases the soil strength and significantly reduces its dispersion.

2.7 Recycled Gypsum

Gypsum is the common name of hydrated calcium sulphate, which has the chemical formula $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. Gypsum is obtained in two ways, being either:

- mined from naturally-occurring deposits, or
- Obtained as a co-product from the manufacture of phosphoric acid.

Recycling of Gypsum can be made from three main types of gypsum waste based on their origin and are: -

- Gypsum waste from the manufacturing of gypsum products,
- Gypsum waste from new construction (primarily consists of off-cuts of plasterboard (drywall, wallboard or gyprock) when the boards have been cut to fit the dimensions of the wall or ceiling) and,

- Gypsum waste from demolition and reconstruction (This waste arises when already installed plasterboards (drywalls, wallboards or gyprock boards), that usually have been installed many years ago, are taken out in connection with that the building is demolished or renovated).

Gypsum is fully recyclable and, as a consequence, gypsum waste is one of the few construction materials for which closed loop recycling is possible. Closed loop recycling of gypsum products involves the collection and processing of the gypsum waste, and the delivery of the obtained recycled gypsum to the manufacturer of gypsum products. Gypsum waste can be turned into recycled gypsum by processing the gypsum waste in such a way that the contaminants are removed and the paper facing of the plasterboard is separated from the gypsum core through mechanical processes including grinding and sieving in specialized equipment.

Poor soil structure can be associated with high concentrations of sodium in the soil, compared to calcium. When soils with high exchangeable sodium are wet, the clay particles disperse, and the soil loses its defined structure resulting in the erosion of soil particles.

The structure of sodic soil can be improved by applying calcium compounds such as gypsum (calcium sulphate). As the gypsum dissolves, it releases calcium ions that displace sodium on the clay colloids.

CHAPTER 3 DATA COLLECTION AND SAMPLING AREA DESCRIPTION

During the survey stage of Adama – Welenchity railway segment sampling of the soil was undertaken and it has been tried to see the general condition of the sampling area.

3.1 Topography and Climate

At the starting point of Adama – Welenchity railway line on the LHS 1km offset Ignimbrite Rock Mountain exist, on the RHS a rolling train with frequent appearance of big gorge of erosion gullies, from this Ignimbrite rock section onwards till it reaches Welenchity town the terrain is rolling.

The elevation of the starting point is 1431m above sea level with a mean elevation of 1475m above sea level around the termination point.

The prominent rainy season locally known as “Kiremt” with highest erosion of the sub grade generally occurs from July to September. The mean annual temperature and rain fall obtained from National Metrological Service Agency from year 1981 – 2013 in Adama and Welenchity stations is shown in Table 3.1-3.3.

Table 3-1: Annual Temperature for Nazret year 1981 - 2013

Temperature (0C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	20	22	23	23	24	24	21	21	21	20	20	19
Maximum	31	33	32	34	34	33	30	28	31	31	31	31
Minimum	9	10	13	13	13	15	11	14	14	10	8	8

Table 3-2: Annual Rainfall for Nazret year 1981 - 2013

Rainfall (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	15	30	55	57	63	58	241	227	105	35	11	8
Maximum	73	184	167	183	260	152	509	344	192	165	70	51
Minimum	0	0	0	0	0	0	114	113	20	0	0	0

Table 3-3: Annual Rainfall for Welenchity year 1981 – 2013

Rainfall (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	13	34	66	67	51	52	194	226	82	30	11	9
Maximum	92	190	225	286	273	146	541	836	236	179	52	98
Minimum	0	0	0	0	0	0	69	93	8	0	0	0

3.2 Soil and Geology

As visually inspected almost the whole section of Adama – Welenchity sub grade is covered by grayish silty clay soil. As per the geological and soil maps of Ethiopia (Mengesh, 1990), the Adama – Welenchity section belongs to Dino formation (Qd) which includes (Ignimbrite, Tuff, coarse Pumice, water lain Pyroclastic rocks with rare intercalations of lacustrine sediments) and Nazret series (Nn) which includes (Ignimbrites, unwelded tuffs, ash flows, rhyolitic flows, domes and trachyte) formations.

As seen from the downstream side of existing Adama – Welenchity sub grade soil, thickness of the grayish silty clay soil exceeds 10meter.

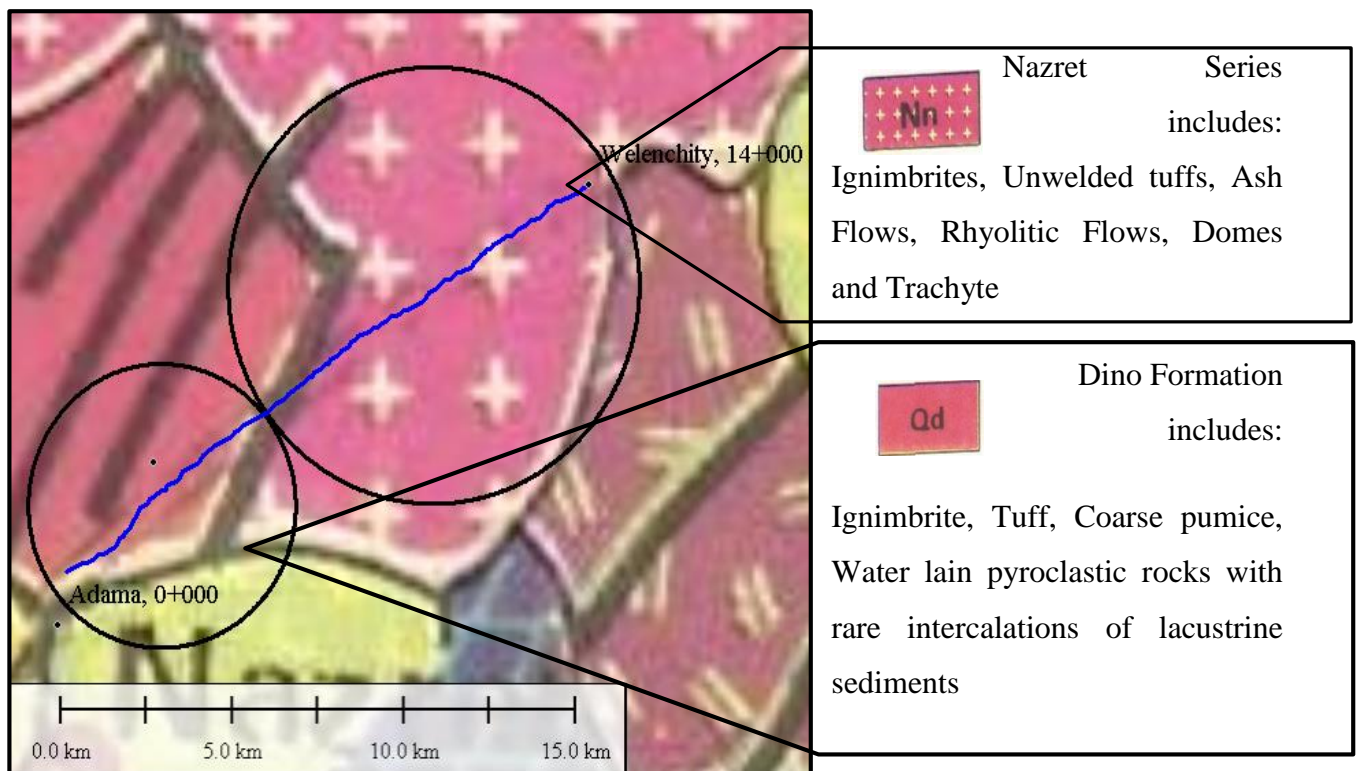


Figure 3-1: Geological and Soil Map of the Area Pilot Study Area

3.3 Soil sampling

Sampling of Adama – Welenchity silty clay soil was undertaken to know the property of the sub grade and also to suggest the best stabilization method to be adopted so that the soil will be used as a sub grade and embankment construction material.

10 sub grade soil samples of sub grade soil were brought from site. Sampling of the soil was undertaken 1meter below the natural ground level adjacent to the railway line. The upper 10cm of the sub grade is covered by silty sand, between 10cm and 70cm it is a volcanic ash cover, below 70cm the grayish silty clay soil encounters.

Sampling of the soil was undertaken adjacent to the railway line. The interior of the sampling bag was covered by plastic to preserve the natural moisture content of the soil.

A)



B)



Figure 3-2: erosion gullies on Adama – Welenchity route sections

- a) 5m width by 10m depth**
- b) 3.5m width by 5m depth**

CHAPTER 4 DISCUSSION AND ANALYSIS OF LABORATORY TEST RESULT

4.1 General

The soil and sediments around Adama town are highly susceptible to erosion. Simply avoiding the use of erodible materials is costly where alternatives are scarce. Constructing embankments to survive the cyclic wet season from material susceptible to erosion, is a major challenge. Dispersive materials can erode internally by the formation of pipes or tunnels. Piping erosion can be difficult to detect and can cause severe internal damage to embankments before being detected.

Embankments, channels and other areas are susceptible to severe erosion, when dispersive soils are used for construction. The erosion of clayey soil due to flow of rain water is a critical factor in long term performance of earth structures. When dispersive soils are used for embankment construction it becomes essential to test the erodability especially during conditions of high surface flow. Erosion of embankment can also manifest itself as the internal erosion which creates a progressive removal of soil particles along the internal pore channels termed as “piping”.

The dispersive nature of the soil minerals and its erodability can be assessed by a “pinhole test”. This comprises of measuring the rate of flow through a 1mm diameter hole in the test soil of standard dimension under specified condition. The erodability is decided based on increase in rate of flow and turbidity of the outflow. The dispersive soil can also have a low resistance to erosion and have low permeability in an intact state; hence in this chapter attempts which are made to alter this basic characteristic by stabilizing with suitable additives will be discussed. The effect of stabilization agents are studied through the, pinhole, double hydrometer, crumb test and chemical tests. The strength development taken place through the change in the microstructure and mineralogy of the soil has also been discussed.

4.2 Evaluation of Dispersiveness of the Soil before Stabilization

To check the extent/rate of dispersiveness of the Adama-Welenchity sub grade soil the samples were tested with the following dispersive soil identification laboratory tests. The tests are: -

- The pinhole test
- The crumb test
- The double hydrometer test and
- Chemical tests

These tests are commonly used in the United States, Australia, and South Africa as an identification test for dispersive soil. The laboratory tests undertaken to analyze dispersive soil of the route corridor are under taken in water works design and supervision enterprise, transport construction design Share Company and Beza consulting Engineers central laboratory.

4.2.1 Pinhole test

The pinhole test provides one of the most reliable method of identifying the dispersiveness characteristics of clay soils that are to be or have been used in earth structures construction. The piping failures of a number of homogeneous earth structures, erosion along canal banks, and rainfall erosion of embankments have been attributed to the colloidal erosion along cracks or other flow channels formed in masses of dispersive clay.

The pinhole test measures the erodibility/dispersibility of a compacted soil samples in which water is allowed to flow through a small hole punched through the center of the specimen. The test is generally considered in the literature to be one of the most reliable physical test to determine the dispersibility of soils since it simulates the action of water draining through a pipe/crack in the soil. The pinhole, which is punched through the center of the compacted sample, is 1mm in diameter and water flows through the sample at a heads of 50mm, 180mm, 380mm and 1020mm during testing (Sherard et al, 1976a). The flow rate, effluent turbidity and size of pinhole at the end of each test are the parameters recorded. If the effluent is highly turbid (murky) and the pinhole is enlarged, then the soil is classified as being dispersive. If the opposite is observed, i.e.: - the effluent is clear and the pinhole size remains unaltered, then the soil is considered non-dispersive. In some cases, the water may be clear but the pinhole could be severely enlarged, in which case erodibility but not depressiveness is indicated.

The pinhole test method is based on the guidelines described in ASTM D-4647. As stated in the ASTM manual, the test was developed for the direct measurement of the erodibility of fine grained soils, using the flow of water passing through a small hole in the specimen.

The main objective was also stated as being a reliable way of identifying dispersive soils. It should, however, be noted that all dispersive soils can be erodible but not all erodible soils are necessarily dispersive (Paige-Green, 2008).

The pinhole test procedure involves separating the material finer than 2mm and compacting it into a cylinder 34mm in diameter. According to the guidelines and test methods, the material is compacted at moisture contents at or close to the optimum moisture content obtained from the compaction test. The material is compacted in a cylinder on top of pea gravel and a wire screen. After compaction, a 1mm hole is punched through the center of the specimen and the remainder of the cylinder is filled with pea gravel. After the specimen is prepared and the apparatus assembled, water is percolated through the pinhole under heads of 50, 180 and 380mm for periods of 5- 10 minutes at each head. The quantity of flow and time at the different flow volumes is measured continuously and recorded on sheets. The turbidity of the effluent (color of the water) during the test is also recorded.

A pinhole test undertaken on the samples brought from site show that the sub grade soil is Dispersive. When tested at 50mm head after 10minutes the color of the effluent become dark with a flow rate of 1.2ml/sec and 1.4ml/sec for sample TP1 and TP4 respectively. The size of the pinhole was found to be >2x the original size for both samples.

Table 4-1: pinhole test result

Test no	Classification	Head (mm)	Time for Test	Rate of flow (ml/sec)	Color	Hole Dia. After test, mm
Test pit 1	D2	50	10	1.2	Distinct to slight	>2x
Test pit 4	D2	50	10	1.4	Distinct to slight	>2x



Figure 4-2: Diameter of the hole after the test



Figure 4-1: effluent color after 30 minute



Figure 4-3: leached soil at the front face

As seen from the test, the material samples which are compacted to undertake the pinhole test inside of the cylinder is seen to be leaching especially the one at the back and front side of the mesh. In addition to heavy erosion of the soil particles around punched hole there was also heavy erosion of soil particles around periphery of the cylinder. As per the pinhole test result the soil belongs to the D2 (dispersive soil) family which fails under 50mm head.

4.2.2 Double Hydrometer Test

The soil conservation service (SCS) double hydrometer test is one of the first methods developed to assess the dispersiveness of soils. The test assesses the dispersivity of soil by comparing the natural tendency of the clay fraction in the soil to go into suspension in water with an identical test in which conventional dispersants and mechanical breakdown are used. The procedure involves the determination of the percentage of particles in the soil that are finer than 0.005mm using the standard hydrometer test for particle size distribution. A parallel test is carried out, in which no chemical dispersant is added and the sample is not mechanically agitated. The quantity of particles finer than 0.005mm in the parallel test is expressed as a percentage of this fraction determined in the standard test, which is defined as the dispersion ratio or dispersivity of the soil (Elges, 1985). Soils having dispersion ratios greater than 50% are considered highly dispersive, between 30 and 50% are moderately dispersive and below 30% are non-dispersive (Elges 1985).

The table below summarizes the procedures carried out for hydrometer testing, focusing on the main aspects of the testing procedure. Main activities in testing samples using the hydrometer test for the determination of clay fraction of a soil as per ASTM D422-63

- Amount of dry soil required for test : Sandy 100gm
Silty/Clayey 50gm
- Pre-treatment : None
- Dispersant : 125ml sodium hexametaphosphate solution at 40gm/l
- Soaking : Sample soaked for minimum of 16hrs
- Dispersion : Disperse for 1 minute with a mechanical stirring apparatus
- Hydrometer readings : Taken at 2 min; 5min; 15min; 30min; 60min; 250min and 1440min
- Analysis : Equations used to calculate maximum diameter of particles in suspension (Stoke's Law)
- Temperature : Constant temperature at or near 200c is required

Most literatures indicate that during studies of dispersive soils the initial indicator of dispersivity of the material is generally classified on the basis of the double hydrometer test by means of various indicator graphs/plots. Most of the rating systems used currently in different literatures and South Africa manual seem to have been based on the initial classification of dispersiveness of materials by the double hydrometer test.

The charts below shows the double hydrometer test result obtained on the material samples

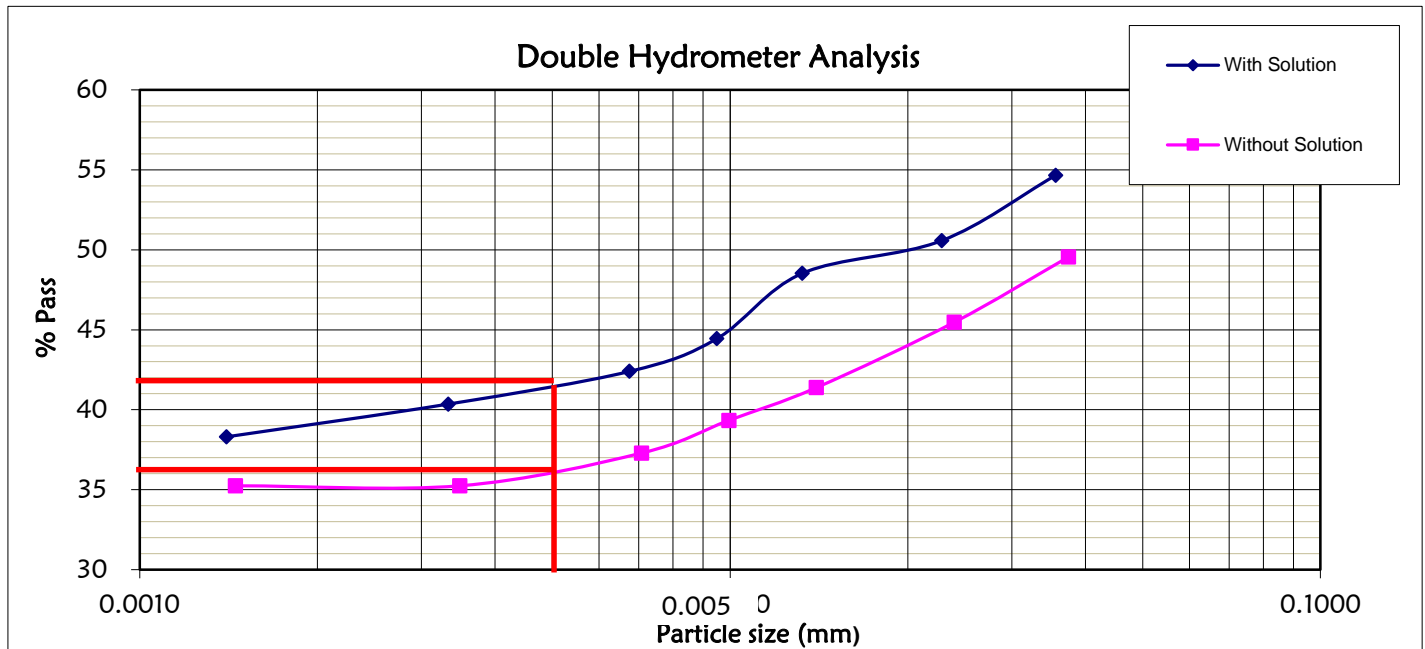


Figure 4-4: double hydrometer test result of TP-1

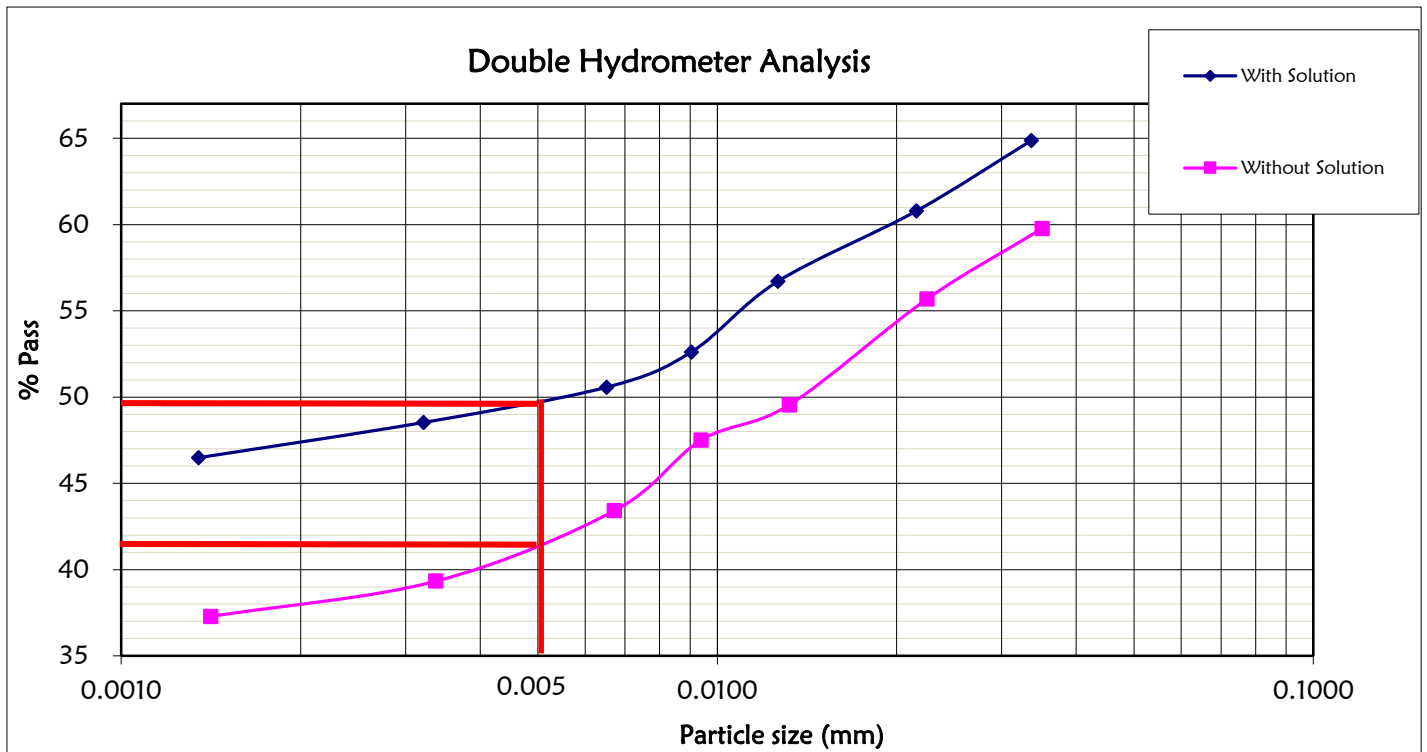


Figure 4-5: double hydrometer test result of TP-4

Remark: - the red line is used to show the percentage passing of 0.005mm sieve

As seen from the Double hydrometer test result the sub grade soil along the pilot study area is dominated by fine grained soil with more than 50% by weight of material pass the 0.075mm sieve. On test pit 1 the percentage by weight of material passing 0.075mm sieve is 61% and on test pit 4 the percentage by weight of material passing the 0.075mm sieve is 71%. And also the sub grade soil is dominated by high proportion of clay particles.

Summary of the test result of double hydrometer is shown in the table below: -

Table 4-2: double hydrometer test result

Material type	TP1 (percentage of different size of particles)	TP4 (percentage of different size of particles)
Particles larger than 2mm	0%	0%
coarse sand (2-0.425mm)	15%	6%
fine sand (0.425-0.075mm)	24%	23%
silt (0.075-0.002)	22%	24%
Clay (<0.002mm)	39%	47%

From the particle size analysis undertaken on the sub grade soil of Adama – Welenchity 61% (for TP1) and 71% (for TP4) of the soil belongs to the silt and clay size classification.

The amount of particles smaller than 5- μm determined without application of dispersion agent and mechanical agitation was compared with the total amount of particles smaller than 5- μm determined by applying of dispersion agent and mechanical agitation.

The percentage of material passing the 0.005mm sieve with and without the application of dispersing agent is 41.54 and 36.21% respectively for TP1 and 49.64 and 41.32% respectively for TP4. The percent dispersion value of the sub grade soil of TP1 and TP4 are as follow

$$\% \text{ Dispersion} = \frac{\% \text{ passing } 5\mu\text{m without dispersion aggent}}{\% \text{ passing } 5\mu\text{m with dispersion aggent}} * 100$$

$$\% \text{ Dispersion (TP1)} = \frac{36.21}{41.54} * 100 = 87.2\%$$

$$\% \text{ Dispersion (TP4)} = \frac{41.32}{49.64} * 100 = 83.24\%$$

Soil with % dispersion more than 50% are classified as dispersive soil. So, the Adama – Welenchity sub grade soil is classified as dispersive soil based up on the double hydrometer test result. The dispersive clay of Adama – Welenchity will normally deflocculates when exposed to water of low-salt concentration. The dispersive nature of the particles combined with its fine nature has contributed to erosive nature of the sub grade.

4.2.3 Crumb test

The crumb test is the simplest and easiest of the physical tests and is often used as a preliminary test to indicate the tendency of the particles to deflocculate in solution. The test, which can also be carried out in the field, involves inserting a crumb of soil in water in a beaker and observing the reaction as the crumb begins to hydrate. The test is primarily a visual assessment of the behavior of the soil in solution. After 10 minutes, the soil crumb and the solution in the beaker are observed and the soil is classified according to the quantity of colloids in suspension.

The method mostly followed currently, which can be carried out in the laboratory, involves placing a crumb of soil in a beaker of solution and observing the reaction as the crumb begins to hydrate.

As per ASTM D- 6572 results from the crumb test indicates that sub grade soil sample taken from TP1 and TP4 belongs to a dispersive soil of grade- 3. With a moderate reaction of an easily visible cloud with suspended clay colloids is seen around all of the outside soil crumb surface. The cloud extend up to 10mm (3/4 in.) away from the soil crumb mass along the bottom of the dish.

After 10 minutes most of the samples observed are classified as being dispersive. Settlement of the soil particles generally begins after approximately 15 minutes and the maximum settlement is attained after 2 hours.

4.2.4 Chemical Test Analyses

The chemical tests undertaken on the soil samples helped us to know the chemical composition and proportion of the clay minerals, especially the cation exchange capacity of the clay and the extent to which the clay is expected to be dispersive by analyzing the chemical composition. We have undertaken chemical analysis on the soil sample and found test result which shows the dispersive nature of the soil. The result obtained and their implication on the property of the soil is expressed here under.

4.2.4.1 Cation Exchange Capacity (CEC)

The surface of clay particles are negatively charged and as such are capable of storing positively charged ions and organic matters (i.e. cations Ca^{2+} , Mg^{2+} , Na^{+} , K^{+} , nitrogen and organic carbon). The cation exchange capacity (CEC) of a soil is the total sum of exchangeable cations and/or organic matter that it can adsorb at a specific PH. Cation exchange of exchangeable cations is reversible chemical reactions and is important in terms of soil dispersibility studies.

As seen from the test result cation exchange capacity of TP1 sub grade soil is 32.79meq/100gm. CEC is expressed in terms of either mill equivalents of adsorbed cations per one-hundred grams soil (meq/100g), or centimoles of charge per kilogram (cmol(+)/kg). CEC of a soil indirectly depends on the particle size of a soil, clay particles have high CEC values. As seen from the double hydrometer test result more than 61% of

the TP1 sub grade soil particles are clay and silt sizes. The high CEC value obtained is due to the high percentage of clay and silt size particles in the soil.

Inferences as to the clay minerals present in soil can therefore be made from the CEC. Generally it has been found that clay minerals exhibit a range of values of CEC as measured by the ammonium acetate method (cmol (+)/kg). As seen from the test result and the interface table below the clay mineralogy dominating the sub grade soil of TP1 is illite mineral.

Table 4-3: interface between clay mineralogy and CEC/ (Bolt and Bruggenwert, 1978)

Clay	Mineral	Gibbsite	Kaolinite	Illite and Chlorite	Smectite	Vermiculite
cmol(+)/kg	CEC	0-4	3-15	10-40	80-150	100-150

4.2.4.2 Exchangeable Sodium Percentage (ESP)

The presence of excessive amounts of exchangeable sodium reverses the process of aggregation and causes soil aggregates to disperse into their constituent individual soil particles. Deflocculation occurs because unlike the polyvalent cations of calcium and aluminum, sodium is monovalent.

A sodic soil contains a high level of sodium relative to the other exchangeable cations (i.e. calcium, magnesium and potassium). A soil is considered dispersive when the Exchangeable Sodium Percentage (ESP) is greater than 10%. The exchangeable sodium percentage (ESP) is calculated as follows:

$$ESP = \frac{Na}{\text{Cation Exchange Capacity (CEC)}} * 100$$

As seen from the test result on TP1 of Adama – Welenchity sub grade soil the sodium ion concentration is 10.47meq/100gm of soil. Exchangeable sodium percentage (ESP) value is obtained by dividing sodium ion concentration with cation exchange capacity of the soil and is found to be 31.93%. The sodic/dispersive soil of Adama – Welenchity

is highly susceptible to erosive soil loss during intense rainfall via erosion due to its high sodium percentage.

In order to counteract the effect of excessive sodium on the exchange complex and to reinitiate the process of soil aggregation, calcium needs to be reintroduced into soil solution. This is best achieved by the application of gypsum. This is because the calcium (Ca^{2+}) in gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) displaces sodium (Na^+) on the exchange site. In turn, the sodium reacts with sulfate (SO_4^{2-}) to form sodium sulfate (Na_2SO_4), which is a highly water soluble material that leaches from the soil.

The addition of gypsum leads to the removal of sodium and its replacement by calcium on the exchange sites, which reduces deflocculation and allows natural aggregation of particles that eventually, restores good soil structure. Gypsum is very useful when soil structure deteriorates because of high sodium. The detail of this process will be expressed in section which follows.

4.2.5 Summary

The dispersivity characteristics of Adama – Welenchity sub grade soil had been investigated by the four principal tests used for identification of dispersive soils. All the four tests shows that the existing sub grade soil is dispersive and susceptible to erosion. The physical interpretation of all the test results obtained and the root cause for those test results have been identified. Taking into consideration the test results obtained and the consistency between the tests, it can be said that the Adama – Welenchity sub grade soil is dispersive soil. The summary of the test results of each of the identification tests is as follows:

- Pinhole test: - D2 (dispersive soil)
- Double hydrometer test percent dispersion value:
TP1=87.17% and TP2=83.24%
- Crumb test: - dispersive soil of grade-3
- CEC: - 32.79meq/100gm
- ESP: - 31.93%

4.3 Stabilization of Dispersive Soil

Soil stabilization is a general term that involves the use of mechanical or chemical modifiers to enhance specific requirement of the soil. The process is often called soil modification when the purpose is to change the physical properties and thereby improve the quality of the subgrade soil (ERA geotechnical manual, 2013).

Relative to remediation of dispersivity of a soil, Gypsum from both natural and byproduct sources is the most effectively used amendment. Gypsum produces electrolytes and Ca ions upon dissolution which displace Na ions on the exchangeable complex. Chemically known as “calcium sulfate dihydrate,” gypsum contains calcium, sulfur bound to oxygen, and water.

Gypsum, in addition to prevention and being used as a correction measure for sodicity, will improve soil strength. Advantages of using gypsum as a stabilizer includes: -

- **Gypsum Improves Soil Structure**
Gypsum provides calcium which is needed to flocculate clays.
- **Gypsum Helps Reclaim Sodic Soils**
Where the exchangeable sodium percentage (ESP) of sodic soils is too high, it has to be decreased for soil improvement in its erosion behavior. The most economical way is to add gypsum which supplies calcium. The calcium replaces the sodium held on the clay-binding sites. The sodium can then be leached from the soil as sodium sulfate.
- **Gypsum Improves Water Runoff and Erosion**
Gypsum improves water infiltration rates into the soils.

One of the objective of this research was to improve the stability of dispersive soils of Adama – Welenchity by increasing infiltration rates and decreasing runoff and erosion. And to improve the natural soils so that it will be used for the construction of highway and railway embankments. To attain this goals the soil sample will be mixed with recycled gypsum.

4.3.1 Mixing Dispersive Soil with Gypsum

The dispersive soil of Adama – Welenchity has been mixed with recycled gypsum with a proportion of 1%, 3%, 5% and 7% by weight of soil. Sufficient quantity of the soil was prepared and made ready for mixing. Gypsum is added to the separately prepared soil samples with a proportion stated above and mixed with the soil thoroughly until the color of the mixture is uniform. The soil gypsum mixture is tested with dispersive soil identification tests expressed above and the decrease in dispersion by the application of different percentage of stabilizer is recorded and presented in the section which follows.



Figure 4-7: natural soil sample before mixing



Figure 4-6: mixing dispersive soil with gypsum

4.4 Evaluation of Dispersiveness of the Soil after Stabilization

The clay sample which was classified as dispersive after undertaking identification tests such as double hydrometer, pinhole, crumb and chemical tests, was mixed with different percentage amount of recycled gypsum taken from family trading gypsum producing factor to make the soil resistant to water erosion. In the natural state, the dispersion potential of the clay sample of TP1 was found to be 87.17 percent and it is classified as dispersive, as it is expressed in section 4.2.2.

The dispersion potential of the soil after chemical stabilization was determined by double hydrometer test. The optimum gypsum content was specified based upon the result of double hydrometer test. After specifying the required optimum gypsum content which will

make the dispersive soil resistant to erosion other dispersive soil identification tests have been undertaken. The detail of each test with their findings are shown in the section from 4.4.1 to 4.4.3.

4.4.1 Double Hydrometer test

The double hydrometer test was undertaken on the soil sample to check the dispersion property of the stabilized soil. The dispersive sub grade is stabilized with 1%, 3%, 5% and 7% by weight of soil with recycled gypsum. The percent dispersion value of stabilized soil was recorded and is shown in the Figure below; as seen from test results the percent dispersion of the soil decreases when the concentration of gypsum increases.

The optimum recycled gypsum content which make the dispersive soil resistant to erosion is 5 percent. The dispersion potential from using 5 percent recycled gypsum is 24.72% which is categorized as non-dispersive soil. The dispersion potential of the soil changes from 87.17% to 51.99 % with the addition of 1% recycled gypsum, when the gypsum content increments from 1% - 3% the dispersion potential of the soil decreases from 51.99% - 30.03% and it becomes on the margin between intermediate dispersive and non-dispersive soil categories. With the addition of 5% gypsum content the dispersion potential of the soil decreases to 24.72% and be categorized as non-dispersive soil. As seen from the figure below the dispersion potential of the soil decreases quickly during initial stages of gypsum applications. In the subsequent application of gypsum dispersive potential of soil decreases in less speed than the initial application stage. The optimum gypsum content in reducing dispersion potential of the soil and make it non-dispersive was 5 percent.

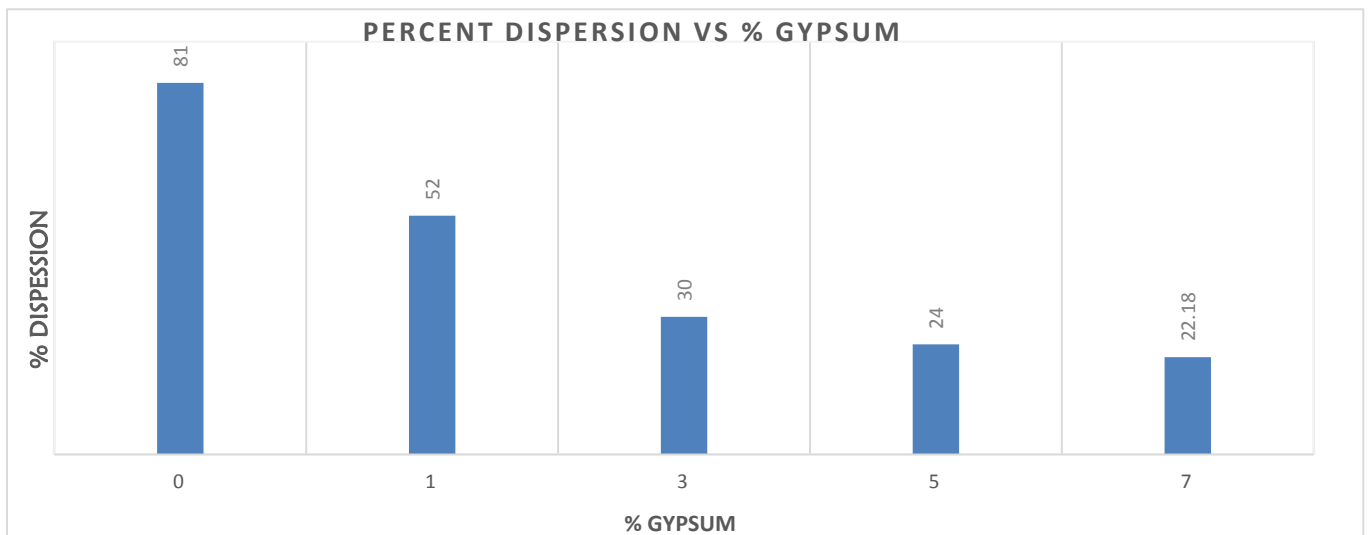


Figure 4-8: dispersion potential Vs % of gypsum



Figure 4-9: dispersion potential determination with different percentage of gypsum

4.4.2 Pinhole test

After the optimum gypsum content has been determined and fixed in the double hydrometer test, depressiveness characteristics of the soil at 5% gypsum content is checked using the pinhole test. In the pinhole test, the results were recorded in terms of cloudiness of flow, final flow rate, and erosion rate around the hole created in samples, with given hydraulic head. Summary of the result and, categorization of stabilized soil specimens are given in Table 4.5 below. The use of 5 percent gypsum has changed the designation of sample from D2 (dispersive soil category) to ND1 (non-dispersive soil category).

Table 4-4: pinhole test result after stabilization with 5% gypsum (TP-1)

Classification	Head (mm)	Time for Test	Rate of flow (ml/sec)	Color	Hole Dia. After test, mm
ND1	1020	5	1.9	Crystal clear	No erosion

The result of pinhole test carried out on samples stabilized with 5% gypsum, in terms of final flow rates, are given in Figures 4.10 below. When the flow is checked at a hydraulic head of 50mm the flow/discharge through the hole is below 1.2ml/sec, the stabilized soil

sample is then checked with a head of 180mm-380mm and flow through the hole is found to be below 2.5ml/sec. as per sherard and lock if the flow rate is below those specified for the above heads it should have to be checked at a head of 1020mm for non-dispersive soil categorization. When tested with 1020mm head the flow rate is 1.9ml/sec which will be categorized under non-dispersive soil category of ND1. As seen from the test result pinhole diameter remains the same with increasing gypsum percentage.

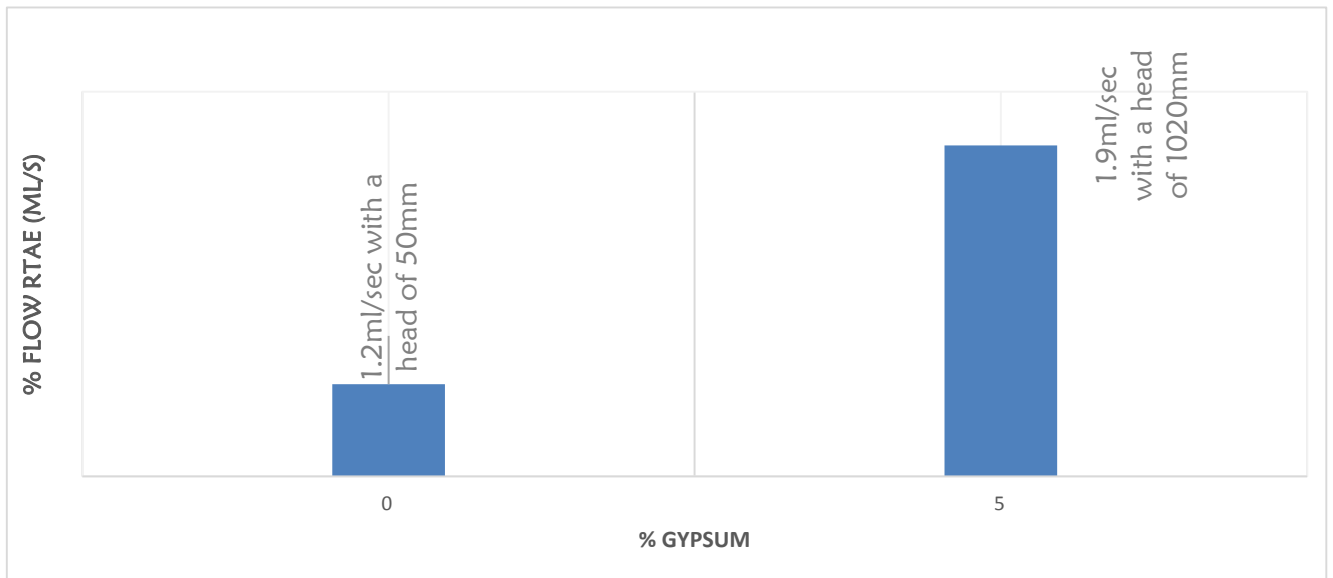


Figure 4-10: pinhole test result before and after stabilization with 5% gypsum

4.4.3 Chemical test

Chemical analysis test have been undertaken on the soil sample stabilized with 5% gypsum and it was found that the calcium ion concentration has been increased from 8.84meq/100gm to 17.31meq/100gm. The sodium ion concentration has decreased from 10.47meq/100gm to 2.1meq/100gm. The calcium ion from gypsum has displaced the sodium ion in the soil.

The method of dispersive soil stabilization with gypsum involve creating a flocculated soil structure. This was achieved by replacing monovalent cations (Na^+) on the clay surface with multivalent cations (Ca^{2+}). The manner in which cations are exchanged is explained by considering colloids that are in a solution. The adsorbed ions continually move back and forth (within a limited range) from the surface of the particles. If electrolytes are added to the solution, cations are set in random motion and some of them slip between the negative wall of the clay surface and the adsorbed/oscillating ions. These electrolytic cations then become preferentially adsorbed and some previously-oscillating surface ions

are released and remain in the solution as exchanged ions. The efficiency with which ions replace each other in a clay soil is dependent upon relative concentration or number of ions and number of charges on the ions.

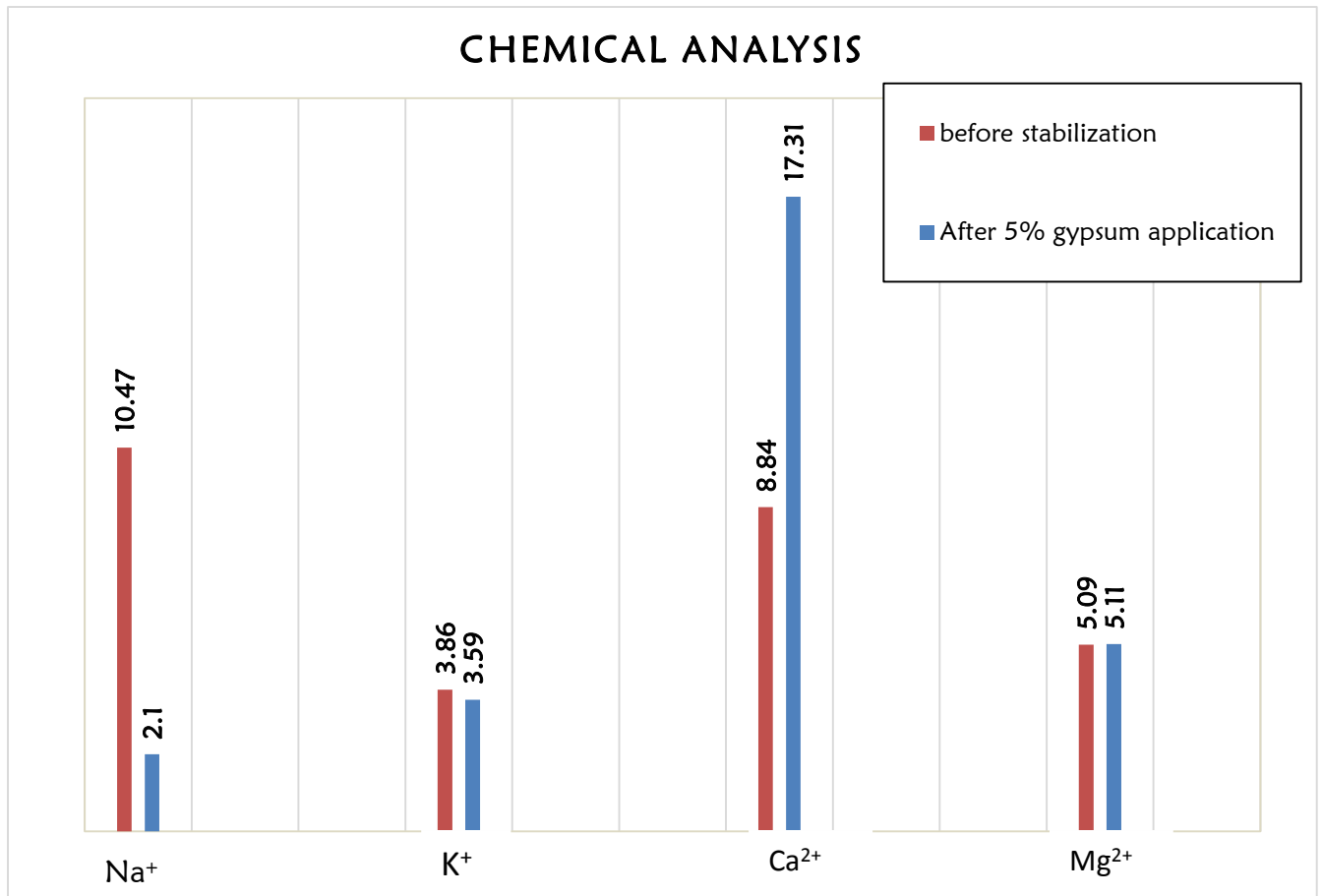


Figure 4-11: Chemical analysis test result before and after stabilization with 5% gypsum (TP-1)

The exchangeable sodium percentage of the dispersive sub grade soil decreases from 31.93% to 6.54% by stabilization with 5% gypsum. The chemical analysis test result shows the addition of 5% recycled gypsum will make the dispersive sub grade resistant to erosion and be categorized as non-dispersive soil.

The dispersive soil of Adama – Welenchity was made non dispersive by mixing the soil with 5% by weight of recycled gypsum. To use the stabilized soil for embankment construction purpose it should qualifies the specification requirements set for embankment. To check whether the sub grade soil qualifies the specification requirement of embankment construction materials index and strength properties have been checked and is presented in the section which follows.

4.5 Index and Strength Properties of Adama – Welenchity Dispersive Soil

4.5.1 General

The behavior of soils should have to be understood by conducting tests on physical attributes of the soil particle and soil aggregate constituents. The physical properties of soils which serve mainly for identification and classification purpose are commonly known as index properties which can be determined by simple laboratory tests.

The Adama – Welenchity sub grade soil had been tested with index property identification tests to check and see their engineering property. The tests which are done and explanations forwarded are as follow:

4.5.2 Plasticity Index of Soils

The plasticity of a soil is its ability to undergo deformation without cracking or fracturing. A plastic soil can be molded into various shapes when it is wet. Plasticity in soils is due to presence of clay minerals. The clay particles carry a negative charge on their surface. In contact with water clay particles are separated by layers of adsorbed water which allow them to slip over one another. When the soil is subjected to deformations, the particles do not return to their original positions, with the result that the deformations are plastic /irreversible, (Arora, 2000).

An indication of the nature of the material along any soil may be given by a variation in plasticity index (PI). The PI is influenced by the type and proportion of clay particles present within the material, and high PI values are often indications of the potential for expansion.

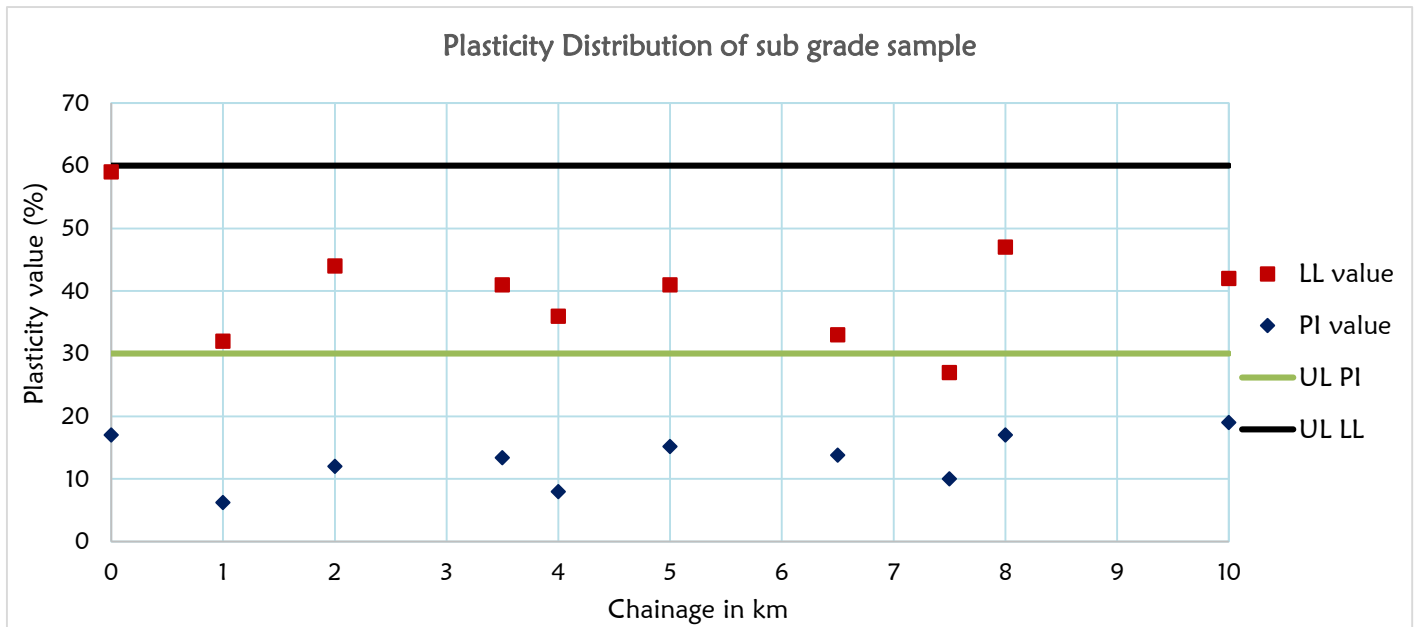


Figure 4-12: Plasticity Index and Liquid Limit Values on dispersive soils of Adama - Welenchity

The variation of PI along Adama – Welenchity dispersive sub grade soil is presented in the figure above which shows values ranging between 6% and 19%. In addition their liquid limit is in the range of 27% to 59%. As per ERA manual soil having a liquid limit exceeding 60% or a plasticity index exceeding 30 when determined in accordance with the requirements of AASHTO T-89 and T-90 are considered poor road bed foundations. As we can see from the above chart the sub grade soil have got a plasticity index and liquid limit value below the specified limits and is considered as suitable sub grade foundation. The values of PI plotted above have been corrected for their grading and the weighted values (PI_w) are given in the figure below.

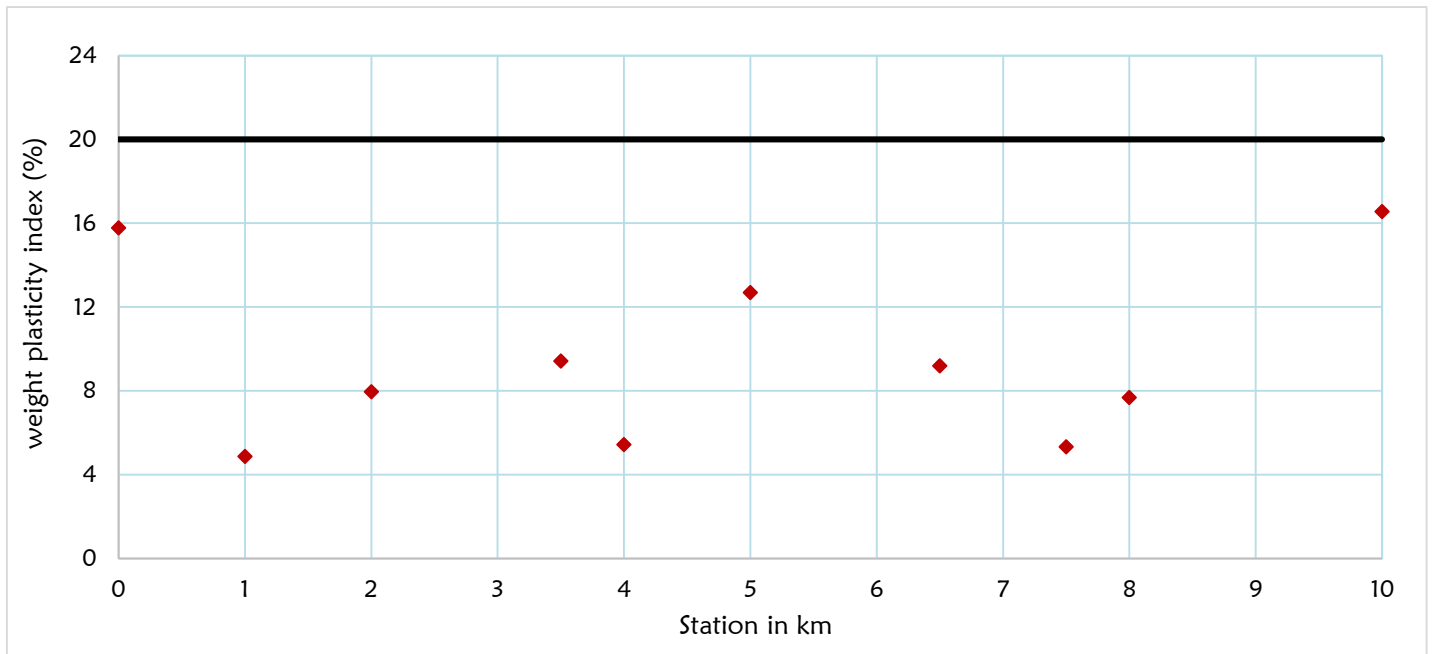


Figure 4-13: Weighted Plasticity Index Values on dispersive soil of Adama - Welenchity

The Ethiopian Roads Authority (ERA) Site Investigation Manual (2002) Chapter 5 notes that expansive soils are indicated by PIw values greater than 20 (indicated by the straight line on the Figure above). As shown on the figure above the weighted plasticity index value of the dispersive soil stretch is below 20 and is considered as non-expansive as per ERA manual. The correlation between Atterberg limits and the presence of clay minerals is strongly positive. It also seems that the finer the particle sizes within the clay the greater the potential for swell (due to a larger surface area).

The plasticity chart on the figure below helps to classify the type of soils based on their plasticity characteristics (i.e. Atterberg Limits and Indices of soils). Generally materials falling above the A-Line are classified as clays and below the A-Line are classified as silts. The line labelled “A” above a liquid limit of 50 separates soils of high plasticity, or clays (above line), from silts, (below line). At liquid limits less than 50, line “A” separates soils of medium plasticity clay (above line) from soils of medium plasticity silt (below “A” line). Using this graph, critical lower limits of liquid limit and plasticity index can be ascertained. Soils that have high or very high shrinkage and swell potential and compressibility would have liquid limits greater than 50. Soils with moderate to low

shrink-swell potential and compressibility have liquid limits ranging below 50 (Arora, 2000).

As seen from the chart below majority of the dispersive sub grade soil samples of Adama - Welenchity belongs to CL (inorganic clay of low to medium plasticity) and ML (inorganic silts of low plasticity) family of USC soil classification system. The general behavior of this soil groups is expressed here under

Table 4-5: properties of the CL soil group (Arora, 2000)

Station (km)		Soil Group	Permiability	Compresebility	Shear Strength	Workability
From	To					
0	10	ML, CL (medium & low) plasticity silt & clays	Medium	Fair	Fair	Fair and good to fair respectively

As seen from the table above the dispersive sub grade soil is grouped under fair and good to fair soil classification system from Atterberg limit point of view. An indication as to the nature of the soil may be given by the variation in Plasticity Index (PI). The plasticity chart of sub grade soil is presented in Figure below.

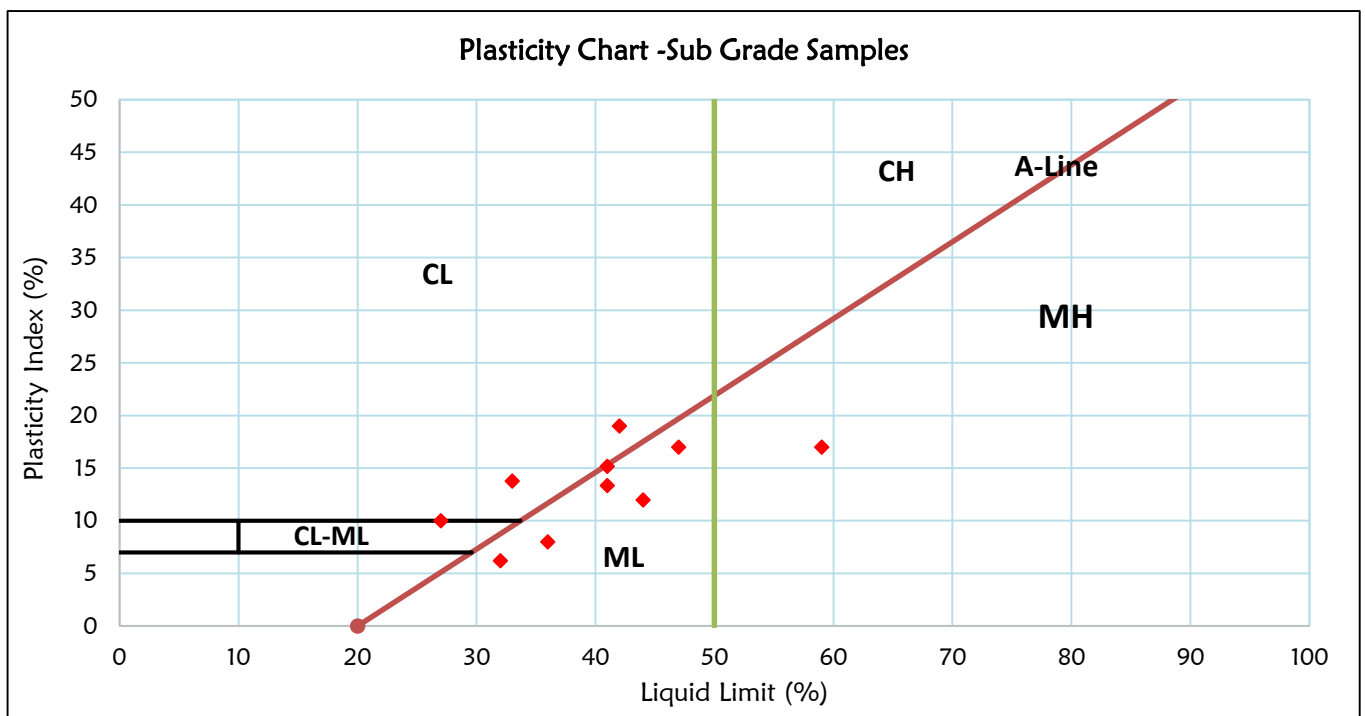


Figure 4-14: Plasticity Chart of the Subgrade

The Atterberg limit provide a means of determining the standard of performance and level of sensitivity to volumetric change due to moisture influx.

4.5.3 Classification Grading

Particle Size Distribution (Grading) tests have been carried out on samples recovered from the trial pits. The results are summarized on the Figure below in terms of the percentage of silt and clay (<0.075 mm), the percentage fine and medium sand (0.075-0.425 mm), percentage coarse sand (2-0.425), and gravel (2-75).

From the particle size distribution curve the dispersive soil is highly dominated by silt and clay fractions of more than 65% on average. However, the sand and coarse particle fraction is below 35%. The dispersive sub grade soil is classified as fine grained in both AASHTO and USCS soil classification system.

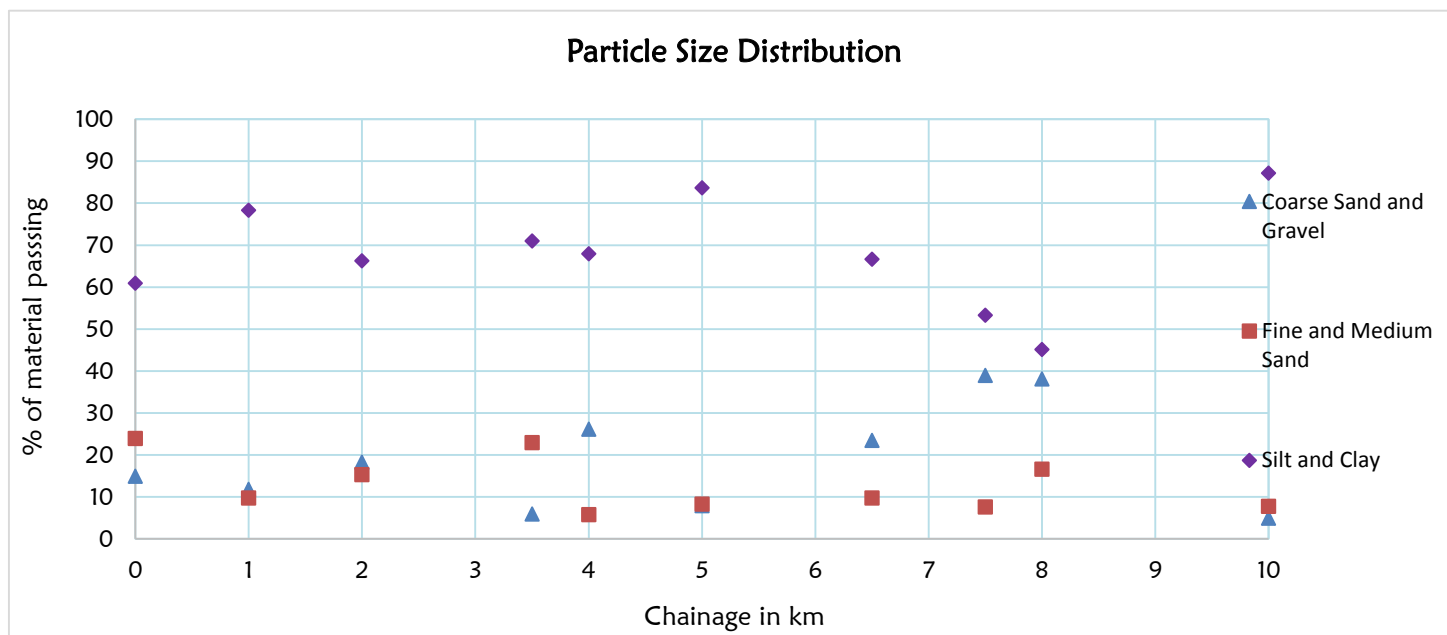


Figure 4-15: Particle Size Distribution of Sub grade Soils along the road alignment

4.5.4 Sub Grade Strength

Moisture – Density Relationship

The moisture content and density relationship (AASHTO T99 or T180) for a soil is a critical factor affecting strength and deformation properties of any prepared soil. Careful laboratory testing to establish this relationship is critical for its use in specifications to ensure adequate quality control of the material used in construction and to provide the desired structural capacity in the roadbed by attaining the maximum density. The

laboratory data is critical for accurately monitoring a project during construction and for knowing the compacted density at all times. This importance extends beyond design requirements to determining density and moisture values of the roadbed material anytime rehabilitation is planned because these values will exhibit seasonal variation.

A proctor compaction curve indicates maximum density and optimum moisture content which are the two principal output values from this test. It must be remembered that each soil have an individual relationship of moisture and maximum dry density that must be established in the laboratory. The moisture density state of a compacted soil affects the strength and deformation characteristics of the soil in the track structure which is related to its structural adequacy.

Soil samples obtained from test pits have been compacted in the laboratory at various moisture contents to derive a dry density versus moisture content relationship. Compaction was carried out according to AASHTO T180 on samples recovered from the test pits. The Maximum Dry Density (MDD) obtained from laboratory tests is summarized in Figure below:

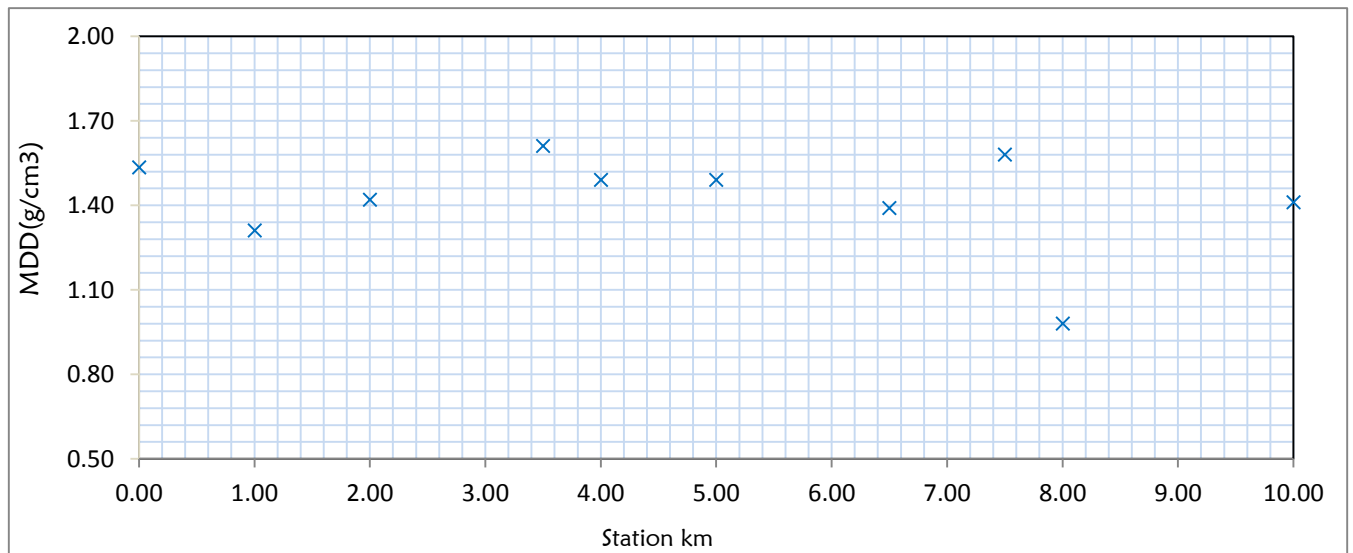


Figure 4-16: Variation of Maximum Dry Density along the route (T180 Compaction)

As expressed in ERA and other manuals the relationship of density and moisture content is specific to the nature of the subgrade soil. As the moisture content increases at constant density the CBR decreases quite quickly. If the soil becomes saturated, i.e. the air voids become filled with water and decrease to zero, the soil becomes very weak indeed.

The moisture content is adjusted during construction in order to make it easier to achieve a high level of compaction. Upon completion of the construction operations, the density of the compacted subgrade soil will remain approximately the same except for some residual compaction under traffic and possible volume variations of certain moisture sensitive soils. However the moisture content of the subgrade will change, depending on climate, soil properties, depth of water table, rainfall and drainage. It is knowledge of this condition of the subgrade that is required in the design process. The dispersive soil of Adama – Welenchity have got OMC value between 15 - 31%. The values of Optimum Moisture Content (OMC) obtained from the compaction tests are presented in the Figure below.

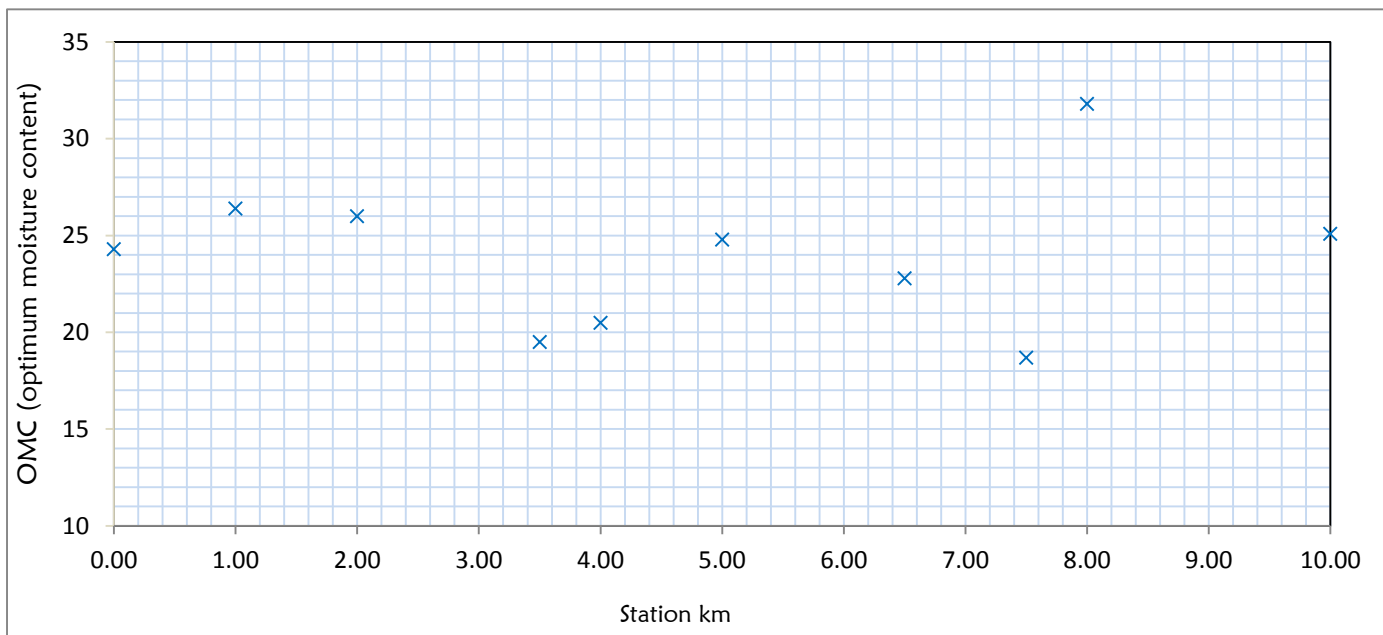


Figure 4-17: Variation of Optimum Moisture Content (T180) along the road

California bearing ratio

Soaked CBR test was carried out on disturbed samples of soil recovered from trial pits on the dispersive soil of Adama – Welenchity to determine the shear strength of the subgrade material.

Three-point CBR test (i.e., 10, 30 and 65 blows of the hammer) was undertaken in accordance with AASHTO T-193. This form of testing is preferred as it can give information of the variation of strength that can be developed with increasing compactive

effort. The stronger the sub grade (the higher the CBR reading) the less thick it is necessary to design and construct the railway track structure and road pavement, this gives considerable cost saving. Conversely if CBR test indicates the sub grade is weak (a low CBR reading) we must construct a suitable thicker track structure and road pavement to spread the axle/wheel load over a greater area of the weak sub grade in order that the weak sub grade material is not deformed, causing the track structure/road pavement to fail.

CBR-swell values are determined on disturbed samples of soil recovered from trial pits of dispersive soil to evaluate potential to heave of the material. The dispersive soil have got a CBR swell value of below 2%, which is categorized as good foundation material as per ERA manual.

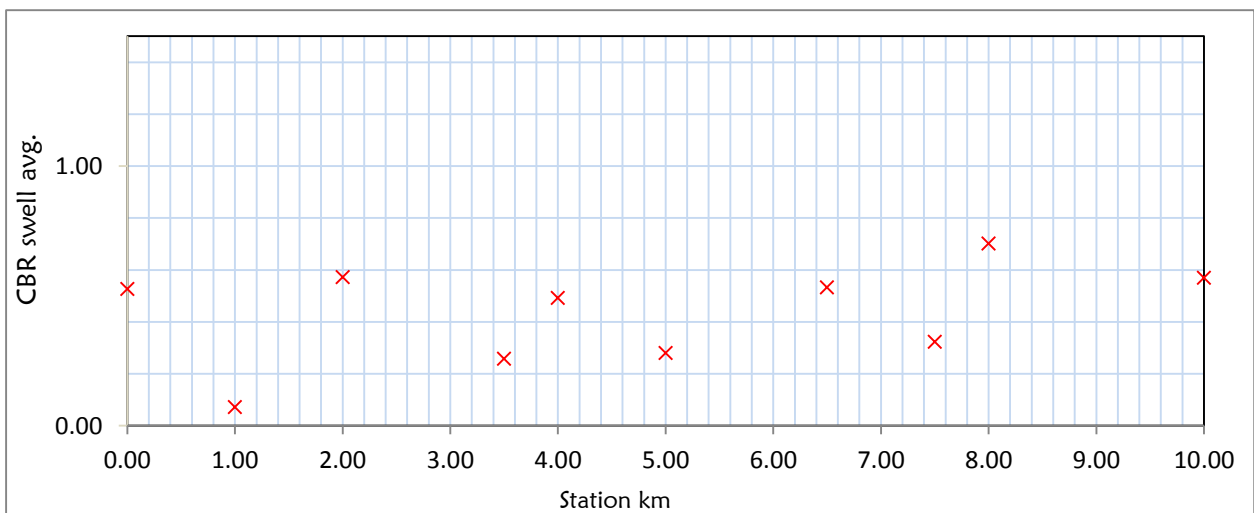


Figure 4-18: Variation of CBR swell along the alignment

The dispersive sub grade soil have got an average CBR value of 21. The minimum CBR value obtained is 9. The sub grade soil along Adama – Welenchity have good CBR and low CBR swell.

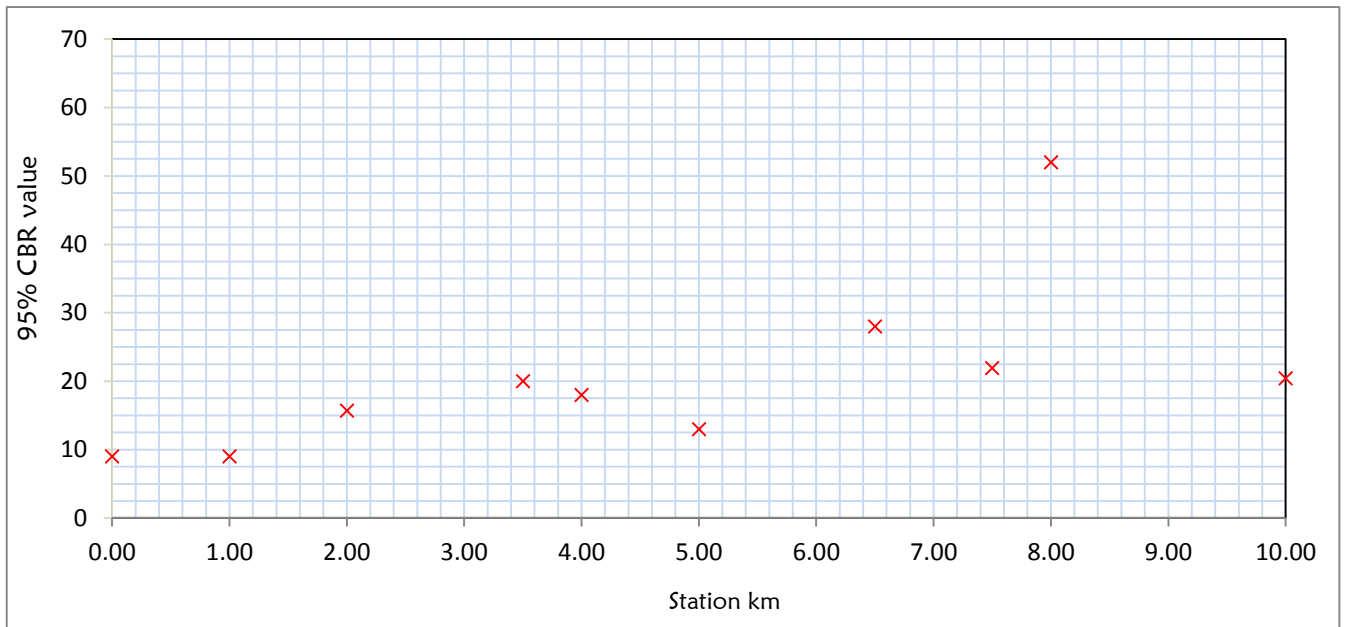


Figure 4-19: Variation of CBR along the alignment

To sum up; according to different manuals and as it can be observed from the laboratory test result analysis made above; the natural dispersive soil of Adama – Welenchity sub grade material have got good CBR and plasticity values which qualifies the specification for embankment and road bed soil. The only drawback while using this dispersive soil was its susceptibility to erosion when it is in contact with rainfall water. As expressed previously by addition of 5% recycled gypsum we can make the soil to be non-dispersive and be used for the construction of railway and/ road embankment construction. The detail laboratory test results are presented as a standalone document in Annex of this report.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based upon the existing reality of Adama – Welenchity pilot stretch area and test result analysis the following conclusions can be drawn:

- Dispersive soil identification tests indicated that the sub grade soil of Adama – Welenchity area is dispersive having high concentration of sodium ion inside of the diffusion double layer. The average value of identification test results before the soil is stabilized with recycled gypsum are: -
 - ✓ Pinhole test: - D2 (dispersive soil)
 - ✓ Double hydrometer test percent dispersion value:
TP1=87.17% and TP2=83.24%
 - ✓ Crumb test: - dispersive soil of grade-3
 - ✓ CEC: - 32.79meq/100gm
 - ✓ ESP: - 31.93%
- As seen from engineering index and strength tests carried out on the soil sample the dispersive soils have got good CBR and PI value which qualifies the specification requirement of embankment.
- The PI value of the dispersive soils is below 25% with majority of the samples test have got a PI value below 20%
- From the gradation charts and the soil classifications made, Adama – Welenchity soil is a fine-grained soil
- The A-line indicates that the sub grade soil belongs to CL (inorganic clay of low to medium plasticity) and ML (inorganic silts of low plasticity) group of Unified Soil Classification system.
- The CBR swell value obtained on the soil group is below 2%. Low CBR swell and Low plasticity values shows the low expansive nature of the soil.

- The average CBR value obtained on the samples recovered from the trial pits is more than 21%. This shows that the sub grade soil have got good shear strength value.
- The dispersive soil was mixed with different percentages of recycled gypsum (1%, 3%, 5% and 7%). As seen from the test result 5% gypsum content provide the flocculated structure which makes the soil to be categorized as non-dispersive. The identification test results obtained with 5% application of recycled gypsum are: -

- ✓ Pinhole test result – ND1 (non-dispersive soil)
- ✓ Crumb test result – non-dispersive soil
- ✓ Double hydrometer test result (% dispersion) – 24.72%
- ✓ CEC: - 32.09meq/100gm
- ✓ ESP: - 6.54%

As seen from the test result the investigated soil become non – dispersive with the application of 5% recycled gypsum.

- With a 5% application of recycled gypsum, the soil can be used for railway and road embankment construction. It qualifies embankment construction material specification for road and railway lines.

5.2 Recommendations

- The result obtained will be used as a basis for further research in the area of dispersive soil
- A research has to be undertaken in using dispersive soil by stabilizing with other cost effective stabilizations materials.
- The tests used to identify dispersivity behavior specially the pinhole test is available in few institution. It should have to be available in the Addis Ababa Institute of Technology Laboratory to initiate those who are working in this soil.

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APPENDIX A