Effect of Heat on the Properties of Expansive Soils

Denkayehu Nega Bashaw

A Thesis Submitted to the Department of Civil Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfilment of the Requirement for the Degree of Master's in Geotechnical Engineering

Office of Graduate Studies

Adama Science and Technology University

September 2023

Adama, Ethiopia

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Declaration

I hereby declare that this Master Thesis entitled "Effect of Heat on the Properties of Expansive Soils" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

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I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "Effect of Heat on the Properties of Expansive Soils" prepared under my/our guidance by Denkayehu Nega Bashaw submitted in partial fulfilment of the requirements for the degree of Mater's of Science in Geotechnical Engineering. Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

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Approval Page

I/we, the advisors of the thesis entitled "Effect of Heat on the Properties of Expansive Soils" and developed by Denkayehu Nega Bashaw, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by Denkayehu Nega Bashaw have read and evaluated the thesis entitled "Effect of Heat on the Properties of Expansive Soils" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Geotechnical Engineering.

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ABSTRACT

Expansive soils, known for having negative effects on construction projects, create difficulties due to their unpredictable volume fluctuations in reaction to moisture variations. The issues these soils present cannot always be solved by using conventional soil stabilizing techniques.

The primary objective of this research entitled The Effect of Heat Treatment on the Properties of Expansive Soils was to examine the viability of adopting heat treatment as a novel method to improve the engineering properties of expansive soils. It aims to produce mineralogical modifications and positive physical behaviour improvements that reduce swelling and shrinking and improve load bearing property by submitting soil samples to regulated heat treatment.

The employed methodology involves laboratory experiments encompassing soil sample collection, controlled heat treatment using digital thermostat furnace with temperatures ranging from 100°C to 600°C for a duration of one hour. These tests cover Free Swell, Linear Shrinkage, Sieve Analysis, Atterberg Limits, Compaction tests and CBR . Data analysis and optimization was followed to establish relationships between treatment parameters and property enhancements.

The results of the study indicate that heat treatment can actually improve the engineering properties of expansive soils by decreasing plasticity and swelling properties and increasing density and CBR. In this particular study, most of the improvements were achieved at a temperature of 500°C.

***Key Words:* Expansive soils, Heat treatment, Engineering properties, Plasticity, Swelling , Soil stabilization, Mineralogical alterations**

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CHAPTER 1

1 INTRODUCTION

This research was conducted to examine the effect of heat treatment to improve the engineering qualities of expansive soils. It is thought that by subjecting these soils to carefully regulated heat settings, mineralogical modifications and changes in physical behaviour can be achieved, lessening the difficulties brought on by swelling and shrinkage. The study looked at how heat treatment affects expansive soils' particle size distribution, plasticity, free swell, specific gravity, compaction and CBR characteristics.

1.1 Background

Due to their peculiar behaviour of undergoing considerable volume changes in reaction to changes in moisture content, expansive soils, provide an enduring geotechnical difficulty in the building industry (Yariv, 1975) These clay-based soil types are distinguished by their capacity to expand when exposed to moisture and contract when dried out. Cracks, settlements, and structural failures can result from such volume variations, which can also cause catastrophic damage to infrastructure such as buildings, roads, pipelines, and retaining walls. Expansive soils are quite common around the world, which makes them a serious safety issue for construction projects as well as a financial one in terms of maintenance and repair expenses.

Clay minerals, which are found in various mineralogical groups, make up the majority of the minerals in expansive soils. Montmorillonite, illite, smectite, bentonite, beidellite, vermiculite, attapulgite, nontronite, and chlorite are some of the most prevalent varieties of expansive clays. These clays' expanding behaviour is influenced by unique chemical and mineralogical properties that each of them exhibits.

Tests to identify expansive clays include mineralogical tests, indirect tests and direct measurements. For practicing engineers only direct measurements such as index properties is relevant and hence this research used the direct measurements to measure the index and engineering properties of the expansive clay sample

Some of the common methods of stabilization of expansive soils include chemical stabilization (treating with cement, commercially manufactured chemicals, etc), physical stabilization (blending with non-expansive soils, fly ash, slag, and undercutting and replacement) and moisture barriers (fill blanketing, etc).

All of these methods have benefits and drawbacks, but they all provide solutions to the problems that expansive soils provide. As a substitute strategy to enhance the engineering properties of expansive soils, the development of novel and sustainable methods for stabilizing soil, such as heat treatment, has attracted attention. The goal of heat treatment is to alter the physical behaviour of soils and produce mineralogical changes that will lessen their propensity for swelling and shrinkage. This is accomplished by exposing soil samples to regulated temperature settings.

Studies looking into how well heat treatment works on expansive soils have shown encouraging findings. However, there are still issues with the thorough evaluation of its impacts on a variety of engineering properties and the optimization of treatment parameters for diverse soil types. By performing a comprehensive analysis of the effects of heat treatment on the engineering characteristics of expansive soils and figuring out the ideal circumstances for maximizing property enhancement, this research sought to close these gaps.

Insights into the mechanisms underpinning heat treatment's impacts on expansive soils is provided by this research, which is likely to advance the area of geotechnical engineering. The findings of this study could revolutionize present construction techniques and provide workable answers to the ongoing problems faced by expansive soils in infrastructure projects.

Previous researches on the effect of heat treatment on the properties of expansive soils showed that heat induces mineralogical changes within these soils which resulted in appreciable improvements in engineering properties. (Kantheti N V K Hanuma, Dr. D.S.V.Prasad, June -2017)

1.2 Statement of the Problem:

Expansive soils, which are known for their propensity to significantly increase in volume in reaction to moisture fluctuations, present considerable challenges to the construction sector. These soils, often referred to as shrink-swell soils, are well known for undermining foundations, pavements, and buildings due to their unpredictable nature. (Chijioke Christopher Ikeagwuani, 2019)The expansion and contraction of these soils can result in cracks, settlements, and other structural issues, which can be very expensive to maintain and repair.

Innovative solutions are required to solve this enduring issue since conventional soil stabilization techniques fall short in their ability to effectively mitigate the negative consequences of expansive soils. Especially , for road construction projects where suitable replacement borrow material or other soil improvement materials are not found within an economical hauling distance this becomes even more relevant.

Moreover, undercutting and replacement of the expansive soil, which is the common method of treatment in road construction projects, is not only very uneconomical, but also environmentally destructive in that both the undercutting and the wasting exercises of the expansive soil do consume a lot of fuel energy, over and above the same destructive and uneconomical necessity of excavating, hauling and placing of the borrowed suitable material. The environmental and landscape disfigurement involved is also huge. On the other hand, heat treatment would minimise these exercises by limiting them to the modification of the in-situ natural material itself and the utilization of the same.

The other less common but alternative solution exercised in the road construction sector in the country is the use of cement treatment. However, not only cement is found in the country in specific geographical locations, making the application unpractical due to the long hauling distance, but also the exercise is limited to the stabilization of subgrade and upper lying pavement layers due to economic limitations.

As mentioned above, when the availability of suitable replacement borrowed material is not located within the proximity of the construction project, the only economically viable and handy method should be the use of heat treatment to improve the in-situ material.

However, due to the absence of the awareness of the merits of heat treatment to solve the challenges posed by expansive soils on the part of not only the planning and implement bodies, but also the road contractors, many road projects located in predominantly black cotton corridors are only treated using conventional stabilization methods such as replacement with suitable borrow material and sometimes chemical treatments.

Therefore, this research is hopped to contribute in this regard by creating awareness of the merits of heat treatment and encouraging further researches toward the actual implementation of the same through funded studies.

1.3 Research Objectives:

1.3.1 General Objectives

The objective of this research is to investigate the potential of heat treatment in improving the properties of expansive soils.

1.3.2 Specific Objectives

The specific objectives of this study is to:

- evaluate the effectiveness of heat treatment in reducing the swelling potential of expansive soils.
- assess the changes in plasticity, grain size distribution, maximum dry density and CBR resulting from heat treatment.
- determine the optimal temperature and duration of heat treatment required for maximum enhancement of engineering properties.

1.4 Hypotheses

In line with these objectives, our hypotheses are as follows:

1. The application of heat treatment will result in a significant reduction in the swell potential and plasticity of expansive soils.
2. Heat treatment will lead to an improvement in the grain size distribution and load-bearing capacity of expansive soils.

3. There is an optimal temperature for each expansive soils where the improvements in the engineering properties make the soil suitable for most construction projects.

1.5 Significance of the Study

This research proposal seeks to address the existing gaps by conducting a systematic investigation into the effects of heat treatment on a variety of engineering properties of expansive soils. By comprehensively evaluating changes in plasticity, grain size distribution, load-bearing capacity, swell, and shrinkage under a range of treatment conditions, the study aims to provide valuable insights into the potential of heat treatment as a solution for managing expansive soils in construction projects. The findings have the potential to not only advance the field of geotechnical engineering but also offer innovative and sustainable solutions that can revolutionize current soil stabilization practices (Charles K. Kabubo et al, January 2017)

1.6 Scope of the Study:

The scope of this study encompasses the following aspects:

1. Laboratory Experiments: The research was focused on conducting laboratory experiments to investigate the effects of heat treatment on expansive soil samples. Various treatment temperatures from 100^{o}C to 600^{o}C for a duration of one hour were examined and assessed on their impact on engineering properties.
2. Engineering Property Evaluation: The study comprehensively evaluated the changes in engineering properties of expansive soils after heat treatment which would make them suitable specially for road construction projects . This includes assessments of swelling potential, plasticity properties, grain size distribution, CBR, and linear shrinkage.
3. Optimization: The research has identified the optimal temperature and duration of heat treatment required to achieve the maximum improvement in engineering properties.
4. Analysis and Interpretation: Data obtained from laboratory tests were analysed and statistically interpreted to establish relationships between heat treatment parameters and property enhancements.
5. Practical Implications: While the research focuses on laboratory investigations, the findings could have practical implications for construction projects involving expansive soils, potentially leading to alternative soil stabilization practices.

CHAPTER 2

2 LITERATURE REVIEW

2.1 General

Expansive soils have long been recognized as a challenging geotechnical issue, impacting infrastructure projects globally. The literature on soil stabilization techniques is extensive, and recent studies have shown an increased interest in the potential of heat treatment as an alternative solution.

Expansive soils have different chemical compositions that makes them highly, moderately or minimally expansive and depending on that their impacts on the construction sector. They can be categorized into three major groups in terms of their chemical composition.

Montmorillonite: The smectite category of clay minerals includes the swelling material montmorillonite. It has the following chemical composition: $(Na, Ca)_{0.33}(Al, Mg)_2(Si_4O_{10})(OH)_2.nH_2O$. Diameter ranges from 0.05-10µm and with SSA of 700-800m²/g (Chen, Foundations on expansive soils, 1975)

The material has an unusual crystal structure with sheets that resemble layers and can expand and contract as a result of water molecules intercalating in them. The capacity of montmorillonite to absorb water and expand in volume, causing soil swelling, is what causes this expansive tendency. Exchangeable cations between the mineral layers hydrate, which causes the expansion.

Illite: It is a mica-group clay mineral that does not swell as much as the smectite group. $K_{0.65-0.85}Al_{2.0-2.5}Si_{3.5-4.0}O_{10}(OH)_2(OH,F)_2$ is its chemical formula. Diameter ranges from 0.5-10µm and with SSA of 60-180m²/g (Chen, Foundations on expansive soils, 1975)

Illite and montmorillonite both have layered structures, however Illite is less aggressive in the expanding qualities connected to interlayer water absorption. Illite, however, can influence soils' general engineering behaviour by enhancing their flexibility and compressibility.

Kaolinite: consists of one silica tetrahedral sheet and one alumina octahedral sheet or 1:1 lattice type with typical basal spacing of about 7.2Å, is non-swelling clay mineral with the chemical composition $Al_2Si_2O5(OH)_4$. It has a platy crystal structure that resists interlayer water absorption.

The basic kaolin mineral structure comprising the minerals kaolinite, dickite, nacrite, and halloysite is a layer of a single tetrahedral sheet and a single octahedral sheet. These two sheets are combined to form a unit in which the tips of the silica tetrahedrons are joined with the octahedral sheet. All of the apical oxygens of the silica tetrahedrons point in the same direction so that these oxygens and/or hydroxyls, which may be present to balance the charges, are shared by the silicones. (Murray, 2006)

Kaolinite diameter ranges from 0.5-4µm and with SSA of 10-20m²/g (Chen, Foundations on expansive soils, 1975) and it has less plasticity and capacity for adsorbing cations than Illite and smectite.

Kaolinite helps make soils cohesive and fine-grained even though it is not the cause of expansive behaviour. In comparison to montmorillonite-rich soils, kaolinite-rich soils often have lower plasticity and display less volume change.

Soil stabilization is defined as chemical or mechanical treatment designed to increase or maintain the stability of soil mass and also improve its engineering properties

Given the challenges posed by expansive soils, various soil stabilization techniques have been developed to mitigate their effects and improve their engineering properties. Some commonly used techniques include;

1. Chemical Stabilization: In order to change the qualities of the soil and lessen its expansiveness, this method entails adding chemical agents to the soil. Common chemical additives include fly ash, lime, and cement. These substances interact with soil particles to strengthen them and lessen their sensitivity to swelling and shrinking. (Dharmendra Barman, 2022)

2. Mechanical Stabilization: Through compaction, mixing, or reinforcement, mechanical stabilization techniques aim to change the soil's crystalline structure. These methods increase the soil's ability to support weight and lessen the likelihood that it may expand or contract. Compaction grouting, lime-cement columns, and soil mixing are a few examples of mechanical stabilizing techniques. (Sir Armand Augustin Fondjo, 2021)

3. Moisture Control: Expansive soils' volume variations can be minimized by controlling their moisture content. Techniques like moisture barriers, surface drainage systems, and vegetation control can reduce the potential for swelling and shrinking by limiting the range of soil moisture changes. (Ardani, 1992)

4. Geosynthetic Reinforcement: Expansive soils can be stabilized and strengthened using geosynthetics like geotextiles and geogrids. By giving the soil tensile strength, these materials increase the soil's capability for bearing weight and lessen deformations. (Satyam, 2022)

5. Chemical Grouting: Chemical agents are injected into the soil during chemical grouting to produce a stable mass with fewer cavities. With this method, the soil's permeability is decreased and its shear strength is increased, improving stability and minimizing volume changes.

Grouting is a process of injection of setting fluids in to the voids of the alluvium, or into the fissures of rock either to reduce permeability or to increase strength or both. The success of the grouting is mainly dependent on selection and type of grout materials and suitable grouting techniques. There are many materials used for grouting, cement is most common. Chemical compounds such as lignin, silicates, acrylic, and urea or epoxy resins and polyurethanes complying with environmental laws may be used in geotechnical injection projects. First successful application of injection technology for soil improvement was by Berigny in 1802 (Khushali1*, 2020)

(Chen, Foundations on expansive soils, 1975) concluded in their studies that expansive soils or Black Cotton Soils are normally found in semi – arid regions of tropical and temperate climate zones. They further highlighted that such soil exist in abundance in those areas, where the annual evaporation exceeds the precipitation. It was further stressed in the study that sticky plastic nature of black cotton soils particles causes them to pack up under wheels, animal's feet and clog cultivation implements. They make the soil extremely difficult to extract or dislodge. The cracks measuring 70 mm wide and over 1 m deep were observed. The study has shown that these cracks can extend up to 3m or more in case of high deposits.

Black Cotton soil is predominantly clayey. For treatment in road building, it is so complicated that clods cannot be readily crushed. These flaws will affect the road's future performance. Moreover, softened subgrade tends to float upward into the pavement surface when the sub-base consists of stone slugs with many voids. Every rainy season Black Cotton soil infiltration causes the road to collapse. (Amol Eknath Thoke1, 2021)

The liquid limit can be considered to be a measure of the quantity of water attracted by these particles for a given value of undrained shear strength thus making it possible to correlate this parameter with the compressibility. Study has also revealed that the black cotton soil is very hard when dry, but loses its strength completely, in wet condition. Study has shown that 40 to 60% of black cotton soil has a size less than 0.001 mm. (Ahamed1, 2019)

(Fuhai Zhang, 2019) proposed that Polyvinyl alcohol (PVA) and K_2CO_3 combination can be used to improve the properties of expansive clays. In this paper Free swell tests, oedometric swell tests, unconfined compression tests, and direct shear tests were performed to investigate the effectiveness of the PVA and K_2CO_3 combination to control the volume change and increase the soil strength. Microstructures of the natural expansive soil and the stabilized soil were also studied with SEM photos. SEM photos showed a homogenous and dense microstructure after stabilization. In addition, a laboratory soil column model was built to study the ability of this stabilizer combination to stabilize expansive soils by directly spraying the solution on the ground surface. All these test results show that the combination of PVA and K_2CO_3 is able to effectively stabilize the natural expansive soil and increase the shear strength. It is possible to directly spray the stabilizer solution on the soil surface to form a relatively thick layer of the stabilized expansive soil.

(Ji-ru, Z., Xing, C., 2002) undertake to study the individual and admixed effects of lime and fly ash on the geotechnical characteristics of expansive soil. Lime and fly ash were added to the expansive soil at 4%–6% and 40%–50% by dry weight of soil, respectively. Testing specimens were determined and examined in chemical composition, grain size distribution, consistency limits, compaction, CBR, free swell and swell capacity. It is revealed that a change of expansive soil texture takes place when lime and fly ash are mixed with expansive soil. Plastic limit increases by mixing lime and liquid limit decreases by mixing fly ash, which decreases plasticity index. As the amount of lime and fly ash is increased, there are an apparent reduction in maximum dry density, free swell and swelling capacity under 50 kPa pressure, and a corresponding increase in the percentage of coarse particles, optimum moisture content and CBR value. Based on the results, it can be concluded that the expansive soil can be successfully stabilized by lime and fly ash.

(Ahmed S. A. Al-Gharbawi et al, 2022) showed that three percentages of lime, cement, and silica fume (5, 7, 9%) are used to stabilize the expansive soil, and the work is divided into two sections: the first is using a consolidation test to record the free swell and swell pressure for the untreated and treated soils; in the second part, the grouting technique is utilized as a process that can be applied in the field to maintain the improvement in the bearing capacity. It is concluded that the soil stabilized with different percentages of lime, cement, and silica fume exhibits a decrease in both free swell and swelling pressure by approximately 65% and 76%, respectively, as compared with untreated soil. The soil grouted with silica fume increases the bearing capacity of footings resting on the grouted soil by approximately 64% to 82% for the soil treated with 5% and 9% silica fume, respectively, as compared with untreated soil.

Another method that falls under both chemical and physical stabilization is heat stabilization of expansive clays which improves both the engineering properties of the soil and its chemical properties. Relatively few researches were conducted on heat treatment to improve the engineering and index properties of expansive soils.

Stabilization of expansive soils, specifically red clays and black soils, using heat indicates that the index properties of both soils shows marked improvement when subjected to temperatures exceeding 400^{o}C. (Kantheti N V K Hanuma, Dr. D.S.V.Prasad, June -2017)

The above document shows that Liquid limit decreased at 66% from 100°C to 400°C for black cotton soil, whereas 68% for red soil, Black cotton soil is converted into non plastic soil at 400°C and 62% decreased for red soil, Soaked CBR values are almost doubled for both black cotton soil and red soil comparing with 100°C to 400°C, Unconfined compressive strength is decreased with increase in temperature, since the initial clay sample is converted into coarse grained sample at 400°C. They also indicate that, this method, however, is more suitable for soil layers where rainy and cold weather conditions prevail, since these plastic soils swell highly with increase in moisture content. It is best suited for high plastic (CH) soils compared to less plastic (CL) soils. Also it is not economical to use less plastic soils.

On the other hand (Charles K. Kabubo et al, January 2017) show that the black cotton soil under study experienced irreversible chemical changes when subjected to heat at 600^0C since the tests were done on the soil after it cooled to room temperature which allowed for any possible reversal. This resulted in the following: The maximum dry density increased by 15%, reducing capacity for water ingress, The particle size distribution altered, The clay fraction diminished, and the soil became predominantly sand with a significant amount of gravel, and a reduction in the silt fraction.

According to the above source. there was a reduction in silicon oxide by 31%, and an increase of aluminium and iron oxides by 56% and 4% respectively. These changes are irreversible. The strength increased as measured by the CBR which increased from 1 to 3 and The plasticity and swelling characteristics reduced as measured by the Plasticity Index, Linear Shrinkage and the Free Swell which reduced by 30%, 27% and 38% respectively.

Previous research has explored various techniques for the stabilization of expansive soils, including chemical stabilization, mechanical stabilization, and thermal stabilization (Sir Armand Augustin Fondjo, 2021)

Heat treatment, as a thermal stabilization method, has shown promise in reducing the swell potential of expansive soils and improving their load-bearing capacity (Charles K. Kabubo et al, January 2017)

Several laboratory tests, including the swell test, shear strength test, and Atterberg limits test, have been commonly employed to evaluate the effects of heat treatment on expansive soils (Kantheti N V K Hanuma, Dr. D.S.V.Prasad, June -2017)

Several key areas have emerged in the literature:

2.2 Mechanisms of Heat Treatment

Heat treatment, as a soil stabilization technique, operates through intricate mechanisms that bring about changes in the mineralogical and physical properties of expansive soils.

Understanding these mechanisms is crucial for assessing the effectiveness of heat treatment in mitigating the expansive behaviour of soils.

At the core of heat treatment is the controlled application of elevated temperatures to soil samples. This controlled heating induces several key mechanisms:

2.2.1 Changes in Clay Mineral Structure

Clay minerals, particularly those in the smectite group like montmorillonite, are responsible for the expansive properties of soils. These minerals have a unique layered crystal structure with spaces between the layers that can accommodate water molecules and ions. When subjected to heat, the energy provided disrupts the bonds between these layers, leading to alterations in the crystal structure. This process is known as dehydroxylation, where hydroxyl (OH) groups are removed from the clay mineral layers. (Vassallo, 1996)

2.2.2 Interlayer Water Content

Heat treatment reduces the interlayer water content of clay minerals. (Heller-Kallai, 2006)In their natural state, clay minerals have water molecules held within the interlayer spaces. These interlayer water molecules play a significant role in the expansive behaviour of the soil. As the temperature increases, these water molecules are released, causing a reduction in the swelling potential of the soil. The treatment leads to a decrease in the number of available interlayer sites for water absorption, thereby mitigating the soil's propensity for swelling.

2.2.3 Mineral Transformation

The application of heat also induces mineral transformations. For instance, the dehydroxylation process can lead to the conversion of certain clay minerals into non-swelling minerals. This transformation can significantly reduce the soil's capacity to undergo volumetric changes upon wetting and drying. Additionally, heat treatment can influence the crystallinity of clay minerals, affecting their physical behaviour. (Ahmed Z. Khalifa a, 2020)

2.2.4 Microstructure Alterations

Heat treatment results in microstructure alterations within the soil matrix. (A.E. Karantzalis, 2008)The heat-induced changes in clay mineral structure and interlayer spacing can affect the arrangement of particles within the soil. This, in turn, influences properties such as permeability and shear strength. Reduced inter-particle spacing and enhanced particle-to-particle bonding can contribute to decreased permeability and improved shear strength.

2.3 Influence of Temperature and Duration

The effectiveness of heat treatment is intricately linked to the temperature and duration of exposure. Higher temperatures and longer exposure times can induce more significant changes in soil properties. However, there is a critical balance to strike, as excessively high temperatures or prolonged exposure can lead to adverse effects such as soil hardening or mineral degradation.

Understanding these mechanisms and their interplay is essential for optimizing heat treatment as a soil stabilization technique. The temperature and duration parameters must be carefully tailored to the specific soil type and project requirements to achieve the desired property enhancements effectively.

2.3.1 Effect on Swelling Behaviour

One of the primary concerns associated with expansive soils is their propensity to undergo significant volume changes in response to variations in moisture content. This behaviour can result in structural damage, foundation instability, and costly maintenance for infrastructure built on or near expansive soils. The literature has extensively explored the effects of heat treatment on mitigating this swelling behaviour, shedding light on its potential as an effective soil stabilization technique. (Kantheti N V K Hanuma, Dr. D.S.V.Prasad, June -2017)

2.3.2 Long-Term Stability

An important aspect to note is that the reduction in swelling potential achieved through heat treatment is not merely a short-term solution. Research has indicated that the improvements in soil stability and the reduction in swelling behaviour are sustained over the long term.

This durability is particularly significant in regions with varying climatic conditions where soil moisture content fluctuates seasonally. (Charles K. Kabubo et al, January 2017)

2.3.3 Increased Load-Bearing Capacity:

In addition to shear strength improvements, heat treatment has been shown to increase the load-bearing capacity of treated soils. This enhancement is particularly valuable in construction projects where foundations and structures must withstand substantial loads. The mechanisms contributing to this improvement include the enhanced shear strength resulting from heat treatment directly contributes to the soil's ability to bear increased loads. Structures founded on treated soils benefit from the increased stability and reduced risk of settlement or failure.

2.3.4 Reduction in Settlement

Expansive soils are known to undergo settlement when subjected to wetting and drying cycles. Heat treatment, by reducing the soil's swelling potential, minimizes the extent of settlement. This reduction in settlement ensures that foundations and structures remain stable and level over time. (Kantheti N V K Hanuma, Dr. D.S.V.Prasad, June -2017)

2.3.5 Long-Term Performance:

Research has indicated that the load-bearing capacity enhancements achieved through heat treatment are sustained over the long term. This durability is crucial in ensuring the reliable and safe operation of infrastructure projects (Charles K. Kabubo et al, January 2017)

2.3.6 Reduction in Differential Settlement

Heat treatment not only increases the load-bearing capacity of expansive soils but also helps in reducing differential settlement. This is vital for structures where uniform settlement is essential to prevent structural damage.

2.3.7 Permeability and Durability:

Heat treatment's influence on permeability and durability has also been explored. Some studies suggest that heat treatment can increase permeability due to changes in soil structure, while others investigate the durability of treated soils under varying environmental conditions. (Majed M Abu-Zreig a, 2001)

2.4 Optimization of Treatment Parameters

Researchers have investigated optimal temperature and duration for heat treatment. Different soil types and mineral compositions may require specific treatment parameters to achieve the desired improvements in engineering properties. (Kantheti N V K Hanuma, Dr. D.S.V.Prasad, June -2017)

In summary, the literature consistently supports the effectiveness of heat treatment in improving the shear strength and load-bearing capacity of expansive soils. These improvements are achieved through mineralogical alterations, microstructure enhancements, reduction in swelling potential, and long-term stability. These findings highlight the potential of heat treatment as a valuable technique for ensuring the stability and longevity of construction projects on expansive soils.

CHAPTER 3

3 METHODOLOGY

3.1 Soil Sample Collection

Samples of expansive soils were collected from representative locations in Adama – Awash Expressway Project about 2.5km LHS from Adama town along the proposed expressway road corridor. The sampling was done using test pits hand-dug up to a depth of 1.5m; expansive soil samples were collected by avoiding the top 300mm top soil while including the soil along the depth of the expansive section.

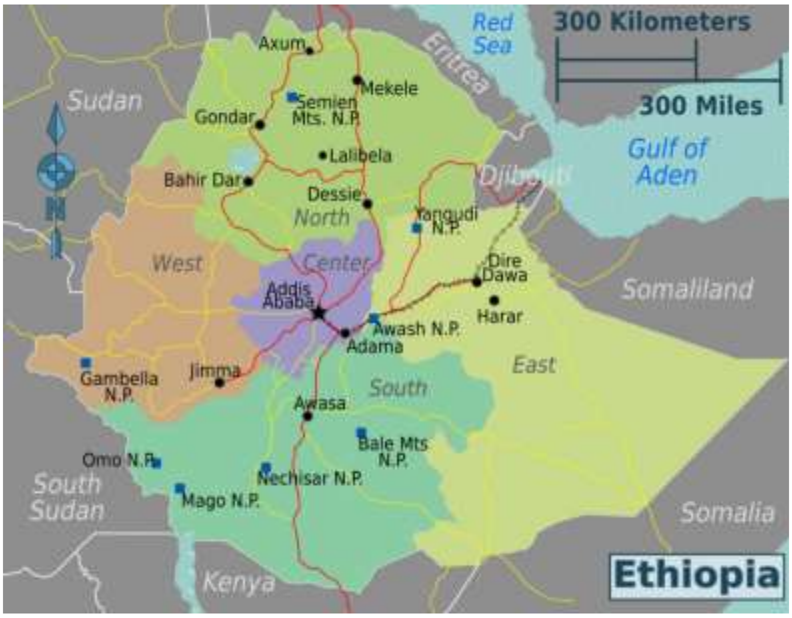

FIGURE 1 LOCATION MAP OF AWASH-ADAMA ROAD *(wikivoyage.org/wiki/Ethiopia, 2023)*

FIGURE 2 SAMPLING AND PREPARATION

Soil engineering properties were characterized through laboratory tests.

3.2 Heat Treatment

Soil samples were subjected to controlled thermal conditions using a heating chamber. An incinerator or furnace which is located in Selam Children's Village in Wereda 11, Yeka Subcity, Kotebe Near Hanamariam Church , Addis Ababa, Ethiopia was employed in this research to heat treat the soil samples in bulk for Proctor and CBR tests. The specimens for small scale laboratory tests such as Atterberg limits and hydrometer analysis, free swell and linear shrinkage tests were heat treated using a laboratory furnace as indicated in the figure below.

FIGURE 3 LABORATORY FURNACE USED FOR HEAT TREATMENT

Different temperature and duration combinations can be used to identify optimal treatment conditions. In this particular research the soil sample was subjected to 100oC, 200oC, 300oC, 400oC, 500oC and 600oC for a duration of one hour to investigate the improvements in soil engineering properties and identify the optimum temperature which would make the soil suitable for construction projects under the context of ERA (Ethiopian Road Administration) construction material specifications. The two hours period for treating the soil was chosen because of two reasons: first the soil will deteriorate in to light weight elements or ash because of the prolonged heat, and second the practical application would not be excessively uneconomical due to the energy expense of excessive heating.

3.3 Laboratory Testing

The control test was carried out on the untreated expansive soil to get the natural soil properties by which the improvements after heat treatment would be measured. All the tests carried out on the treated samples were also carried out on the control test, such as, Free Swell Test, CBR Test, The Atterberg Limits Test, Sieve Analysis Test and The Hydrometer Test. In this particular exercise, the specimen tested at 100^{o}C is regarded as the control test.

The following laboratory tests were conducted on heat-treated soil samples. The tests were selected in line with ERA (Ethiopian Roads Administration) Specification requirements for embankment materials to be used on road construction projects. (ERA, 2013)

Type of test	Testing method
Atterberg limits test	ASTM D4318-17e1
Sieve Analysis Test	ASTM D422-63(2007)
Proctor Compaction Test	(AASHTO T 180-95)
California Bearing Ratio (CBR)	(AASHTO T 193-93)
Linear Shrinkage Test	BS1377 (Part 2) :1990
Free Swell Test	(ASTM, D4546-17 2021)
Hydrometer Analysis	(ASTM D422-63, 2002)

3.3.1 The Atterberg Limits Test

The liquid limit, plastic limit, and plasticity index of the heat-treated soils is conducted according to ASTM D4318-17e1. This test is crucial for understanding changes in the plasticity and consistency of the soil resulting from heat treatment.

Test Objective: To determine the liquid limit, plastic limit, and plasticity index of heat-treated soils.

Heat-treated soil samples were prepared and moistened to a specified consistency. The liquid limit test was conducted using (ASTM D4318-17e1, 2018) procedures to determine the moisture content at which the soil behaves as a liquid. Then the plastic limit test was conducted to determine the moisture content at which the soil can be rolled into a 1/8-inch diameter thread without crumbling. The plasticity index was calculated as the difference between the liquid limit and plastic limit.

FIGURE 4 LABORATORY TESTING OF PLASTICITY OF SOIL

3.3.2 Linear shrinkage test

The Linear Shrinkage tests on the heat treated soil was carried out in accordance with BS1377 (Part 2) :1990. (Standard B. , 2003) . The plastic soil is moulded into a mould

/trough using a spatula carefully by extruding the trapped air bubbles, and trimmed. The shrinkage is read after a reasonable time after all the moisture has been dried and no more weight difference is registered.

FIGURE 5 LINEAR SHRINKAGE TESTING

3.3.3 Sieve Analysis Test

The Sieve Analysis Test, following ASTM D422-63(2007), was conducted on the heat-treated soil to characterizes the particle size distribution. This analysis is essential for assessing changes in grain size distribution due to heat treatment.

Test Objective: To characterize the particle size distribution of heat-treated soils samples were air-dried to remove moisture and weighed and sieved them through a set of standard sieves. The retained weight was recorded on each sieve and calculation was made of the percentage of soil retained on each sieve and the particle size distribution curve plotted based on the results.

3.3.4 The Hydrometer Test

The hydrometer analysis was conducted on the heat treated soil, following the appropriate standards, (422-63, Standard Test Method for Particle-Size Analysis of Soils1, 2002) is used to determine the particle size distribution of fine-grained soils. This test provides precise data on the soil's particle size distribution, particularly for smaller particles, complementing the information obtained from the Sieve Analysis Test.

Test Objective: To determine the particle size distribution of fine-grained soils. The soil was prepared by making a suspension dispersing a known amount of heat-treated soil in water. The suspension was placed in a hydrometer cylinder and allowed it to settle and then measurement was made of the sedimentation rate of the particles using a hydrometer at specified time intervals. Then calculation of the particle size distribution based on sedimentation data was carried out.

3.3.5 Free Swell Test

The Free Swell Test was conducted on the heat treated soil in accordance with relevant standards (ASTM, D4546-17 2021), which measures the degree of swelling exhibited by the soil when exposed to water. This test is instrumental in quantifying the reduction in soil's free swell potential achieved through heat treatment.

Test Objective: To determine the liquid limit, plastic limit, and plasticity index of heat-treated soils.

The sample was oven-dried at 100^{o}C of about 00 grams accurately using a balance and placed the weighed dry soil in a graduated cylinder. Then distilled water was gradually added while stirring continuously. Then record of the initial volume (V0) of the soil mixture in the container was taken and allowed the soil to swell freely and stabilize. Once the soil swelling has stabilized, measure of the final volume (V1) of the soil-water mixture was taken. The Free Swell (%) is calculated from the formula FS = [(V1 - V0) / V0] × 100. The average of three testes was taken to the final result.

3.3.6 Proctor Test

Proctor test was conducted according to ASTM D698 test procedures on the heat treated soil with objective to determine the maximum dry density and optimum moisture content of the soil sample for compaction purposes. The prepared sample (pass 19mm sieve) was taken (around 2.5 kg) accurately using a balance and the weight was recorded and divided into two portions. The moisture content of one portion was determined by weighing it and then drying it in an oven at a 110°C until a constant weight is achieved and the moisture content was calculated using the formula: Moisture Content (%) = [(Initial wet weight - Dry weight) / Dry weight] × 100. Then the remaining portion of the soil sample was placed in the mould in approximately three equal layers and each layer compacted uniformly according to the test standard. The test was repeated using the same dry soil sample at varying moisture contents by adding water to each sample incrementally, ensuring thorough mixing, until a range of moisture contents is achieved.

The results were plotted as the dry density (Y-axis) against moisture content (X-axis) to create the compaction curve. The point on the compaction curve where the dry density is highest is the optimum moisture content (OMC), and the maximum dry density (MDD) is the corresponding dry density.

The Proctor Test is essential for determining the compaction characteristics of soil and optimizing moisture content for construction purposes. It helps ensure that soil is compacted to the desired density and moisture content, which is critical for the stability of construction projects.

3.3.7 Load-Bearing Capacity Test (CBR Test)

The California Bearing Ratio (CBR) test was conducted on the heat treated soil samples following the procedures outlined in (ASTM, ASTM.org, D1883-17), to evaluate the bearing capacity of the heat-treated soils. This test is particularly relevant for assessing the load-bearing capacity enhancements achieved through heat treatment.

Test Objective: To evaluate the load-bearing capacity of heat-treated soils.

Heat-treated soil samples were compacted into a CBR mould to MMD and a static load was applied incrementally to a cylindrical piston placed on the soil sample where measurement of the penetration of the piston into the soil at each load increment was read. The CBR value was calculated as the ratio of the load required to penetrate the soil to a specified depth to the load required for a standard material. The test was repeated for multiple samples and the average CBR value was calculated.

These short test procedures provide an overview of the steps followed in each laboratory test for evaluating the effects of heat treatment on the expansive soil specimen. Specific details, equipment calibration, and adherence to relevant standards is followed during the whole testing.

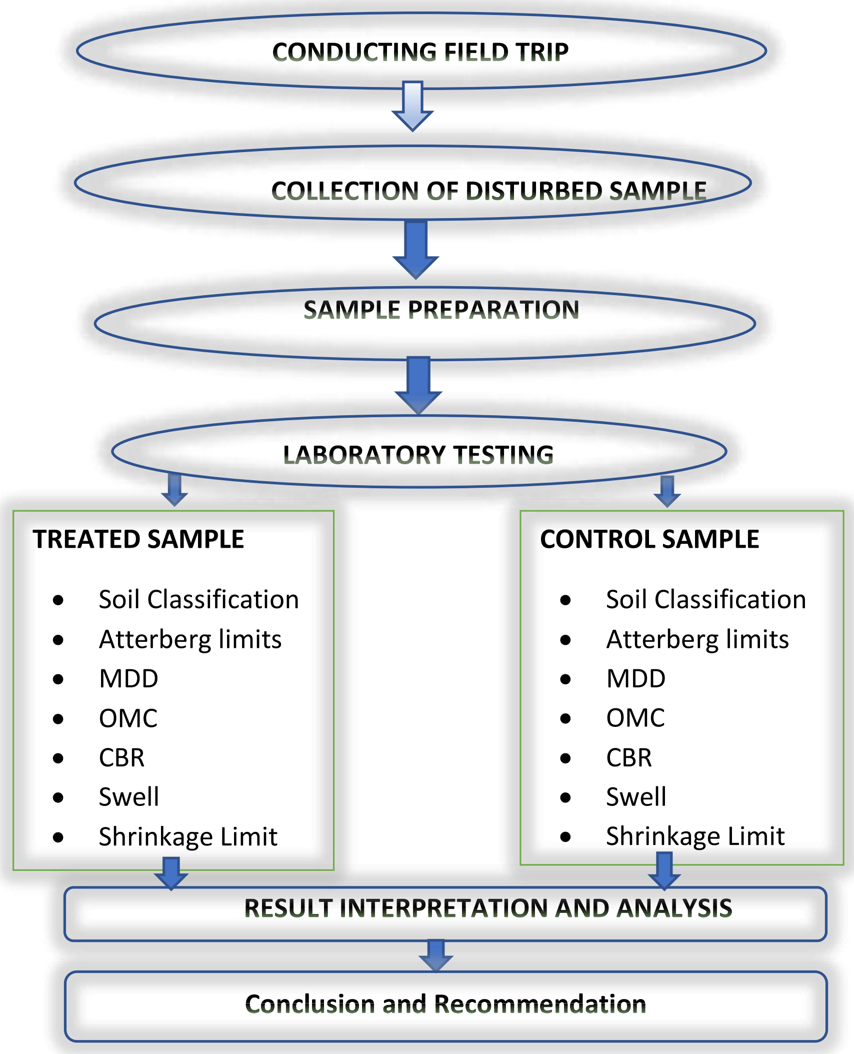

FIGURE 6 FLOW CHART OF THE RESEARCH METHODOLOGY

CHAPTER 4

4 RESULTS AND DISCUSSION

4.1 Lab Results and Analysis

Data obtained from laboratory tests is statistically analysed. Relationships between heat treatment parameters and property enhancements was established through graphical as well as numerical data analysis. The laboratory results of the heat treatment on the expansive soil samples provide valuable insights into the effects of varying temperatures on the engineering properties of the soil

4.1.1 Free Swell

Free swell is a crucial property for expansive soils as it measures the potential for soil expansion when exposed to water. Free Swell decreased from 75% at 100°C to 55% at 600°C, marking a significant reduction of approximately 26.7% in the potential for soil expansion upon wetting. This decrease is a significant improvement favourable for construction purposes with incremental amount of heat.

This result is also consistent with other similar researches done on the effect of heat on expansive soils in that Free Swell of Black cotton soil is decreased from 75.6 to 20.5 and for Red soil 121.5 to 32.33 that it is clearly indicative of the change in clay mineral structure influenced by heating. (Kantheti N V K Hanuma, Dr. D.S.V.Prasad, June -2017)

Heat treatment reduces the interlayer water content of clay minerals. (Heller-Kallai, 2006)In their natural state, clay minerals have water molecules held within the interlayer spaces. These interlayer water molecules play a significant role in the expansive behaviour of the soil. As the temperature increases, these water molecules are released, causing a reduction in the swelling potential of the soil. The treatment leads to a decrease in the number of available interlayer sites for water absorption, thereby mitigating the soil's propensity for swelling.

This result proves that heat treatment is one possible option for improving the swelling potential of expansive soils.

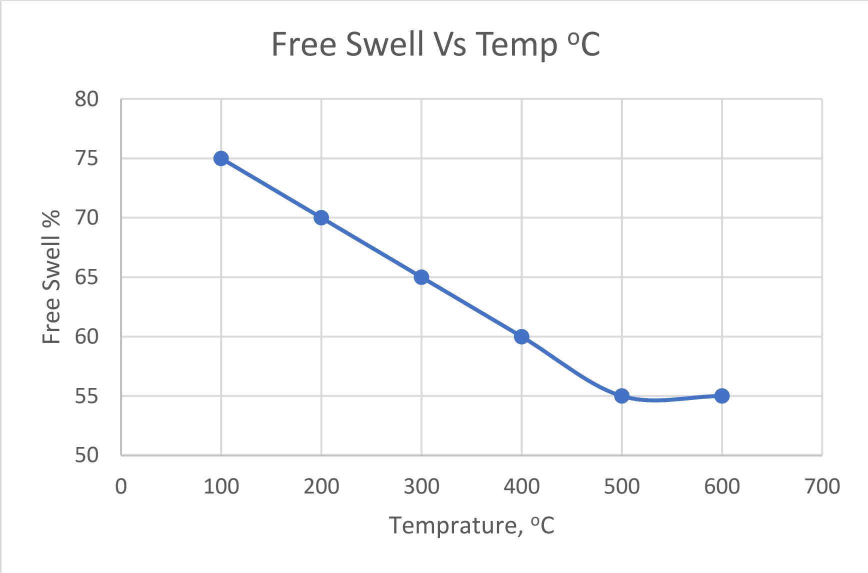

FIGURE 7 . FREE SWELL VS TEMPERATURE

4.1.2 Linear Shrinkage

Linear shrinkage is a measure of a soil's tendency to contract or shrink upon drying. The decrease in linear shrinkage from 15% at 100°C to 11% at 600°C indicates that higher temperatures result in reduced soil shrinkage which represents a decrease of approximately 26.7%. This is a positive outcome for constructions as it suggests improved volume stability and reduced risk of soil cracking.

As can be seen from the results depicted below, the linear shrinkage decreased as the temperature increased.

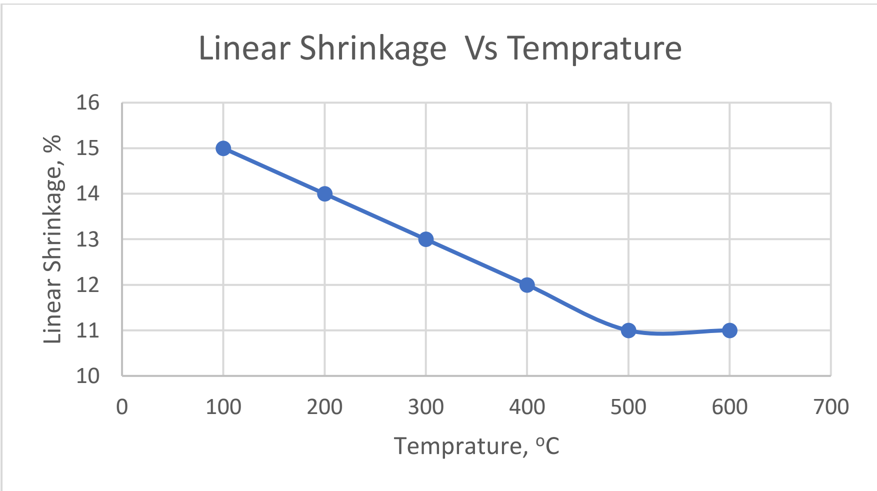

FIGURE 8 LINEAR SHRINKAGE VS TEMPERATURE

(Charles K. Kabubo et al, January 2017) indicated in their research that the linear shrinkage decreased from 15 to 11 due to combustion of organic matter, the potential to swell reduced, and the soil behaved like a cohesionless soil, which agrees with the findings of Wang et al. (2008).

However, as can be seen from the above results the maxim improvement of free swell for this particular expansive soil was achieved at 500°C probably indicating that there could be an optimum temperature at which no more improvements in engineering properties are achieved.

4.1.3 Liquid Limit and Plastic Limit

Liquid Limit decreased from 66% at 100°C to 56% at 600°C, representing a reduction of approximately 15.2% in liquid limit. Simultaneously, Plastic Limit decreased from 33% at 100°C to 28% at 600°C, indicating a reduction of approximately 15.2% in plastic limit. The Plastic Index decreased from 33% to 28%, demonstrating a reduction of approximately 15.2% in soil plasticity. These reductions collectively suggest that heat treatment results in lower soil plasticity and increased resistance to moisture-induced volume changes.

It is also clear from the proceeding data that heat treatment does indeed improve the engineering property of the soil, especially the liquid limit.

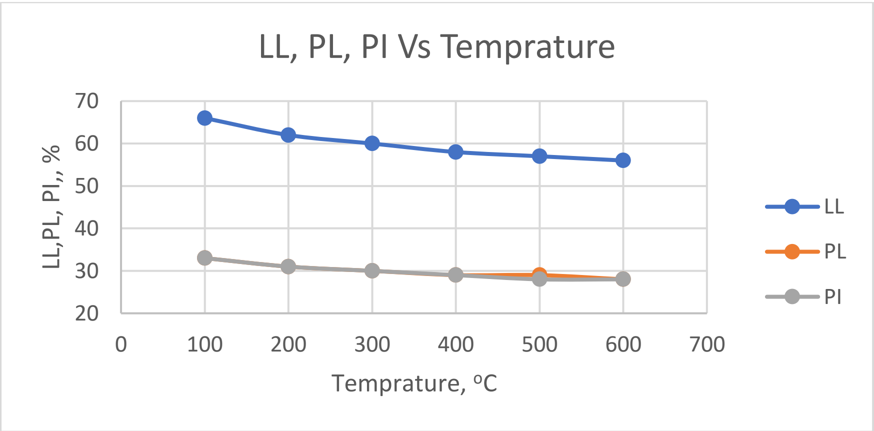

FIGURE 9 LL, PL & PI VS TEMPERATURE

Other researchers also reached similar conclusion with respect to the effect of heat on the plasticity of expansive soils in that heating reduced the plasticity index 30 to 21 (Charles K. Kabubo et al, January 2017) and Liquid limit of Black cotton soil is decreased from 44 to 15,for Red soil 76 to 24 with the increase in temperature from100°C to 400°C (Kantheti N V K Hanuma, Dr. D.S.V.Prasad, June -2017).

Improving the plasticity of expansive soils offers several significant benefits in construction and geotechnical engineering. Expansive soils, characterized by their high plasticity and sensitivity to moisture content, can present challenges in various building and infrastructure projects. Here are the key benefits of enhancing the plasticity of expansive soils:

Enhanced Workability: Improved plasticity makes expansive soils more workable during construction. This means that earthmoving, grading, and shaping operations become more efficient and manageable, reducing construction time and costs.

Reduced Shrinkage and Cracking: One of the primary issues with expansive soils is their tendency to shrink and crack as they dry out. Enhancing plasticity helps mitigate this problem by reducing the degree of shrinkage, minimizing the occurrence of surface cracks, and preserving the integrity of structures built on such soils.

Improved Compaction: Soils with improved plasticity are easier to compact effectively. Adequate compaction is crucial for achieving the desired density and stability in construction projects, reducing the risk of differential settlement and structural damage.

Better Foundation Support: Enhanced plasticity contributes to increased bearing capacity. Foundations constructed on soils with improved plasticity have greater stability and can support heavier loads, ensuring the safety and longevity of structures.

Minimized Differential Settlement: By improving plasticity, the soil's response to moisture fluctuations becomes more predictable and consistent. This reduces the risk of differential settlement, where different parts of a structure settle unevenly, which can lead to structural problems.

Optimized Moisture Content: Improved plasticity allows for more precise control over the moisture content of the soil. This is crucial during construction, as maintaining the soil at or near its optimum moisture content ensures that compaction and stability objectives are met.

Reduced Maintenance: Structures built on soils with enhanced plasticity are less prone to soil-related issues, such as cracking or settling, which can reduce the need for costly maintenance and repairs over time.

Increased Foundation Options: Improved plasticity expands the range of foundation options available for construction on expansive soils. It may allow for the use of shallow foundations, such as spread footings or slab-on-grade, instead of costly deep foundations like piles or caissons.

Reduced Project Costs: Enhancing plasticity can lead to overall cost savings in construction projects. It minimizes the need for extensive soil replacement, excavation, and the disposal of unsuitable soil, resulting in lower project expenses.

Environmental Benefits: By optimizing the plasticity of existing soils, construction projects can minimize the environmental impact associated with soil excavation, transportation, and disposal. This aligns with sustainable construction practices and reduces energy consumption and greenhouse gas emissions.

Risk Mitigation: Improved plasticity reduces the risks associated with expansive soils, offering a more stable and reliable foundation for structures. This, in turn, enhances project success and longevity.

In summary, the benefits of enhancing the plasticity of expansive soils include improved workability, reduced shrinkage and cracking, enhanced foundation support, minimized differential settlement, cost savings, and environmental sustainability. These advantages make plasticity improvement a valuable strategy for mitigating the challenges posed by expansive soils in construction and engineering projects.

4.1.4 Specific Gravity

Specific Gravity decreased from 2.64 to 2.56, indicating a reduction of approximately 3.03% in soil density as a result of heat treatment. While this decrease may be advantageous for certain construction applications, it should be considered alongside other properties such as bulk density and dry density, which have more bearing on the performance of the soil as construction material.

The following data shows specific gravity of the soil decreased as heat treatment increases.

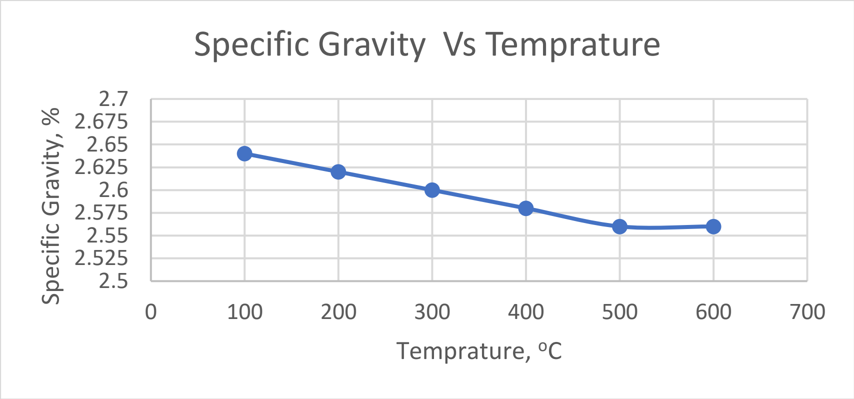

FIGURE 10 SPECIFIC GRAVITY VS TEMPERATURE

4.1.5 Sieve Analysis

The sieve analysis was conducted in two different laboratories and the results obtained are quite inconsistent in that while the results from the one laboratory indicate a consistent decrease in the particle size of the soil with increase in heat treatment, the result from the other laboratory implies that grain size decreases with increase in treatment temperature. Hence the effect of heat treatment on the grain size distribution of the expansive soil is inconclusive under this particular research as shown in the tables below.

TABLE 1 TEST RESULTS OF SIEVE ANALYSIS AS OBTAINED FROM ICT LABOTRATORY

	Percentage Passing Sieve Size				
Temperature ºC	4.75mm	2.00mm	0.425mm	0.075mm	Remark
100	99	98	94	89	Control Test
200	99	98	95	90	Oven Treated
300	100	99	95	91	Oven Treated
400	100	99	96	92	Furnace Treated

500	100	99	97	93	Furnace Treated
600	100	99	97	94	Furnace Treated

TABLE 2 TEST RESULTS OF SIEVE ANALYSIS AS OBTAINED FROM JMC LABOTRATORY

	Percentage Passing Sieve Sizes			
Temperature ^oC	2.00mm	0.425mm	0.075mm	Remark
100	96.92	87.22	72.91	Control Test
200	96.48	85.68	69.71	Oven Treated
300	94.38	81.00	64.38	Oven Treated
400	94.07	88.80	69.73	Furnace Treated
500	95.88	91.29	74.47	Furnace Treated
600	96.12	91.76	74.94	Furnace Treated

However, all other similar researches conducted on the effect of heat treatment on the properties of expansive soils unequivocally indicate that grain size increases with the increase in treatment temperature consistently.

According to (Charles K. Kabubo et al, January 2017) while the grading results for the neat material, shows that the material is predominantly clay (less than 0.002mm) at 37%, with a significant amount of silt (0.002-0.006mm) of one third (33%), the grading results for the heated material, shows that the material is predominantly sand (0.006-2.0mm) at 45%, with a significant amount of gravel (greater than 2.00mm) of slightly more than one third (35%). The silt fraction (0.002-0.006mm) is 19%, while the clay fraction diminished. These results are consistent with those of Wang et al. (2008), as quoted by Charles K. Kabubol et al, who obtained a clay percentage of about 12% for commercial expansive WB at 6000C, attributing it to destruction of the crystal structure of WB from dihydroxylation as the temperature increased beyond 400°C leading to formation of larger particles possibly due to electro-chemical bonds resulting in formation of larger particles.

According Bell (1993), soil at temperatures of between 200 and 400°C begins to aggregate into granules and when the soil is heated to temperature of 400°C to 600°C, some irreversible changes which make the soil non-plastic and non-expansive. Wang et al. (2008) also suggested that the formation of the larger particles is irreversible.

4.1.6 Density Tests

The MDD increased from 1.28g/cc at 100°C to 1.43g/cc which indicates heat treatment has a positive impact on the dry density of expansive soils. This is a 12% increase which would have a positive implications on the load bearing capacity of the soil in practice.

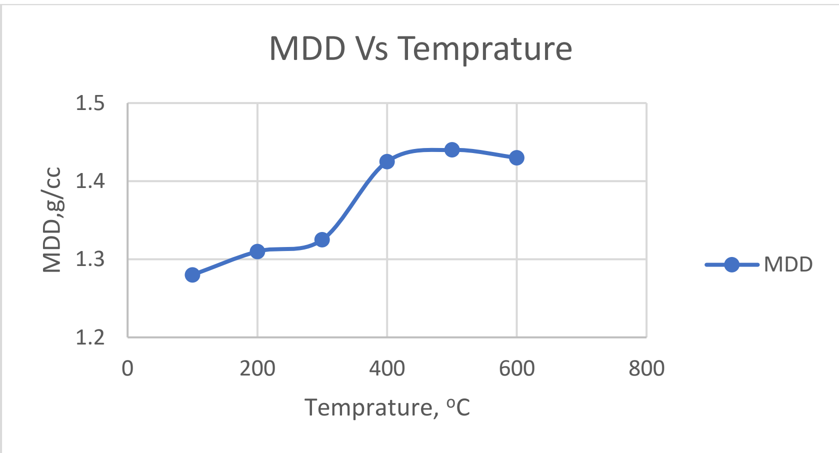

FIGURE 11 MDD VS TEMPERATURE

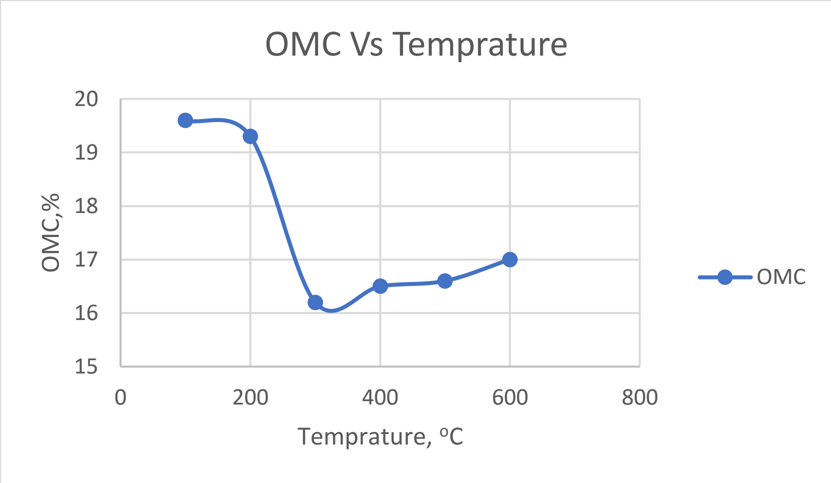

FIGURE 12 OMC VS TEMPERATURE

The study conducted by (Charles K. Kabubo et al, January 2017) shows the compaction results for neat soil, giving the maximum dry density (MDD) as 1272 Kg/m3 at an optimum moisture content (OMC) of 29.5%, whereas the compaction results for heated soil, giving the MDD of 1465 Kg/m3 at an OMC of 29.0%. The heated soil has a higher MDD at about the same OMC as the neat soil, meaning that it will be stronger in service. This is probably due to formation of granules (Bell, 1993) which seem to bond better.

An improved dry density would have many positive implications which would make the expansive soil a valuable asset rather than a waste in construction projects such as contributes to the structural integrity of foundations, roads, embankments, and other structures, reducing the risk of settlement or structural failure. Properly compacted soils have higher load-bearing capacity. By controlling dry density, construction engineers can ensure that the soil can support the anticipated loads, whether it's for buildings, pavements, or retaining walls. Dry density is a critical factor in slope stability. Well-compacted soil is less prone to erosion and slippage, making it essential for the construction of embankments, dams, and slopes in road construction and civil engineering projects.

Proper compaction reduces the potential for soil settlement over time. This is particularly important in residential and commercial construction to prevent uneven settling of structures, which can lead to structural damage. Controlled dry density can affect the permeability of the soil. Well-compacted soils often have lower permeability, which can be beneficial for controlling groundwater and surface water flow, reducing the risk of flooding and erosion. Moreover, consistent dry density ensures uniform support for foundations. This uniformity helps prevent differential settlement, which can cause structural problems in buildings and infrastructure.

Therefore, heat treatment of expansive soils enables achieving the desired dry density during construction which in turn reduces the need for costly corrections and repairs later in the project's life cycle. Proper compaction minimizes the risk of rework and associated expenses. Structures built on well-compacted soils tend to have a longer lifespan. This longevity is essential for reducing maintenance and replacement costs over the years. Ensuring proper dry density contributes to the overall safety of a construction site. Stable soils reduce the risk of accidents and mishaps, ensuring a safer working environment for construction workers. Proper compaction can minimize soil erosion and prevent sediment runoff into nearby water bodies, thus reducing the environmental impact of construction projects. Many construction projects are subject to regulatory requirements for compaction. Meeting these standards for dry density is essential for obtaining permits and approvals.

In summary, understanding and achieving the correct dry density in construction is critical for ensuring the stability, safety, and long-term performance of structures. It plays a pivotal role in the overall success of construction projects, from residential buildings to large-scale infrastructure developments and heat treatment of expansive soils can have huge implications for the construction industry.

4.1.7 CBR Tests

The increase in CBR from 2.2 at 100°C to 7.5 at 600°C is a positive sign, showing an increase of approximately 500% in load-bearing capacity. This is a very promising result implying that heat treatment can have such a big impact on the bearing capacity of expansive soils even at relatively lower temperatures. The result shows a CBR of 5% at 300°C heat treatment, which indicates that expansive soils are very sensitive to heat even at temperatures as low as 300°C.

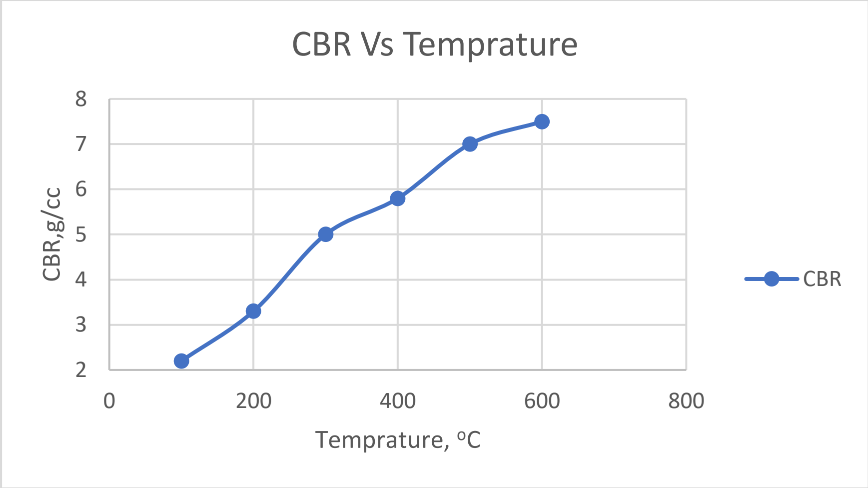

FIGURE 13 CBR VS TEMPERATURE

Other researchers also reported that heating increased the CBR from 1 to 3, probably as a result of breaking of the montmorillonite structure, largely attributed to the expansive behaviour and low strengths of expansive clays.

In summary, the laboratory results indicate that heat treatment has a significant impact on the engineering properties of the expansive soil. It reduces soil shrinkage, free swell, plasticity, and specific gravity while improving load-bearing capacity (CBR). However, the decrease in MDD at higher temperatures may require careful consideration in construction planning. Overall, the results suggest that controlled heat treatment can effectively enhance the suitability of expansive soil for construction applications, particularly in terms of volume stability and load-bearing capacity.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This research conclusively proved that heat treatment can improve the engineering properties of expansive soils. The application of heat treatment will result in a significant reduction in the swell potential of expansive soils.

The increase in CBR from 2.2 at 100°C to 7.5 at 600°C, MDD increased from 1.28g/cc at 100°C to 1.43g/cc which indicates heat treatment has a positive impact on the dry density of expansive soils. This is a 12% increase which would have a positive implications on the load bearing capacity of the soil in practice.

Specific Gravity decreased from 2.64 to 2.56, indicating a reduction of approximately 3.03%, Liquid Limit decreased from 66% at 100°C to 56% at 600°C, representing a reduction of approximately 15.2% in liquid limit. Simultaneously, Plastic Limit decreased from 33% at 100°C to 28% at 600°C, indicating a reduction of approximately 15.2% in plastic limit. The Plastic Index decreased from 33% to 28%, demonstrating a reduction of approximately 15.2% in soil plasticity.

The decrease in linear shrinkage from 15% at 100°C to 11% at 600°C indicates that higher temperatures result in reduced soil shrinkage which represents a decrease of approximately 26.7% in linear shrinkage with increasing temperature

Heat treatment will lead to an improvement in the grain size distribution and load-bearing capacity of expansive soils because the mineralogical and chemical composition of expansive soils will undergo substantial alterations due to heat treatment.

It also indicated that there is an optimal temperature for each expansive soil where the improvements in the engineering properties is effective and tenable. In this particular research an optimal temperature of 500°C is identified as the optimal temperature at which most engineering properties of the expansive clay showed marked improvement.

Through the investigation of heat treatment as a means to enhance the engineering properties of expansive soils, this research contributes to the advancement of geotechnical engineering knowledge and provide innovative solutions for managing problematic soils. The outcomes of this study could offer new insights into soil stabilization practices and provide a promising avenue for addressing the persistent challenges posed by expansive soils in infrastructure projects.

5.2 Recommendation

In this research an optimal temperature of 500^{o}C is identified where most engineering properties of the expansive soil improved appreciably. As can be seen from the above laboratory results, most of the property enhancements are attained at 500^{o}C such as the Linear shrinkage, the Free swell, Plasticity Index and especially the MDD, and CBR.

However, specific study should be done to decide the optimal temperature for the improvement of the engineering properties of expansive soils as many parameters and factors could alter the optimal temperature for heat treatment for individual soils.

The positive result obtained from this and other similar researches should encourage similar more advanced studies in to the practical application of heat treatment as a mechanism to mitigate the problems caused by expansive soils in the construction sector in the country.

CHAPTER 6

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7 APPENDICES

7.1 Appendix 1: Detailed Laboratory Test Results

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SUMMARY OF TEST RESULTS

LAB NUMBER	: EHTMPES 1289/23
REQUSTED BY	: Dinkayehu Nega Bashew
PROJECT	: Effect of Heat Treatment Mile Proposal of Expansive Soil
MATERIAL TYPE	: Expansive Soil
MATERIAL DESCRIPTION	: On Treated
TYPE OF TESTS	: Sieve analysis, Plasticity Index, Specific Gravity, Free Swell and Linear Shrinkage
TEST SPECIFIED BY	: Dinkayehu Nega Bashew
SAMPLED BY	: Dinkayehu Nega Bashew
SUBMITTED BY	: Dinkayehu Nega Bashew On: 21.08.2023
REPORTED TO	: Dinkayehu Nega Bashew On: 18.09.2023

Sl. No.	Station / Location (Km)	On Treated Temperature °C	Sieve analysis % Pass (AASHTO T 88) Wet				Atterberg's Limit (AASTHO T89/T 90)			Specific Gravity	Free Swell %	Linear Shrinkage %
			4.75 mm	2.00 mm	0.425 mm	0.075 mm	LL %	PL %	PI %			
1	Adama to Awash Road Project	100 °C	99	98	94	89	66	33	33	2.64	75	15
2		200 °C	99	98	95	90	62	31	31	2.62	70	14
3		300 °C	100	99	95	91	60	30	30	2.60	65	13
4		400 °C	100	99	96	92	58	29	29	2.58	60	12

REMARK :

Checked by:

Approved by:

ICT ENGINEERING PLC Addis Ababa

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ICT ENGINEERING PLC
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ICT ENGINEERING PRIVATE LIMITED COMPANY

SUMMARY OF TEST RESULTS

LAB NUMBER	: EHTMPES 1289/23
REQUSTED BY	: Dinkayehu Nega Bashew
PROJECT	: Effect of Heat Treatment Mile Proposal of Expansive Soil
MATERIAL TYPE	: Expansive Soil
MATERIAL DESCRIPTION	: On Treated
TYPE OF TESTS	: Sieve analysis, Plasticity Index, Specific Gravity, Free Swell and Linear Shrinkage
TEST SPECIFIED BY	: Dinkayehu Nega Bashew
SAMPLED BY	: Dinkayehu Nega Bashew
SUBMITTED BY	: Dinkayehu Nega Bashew On: 21.08.2023
REPORTED TO	: Dinkayehu Nega Bashew On: 18.09.2023

Sl. No.	Station / Location (Km)	On Treated Temperature °C	Sieve analysis % Pass (AASHTO T 88) Wet				Atterberg's Limit (AASHTO T89/T 90)			Specific Gravity	Free Swell %	Linear Shrinkage %
			4.75 mm	2.00 mm	0.425 mm	0.075 mm	LL %	PL %	PI %			
5	Adama to Awash Road Project	500 °C	100	99	97	93	57	29	28	2.56	55	11
6		600 °C	100	99	97	94	56	28	28	2.56	55	11

REMARK :

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Approved by:

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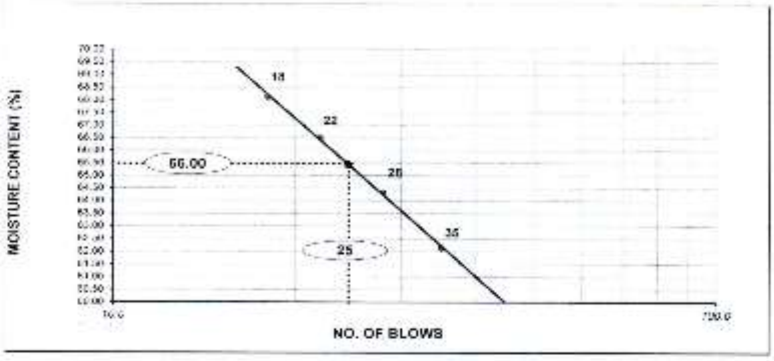
ICT ENGINEERING PRIVATE LIMITED COMPANY

Atterberg's Limit (AASHTO-T 89/T 90)

LAB NUMBER	: EHTMPES 1289/23
REQUESTED BY	: Dinkayehu Nega Bashew
PROJECT	: Effect of Heat Treatment Mile Proposal of Expansive Soil
SAMPLE STATION	: Adama to Awash Road Project
SAMPLE DESCRIPTION	: On Treated at Temperature 100 °C
TYPE OF MATERIAL	: Expansive Soil
SAMPLED BY	: Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY	: Dinkayehu Nega Bashew
REPORTED TO	: Dinkayehu Nega Bashew

DATE SAMPLED	: -
DATE SUBMITTED	: 21.08.2023
DATE TESTED	: 28.08.2023
DATE ISSUED	: 29.08.2023
DEPTH (m)	: -

	LIQUID LIMIT				PLASTIC LIMIT	
No. Blows	35	28	22	18		
Wt. of cont. + wet soil (g.) = (w_1)	46.83	48.62	47.92	48.68	24.37	22.83
Wt. of cont. + dry soil (g.) = (w_2)	38.20	39.08	38.53	38.60	24.08	22.56
Wt. of container (g.) = (w_3)	24.31	24.25	24.41	24.66	23.26	21.73
Mass of moisture (g.) (w_1-w_2) = x	8.63	9.54	9.39	10.18	0.28	0.27
Wt. of dry soil (g.) (w_2-w_3) = y	13.89	14.83	14.12	14.84	0.84	0.83
Moisture Content (%) = $\frac{x}{y}\cdot 100$	62.13	64.33	66.60	68.14	33.33	32.53
					32.9	



LIQUID LIMIT (%)	66
PLASTIC LIMIT(%)	33
PLASTICITY INDEX(%)	33

Remark :

Tested by: **Checked by:** **Approved by:**

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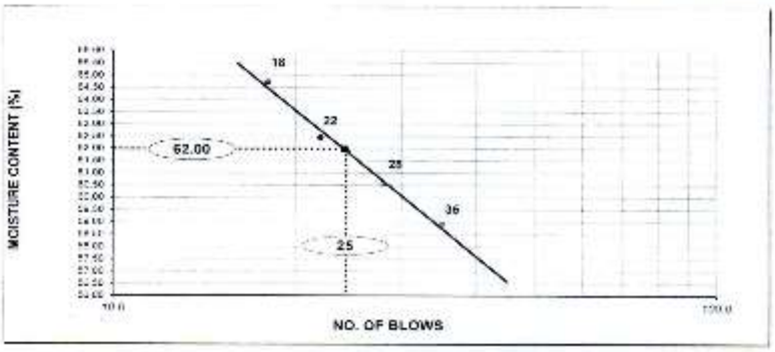
ICT ENGINEERING PRIVATE LIMITED COMPANY

Atterberg's Limit (AASHTO-T 89/T 90)

LAB NUMBER : EHTMPES 1289/23
REQUESTED BY : Dinkayehu Nega Bashew
PROJECT : Effect of Heat Treatment Mile Proposal of Expansive Soil
SAMPLE STATION : Adama to Awash Road Project
SAMPLE DESCRIPTION : On Treated at Temperature 200 °C
TYPE OF MATERIAL : Expansive Soil
SAMPLED BY : Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY : Dinkayehu Nega Bashew
REPORTED TO : Dinkayehu Nega Bashew

DATE SAMPLED : -
DATE SUBMITTED : 21.08.2023
DATE TESTED : 28.08.2023
DATE ISSUED : 29.08.2023
DEPTH (m) : -

	LIQUID LIMIT				PLASTIC LIMIT	
No. Blows	35	28	22	18		
Wt.of cont. + wet soil (g.) =(w_1)	46.14	48.82	47.48	51.34	24.41	22.82
Wt.of cont. + dry soil (g.) =(w_2)	37.22	39.08	38.63	39.60	24.36	22.56
Wt.of container (g.) =(w_3)	22.08	23.33	24.20	21.21	24.20	21.73
Wt.of moisture (g.) (w_1-w_2)=x	8.92	9.54	8.85	11.84	0.05	0.26
Wt.of dry soil (g.) (w_2-w_3)=y	16.14	15.75	14.33	18.29	0.16	0.83
Moisture Content (%) = $\frac{x}{y}$ *100	58.92	60.57	62.46	64.73	31.25	31.33
					31.3	



LIQUID LIMIT (%)	62
PLASTIC LIMIT(%)	31
PLASTICITY INDEX(%)	31

Remark : -

Tested by: Checked by: Approved by:

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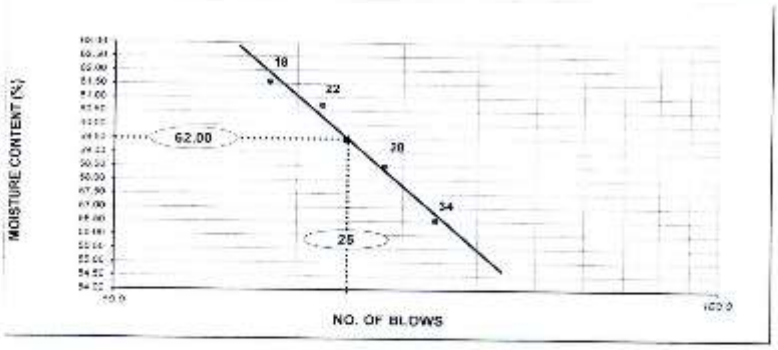
ICT ENGINEERING PRIVATE LIMITED COMPANY

Atterberg's Limit (AASHTO-T 89/T 90)

LAB NUMBER	: EHTMPES 1289/23	DATE SAMPLED	: -
REQUESTED BY	: Dinkayehu Nega Bashew	DATE SUBMITTED	: 21.08.2023
PROJECT	: Effect of Heat Treatment Mile Proposal of Expansive Soil	DATE TESTED	: 28.08.2023
SAMPLE STATION	: Adama to Awash Road Project	DATE ISSUED	: 29.08.2023
SAMPLE DESCRIPTION	: On Treated at Temperature 300 °C	DEPTH (m)	: -
TYPE OF MATERIAL	: Expansive Soil		
SAMPLED BY	: Dinkayehu Nega Bashew		
SAMPLE AND TEST ORDER SUBMITTED BY	: Dinkayehu Nega Bashew		
REPORTED TO	: Dinkayehu Nega Bashew		

	LIQUID LIMIT				PLASTIC LIMIT	
No. Blows	34	28	22	18		
Wt.of cont. + wet soil (g.) =(w_1)	43.84	48.25	44.88	47.80	21.61	24.77
Wt.of cont. + dry soil (g.) =(w_2)	37.09	38.14	37.09	38.47	21.38	24.53
Wt.of container (g.) =(w_3)	25.15	20.86	24.26	23.32	20.52	23.73
Mas of moisture (g.) (w_1-w_2)=x	6.75	10.11	7.79	9.33	0.25	0.24
Wt.of dry soil (g.) (w_2-w_3)=y	11.94	17.28	12.83	15.15	0.84	0.80
Moisture Content (%) = $\frac{x}{y}$ ×100	56.63	58.51	60.72	61.58	29.76	30.00
					29.9	



LIQUID LIMIT (%)	60
PLASTIC LIMIT(%)	30
PLASTICITY INDEX(%)	30

Remark : ______

Tested by: ______ Checked by: ______ Approved by: ______

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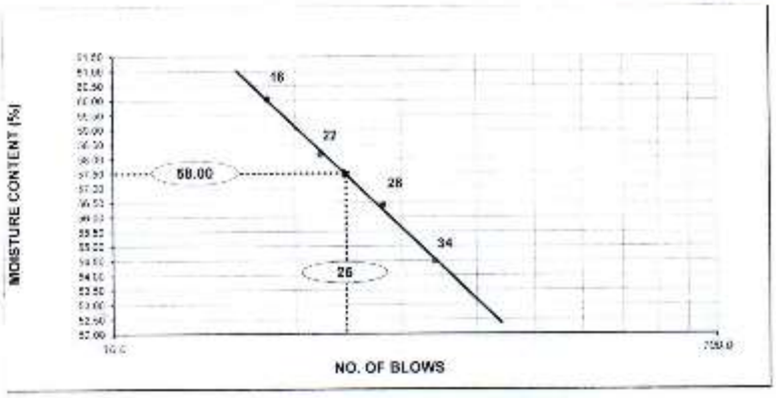
Atterberg's Limit (AASHTO-T 89/T 90)

LAB NUMBER	: EHTMPES 1289/23
REQUESTED BY	: Dinkayehu Nega Bashew
PROJECT	: Effect of Heat Treatment Mile Proposal of Expansive Soil
SAMPLE STATION	: Adama to Awash Road Project
SAMPLE DESCRIPTION	: On Treated at Temperature 500 °C
TYPE OF MATERIAL	: Expansive Soil
SAMPLED BY	: Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY	: Dinkayehu Nega Bashew
REPORTED TO	: Dinkayehu Nega Bashew

DATE SAMPLED	: -
DATE SUBMITTED	: 21.08.2023
DATE TESTED	: 28.08.2023
DATE ISSUED	: 29.08.2023
DEPTH (m)	: -

	LIQUID LIMIT				PLASTIC LIMIT	
No. Blows	34	28	22	18		
Wt. of cont. + wet soil (g.) = (W_1)	44.95	48.02	46.84	48.18	24.49	22.74
Wt. of cont. + dry soil (g.) = (W_2)	36.22	39.08	38.53	38.69	24.29	22.66
Wt. of container (g.) = (W_3)	20.20	23.23	24.24	22.89	23.60	22.34
Mas of moisture (g.) (W_1-W_2)=x	8.73	8.94	8.31	9.49	0.20	0.08
Wt. of dry soil (g.) (W_2-W_3) =y	16.02	15.86	14.29	15.80	0.69	0.31
Moisture Content (%) = x/y ×100	54.49	56.40	58.15	60.06	28.99	29.03
					29.0	



LIQUID LIMIT (%)	58
PLASTIC LIMIT(%)	29
PLASTICITY INDEX(%)	29

Remark : Sample description and date Sampled are not mentioned in the request letter.

Tested by: Checked by: Approved by:

ICT ENGINEERING PLC Addis Ababa

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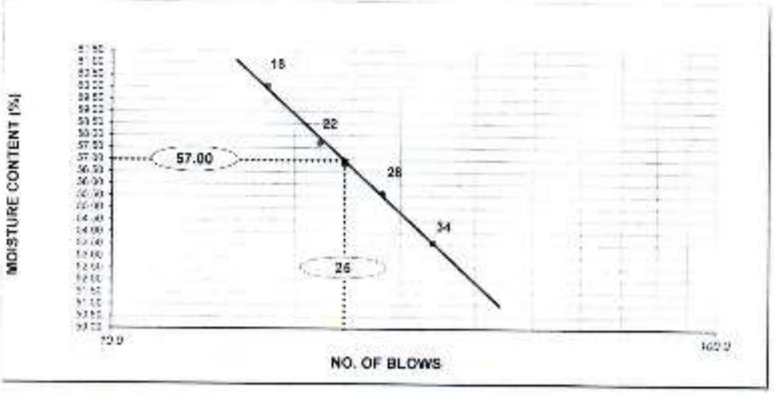
ICT ENGINEERING PRIVATE LIMITED COMPANY

Atterberg's Limit (AASHTO-T 89/T 90)

LAB NUMBER : EHTMPES 1289/23
REQUESTED BY : Dinkayehu Nega Bashew
PROJECT : Effect of Heat Treatment Mix Proposal of Expansive Soil
SAMPLE STATION : Adama to Awash Road Project
SAMPLE DESCRIPTION : On Treated at Temperature 500 °C
TYPE OF MATERIAL : Expansive Soil
SAMPLED BY : Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY : Dinkayehu Nega Bashew
REPORTED TO : Dinkayehu Nega Bashew

DATE SAMPLED : -
DATE SUBMITTED : 21.08.2023
DATE TESTED : 28.08.2023
DATE ISSUED : 29.08.2023
DEPTH (m) : -

	LIQUID LIMIT				PLASTIC LIMIT	
No. Blows	34	28	22	18		
Wt.of cont. + wet soil (g.) =(w₁)	44.93	47.95	46.91	48.18	24.72	23.89
Wt.of cont. + dry soil (g.) = (w₂)	36.31	39.18	38.61	38.69	24.31	23.28
Wt.of container (g.) = (w₃)	20.22	23.41	24.23	22.89	22.90	21.20
Mass of moisture (g.) (w₁-w₂)=x	8.62	8.77	8.30	9.49	0.41	0.61
Wt of dry soil (g.) (w₂-w₃)=y	16.09	16.77	14.38	15.80	1.41	2.08
Moisture Content (%) = x/y ×100	53.57	55.61	57.72	60.06	29.08	29.33
					29.2	



LIQUID LIMIT (%)	57
PLASTIC LIMIT(%)	29
PLASTICITY INDEX(%)	28

Remark :

Tested by: Checked by: Approved by:

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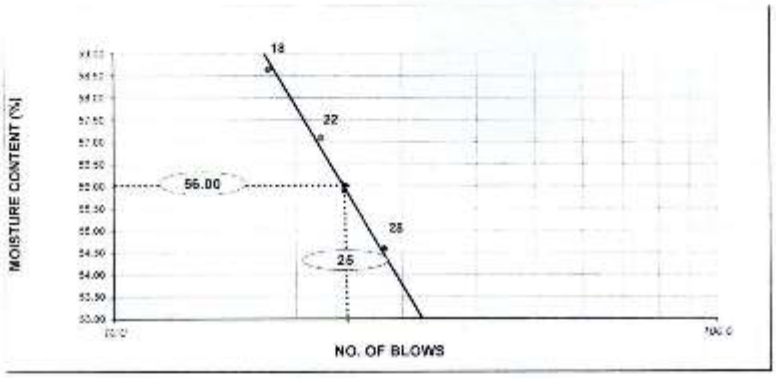
ICT ENGINEERING PRIVATE LIMITED COMPANY

Atterberg's Limit (AASHTO-T 89/T 90)

LAB NUMBER	: EHTMPES 1289/23	DATE SAMPLED	: -
REQUESTED BY	: Dinkayehu Nega Bashew	DATE SUBMITTED	: 21.08.2023
PROJECT	: Effect of Heat Treatment Mile Proposal of Expansive Soil	DATE TESTED	: 28.08.2023
SAMPLE STATION	: Adama to Awash Road Project	DATE ISSUED	: 29.08.2023
SAMPLE DESCRIPTION	: On Treated at Temperature 600 °C	DEPTH (m)	: -
TYPE OF MATERIAL	: Expansive Soil		
SAMPLED BY	: Dinkayehu Nega Bashew		
SAMPLE AND TEST ORDER SUBMITTED BY	: Dinkayehu Nega Bashew		
REPORTED TO	: Dinkayehu Nega Bashew		

	LIQUID LIMIT				PLASTIC LIMIT	
No. Blows	35	28	22	18		
Wt. of cont. + wet soil (g.) = (w_1)	43.70	46.45	44.75	45.70	24.33	22.73
Wt. of cont. + dry soil (g.) = (w_2)	37.30	38.60	37.39	37.53	24.13	22.65
Wt. of container (g.) = (w_3)	25.01	24.22	24.50	23.60	23.40	22.36
Mass of moisture (g.) (w_1-w_2)=x	6.40	7.85	7.36	8.17	0.20	0.08
Wt. of dry soil (g.) (w_2-w_3) = y	12.29	14.38	12.89	13.93	0.73	0.29
Moisture Content (%) = $\frac{x}{y}$ · 100	52.07	54.69	57.10	58.66	27.40	27.59
					27.5	



LIQUID LIMIT (%)	56
PLASTIC LIMIT(%)	28
PLASTICITY INDEX(%)	28

Remark :

Tested by: Checked by: Approved by:

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ICT ENGINEERING PRIVATE LIMITED COMPANY

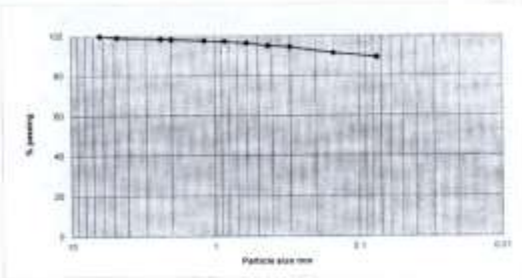
ICT Precision in every task

SIEVE ANALYSIS RECORD (AASHTO-T 88)

LAB NUMBER	: EHTMPES 1289/23	DATE SAMPLED	: -
REQUSTED BY	: Dinkayehu Nega Bashew	DATE SUBMITTED	: 21.08.2023
PROJECT	: Effect of Heat Treatment Mile Proposal of Expansive Soil	DATE TESTED	: 28.08.2023
SAMPLE STATION/CHAINAGE (Km)	: Adama to Awash Road Project	DATE ISSUED	: 29.08.2023
MATERIAL DESCRIPTION	: On Treated at Temperature 100 °C	DEPTH (Cm)	: -
TYPE OF MATERIAL	: Expansive Soil		
SAMPLED BY	: Dinkayehu Nega Bashew		
SAMPLE AND TEST ORDER SUBMITTED BY	: Dinkayehu Nega Bashew		
REPORTED TO	: Dinkayehu Nega Bashew		
	WET/DRY	WEIGHT OF SAMPLE (gm.)	1236

Sieve Size (in mm)	Weight retained (in gm)	% age retained	Cumulative % age retained	% age Pass
100.00	-	-	-	-
75.00	-	-	-	-
63.00	-	-	-	-
50.00	-	-	-	-
37.50	-	-	-	-
25.00	-	-	-	-
19.00	-	-	-	-
12.50	-	-	-	-
9.50	-	-	-	-
6.30	0	0.00	0.00	100.00
4.75	10	0.81	0.81	99.19
2.36	8	0.65	1.46	98.54
2.00	3	0.24	1.70	98.30
1.18	8	0.65	2.35	97.65
0.850	5	0.40	2.75	97.25
0.600	11	0.89	3.64	96.36
0.425	18	1.46	5.10	94.90
0.300	6	0.49	5.58	94.42
0.150	40	3.24	8.82	91.18
0.075	23	1.86	10.68	89.32

Grain size analysis distribution Chart



Remark : ______

Tested by: ______ Checked by: ______ Approved By: ______

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ICT ENGINEERING PRIVATE LIMITED COMPANY

SIEVE ANALYSIS RECORD (AASHTO-T 88)

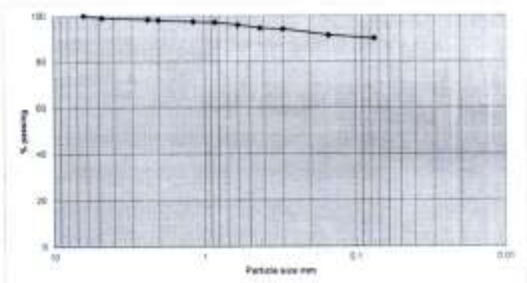
LAB NUMBER : EHTMPES 1289/23
REQUSTED BY : Dinkayehu Nega Bashew
PROJECT : Effect of Heat Treatment Mile Proposal of Expansive Soil
SAMPLE STATION/CHAINAGE (Km) : Adama to Awash Road Project
MATERIAL DESCRIPTION : On Treated at Temperature 200 °C
TYPE OF MATERIAL : Expansive Soil
SAMPLED BY : Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY : Dinkayehu Nega Bashew
REPORTED TO : Dinkayehu Nega Bashew

DATE SAMPLED : -
DATE SUBMITTED : 21.08.2023
DATE TESTED : 28.08.2023
DATE ISSUED : 29.08.2023
DEPTH (Cm) : -

WET/DRY WEIGHT OF SAMPLE (gm.) 1046

Sieve Size (in mm)	Weight retained (in gm)	% age retained	Cumulative % age retained	% age Pass
100.00	-	-	-	-
75.00	-	-	-	-
63.00	-	-	-	-
50.00	-	-	-	-
37.50	-	-	-	-
25.00	-	-	-	-
19.00	-	-	-	-
12.50	-	-	-	-
9.50	-	-	-	-
6.30	0	0.00	0.00	100.00
4.75	10	0.96	0.96	99.04
2.36	8	0.76	1.72	98.28
2.00	2	0.19	1.91	98.09
1.18	7	0.67	2.58	97.42
0.850	4	0.38	2.96	97.04
0.600	11	1.06	4.02	95.98
0.425	15	1.43	5.45	94.55
0.300	5	0.48	5.93	94.07
0.150	28	2.68	8.60	91.40
0.075	15	1.43	10.04	89.96

Grain size analysis distribution Chart



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ICT ENGINEERING PRIVATE LIMITED COMPANY

SIEVE ANALYSIS RECORD (AASHTO-T 88)

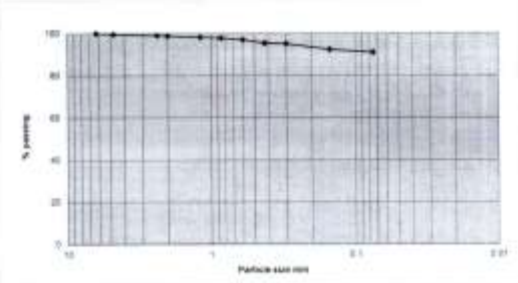
LAB NUMBER	: EHTMPES 1289/23
REQUSTED BY	: Dinkayehu Nega Bashew
PROJECT	: Effect of Heat Treatment Mile Proposal of Expansive Soil
SAMPLE STATION/CHAINAGE (Km)	: Adama to Awash Road Project
MATERIAL DESCRIPTION	: On Treated at Temperature 300 °C
TYPE OF MATERIAL	: Expansive Soil
SAMPLED BY	: Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY	: Dinkayehu Nega Bashew
REPORTED TO	: Dinkayehu Nega Bashew

DATE SAMPLED	: -
DATE SUBMITTED	: 21.08.2023
DATE TESTED	: 28.08.2023
DATE ISSUED	: 29.08.2023
DEPTH (Cm)	: -

WET/DRY WEIGHT OF SAMPLE (gm.) 1737

Sieve Size (in mm)	Weight retained (in gm)	% age retained	Cumulative % age retained	% age Pass
100.00	-	-	-	-
75.00	-	-	-	-
63.00	-	-	-	-
50.00	-	-	-	-
37.50	-	-	-	-
25.00	-	-	-	-
19.00	-	-	-	-
12.50	-	-	-	-
9.50	-	-	-	-
6.30	0	0.00	0.00	100.00
4.75	8	0.46	0.46	99.54
2.36	10	0.58	1.04	98.96
2.00	3	0.17	1.21	98.79
1.18	10	0.58	1.78	98.22
0.850	7	0.40	2.19	97.81
0.600	15	0.86	3.05	96.95
0.425	26	1.50	4.55	95.45
0.300	7	0.40	4.95	95.05
0.150	47	2.71	7.66	92.34
0.075	25	1.44	9.10	90.90

Grain size analysis distribution Chart



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SIEVE ANALYSIS RECORD (AASHTO-T 88)

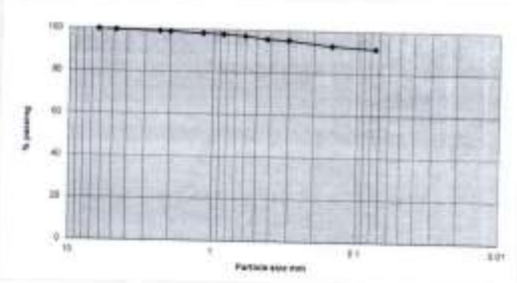
LAB NUMBER : EHTMPES 1289/23
REQUSTED BY : Dinkayehu Nega Bashew
PROJECT : Effect of Heat Treatment Mile Proposal of Expansive Soil
SAMPLE STATION/CHAINAGE (Km) : Adama to Awash Road Project
MATERIAL DESCRIPTION : On Treated at Temperature 400 °C
TYPE OF MATERIAL : Expansive Soil
SAMPLED BY : Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY : Dinkayehu Nega Bashew
REPORTED TO : Dinkayehu Nega Bashew

DATE SAMPLED : -
DATE SUBMITTED : 21.08.2023
DATE TESTED : 28.08.2023
DATE ISSUED : 29.08.2023
DEPTH (Cm) : -

WET/DRY WEIGHT OF SAMPLE (gm.) 1833

Sieve Size (in mm)	Weight retained (in gm)	% age retained	Cumulative % age retained	% age Pass
100.00	-	-	-	-
75.00	-	-	-	-
63.00	-	-	-	-
50.00	-	-	-	-
37.50	-	-	-	-
25.00	-	-	-	-
19.00	-	-	-	-
12.50	-	-	-	-
9.50	-	-	-	-
6.30	0	0.00	0.00	100.00
4.75	7	0.38	0.38	99.62
2.36	10	0.55	0.93	99.07
2.00	3	0.16	1.09	98.91
1.18	11	0.60	1.69	98.31
0.850	7	0.38	2.07	97.93
0.600	13	0.71	2.78	97.22
0.425	26	1.42	4.20	95.80
0.300	7	0.38	4.58	95.42
0.150	45	2.45	7.04	92.96
0.075	23	1.25	8.29	91.71

Grain size analysis distribution Chart



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SIEVE ANALYSIS RECORD (AASHTO-T 88)

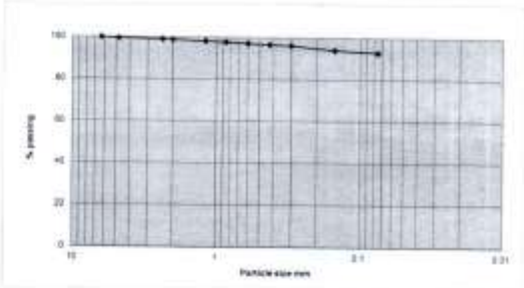
LAB NUMBER : EHTMPES 1289/23
REQUSTED BY : Dinkayehu Nega Bashew
PROJECT : Effect of Heat Treatment Mile Proposal of Expansive Soil
SAMPLE STATION/CHAINAGE (Km) : Adama to Awash Road Project
MATERIAL DESCRIPTION : On Treated at Temperature 500 °C
TYPE OF MATERIAL : Expansive Soil
SAMPLED BY : Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY : Dinkayehu Nega Bashew
REPORTED TO : Dinkayehu Nega Bashew

DATE SAMPLED : -
DATE SUBMITTED : 21.08.2023
DATE TESTED : 28.08.2023
DATE ISSUED : 29.08.2023
DEPTH (Cm) : -

WET/DRY WEIGHT OF SAMPLE (gm.) 1913

Sieve Size (in mm)	Weight retained (in gm)	% age retained	Cumulative % age retained	% age Pass
100.00	-	-	-	-
76.00	-	-	-	-
63.00	-	-	-	-
50.00	-	-	-	-
37.50	-	-	-	-
26.00	-	-	-	-
19.00	-	-	-	-
12.50	-	-	-	-
9.50	-	-	-	-
6.30	0	0.00	0.00	100.00
4.75	8	0.42	0.42	99.58
2.36	9	0.47	0.89	99.11
2.00	5	0.26	1.15	98.85
1.18	13	0.68	1.83	98.17
0.850	8	0.42	2.26	97.76
0.600	11	0.58	2.82	97.18
0.425	10	0.52	3.35	96.65
0.300	9	0.47	3.82	96.18
0.150	41	2.14	5.96	94.04
0.075	22	1.15	7.11	92.89

Grain size analysis distribution Chart



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SIEVE ANALYSIS RECORD (AASHTO-T 88)

LAB NUMBER : EHTMPES 1289/23
REQUSTED BY : Dinkayehu Nega Bashew
PROJECT : Effect of Heat Treatment Mile Proposal of Expansive Soil
SAMPLE STATION/CHAINAGE (Km) : Adama to Awash Road Project
MATERIAL DESCRIPTION : On Treated at Temperature 600 °C
TYPE OF MATERIAL : Expansive Soil
SAMPLED BY : Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY : Dinkayehu Nega Bashew
REPORTED TO : Dinkayehu Nega Bashew

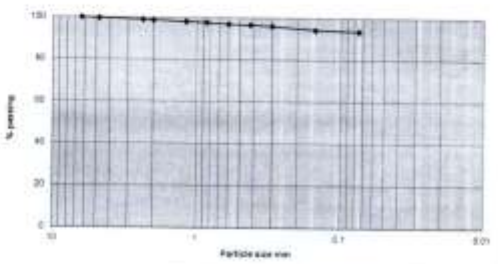
DATE SAMPLED : -
DATE SUBMITTED : 21.08.2023
DATE TESTED : 28.08.2023
DATE ISSUED : 29.08.2023
DEPTH (Cm) : -

WET/DRY

WEIGHT OF SAMPLE (gm.) 2013

Sieve Size (in mm)	Weight retained (in gm)	% age retained	Cumulative % age retained	% age Pass
100.00	-	-	-	-
75.00	-	-	-	-
63.00	-	-	-	-
50.00	-	-	-	-
37.50	-	-	-	-
25.00	-	-	-	-
19.00	-	-	-	-
12.50	-	-	-	-
9.50	-	-	-	-
6.30	0	0.00	0.00	100.00
4.75	8	0.40	0.40	99.60
2.36	13	0.65	1.04	98.96
2.00	7	0.35	1.39	98.61
1.18	11	0.55	1.94	98.06
0.850	8	0.40	2.33	97.67
0.600	14	0.70	3.03	96.97
0.425	7	0.35	3.38	96.62
0.300	11	0.55	3.92	96.08
0.150	35	1.74	5.66	94.34
0.075	15	0.75	6.41	93.59

Grain size analysis distribution Chart



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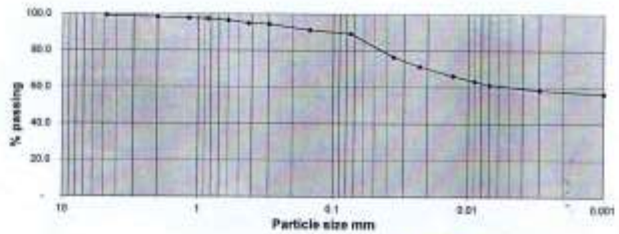
PARTICLE- SIZE ANALYSIS OF SOILS (ASTM D 422)

LAB NUMBER	: EHTMPES 1289/23
SUNMITTED BY	: Dinkayehu Nega Bashew
MATERIAL DESCRIPTION	: Expansive Soil On Treated at Temprearature 100°C
PROJECT	: Effect of Heat Treatment Mile Propsal of Expansive Soil
SAMPLED BY	: Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY	: Dinkayehu Nega Bashew
DATE SAMPLED	: -
DATE SUBMITTED	: 21.08.2023
DATE TESTED	: 08.09.2023
DATE ISSUED	: 18.09.20123

Material Type	Depth (m)	Specific Gravity	Hydrometer Test Result																		
Treated Disturbed Soil	–	2.64	Grain Size (mm)	4.75	2.000	1.180	0.850	0.600	0.425	0.300	0.150	0.075	0.036	0.023	0.013	0.009	0.007	0.003	0.001
			% Pass	99.2	98.3	97.7	97.3	96.4	94.9	94.4	91.2	89.3	76.5	71.4	66.2	63.2	61.2	58.3	56.2

Gravel %:	0.8
Sand %	9.9
Silt %	32.0
Clay %	57.3



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E-mail: n.akhtar1974@yahoo.com

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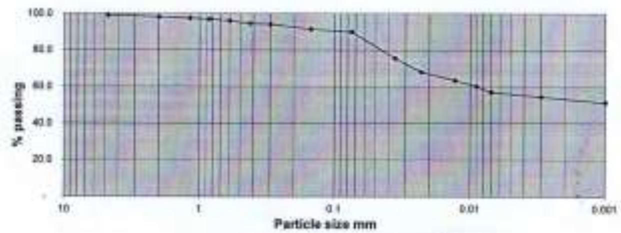
PARTICLE- SIZE ANALYSIS OF SOILS (ASTM D 422)

LAB NUMBER : EHTMPES 1289/23
SUNMITTED BY : Dinkayehu Nega Bashew
MATERIAL DESCRIPTION : Expansive Soil On Treated at Temprearature 200°C
PROJECT : Effect of Heat Treatment Mile Propsal of Expansive Soil
SAMPLED BY : Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY : Dinkayehu Nega Bashew

DATE SAMPLED : -
DATE SUBMITTED : 21.08.2023
DATE TESTED : 08.09.2023
DATE ISSUED : 18.09.20123

Material Type	Depth (m)	Specific Gravity	Hydrometer Test Result																	
Treated Disturbed Soil	-	2.62	Grain Size (mm)	4.75	2.000	1.180	0.850	0.600	0.425	0.300	0.150	0.075	0.036	0.023	0.013	0.009	0.007	0.003	0.001
			% Pass	99.0	98.1	97.4	97.0	96.0	94.6	94.1	91.4	90.0	75.5	68.0	63.2	60.0	56.8	54.3	51.2

Gravel %: 1.0
Sand % 9.0
Silt % 37.2
Clay % 52.8



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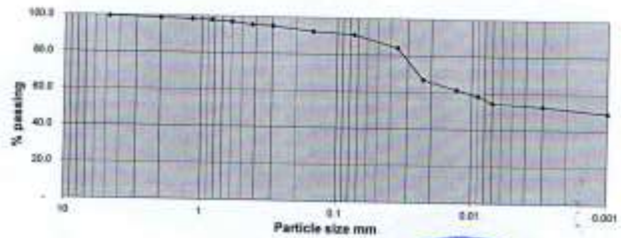
PARTICLE- SIZE ANALYSIS OF SOILS (ASTM D 422)

LAB NUMBER : EHTMPES 1289/23
SUNMITTED BY : Dinkayehu Nega Bashew
MATERIAL DESCRIPTION : Expansive Soil On Treated at Temprearature 300°C
PROJECT : Effect of Heat Treatment Mile Propsal of Expansive Soil
SAMPLED BY : Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY : Dinkayehu Nega Bashew

DATE SAMPLED : -
DATE SUBMITTED : 21.08.2023
DATE TESTED : 08.09.2023
DATE ISSUED : 18.09.20123

Material Type	Depth (m)	Specific Gravity	Hydrometer Test Result																	
Treated Disturbed Soil	-	2.60	Grain Size (mm)	4.75	2.000	1.180	0.850	0.600	0.425	0.300	0.150	0.075	0.036	0.023	0.013	0.009	0.007	0.003	0.001
			% Pass	99.5	98.8	98.2	97.8	97.0	95.5	95.1	92.3	90.9	84.1	66.8	61.5	58.2	54.3	52.6	49.2

Gravel %: 0.5
Sand % 8.6
Silt % 40.0
Clay % 50.9



Remark : -

Tested by:

Checked by:

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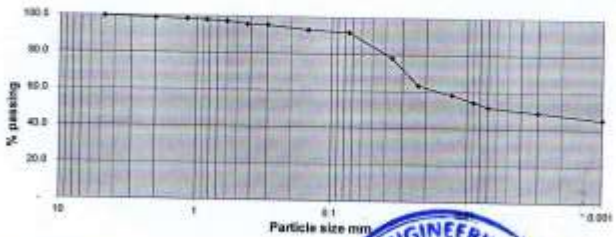
PARTICLE- SIZE ANALYSIS OF SOILS (ASTM D 422)

LAB NUMBER	: EHTMPES 1289/23	DATE SAMPLED	: --
SUNMITTED BY	: Dinkayehu Nega Bashew	DATE SUBMITTED	: 21.08.2023
MATERIAL DESCRIPTION	: Expansive Soil On Treated at Temprearature 400°C	DATE TESTED	: 08.09.2023
PROJECT	: Effect of Heat Treatment Mile Propsal of Expansive Soil	DATE ISSUED	: 18.09.20123
SAMPLED BY	: Dinkayehu Nega Bashew		
SAMPLE AND TEST ORDER SUBMITTED BY	: Dinkayehu Nega Bashew		

Material Type	Depth (m)	Specific Gravity	Hydrometer Test Result																
Treated Disturbed Soil	--	2.58	Grain Size (mm)	4.75	2.000	1.180	0.850	0.600	0.425	0.300	0.150	0.075	0.036	0.023	0.013	0.009	0.007	0.003	0.001
			% Pass	99.6	98.9	98.3	97.9	97.2	96.8	95.4	93.0	91.8	78.2	63.2	58.2	54.3	51.5	48.8	45.2

Gravel %: 0.4
Sand % 7.8
Silt % 44.8
Clay % 47.0



Remark : -

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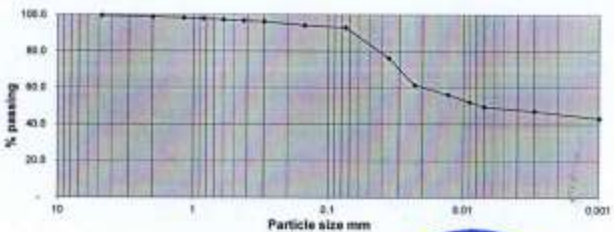
PARTICLE- SIZE ANALYSIS OF SOILS (ASTM D 422)

LAB NUMBER : EHTMPES 1289/23
SUNMITTED BY : Dinkayehu Nega Bashew
MATERIAL DESCRIPTION : Expansive Soil On Treated at Temprearature 500°C
PROJECT : Effect of Heat Treatment Mile Propsal of Expansive Soil
SAMPLED BY : Dinkayehu Nega Bashew
SAMPLE AND TEST ORDER SUBMITTED BY : Dinkayehu Nega Bashew

DATE SAMPLED : -
DATE SUBMITTED : 21.08.2023
DATE TESTED : 08.09.2023
DATE ISSUED : 18.09.20123

Material Type	Depth (m)	Specific Gravity	Hydrometer Test Result																
Treated Disturbed Soil	-	2.56	Grain Size (mm)	4.75	2.000	1.180	0.850	0.600	0.425	0.300	0.150	0.075	0.036	0.023	0.013	0.009	0.007	0.003	0.001
			% Pass	99.6	98.9	98.2	97.8	97.2	96.7	96.2	94.0	92.9	76.2	61.2	56.0	52.0	49.3	47.0	43.0

Gravel %: 0.4
Sand % 6.7
Silt % 47.9
Clay % 45.0



Remark : -

Tested by:

Checked by:

Approved by:

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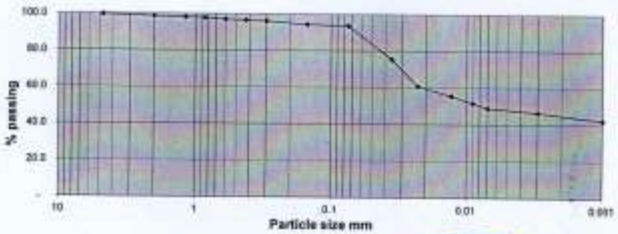
PARTICLE- SIZE ANALYSIS OF SOILS (ASTM D 422)

LAB NUMBER	: EHTMPES 1289/23	DATE SAMPLED	: –
SUNMITTED BY	: Dinkayehu Nega Bashew	DATE SUBMITTED	: 21.08.2023
MATERIAL DESCRIPTION	: Expansive Soil On Treated at Temprearature 600°C	DATE TESTED	: 08.09.2023
PROJECT	: Effect of Heat Treatment Mile Propsal of Expansive Soil	DATE ISSUED	: 18.09.20123
SAMPLED BY	: Dinkayehu Nega Bashew		
SAMPLE AND TEST ORDER SUBMITTED BY	: Dinkayehu Nega Bashew		

Material Type	Depth (m)	Specific Gravity	Hydrometer Test Result																	
Treated Disturbed Soil	–	2.56	Grain Size (mm)	4.75	2.000	1.180	0.850	0.600	0.425	0.300	0.150	0.075	0.036	0.023	0.013	0.009	0.007	0.003	0.001
			% Pass	99.6	98.6	98.1	97.7	97.0	96.6	96.1	94.3	93.6	75.4	60.6	55.4	51.5	48.8	46.4	42.1

Gravel %: 0.4
Sand % 6.0
Silt % 49.3
Clay % 44.3



Remark : -

Tested by:

Checked by:

Approved by:

ICT ENGINEERING PLC Addis Ababa

We stand Committed to the highest performance standards, fully complying with requirements of the Quality Management System (QMS) and our esteemed Clients.

BUISNESS OFFICE:
Sub City : Kirkos,Woreda: 03
House # 524 near Senay Higher Clinic
P.O Box: 120563- Gotera Post Office, Addis Ababa, ETHIOPIA
Tel.: +251 11 470 2517 Mob: +251 911 68 04 87
E-mail: icteplc@ethionet.et

CENTRAL LABORATORY
Sub City : Kirkos,Woreda: 03
House # 524 near Senay Higher Clinic
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Mob: +251 911 68 04 87
E-mail: n.akhtar1974@yahoo.com

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

SOIL TESTING AND APPROVAL RECORD

RFI No.		LAB REF. NO.	
SOURCE	OGL FROM 1+000 to 3+000 FW	SAMPLEING DATE	25/08/2023
SAMPLING LOCATION	Km.2+500 LHS	SAMPLE DEPTH (M)	0.30 to 1.0 m
PURPOSED TO USE	M.Sc. Research		
MATERIAL DESCRIPTION:	Black Cotton Soil Heated to 100°C		

No.	TEST PERFORMED		TEST RESULTS		TEST METHODS	ACCEPTANCE CRITERIA	APPROVAL STATUS
1	COMPACTION TEST	MDD at 100%	1.288	g/cm³	AASHTO T-180 Method D/ ASTM D 1557		YES NO
		OMC	19.6	%			YES NO
		MDD at 95%	1.224	g/cm³			YES NO
2	CBR	CBR at 95% MDD	2.6	%	AASHTO 193/ ASTM D 1883	> 5	YES NO
		SWELL	6.07	%		< 2	YES NO
3	SOIL PLASTICITY	LIQUID LIMIT (LL)	55.5	%	AASHTO T-89/90/ ASTM D 4318	< 60	YES NO
		PLASTIC LIMIT (PL)	18.7	%	AASHTO T-89/90/ ASTM D 4318		YES NO
		PLASTICITY INDEX(PI)	36.8	%	AASHTO T-89/90/ ASTM D 4318	< 30	YES NO

Note: Attach individual test records and data sheet

Remarks:

Contractor's Representative			Consultant's Representative		
	Signature	Date		Signature	Date
Material Engineer	[signature]	18/Sep/23	Material Engineer		

REC-SQP.05-07-01-V0

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

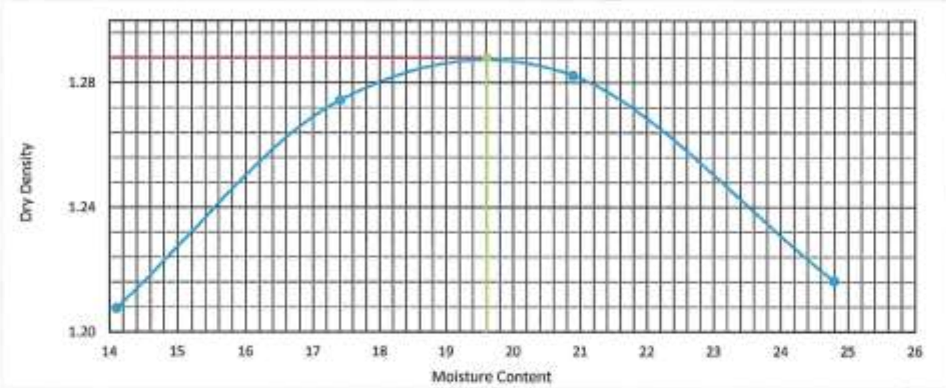
MAXIMUM DRY DENSITY AND MOISTURE CONTENT

(AASTHO T-180)

Format No: 01002/JMC/EHAE/21F/03-R0

RFI No.		Lab Ref No. :	
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Testing:	09/09/2023
Propose Used	M.Sc. Research	Sampled By:	Denkayehu
Type of Method:	A	Tested By:	Jointly
Material Discription	Black Cotton Soil Heated to 100oC	Depth (M)	0.30 to 1.0 m

Description	Test I	Test II	Test III	Test IV	Test V		
	Density Determination						
Water Added %	8%	10%	12%	14%			
Mass of mould + Wet Soil (g)	5430	5540	5590	5560			
Mass of mould, W5 (g)	4150	4150	4150	4150			
Mass of wet soil, W7=W6-W5 (g)	1280	1390	1440	1410			
Volume of mould, V (cc)	929	929	929	929			
Bulk density, γ_m = [(W7-W6)/V] g/cc	1.378	1.496	1.550	1.518		NMC	
	Moisture Content Determination						
Container no	D18	D9	D12	G2		D14	
Mass of container + wet soil, W1 (g)	226.20	222.30	227.00	230.90		280.00	
Mass of container + oven dry soil, W2 (g)	201.10	192.90	192.10	190.00		255.00	
Mass of Water (g) W3=W1-W2	25.10	29.40	34.90	40.90		25.00	
Mass of container, W4 (g)	23.00	24.00	25.00	25.00		28.60	
Mass of Dry Soil (g) W5 = W2-W4	178.10	168.90	167.10	165.00		226.40	
Moisture Content (%) W6= W3/W5*100	**14.09**	**17.41**	**20.89**	**24.79**		**11.04**	
Dry density, $\gamma_d = \gamma_m/(100+W6)*100$ (g/cc)	**1.208**	**1.274**	**1.282**	**1.216**		11.04	



MDD:	1.288 (gm/cc)	OMC:	19.6 %

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

ETHIOPIA-DJIBOUTI TRANSPORT CORRIDOR PROJECT

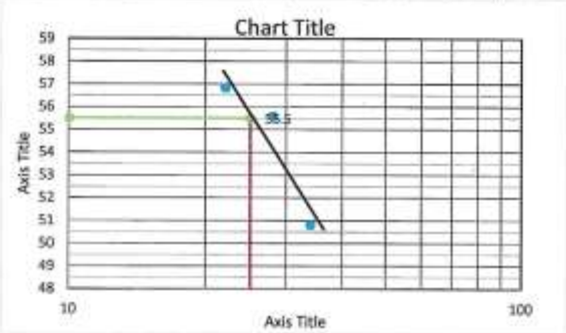
(PHASE-I: DESIGN BUILD OF ADAMA-Km 60 EXPRESSWAY)

ATTERBERG LIMITS

(AASTHO T-89/90) Format No: 01002/JMC/EHAE/21F/02-R0

RFI No.	0	Lab Ref No. :	0
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Testing:	05/09/2023
Propose Used	M.Sc. Research	Sampled By:	Jointly
Material Discription	Black Cotton Soil Heated to 100oC	Tested By:	Jointly

Description	LIQUID LIMIT				PLASTIC LIMIT		
	Test I	Test II	Test III	Test IV	Test I	Test II	Avg.
No of blows/Penetration (mm)	34	28	22				
Container No	C-22	C-28	C-26		C-05	C-10	
Container + Wet soil, W1 (g)	77	67	69		30.6	31.2	
Container + Dry soil, W2 (g)	59	52	52		29.6	30.18	
Weight of Container (g)	23.57	25.01	22.09		24.41	24.54	18.68
Weight of water, W4= W1-W2 (g)	18.00	15.00	17.00		1.00	1.02	
Weight of oven dry sample, W5=W3 - W1 (g)	35.43	26.99	29.91		5.19	5.64	
Water content percentage, 100x(W4/W5)	50.80	55.58	56.84		19.27	18.09	



Grain Size Analysis			
Total Wt.(gm)			908.0
Sieve size mm	Wt. Ret. (g.)	% Retained	% Passing
2.0	28.0	3.08	96.92
0.425	88.0	9.69	87.22
0.075	130.0	14.32	72.91
Pan	662.0	72.91	0.00

LL	PL	PI
55.50	18.68	36.82

Comments:-

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC PROJECTS (I) LTD.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

CALIFORNIA BEARING RATIO TEST

(AASHTO T 193)

Format No: 01002/JMC/EHAE/21F/04A-R0

RFI No.	0.000	Lab Ref. No.	0
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Soaking:	12/09/2023
Propose Used	M.Sc. Research	Date of Testing:	16/09/2023
Material Discription	Black Cotton Soil Heated to 100oC	Depth (m):	0.30 to 1.0 m

DENSITY DETERMINATION

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
MOLD NUMBER	M-22		M-05		M-11	
WEIGHT OF MOLD	7148	7148	7106	7106	7155	7155
WEIGHT OF SOIL + MOLD	10305	10305	10508	10408	10780	10744
WEIGHT OF SOIL	3157	3157	3402	3302	3625	3589
VOLUME OF MOLD	2243	2243	2243	2243	2243	2243
WET DENSITY OF SOIL	1.41	1.41	1.52	1.47	1.62	1.60
DRY DENSITY OF SOIL	1.18	1.17	1.23	1.25	1.34	1.32

MOISTURE DETERMINATION

CONTAINER NUMBER	G-1	G-2	G-3	D-28	D-18	D-13
WET SOIL + CONTAINER (g)	261.00	268.70	285.00	302.70	285.00	265.00
DRY SOIL + CONTAINER (g)	222.40	227.60	235.50	260.60	240.60	224.00
WEIGHT OF WATER (g)	38.60	41.10	49.50	42.10	44.40	41.00
WEIGHT OF CONTAINER (g)	27.20	26.90	27.30	28.70	27.00	27.30
WEIGHT OF DRY SOIL (g)	195.20	200.70	208.20	231.90	213.60	196.70
MOISTURE CONTENT (%)	19.77	20.48	23.78	18.15	20.79	20.84
AVG. MOISTURE CONTENT (%)	20.13		20.96		20.82	

Ring Factor 0.03081 — **PENETRATION TEST DATA**

PENETRATION (mm)	Std. Load	Dial reading	Load (kn)	Cor. Load (kn)	Dial reading	Load (kn)	Cor. Load (kn)	Dial reading	Load (kn)	Cor. Load (kn)
0		0.0	0		0.0	0		0.0	0.0	
0.64		0.0	0.0		4.0	0.1		8.0	0.2	
1.27		2.0	0.1		7.0	0.2		11.0	0.3	
1.96		5.0	0.2		7.0	0.2		14.0	0.4	
2.54	13.54	8.0	0.2	0.2	13.0	0.4	0.4	15.0	0.5	0.5
3.18		9.0	0.3		16.0	0.5		19.0	0.6	
3.81		9.0	0.3		17.0	0.5		27.0	0.8	
4.45		10.0	0.3		17.0	0.5		28.0	0.9	
5.08	20.22	13.0	0.4	0.4	17.0	0.5	0.5	28.0	0.9	0.9
7.62		13.0	0.4		18.0	0.6		31.0	1.0	
10.16		14.0	0.4		19.0	0.6		33.0	1.0	
12.7		17.0	0.5		19.0	0.6		33.0	1.0	
SWELL READING (INITIAL)		3.19			4.19			7.43		
SWELL READING (FINAL)		10.00			13.00			13.00		
PERCENTAGE SWELL		5.85			7.57			4.79		
CBR @ 2.54 mm		1.8			3.0			3.4		
CBR @ 5.08 mm		2.0			2.6			4.3		

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC PROJECTS (I) LTD.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

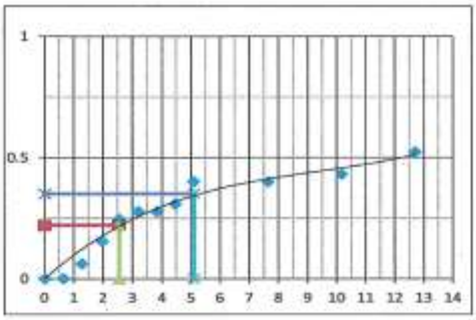
CALIFORNIA BEARING RATIO TEST

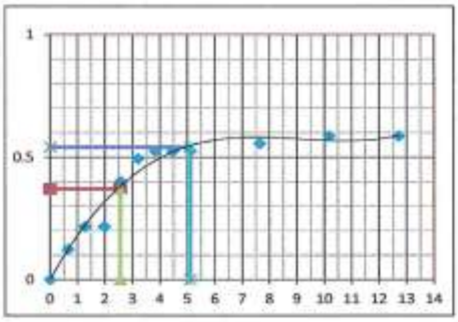
(AASHTO T 193)

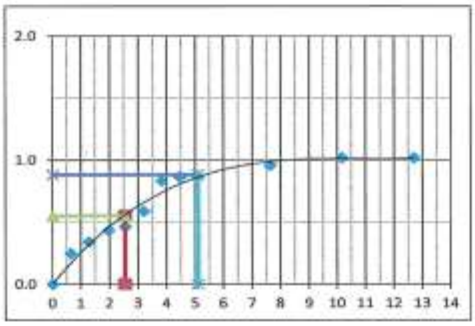
Format No: 01002/JMC/EHAE/21F/048-R0

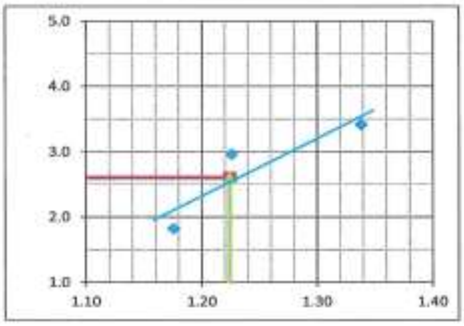
RFI No.	0.000	Lab Ref. No.	00/01/1900
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling	25/08/2023
Location:	Km.2+500 LHS	Date of Soaking	12/09/2023
Propose Used	M.Sc. Research	Date of Testing	16/09/2023
Material Discription	Black Cotton Soil Heated to 100oC	Depth (m)	0.30 to 1.0 m

MDD (gm/cc)	1.288	OMC (%)	19.60









Density @ 95% Compaction (gm/cc)	1.224
CBR @ 95% Compaction (%)	2.6
Swell @ 95% Compaction (%)	6.07

Tested By Contractor's Lab Technician	Checked By Contractor's Material Engineer	Verified by Consultant's Lab Technician	Approved By Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

SOIL TESTING AND APPROVAL RECORD

RFI No.		LAB REF. NO.	
SOURCE	OGL FROM 1+000 to 3+000 FW	SAMPLEING DATE	25/08/2023
SAMPLING LOCATION	Km.2+500 LHS	SAMPLE DEPTH (M)	0.30 to 1.0 m
PURPOSED TO USE	M.Sc. Research		
MATERIAL DESCRIPTION:	Black Cotton Soil Heated to 200°C		

No.	TEST PERFORMED		TEST RESULTS		TEST METHODS	ACCEPTANCE CRITERIA	APPROVAL STATUS
1	COMPACTION TEST	MDD at 100%	1.316	g/cm³	AASHTO T-180 Method D/ ASTM D 1557		YES NO
		OMC	19.0	%			YES NO
		MDD at 95%	1.250	g/cm³			YES NO
2	CBR	CBR at 95% MDD	3.3	%	AASHTO 193/ ASTM D 1883	> 5	YES NO
		SWELL	3.35	%		< 2	YES NO
3	SOIL PLASTICITY	LIQUID LIMIT (LL)	47.0	%	AASHTO T-89/90/ ASTM D 4318	< 60	YES NO
		PLASTIC LIMIT (PL)	16.7	%	AASHTO T-89/90/ ASTM D 4318		YES NO
		PLASTICITY INDEX(PI)	30.3	%	AASHTO T-89/90/ ASTM D 4318	< 30	YES NO

Note: Attach individual test records and data sheet

Remarks:

Contractor's Representative			Consultant's Representative		
	Signature	Date		Signature	Date
Material Engineer		18/sep/23	Material Engineer		

REC-SQP-01-07-01-V0

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

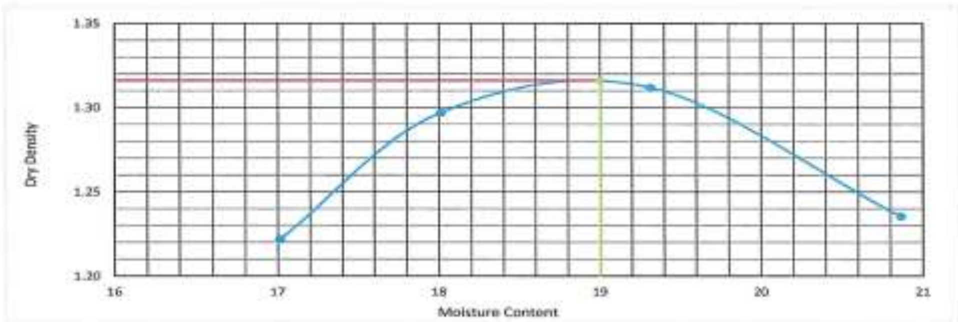
Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

MAXIMUM DRY DENSITY AND MOISTURE CONTENT

(AASTHO T-180) Format No: 01002/JMC/EHAE/21F/03-R0

RFI No.		Lab Ref No. :	
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Testing:	09/09/2023
Propose Used	M.Sc. Research	Sampled By:	Denkayehu
Type of Method:	A	Tested By:	Jointly
Material Discription	Black Cotton Soil Heated to 200oC	Depth (M)	0.30 to 1.0 m

Description	Test I	Test II	Test III	Test IV	Test V		
	Density Determination						
Water Added %	8%	10%	12%	14%			
Mass of mould + Wet Soil (g)	5334	5432	5434	5385			
Mass of mould, W5 (g)	4006	4010	3980	3998			
Mass of wet soil, W7=W6-W5 (g)	1328	1422	1454	1387			
Volume of mould, V (cc)	929	929	929	929			
Bulk density, γ_m = [(W7-W8)/V] g/cc	1.429	1.531	1.565	1.493		**NMC**	
	Moisture Content Determination						
Container no	D50	D6	D1	G23		D8	
Mass of container + wet soil, W1 (g)	239.00	233.00	232.60	233.85		280.00	
Mass of container + oven dry soil, W2 (g)	207.60	201.10	199.00	197.80		255.00	
Mass of Water (g) W3=W1-W2	31.40	31.90	33.60	36.05		25.00	
Mass of container, W4 (g)	23.00	24.00	25.00	25.00		28.60	
Mass of Dry Soil (g) W5 = W2-W4	184.60	177.10	174.00	172.80		226.40	
Moisture Content (%) W6= W3/W5*100	**17.01**	**18.01**	**19.31**	**20.86**		**11.04**	
Dry density, γ_d = γ_m/(100+W6)*100 (g/cc)	**1.222**	**1.297**	**1.312**	**1.235**		**11.04**	



MDD:	1.316 (gm/cc)	OMC:	19.0 %

13/sep/23

Tested By Contractor's Lab Technician	Checked By Contractor's Material Engineer	Verified by Consultant's Lab Technician	Approved By Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

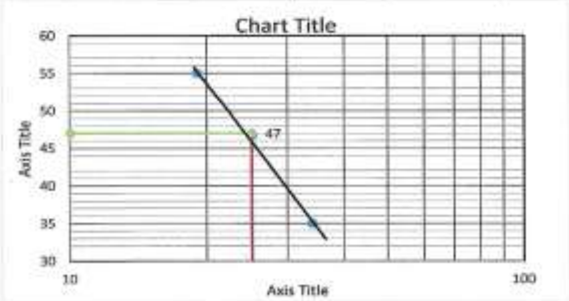
ATTERBERG LIMITS

(AASTHO T-89/90)

Format No: 01002/JMC/EHAE/21F/02-R0

RFI No.	0	Lab Ref No. :	0
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Testing:	05/09/2023
Propose Used	M.Sc. Research	Sampled By:	Jointly
Material Discription	Black Cotton Soil Heated to 200oC	Tested By:	Jointly

Description	LIQUID LIMIT				PLASTIC LIMIT		
	Test I	Test II	Test III	Test IV	Test I	Test II	Avg.
No of blows/Penetration (mm)	34	25	19				
Container No	C-44	C-27	C-55		C-1	C-14	
Container + Wet soil, W1 (g)	66	69	70		33.5	33.6	
Container + Dry soil, W2 (g)	55	55	53		32.1	32.4	
Weight of Container (g)	23.57	25.01	22.09	..	24.41	24.54	16.74
Weight of water, W4= W1-W2 (g)	11.00	14.00	17.00		1.40	1.20	
Weight of oven dry sample, W5=W3 - W1 (g)	31.43	29.99	30.91		7.69	7.86	
Water content percentage, 100x(W4/W5)	35.00	46.68	55.00		18.21	15.27	



Grain Size Analysis			
Total Wt.(gm)			908.0
Sieve size mm	Wt. Ret. (g.)	% Retained	% Passing
2.0	32.0	3.52	96.48
0.425	98.0	10.79	85.68
0.075	145.0	15.97	69.71
Pan	633.0	69.71	0.00

LL	PL	PI
47.00	16.74	30.26

Comments:-

18/sep/23

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC PROJECTS (I) LTD.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

CALIFORNIA BEARING RATIO TEST
(AASHTO T 193)

Format No: 01002/JMC/EHAE/21P/04A-R0

RFI No.	0.000	Lab Ref. No.	0
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Soaking:	12/09/2023
Propose Used	M.Sc. Research	Date of Testing:	16/09/2023
Material Discription	Black Cotton Soil Heated to 200oC	Depth (m):	0.30 to 1.0 m

DENSITY DETERMINATION

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
MOLD NUMBER	M-22		M-05		M-11	
WEIGHT OF MOLD	7148	7148	7106	7106	7155	7155
WEIGHT OF SOIL + MOLD	10450	10512	10560	10460	10780	10744
WEIGHT OF SOIL	3302	3364	3454	3354	3625	3589
VOLUME OF MOLD	2243	2243	2243	2243	2243	2243
WET DENSITY OF SOIL	1.47	1.50	1.54	1.50	1.62	1.60
DRY DENSITY OF SOIL	1.23	1.24	1.24	1.27	1.34	1.32

MOISTURE DETERMINATION

CONTAINER NUMBER	G-1	G-2	G-3	D-28	D-18	D-13
WET SOIL + CONTAINER (g)	261.00	268.70	285.00	302.70	285.00	265.00
DRY SOIL + CONTAINER (g)	222.40	227.60	235.50	260.60	240.60	224.00
WEIGHT OF WATER (g)	38.60	41.10	49.50	42.10	44.40	41.00
WEIGHT OF CONTAINER (g)	27.20	26.90	27.30	28.70	27.00	27.30
WEIGHT OF DRY SOIL (g)	195.20	200.70	208.20	231.90	213.60	196.70
MOISTURE CONTENT (%)	19.77	20.48	23.78	18.15	20.79	20.84
AVG. MOISTURE CONTENT (%)	20.13		20.96		20.82	

Ring Factor 0.03081 **PENETRATION TEST DATA**

PENETRATION (mm)	Std. Load	Dial reading	Load (kn)	Cor. Load (kn)	Dial reading	Load (kn)	Cor. Load (kn)	Dial reading	Load (kn)	Cor. Load (kn)
0		0.0	0		0.0	0		0.0	0.0	
0.64		0.0	0.0		8.0	0.2		13.0	0.4	
1.27		4.0	0.1		11.0	0.3		15.0	0.5	
1.96		8.0	0.2		12.0	0.4		19.0	0.6	
2.54	13.54	12.0	0.4	0.4	16.0	0.5	0.5	21.0	0.6	0.6
3.18		13.0	0.4		19.0	0.6		26.0	0.8	
3.81		17.0	0.5		20.0	0.6		27.0	0.8	
4.45		17.0	0.5		20.0	0.6		29.0	0.9	
5.08	20.22	18.0	0.6	0.6	23.0	0.7	0.7	33.0	1.0	1.0
7.62		19.0	0.6		23.0	0.7		34.0	1.0	
10.16		22.0	0.7		24.0	0.7		36.0	1.1	
12.7		22.0	0.7		24.0	0.7		37.0	1.1	

SWELL READING (INITIAL)	3.19	4.19	1.34
SWELL READING (FINAL)	7.30	7.70	4.40
PERCENTAGE SWELL	3.85	3.30	2.90
CBR @ 2.54 mm	2.7	3.6	4.8
CBR @ 5.08 mm	2.7	3.5	5.0

28/Sep/23

Tested By Contractor's Lab Technician	Checked By Contractor's Material Engineer	Verified by Consultant's Lab Technician	Approved By Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC PROJECTS (I) LTD.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

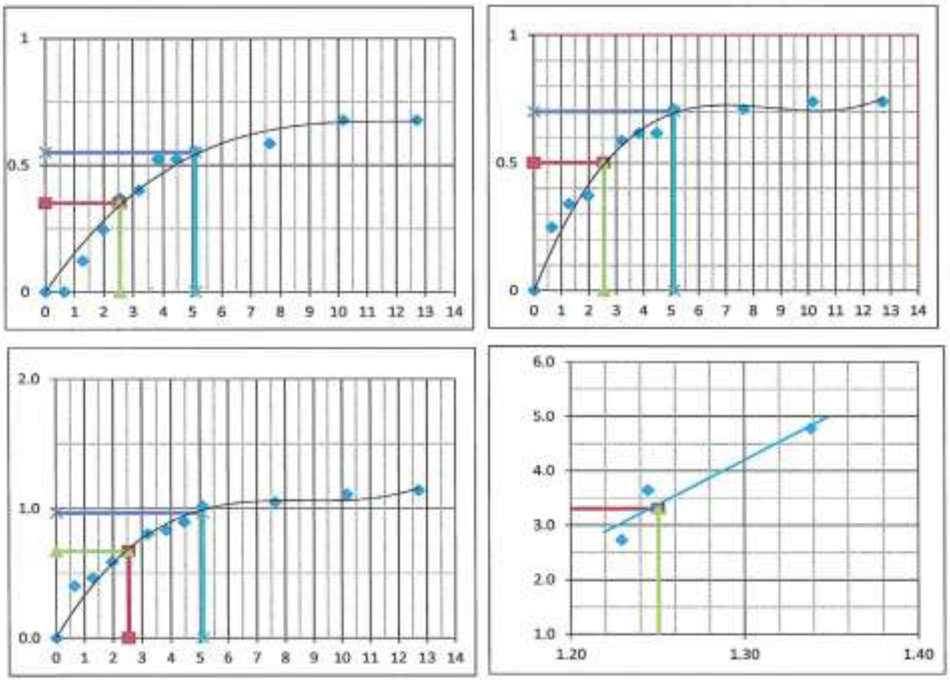
CALIFORNIA BEARING RATIO TEST

(AASHTO T 193)

Format No. 01002/JMC/IJJAIL/21F/04B-R0

RFI No.	0.000	Lab Ref. No.	00/01/1900
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Soaking:	12/09/2023
Propose Used	M.Sc. Research	Date of Testing:	16/09/2023
Material Discription	Black Cotton Soil Heated to 200oC	Depth (m):	0.30 to 1.0 m

MDD (gm/cc)	1.316	OMC (%)	19.00



Density @ 95% Compaction (gm/cc)	1.250
CBR @ 95% Compaction (%)	3.3
Swell @ 95% Compaction (%)	3.35

18 1 Sep /23

Tested By Contractor's Lab Technician	Checked By Contractor's Material Engineer	Verified by Consultant's Lab Technician	Approved By Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

SOIL TESTING AND APPROVAL RECORD

RFI No.		LAB REF. NO.	
SOURCE	OGL FROM 1+000 to 3+000 FW	SAMPLEING DATE	25/08/2023
SAMPLING LOCATION	Km.2+500 LHS	SAMPLE DEPTH (M)	0.30 to 1.0 m
PURPOSED TO USE	M.Sc. Research		
MATERIAL DESCRIPTION:	Black Cotton Soil Heated to 300°C		

No.	TEST PERFORMED		TEST RESULTS		TEST METHODS	ACCEPTANCE CRITERIA	APPROVAL STATUS
1	COMPACTION TEST	MDD at 100%	1.328	g/cm³	AASHTO T-180 Method D/ ASTM D 1557		YES NO
		OMC	16.4	%			YES NO
		MDD at 95%	1.262	g/cm³			YES NO
2	CBR	CBR at 95% MDD	5.0	%	AASHTO 193/ ASTM D 1883	> 5	YES NO
		SWELL	3.53	%		< 2	YES NO
3	SOIL PLASTICITY	LIQUID LIMIT (LL)	44.0	%	AASHTO T-89/90/ ASTM D 4318	< 60	YES NO
		PLASTIC LIMIT (PL)	13.1	%	AASHTO T-89/90/ ASTM D 4318		YES NO
		PLASTICITY INDEX(PI)	30.9	%	AASHTO T-89/90/ ASTM D 4318	< 30	YES NO

Note: Attach individual test records and data sheet

Remarks:

Contractor's Representative			Consultant's Representative		
	Signature	Date		Signature	Date
Material Engineer	[signature]	18/sep/23	Material Engineer		

REC-SQP-01-07-01-V0

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

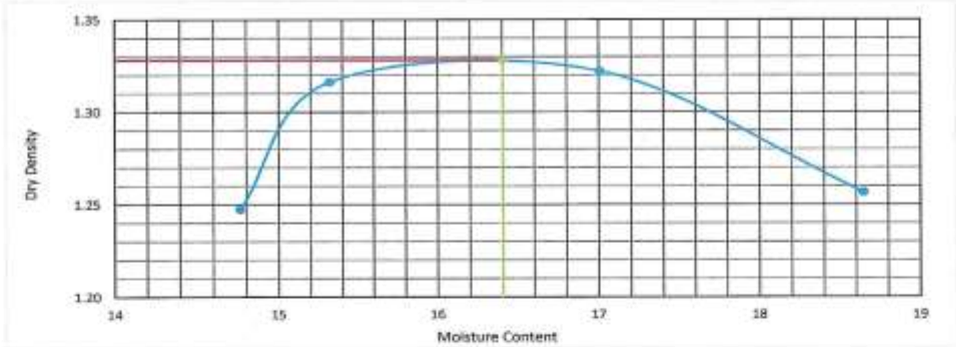
Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

MAXIMUM DRY DENSITY AND MOISTURE CONTENT

(AASTHO T-180) Format No: 01002/JMC/EHAE/21F/03-R0

RFI No.		Lab Ref No. :	
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Testing:	09/09/2023
Propose Used	M.Sc. Research	Sampled By:	Denkayehu
Type of Method:	A	Tested By:	Jointly
Material Discription	Black Cotton Soil Heated to 300oC	Depth (M)	0.30 to 1.0 m

Description	Test I	Test II	Test III	Test IV	Test V		
	Density Determination						
Water Added %	6%	8%	10%	12%			
Mass of mould + Wet Soil (g)	5229	5430	5432	5402			
Mass of mould, W5 (g)	3899	4020	3995	4017			
Mass of wet soil, W7=W6-W5 (g)	1330	1410	1437	1385			
Volume of mould, V (cc)	929	929	929	929			
Bulk density, $\gamma_w = [(W7-W6)/V]$ g/cc	1.432	1.518	1.547	1.491		**NMC**	
	Moisture Content Determination						
Container no	D5	D33	D16	G24		D8	
Mass of container + wet soil, W1 (g)	236.00	240.80	246.65	238.56		280.00	
Mass of container + oven dry soil, W2 (g)	208.60	212.00	214.44	205.00		260.00	
Mass of Water (g) W3=W1-W2	27.40	28.80	32.21	33.56		20.00	
Mass of container, W4 (g)	23.00	24.00	25.00	25.00		28.60	
Mass of Dry Soil (g) W5 = W2-W4	185.60	188.00	189.44	180.00		231.40	
Moisture Content (%) W6= W3/W5*100	**14.76**	**15.32**	**17.00**	**18.64**		**8.64**	
Dry density, $\gamma_d = \gamma_w/(100+W6)*100$ (g/cc)	**1.247**	**1.316**	**1.322**	**1.257**		**8.64**	



MDD:	1.328 (gm/cc)	OMC:	16.4 %

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

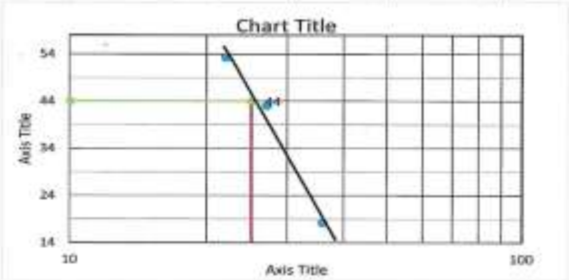
Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

ATTERBERG LIMITS

(AASTHO T-89/90) Format No: 01002/JMC/EHAE/21F/02-R0

RFI No.	0	Lab Ref No. :	0
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Testing:	05/09/2023
Propose Used	M.Sc. Research	Sampled By:	Denkayehu
Material Discription	Black Cotton Soil Heated to 300oC	Tested By:	Jointly

Description	LIQUID LIMIT				PLASTIC LIMIT		
	Test I	Test II	Test III	Test IV	Test I	Test II	Avg.
No of blows/Penetration (mm)	36	27	22				
Container No	C-11	C-3	C-5		C-7	C-33	
Container + Wet soil, W1 (g)	58.6	64	65.43		40	31	
Container + Dry soil, W2 (g)	53.43	52.87	51.23		38.23	30.24	
Weight of Container (g)	25	27	24.55	--	24.41	24.54	13.07
Weight of water, W4= W1-W2 (g)	5.17	11.13	14.20		1.77	0.76	
Weight of oven dry sample, W5=W3 - W1 (g)	28.43	25.87	26.68		13.82	5.70	
Water content percentage, 100x(W4/W5)	18.19	43.02	53.22		12.81	13.33	



Grain Size Analysis			
Total Wt.(gm)			800.0
Sieve size mm	Wt. Ret. (g.)	% Retained	% Passing
2.0	45.0	5.63	94.38
0.425	107.0	13.38	81.00
0.075	133.0	16.63	64.38
Pan	515.0	64.38	0.00

LL	PL	PI
44.00	13.07	30.93

Comments:-

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC PROJECTS (I) LTD.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

CALIFORNIA BEARING RATIO TEST
(AASHTO T 193)

Format No: 01002/JMC./2016/21F/04A-BD

RFI No.	0.000	Lab Ref. No.	0
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling	25/08/2023
Location:	Km.2+500 LHS	Date of Soaking:	12/09/2023
Propose Used	M.Sc. Research	Date of Testing	16/09/2023
Material Discription	Black Cotton Soil Heated to 300oC	Depth (m):	0.30 to 1.0 m

DENSITY DETERMINATION

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
MOLD NUMBER	M-19		M-01		M-14	
WEIGHT OF MOLD	7144	7144	7115	7115	7123	7123
WEIGHT OF SOIL + MOLD	10325	10402	10512	10451	10620	10670
WEIGHT OF SOIL	3181	3258	3397	3336	3497	3547
VOLUME OF MOLD	2243	2243	2243	2243	2243	2243
WET DENSITY OF SOIL	1.42	1.45	1.51	1.49	1.56	1.58
DRY DENSITY OF SOIL	1.22	1.26	1.29	1.28	1.34	1.36

MOISTURE DETERMINATION

CONTAINER NUMBER	G-14	G-31	G-5	D-2	D-11	D-09
WET SOIL + CONTAINER (g)	243.56	234.65	271.43	298.54	276.87	263.60
DRY SOIL + CONTAINER (g)	213.56	206.55	235.50	260.60	242.44	229.61
WEIGHT OF WATER (g)	30.00	28.10	35.93	37.94	34.43	33.99
WEIGHT OF CONTAINER (g)	25.88	24.78	27.90	29.11	28.65	25.87
WEIGHT OF DRY SOIL (g)	187.68	181.77	207.60	231.49	213.79	203.74
MOISTURE CONTENT (%)	15.98	15.46	17.31	16.39	16.10	16.68
AVG. MOISTURE CONTENT (%)	15.72		16.85		16.39	

Ring Factor 0.03081

PENETRATION TEST DATA

PENETRATION (mm)	Std. Load	Dial reading	Load (kn)	Cor. Load (kn)	Dial reading	Load (kn)	Cor. Load (kn)	Dial reading	Load (kn)	Cor. Load (kn)
0		0.0	0		0.0	0		0.0	0.0	
0.64		9.0	0.3		16.0	0.5		20.0	0.6	
1.27		15.0	0.5		17.0	0.5		27.0	0.8	
1.96		17.0	0.5		20.0	0.6		35.0	1.1	
2.54	13.54	17.0	0.5	0.5	25.0	0.8	0.8	39.0	1.2	1.2
3.18		22.0	0.7		28.0	0.9		44.0	1.4	
3.81		29.0	0.9		33.0	1.0		50.0	1.5	
4.45		29.0	0.9		38.0	1.2		54.0	1.7	
5.08	20.22	32.0	1.0	1.0	39.0	1.2	1.2	57.0	1.8	1.8
7.62		34.0	1.0		43.0	1.3		62.0	1.9	
10.16		39.0	1.2		45.0	1.4		64.0	2.0	
12.7		39.0	1.2		45.0	1.4		64.0	2.0	

SWELL READING (INITIAL)	2.22	4.76	4.87
SWELL READING (FINAL)	6.78	8.73	8.67
PERCENTAGE SWELL	3.92	3.41	3.26
CBR @ 2.54 mm	3.9	5.7	8.9
CBR @ 5.08 mm	4.9	5.9	8.7

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC PROJECTS (I) LTD.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

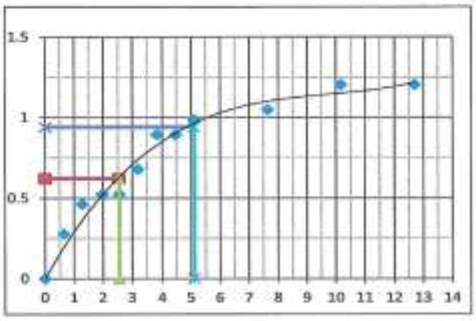
CALIFORNIA BEARING RATIO TEST

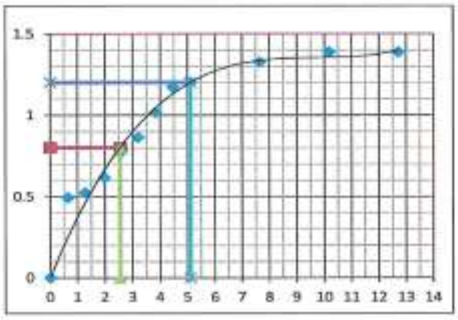
(AASHTO T 193)

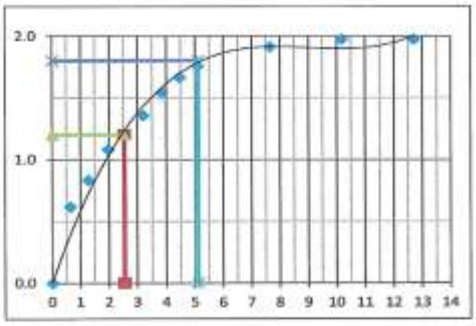
Format No: 01002/JMC/I2IAL/21F/04B-R0

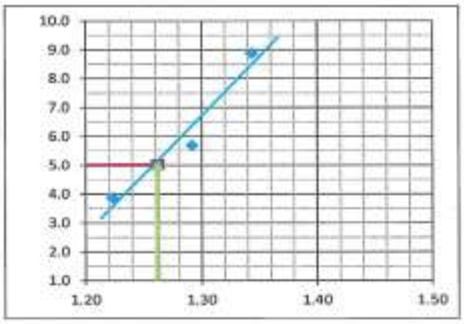
RFI No.	0.000	Lab Ref. No.	00/01/1900
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling	25/08/2023
Location:	Km.2+500 LHS	Date of Soaking	12/09/2023
Propose Used	M.Sc. Research	Date of Testing	16/09/2023
Material Discription	Black Cotton Soil Heated to 300oC	Depth (m):	0.30 to 1.0 m

MDD (gm/cc)	1.328	OMC (%)	16.40









Density @ 95% Compaction (gm/cc)	1.262
CBR @ 95% Compaction (%)	5.0
Swell @ 95% Compaction (%)	3.53

Tested By Contractor's Lab Technician	Checked By Contractor's Material Engineer	Verified by Consultant's Lab Technician	Approved By Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

SOIL TESTING AND APPROVAL RECORD

RFI No.		LAB REF. NO.	
SOURCE	OGL FROM 1+000 to 3+000 FW	SAMPLEING DATE	25/08/2023
SAMPLING LOCATION	Km.2+500 LHS	SAMPLE DEPTH (M)	0.30 to 1.0 m
PURPOSED TO USE	M.Sc. Research		
MATERIAL DESCRIPTION:	Black Cotton Soil Heated to 400°C		

No.	TEST PERFORMED		TEST RESULTS		TEST METHODS	ACCEPTANCE CRITERIA	APPROVAL STATUS
1	COMPACTION TEST	MDD at 100%	1.425	g/cm³	AASHTO T-180 Method D/ ASTM D 1557		YES NO
		OMC	16.5	%			YES NO
		MDD at 95%	1.354	g/cm³			YES NO
2	CBR	CBR at 95% MDD	5.8	%	AASHTO 193/ ASTM D 1883	> 5	YES NO
		SWELL	3.58	%		< 2	YES NO
3	SOIL PLASTICITY	LIQUID LIMIT (LL)	44.0	%	AASHTO T-89/90/ ASTM D 4318	< 60	YES NO
		PLASTIC LIMIT (PL)	15.1	%	AASHTO T-89/90/ ASTM D 4318		YES NO
		PLASTICITY INDEX(PI)	28.9	%	AASHTO T-89/90/ ASTM D 4318	< 30	YES NO

Note: Attach individual test records and data sheet

Remarks:

Contractor's Representative			Consultant's Representative		
	Signature	Date		Signature	Date
Material Engineer		18/Sep/23	Material Engineer		

REC-SQP.01-07-01-V0

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

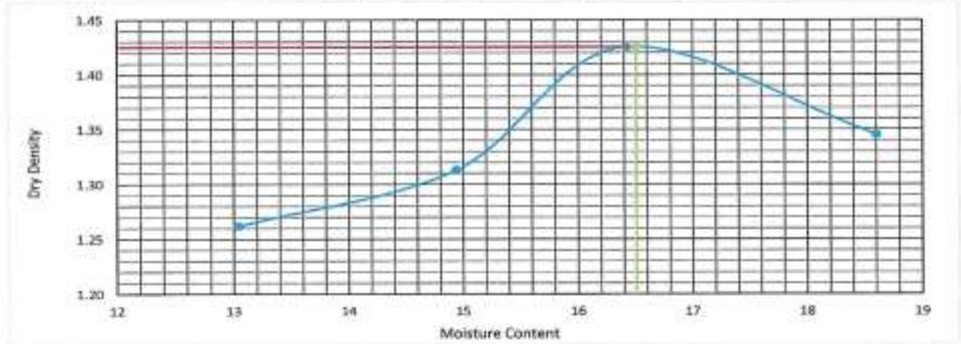
MAXIMUM DRY DENSITY AND MOISTURE CONTENT

(AASTHO T-180)

Format No: 01002/JMC/EHAE/21F/03-R0

RFI No.		Lab Ref No. :	
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Testing:	09/09/2023
Propose Used	M.Sc. Research	Sampled By:	Denkayehu
Type of Method:	A	Tested By:	Jointly
Material Discription	Black Cotton Soil Heated to 400oC	Depth (M)	0.30 to 1.0 m

Description	Test I	Test II	Test III	Test IV	Test V		
	Density Determination						
Water Added %	5%	8%	10%	12%			
Mass of mould + Wet Soil (g)	5002	5413	5523	5499			
Mass of mould, W5 (g)	3677	4011	3982	4017			
Mass of wet soil, W7=W6-W5 (g)	1325	1402	1541	1482			
Volume of mould, V (cc)	929	929	929	929			
Bulk density, γ_m = [(W7-W6)/V] g/cc	1.426	1.509	1.659	1.595		**NMC**	
	Moisture Content Determination						
Container no	D4	D3	D15	G22		D8	
Mass of container + wet soil, W1 (g)	245.66	241.88	245.76	239.00		280.00	
Mass of container + oven dry soil, W2 (g)	219.87	213.43	214.44	205.30		255.00	
Mass of Water (g) W3=W1-W2	25.79	28.45	31.32	33.70		25.00	
Mass of container, W4 (g)	22.00	23.00	23.60	24.10		28.60	
Mass of Dry Soil (g) W5 = W2-W4	197.87	190.43	190.84	181.20		226.40	
Moisture Content (%) W6= W3/W5*100	**13.03**	**14.94**	**16.41**	**18.60**		**11.04**	
Dry density, γ_d = γ_m/(100+W6)*100 (g/cc)	**1.262**	**1.313**	**1.425**	**1.345**		**11.04**	



MDD:	1.425 (gm/cc)	OMC:	16.5 %

Tested By Contractor's Lab Technician	Checked By Contractor's Material Engineer	Verified by Consultant's Lab Technician	Approved By Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

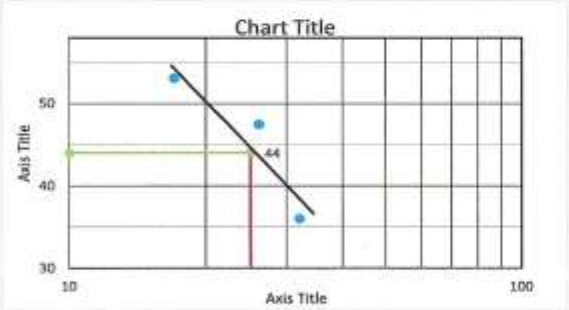
Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

ATTERBERG LIMITS

(AASTHO T-89/90) Format No: 01002/JMC/EHAE/21F/02-R0

RFI No.	0	Lab Ref No. :	0
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Testing:	05/09/2023
Propose Used	M.Sc. Research	Sampled By:	Denkayehu
Material Discription	Black Cotton Soil Heated to 400oC	Tested By:	Jointly

Description	LIQUID LIMIT				PLASTIC LIMIT		
	Test I	Test II	Test III	Test IV	Test I	Test II	Avg.
No of blows/Penetration (mm)	32	26	17				
Container No	C-4	C-32	C-15		C-8	C-19	
Container + Wet soil, W1 (g)	57.5	61	63.3		43	33	
Container + Dry soil, W2 (g)	48.99	49.77	49.88		40.33	31.84	
Weight of Container (g)	25.34	26.1	24.6		23	24	15.10
Weight of water, W4= W1-W2 (g)	8.51	11.23	13.42		2.67	1.16	
Weight of oven dry sample, W5=W3 - W1 (g)	23.65	23.67	25.28		17.33	7.84	
Water content percentage, 100x(W4/W5)	35.98	47.44	53.09		15.41	14.80	



Grain Size Analysis			
Total Wt.(gm)			750.0
Sieve size mm	Wt. Ret. (g.)	% Retained	% Passing
2.0	40.0	5.33	94.67
0.425	44.0	5.87	88.80
0.075	143.0	19.07	69.73
Pan	523.0	69.73	0.00

LL	PL	PI
44.00	15.10	28.90

Comments:-

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC PROJECTS (I) LTD.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

CALIFORNIA BEARING RATIO TEST
(AASHTO T 193)

Format No: 01002/JMC/EHAIC/21F/04A-00

RFI No.	0.000	Lab Ref. No.	0
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Soaking:	12/09/2023
Propose Used	M.Sc. Research	Date of Testing:	16/09/2023
Material Discription	Black Cotton Soil Heated to 400oC	Depth (m):	0.30 to 1.0 m

DENSITY DETERMINATION

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
MOLD NUMBER	M-12		M-45		M-17	
WEIGHT OF MOLD	7096	7096	7212	7213	7114	7114
WEIGHT OF SOIL + MOLD	10445	10550	10734	10820	10860	10832
WEIGHT OF SOIL	3349	3454	3522	3607	3746	3718
VOLUME OF MOLD	2243	2243	2243	2243	2243	2243
WET DENSITY OF SOIL	1.49	1.54	1.57	1.61	1.67	1.66
DRY DENSITY OF SOIL	1.29	1.30	1.36	1.39	1.43	1.42

MOISTURE DETERMINATION

CONTAINER NUMBER	G-16	G-53	G-8	D-3	D-16	D-04
WET SOIL + CONTAINER (g)	244.60	244.00	280.00	299.56	277.20	263.76
DRY SOIL + CONTAINER (g)	214.66	210.00	245.54	262.80	242.13	229.80
WEIGHT OF WATER (g)	29.94	34.00	34.46	36.76	35.07	33.96
WEIGHT OF CONTAINER (g)	25.88	24.78	27.90	29.11	28.65	25.87
WEIGHT OF DRY SOIL (g)	188.78	185.22	217.64	233.69	213.48	203.93
MOISTURE CONTENT (%)	15.86	18.36	15.83	15.73	16.43	16.65
AVG. MOISTURE CONTENT (%)	17.11		15.78		16.54	

Ring Factor **0.03081** — **PENETRATION TEST DATA**

PENETRATION (mm)	Std. Load	Dial reading	Load (kn)	Cor. Load (kn)	Dial reading	Load (kn)	Cor. Load (kn)	Dial reading	Load (kn)	Cor. Load (kn)
0		0.0	0		0.0	0		0.0	0.0	
0.64		15.0	0.5		17.0	0.5		22.0	0.7	
1.27		16.0	0.5		19.0	0.6		27.0	0.8	
1.96		17.0	0.5		21.0	0.6		34.0	1.0	
2.54	13.54	17.0	0.5	0.5	24.0	0.7	0.7	37.0	1.1	1.1
3.18		18.0	0.6		26.0	0.8		47.0	1.4	
3.81		20.0	0.6		27.0	0.8		49.0	1.5	
4.45		24.0	0.7		29.0	0.9		51.0	1.6	
5.08	20.22	24.0	0.7	0.7	34.0	1.0	1.0	54.0	1.7	1.7
7.62		26.0	0.8		37.0	1.1		56.0	1.7	
10.16		28.0	0.9		39.0	1.2		58.0	1.8	
12.7		30.0	0.9		44.0	1.4		62.0	1.9	

SWELL READING (INITIAL)	3.76	5.87	6.45
SWELL READING (FINAL)	8.11	9.87	10.60
PERCENTAGE SWELL	3.74	3.44	3.57
CBR @ 2.54 mm	3.9	5.5	8.4
CBR @ 5.08 mm	3.7	5.2	8.2

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC PROJECTS (I) LTD.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

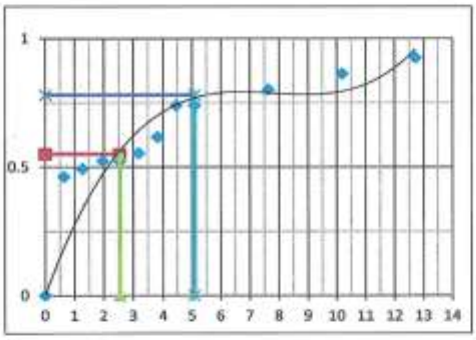
CALIFORNIA BEARING RATIO TEST

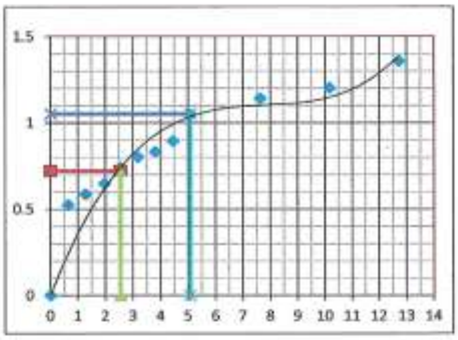
(AASHTO T 193)

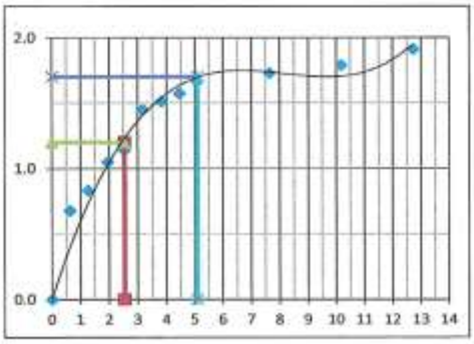
Format No: 01002/JMC/EHAE/25F/04B-B0

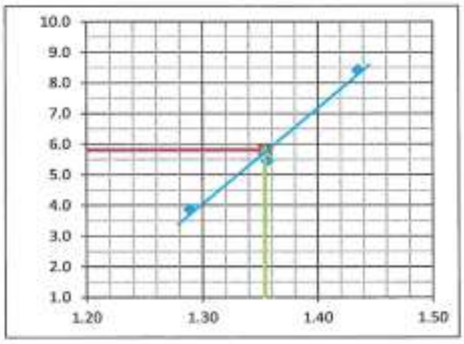
RFI No.	0.000	Lab Ref. No.	00/01/1900
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Soaking:	12/09/2023
Propose Used	M.Sc. Research	Date of Testing:	16/09/2023
Material Discription	Black Cotton Soil Heated to 400oC	Depth (m):	0.30 to 1.0 m

MDD (gm/cc)	1.425	OMC (%)	16.50









Density @ 95% Compaction (gm/cc)	1.354
CBR @ 95% Compaction (%)	5.8
Swell @ 95% Compaction (%)	3.58

Tested By Contractor's Lab Technician	Checked By Contractor's Material Engineer	Verified by Consultant's Lab Technician	Approved By Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

SOIL TESTING AND APPROVAL RECORD

RFI No.		LAB REF. NO.	
SOURCE	OGL FROM 1+000 to 3+000 FW	SAMPLEING DATE	25/08/2023
SAMPLING LOCATION	Km.2+500 LHS	SAMPLE DEPTH (M)	0.30 to 1.0 m
PURPOSED TO USE	M.Sc. Research		
MATERIAL DESCRIPTION:	Black Cotton Soil Heated to 500°C		

No.	TEST PERFORMED		TEST RESULTS		TEST METHODS	ACCEPTANCE CRITERIA	APPROVAL STATUS	
1	COMPACTION TEST	MDD at 100%	1.440	g/cm³	AASHTO T-180 Method D/ ASTM D 1557		YES	NO
		OMC	16.6	%			YES	NO
		MDD at 95%	1.368	g/cm³			YES	NO
2	CBR	CBR at 95% MDD	7.0	%	AASHTO 193/ ASTM D 1883	> 5	YES	NO
		SWELL	1.92	%		< 2	YES	NO
3	SOIL PLASTICITY	LIQUID LIMIT (LL)	40.0	%	AASHTO T-89/90/ ASTM D 4318	< 60	YES	NO
		PLASTIC LIMIT (PL)	14.9	%	AASHTO T-89/90/ ASTM D 4318		YES	NO
		PLASTICITY INDEX(PI)	25.1	%	AASHTO T-89/90/ ASTM D 4318	< 30	YES	NO

Note: Attach individual test records and data sheet

Remarks:

Contractor's Representative			Consultant's Representative		
	Signature	Date		Signature	Date
Material Engineer	[signature]	18/sep/23	Material Engineer		

REC-SQP-03-07-03-V0

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

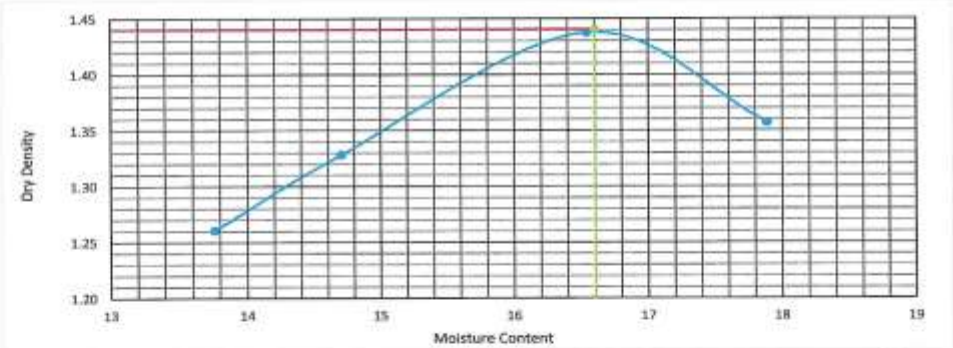
MAXIMUM DRY DENSITY AND MOISTURE CONTENT

(AASTHO T-180)

Format No: 01002/JMC/EHAE/21F/03-R0

RFI No.		Lab Ref No. :	
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Testing:	09/09/2023
Propose Used	M.Sc. Research	Sampled By:	Denkayehu
Type of Method:	A	Tested By:	Jointly
Material Discription	Black Cotton Soil Heated to 500oC	Depth (M)	0.30 to 1.0 m

Description	Test I	Test II	Test III	Test IV	Test V		
	Density Determination						
Water Added %	5%	8%	10%	12%			
Mass of mould + Wet Soil (g)	5010	5423	5534	5489			
Mass of mould, W5 (g)	3678	4008	3978	4003			
Mass of wet soil, W7=W6-W5 (g)	1332	1415	1556	1486			
Volume of mould, V (cc)	929	929	929	929			
Bulk density, γ_m = [(W7-W6)/V] g/cc	1.434	1.523	1.675	1.600		NMC	
	Moisture Content Determination						
Container no	D9	D13	D50	G4		D8	
Mass of container + wet soil, W1 (g)	239.50	251.00	235.00	235.00		280.00	
Mass of container + oven dry soil, W2 (g)	213.20	221.78	205.00	203.00		255.00	
Mass of Water (g) W3=W1-W2	26.30	29.22	30.00	32.00		25.00	
Mass of container, W4 (g)	22.00	23.00	23.60	24.10		28.60	
Mass of Dry Soil (g) W5 = W2-W4	191.20	198.78	181.40	178.90		226.40	
Moisture Content (%) W6= W3/W5*100	13.76	14.70	16.54	17.89		11.04	
Dry density, γ_d = γ_m/(100+W6)*100 (g/cc)	1.260	1.328	1.437	1.357		11.04	



MDD:	1.440 (gm/cc)	OMC:	16.6 %

Tested By Contractor's Lab Technician	Checked By Contractor's Material Engineer	Verified by Consultant's Lab Technician	Approved By Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

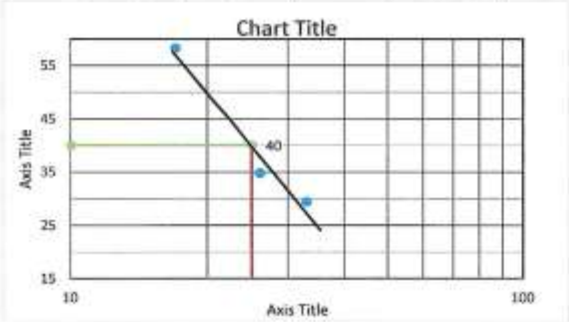
Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

ATTERBERG LIMITS

(AASTHO T-89/90) Format No: 01002/JMC/EHAE/21F/02-R0

RFI No.	0	Lab Ref No. :	0
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Testing:	05/09/2023
Propose Used	M.Sc. Research	Sampled By:	Denkayehu
Material Discription	Black Cotton Soil Heated to 500oC	Tested By:	Jointly

Description	LIQUID LIMIT				PLASTIC LIMIT		
	Test I	Test II	Test III	Test IV	Test I	Test II	Avg.
No of blows/Penetration (mm)	33	26	17				
Container No	C-5	C-31	C-17		C-2	C-1	
Container + Wet soil, W1 (g)	57.5	59.99	65.14		40	37	
Container + Dry soil, W2 (g)	49.66	51.22	50		37	36	
Weight of Container (g)	23	26	24		23	24	14.88
Weight of water, W4= W1-W2 (g)	7.84	8.77	15.14		3.00	1.00	
Weight of oven dry sample, W5=W3 - W1 (g)	26.66	25.22	26.00		14.00	12.00	
Water content percentage, 100x(W4/W5)	29.41	34.77	58.23		21.43	8.33	



Grain Size Analysis			
Total Wt.(gm)			850.0
Sieve size mm	Wt. Ret. (g.)	% Retained	% Passing
2.0	35.0	4.12	95.88
0.425	39.0	4.59	91.29
0.075	143.0	16.82	74.47
Pan	633.0	74.47	0.00

LL	PL	PI
40.00	14.88	25.12

Comments:-

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC PROJECTS (I) LTD.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

CALIFORNIA BEARING RATIO TEST
(AASHTO T 193)

Format No: III002/JMC/EHAE/21F/04A-R0

RFI No.	0.000	Lab Ref. No.	0
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Soaking:	12/09/2023
Propose Used	M.Sc. Research	Date of Testing:	16/09/2023
Material Discription	Black Cotton Soil Heated to 500oC	Depth (m):	0.30 to 1.0 m

DENSITY DETERMINATION

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
MOLD NUMBER	M-12		M-45		M-17	
WEIGHT OF MOLD	7096	7096	7212	7213	7114	7114
WEIGHT OF SOIL + MOLD	10345	10543	10734	10568	10860	10832
WEIGHT OF SOIL	3249	3447	3522	3355	3746	3718
VOLUME OF MOLD	2243	2243	2243	2243	2243	2243
WET DENSITY OF SOIL	1.45	1.54	1.57	1.50	1.67	1.66
DRY DENSITY OF SOIL	1.25	1.30	1.36	1.29	1.43	1.42

MOISTURE DETERMINATION

CONTAINER NUMBER	G-16	G-53	G-8	D-3	D-16	D-04
WET SOIL + CONTAINER (g)	244.60	244.00	280.00	299.56	277.20	263.76
DRY SOIL + CONTAINER (g)	214.66	210.00	245.54	262.80	242.13	229.80
WEIGHT OF WATER (g)	29.94	34.00	34.46	36.76	35.07	33.96
WEIGHT OF CONTAINER (g)	25.88	24.78	27.90	29.11	28.65	25.87
WEIGHT OF DRY SOIL (g)	188.78	185.22	217.64	233.69	213.48	203.93
MOISTURE CONTENT (%)	15.86	18.36	15.83	15.73	16.43	16.65
AVG. MOISTURE CONTENT (%)	17.11		15.78		16.54	

Ring Factor 0.03081

PENETRATION TEST DATA

PENETRATION (mm)	Std. Load	Dial reading	Load (kn)	Cor. Load (kn)	Dial reading	Load (kn)	Cor. Load (kn)	Dial reading	Load (kn)	Cor. Load (kn)
0		0.0	0		0.0	0		0.0	0.0	
0.64		17.0	0.5		19.0	0.6		24.0	0.7	
1.27		19.0	0.6		21.0	0.6		27.0	0.8	
1.96		20.0	0.6		25.0	0.8		34.0	1.0	
2.54	13.54	23.0	0.7	0.7	29.0	0.9	0.9	37.0	1.1	1.1
3.18		26.0	0.8		31.0	1.0		39.0	1.2	
3.81		28.0	0.9		36.0	1.1		45.0	1.4	
4.45		31.0	1.0		38.0	1.2		52.0	1.6	
5.08	20.22	34.0	1.0	1.0	39.0	1.2	1.2	58.0	1.8	1.8
7.62		36.0	1.1		42.0	1.3		61.0	1.9	
10.16		37.0	1.1		45.0	1.4		64.0	2.0	
12.7		39.0	1.2		47.0	1.4		67.0	2.1	

SWELL READING (INITIAL)	3.76	5.87	6.45
SWELL READING (FINAL)	8.11	9.87	10.60
PERCENTAGE SWELL	2.44	1.74	1.57
CBR @ 2.54 mm	5.2	6.6	8.4
CBR @ 5.08 mm	5.2	5.9	8.8

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC PROJECTS (I) LTD.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

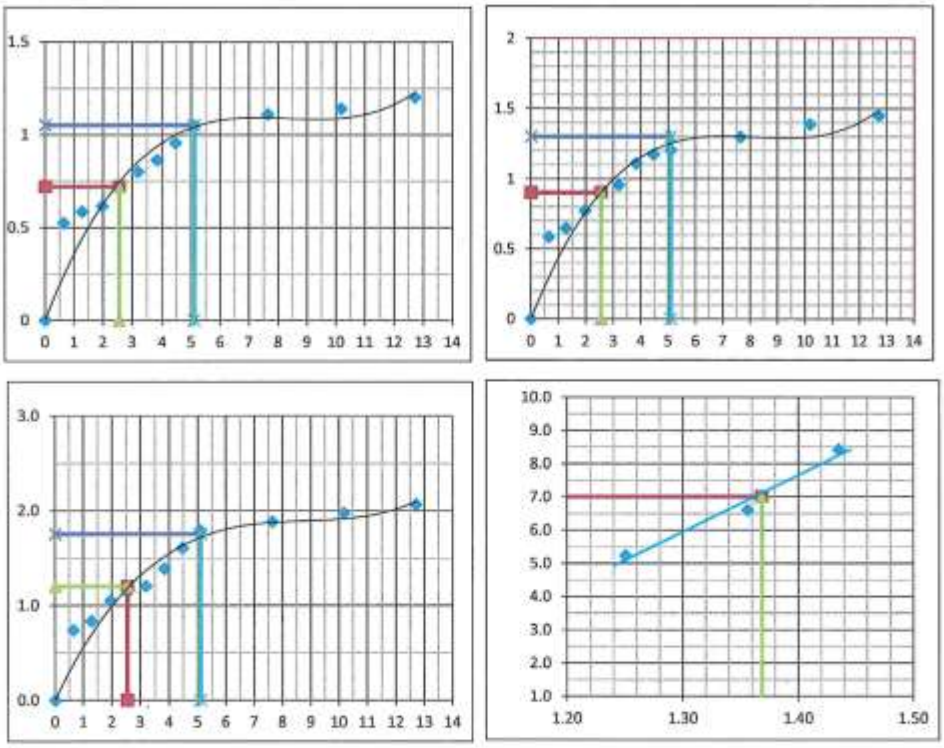
CALIFORNIA BEARING RATIO TEST

(AASHTO T 193)

Format No: 01002/JMC/EHAE/21F/04B-R0

RFI No.	0.000	Lab Ref. No.	00/01/1900
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Soaking:	12/09/2023
Propose Used	M.Sc. Research	Date of Testing:	16/09/2023
Material Discription	Black Cotton Soil Heated to 500oC	Depth (m):	0.30 to 1.0 m

MDD (gm/cc)	1.440	OMC (%)	16.60



Density @ 95% Compaction (gm/cc)	1.368
CBR @ 95% Compaction (%)	7.0
Swell @ 95% Compaction (%)	1.92

Tested By Contractor's Lab Technician	Checked By Contractor's Material Engineer	Verified by Consultant's Lab Technician	Approved By Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

SOIL TESTING AND APPROVAL RECORD

RFI No.		LAB REF. NO.	
SOURCE	OGL FROM 1+000 to 3+000 FW	SAMPLEING DATE	25/08/2023
SAMPLING LOCATION	Km.2+500 LHS	SAMPLE DEPTH (M)	0.30 to 1.0 m
PURPOSED TO USE	M.Sc. Research		
MATERIAL DESCRIPTION:	Black Cotton Soil Heated to 600°C		

No.	TEST PERFORMED		TEST RESULTS		TEST METHODS	ACCEPTANCE CRITERIA	APPROVAL STATUS
1	COMPACTION TEST	MDD at 100%	1.430	g/cm^3	AASHTO T-180 Method D/ ASTM D 1557		YES NO
		OMC	17.2	%			YES NO
		MDD at 95%	1.359	g/cm^3			YES NO
2	CBR	CBR at 95% MDD	7.5	%	AASHTO 193/ ASTM D 1883	> 5	YES NO
		SWELL	1.49	%		< 2	YES NO
3	SOIL PLASTICITY	LIQUID LIMIT (LL)	40.5	%	AASHTO T-89/90/ ASTM D 4318	< 60	YES NO
		PLASTIC LIMIT (PL)	14.6	%	AASHTO T-89/90/ ASTM D 4318		YES NO
		PLASTICITY INDEX(PI)	25.9	%	AASHTO T-89/90/ ASTM D 4318	< 30	YES NO

Note: Attach individual test records and data sheet

Remarks:

Contractor's Representative			Consultant's Representative		
	Signature	Date		Signature	Date
Material Engineer	[signature]	18/Sep/23	Material Engineer		

REC-SQP.01-07-01-V0

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

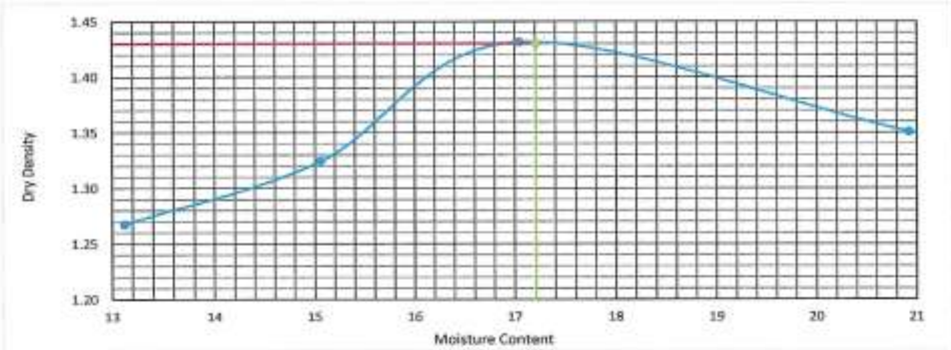
Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

MAXIMUM DRY DENSITY AND MOISTURE CONTENT

(AASTHO T-180) Format No: 01002/JMC/EHAE/21F/03-R0

RFI No.		Lab Ref No. :	
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Testing:	09/09/2023
Propose Used	M.Sc. Research	Sampled By:	Denkayehu
Type of Method:	A	Tested By:	Jointly
Material Discription	Black Cotton Soil Heated to 600oC	Depth (M)	0.30 to 1.0 m

Description	Test I	Test II	Test III	Test IV	Test V		
	Density Determination						
Water Added %	6%	8%	10%	12%			
Mass of mould + Wet Soil (g)	5010	5423	5534	5520			
Mass of mould, W5 (g)	3678	4008	3978	4003			
Mass of wet soil, W7=W6-W5 (g)	1332	1415	1556	1517			
Volume of mould, V (cc)	929	929	929	929			
Bulk density, γ_w = [(W7-W6)/V] g/cc	1.434	1.523	1.675	1.633		**NMC**	
	Moisture Content Determination						
Container no	D50	D11	D2	G4		D8	
Mass of container + wet soil, W1 (g)	222.00	260.00	233.55	238.00		280.00	
Mass of container + oven dry soil, W2 (g)	198.99	229.00	202.99	201.00		260.00	
Mass of Water (g) W3=W1-W2	23.01	31.00	30.56	37.00		20.00	
Mass of container, W4 (g)	23.60	23.00	23.60	24.10		28.60	
Mass of Dry Soil (g) W5 = W2-W4	175.39	206.00	179.39	176.90		231.40	
Moisture Content (%) W6= W3/W5*100	**13.12**	**15.05**	**17.04**	**20.92**		**8.64**	
Dry density, γ_d = γ_w/(100+W6)*100 (g/cc)	**1.268**	**1.324**	**1.431**	**1.350**		8.64	



MDD:	1.430 (gm/cc)	OMC:	17.2 %

Tested By
Contractor's
Lab Technician

Checked By
Contractor's Material Engineer

Verified by
Consultant's Lab Technician

Approved By
Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC - LRBCL Joint Venture.

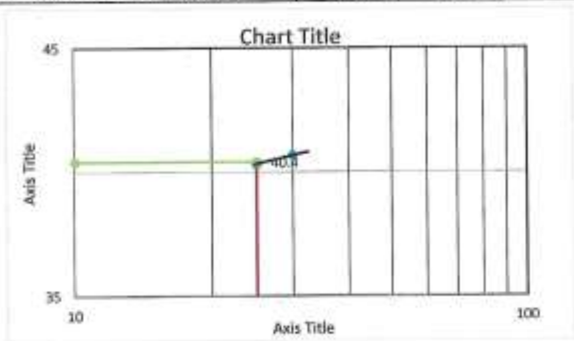
Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

ATTERBERG LIMITS

(AASTHO T-89/90) Format No: 01002/JMC/EHAE/21F/02-R0

RFI No.	0	Lab Ref No. :	0
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Testing:	05/09/2023
Propose Used	M.Sc. Research	Sampled By:	Denkayehu
Material Discription	Black Cotton Soil Heated to 600oC	Tested By:	Jointly

Description	LIQUID LIMIT				PLASTIC LIMIT		
	Test I	Test II	Test III	Test IV	Test I	Test II	Avg
No of blows/Penetration (mm)	30	25					
Container No	C-5	C-31			C-2	C-1	
Container + Wet soil, W1 (g)	61.4	59.2			40	41	
Container + Dry soil, W2 (g)	50.3	49.66			37.77	38.8	
Weight of Container (g)	23	26			22.67	23.6	14.62
Weight of water, W4= W1-W2 (g)	11.10	9.54			2.23	2.20	
Weight of oven dry sample, W5=W3 - W1 (g)	27.30	23.66			15.10	15.20	
Water content percentage, 100x(W4/W5)	40.66	40.32			14.77	14.47	



Grain Size Analysis			
Total Wt.(gm)			850.0
Sieve size mm	Wt. Ret. (g.)	% Retained	% Passing
2.0	33.0	3.88	96.12
0.425	37.0	4.35	91.76
0.075	143.0	16.82	74.94
Pan	637.0	74.94	0.00

LL	PL	PI
40.49	14.62	25.87

Comments:-

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

CLIENT	CONSULTANT	CONTRACTOR
ETHIOPIAN ROAD AUTHORITY	LEA-LASA-UNICONE	JMC PROJECTS (I) LTD.

Effect of Heat On the Properties of Expansive Soils - Denkayehu Nega

CALIFORNIA BEARING RATIO TEST

(AASHTO T 193)

Format No: 01002/JMC/EHAIL/21F/04A-R0

RFI No.	0.000	Lab Ref. No.	0
Source :	OGL FROM 1+000 to 3+000 FW	Date of Sampling:	25/08/2023
Location:	Km.2+500 LHS	Date of Soaking:	12/09/2023
Propose Used	M.Sc. Research	Date of Testing:	16/09/2023
Material Discription	Black Cotton Soil Heated to 600oC	Depth (m):	0.30 to 1.0 m

DENSITY DETERMINATION

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
MOLD NUMBER	M-20		M-4		M-13	
WEIGHT OF MOLD	7096	7096	7209	7209	7111	7111
WEIGHT OF SOIL + MOLD	10300	10450	10710	10745	10910	10934
WEIGHT OF SOIL	3365	3398	3412	3455	3755	3788
VOLUME OF MOLD	2243	2243	2243	2243	2243	2243
WET DENSITY OF SOIL	1.50	1.51	1.52	1.54	1.67	1.69
DRY DENSITY OF SOIL	1.28	1.29	1.31	1.33	1.44	1.45

MOISTURE DETERMINATION

CONTAINER NUMBER	G-19	G-65	G-18	D-3	D-13	D-44
WET SOIL + CONTAINER (g)	244.60	244.00	281.00	297.00	280.00	265.00
DRY SOIL + CONTAINER (g)	213.00	212.00	246.00	261.00	245.00	231.00
WEIGHT OF WATER (g)	31.60	32.00	35.00	36.00	35.00	34.00
WEIGHT OF CONTAINER (g)	25.88	24.78	27.90	29.11	28.65	25.87
WEIGHT OF DRY SOIL (g)	187.12	187.22	218.10	231.89	216.35	205.13
MOISTURE CONTENT (%)	16.89	17.09	16.05	15.52	16.18	16.57
AVG. MOISTURE CONTENT (%)	16.99		15.79		16.38	

Ring Factor 0.03081

PENETRATION TEST DATA

PENETRATION (mm)	Std. Load	Dial reading	Load (kn)	Cor. Load (kn)	Dial reading	Load (kn)	Cor. Load (kn)	Dial reading	Load (kn)	Cor. Load (kn)
0		0.0	0		0.0	0		0.0	0.0	
0.64		19.0	0.6		22.0	0.7		26.0	0.8	
1.27		21.0	0.6		23.0	0.7		28.0	0.9	
1.96		25.0	0.8		27.0	0.8		34.0	1.0	
2.54	13.54	29.0	0.9	0.9	31.0	1.0	1.0	38.0	1.2	1.2
3.18		31.0	1.0		34.0	1.0		39.0	1.2	
3.81		36.0	1.1		36.0	1.1		46.0	1.4	
4.45		38.0	1.2		38.0	1.2		55.0	1.7	
5.08	20.22	39.0	1.2	1.2	40.0	1.2	1.2	58.0	1.8	1.8
7.62		42.0	1.3		42.0	1.3		62.0	1.9	
10.16		45.0	1.4		47.0	1.4		66.0	2.0	
12.7		47.0	1.4		49.0	1.5		69.0	2.1	

SWELL READING (INITIAL)	2.33	4.60	6.43
SWELL READING (FINAL)	8.11	9.77	9.98
PERCENTAGE SWELL	1.97	1.44	1.05
CBR @ 2.54 mm	6.6	7.1	8.6
CBR @ 5.08 mm	5.9	6.1	8.8

Tested By	Checked By	Verified by	Approved By
Contractor's Lab Technician	Contractor's Material Engineer	Consultant's Lab Technician	Consultant's Material Engineer

ICT ENGINEERING PLC

CASH INVOICE

Description Amt

+11,100.00

TXBL1 +11,100.00

TAX1 15.00% +1,665.00

TOTAL +12,765.00

CASH +12,765.00

ITEM# 1

ERCA

PMA0026450

PLC

Cash sales voucher

ICT ENGINEERING PLC

Tel: 0911680487
0911406474

No.PMA0026450

Voucher No	CSV-0000165-23
Date	05-09-2023 12:20 PM
Job	
Store	
Distribution	

	Qty	Unit	Unit Amount	Total
	1.00	PCS	11,100.00	11,100.00

Sub Total		**11,100.00**
VAT(15%)	**11,100.00**	**1,665.00**
Grand Total		**12,765.00**

Five birr Only

Attachment

INVALID WITHOUT FISCAL OR REFUND RECIEPT ATTACHED

ERP system by TOHEY Technologies, Addis Ababa Ethiopia (www.toheytec.com) Page 2

7.2 Appendix 2: Photo

 Sample Preparation	 Sample Preparation
 Plastic Limit Test	 Liquid Limit Test

 Plasticity Index Preparation	 Free Swell Test
 Heat Treatment Using Furnace	 Furnace used for Heat Treatment
 Linear Shrinkage Test	 Plastic Limit Test