ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES DEPARTMENT OF EARTH SCIENCES

# Characterization and Suitability Analysis of Embankment Material with especial consideration to Core and Filter Material - A Case Study of Dendo Dam in Southern Ethiopia

BY: - Mulatu Tumoro Rashe

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the requirements for the Degree of Masters in Engineering Geology

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**THE LORD** is my shepherd; I shall not want. psalm 23:1

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# ABSTRACT

Dendo Dam Project is one of the Bilate Irrigation Projects undertaken by Water Works Design and Supervision Enterprise (WWDSE). The dam site is located around 347km south of Addis Ababa and bounded by geographic coordinates of 395800-399000E and 780200-782800N. The main purpose of this dam project is to provide irrigation to the agricultural land which is situated in the northern part of Lake Abaya, southern part of Ethiopia. The success of this proFigure 1ject will highly depend on the availability of suitable embankment material as it plays great role in the design of the embankment to be constructed. Earth and rock fill embankment dams are tolerable in most of dam site particularly in seismic prone area and since everything from clay to large stones are used in their construction, it requires low capital investment and can be completed in short period of time with minimum environmental impact. However, improper use of construction material and carelessness during investigation stage causes embankment failure by piping and seepage, foundation blowouts, overtopping and others. Therefore, identification of the material based on: engineering, mineralogical, and dynamic property and the site conditions have substantial impact on the long term stability and economic feasibility of a given Embankment project. Therefore, in the light of these important points the main objective of the present study was to Characterize and carry out Suitability Analysis of embankment material with special consideration to core and filter material. For this representative samples were collected from the borrow areas, and laboratory tests were conducted to know index and engineering properties of the soils. The laboratory test conducted on soil samples during present study are: wet sieve analysis, Hydrometer analysis, Atterberg limits, shrinkage limits (linear), proctor compaction, permeability and x-ray diffraction (XRD). Test conducted on sand sample is sieve analysis. Besides, secondary data generated during previous study has also been procured from the project office. Based on the test results generated during both studies (previous and present) characterization and suitability analysis of embankment material was done.

Finally, based on the results and finding of the present study, recommendations have been made.

# CHAPTER-I INTRODUCTION

## 1.1 General

Development and management of water resources is critically important human activity. The quality and availability of water determines levels of public health, food production, the productivity of industry, the generation of energy, and other important aspects of the quality of life. To develop the surface water, construction of dams is the essential first step. Investigation, design and construction of these dams need scientific and systematic study, as its stability and safe functioning is affected by various factors. For the selection of economical dam type it is necessary to analyze the most important factors.

The proper choice of the method of construction is dependent, in part, on the character of material available and in part on economic considerations. It should be the subject of careful investigation study during the preliminary stages of the project. Quality, economy, and safety should all be given careful consideration (William et al., 1945). In addition; geology, topography, foundation condition and environment are also the most important factors which affect the construction and design of any dam type. As suitability of construction material and stability of the dam foundation highly affect the safe functioning of the dam; proper investigation of surface and subsurface condition of dam foundation and suitability of available construction material is very essential.

Earth and rock fill embankment dams are the structures most commonly used to impound water. For these dams most sites are relatively good and, since everything from clay to large stones is used in their construction, it requires low capital investment and can be completed in short period of time with minimum environmental impact. However, improper use of construction material and carelessness during investigation stage causes embankment failure by piping and seepage, foundation failure, overtopping and others.

In Ethiopia due to recurrent drought and rain-fed agriculture in the country, the Government has given priority to the development of irrigated agriculture. Though previously the country was mainly involved in small scale irrigation projects, that do not need sophisticated studies and techniques, recently there are large scale irrigation projects under feasibility and detailed design studies and few projects are under construction. Therefore, characterization of suitable earth material for these embankment dams in terms of geology and foundation condition, engineering properties, mineralogical properties etc. can play a significant role in the economic feasibility, cost effective design, reduction in construction time and structural stability of the projects.

### 1.2 Problem justification

Even though the most economical type of dam will often be one for which materials can be found within a reasonable haul distance from the site, including material which must be excavated from the dam foundation, spillway, outlet works, powerhouse, and other appurtenant structures, the suitability of the material in terms of engineering properties, chemical composition and site condition should be assessed. Most of the time during construction of dams, only engineering properties of materials are considered and the studies does not focus on mineralogy and dynamic properties of materials, which is very essential especially in seismically active area like Dendo dam site. As the desired quality of construction material can be affected by different ways; for the stability safe functioning of the proposed research work various locally available material considering prescribed properties will be advantageous.

Therefore, in the present research work, locally available earth fill embankment materials are characterized in terms of engineering, dynamic and mineralogical properties under varied site condition giving special consideration to core and filter material. Therefore, the study will be useful for proposed Dendo dam project in particular and upcoming earth/rock fill embankment dam projects in the country, in general.

### 1.3 Objective of the study

#### 1.3.1 General objective

- Characterization and suitability analysis of construction material for embankment with special consideration to core and filter.

#### 1.3.2 Specific objectives

- To identify suitable material for embankment based on investigation and findings;
  - Description of types of materials used for different zones of embankment based on engineering, dynamic, mineralogical and site conditions.
- To provide suitable remedial measures to improve unsuitable material for core and filter.
- To characterize the material behavior under different site conditions.

## 1.4 Location and Accessibility

The Dendo dam site is located in Southern National and Nationality People Region accessed through 32 km dry road from Alaba Kulito to left abutment and, 58 km from Welayta Sodo town to the right abutment and construction material sites accessed thorough gravel and dry weathered road. Alaba Kulito and Welayta Sodo are around 315 km and 380 km south of Addis Ababa, respectively, which are connected through asphalt road. The dam site is bounded by geographic coordinates (UTM) of 395800-399000-E and 780200-782800-N.

The dam is earth and rock-fill with 42 m height and reservoir capacity of 52 million $m^3$. The proposed dam will irrigate agriculture land which is mainly characterized by plain land (flood plain) and gentle slope forming land with hills. Dendo dam site falls in between the two small hills.

According to geological map of Ethiopia 1996 the geology of the area is dominantly covered by Rhyolitic volcanic centers such as obsidian pitchstones, pumice, ignimbrite, tuff, subordinate trachyte flow (alkaline and per alkaline in composition) and alluvial and lacustrine deposit such as sand, silt and clay. Rhyolite and rhyolitic ignimbrite are the dominant lithologies on Dendo Mountains and the surroundings.

## 1.5 Significance of the study

Since improper use of construction material is one of the main causes for embankment failure by piping and seepage; the result and findings of the proposed research work will be expected to have a great importance in economic design of the dam and other appurtenant structures and stability of the proposed embankment dam. Based on the recommendation the constraints of construction material will be solved. Besides, the data generated through this study may also be utilized by the later researchers intending to work on the same subject or in the same study area. The study will also be a guide line for geotechnical engineers, engineering geologists, designers and professionals who are involved in construction material assessment and supervision of any type of embankment works.

## 1.6 Methodology

In order to achieve the objectives of the present research work systematic methodology has been adopted. This includes; literature review from both published and unpublished reports on construction materials used for embankment dams and their case studies for dam failure due to improper use of embankment material have been assessed in addition to different books, which are used for better understanding regarding engineering for dams.

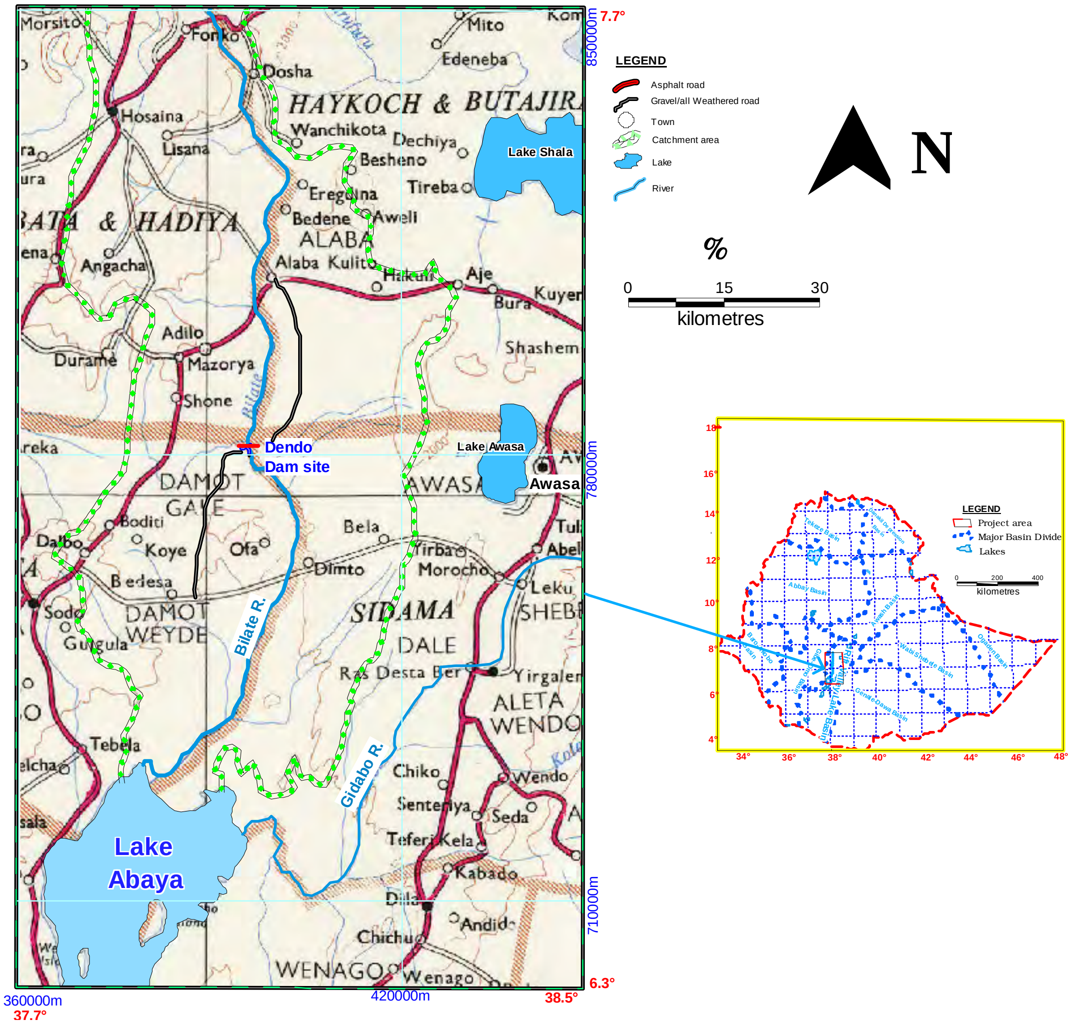





**Figure 1. 1** Location Map of the study area

The secondary data that are collected and analyzed by Water Works Design and Supervision Enterprise (WWDSE) are also used for better interpretation. During geological and geotechnical study by WWDSE different appropriate samples for different zones of the embankment has been collected for laboratory analysis and the test results are interpreted. However, the study lack detailed investigation in engineering, mineralogical, chemical and suitability analysis for core and filter materials. Therefore, to fill this gap in present study field investigation has been carried out. During field investigation of preset study the physiographic and geologic setup of the study area has been described. For this Global Positioning System (GPS) and topographic map in order to locate the exact position of sampling and to get some inputs for the description on the local geology has been used. In addition; using GPS appropriate soil samples from test pits at different depths in borrow area are collected for laboratory analysis and; test results are interpreted. The laboratory test conducted on soil samples are: wet sieve analysis, Hydrometer analysis, Atterberg limits, shrinkage limits (linear), proctor compaction, permeability and x-ray diffraction (XRD). Test conducted on sand sample is sieve analysis. All tests were conducted in the geotechnical laboratory of the Faculty of Technology; Addis Ababa University, except x-ray diffraction of mineralogical analysis (on core material) which was conducted in Central Geological Lab of Ministry of Mine and Energy, Addis Ababa. Based on the literature review, previous works, engineering property, mineralogy, and dynamic characteristics further interpretations were made for the suitability of the construction material for different zones in the embankment.

## 1.7 Application of the results and Limitations

The results and the findings of the present study will be primarily vital for safe and economic design of the proposed dam. The data generated through this study may highlight certain aspects of the suitability of the construction material for the proposed embankment dam. The present research study may also help in improving the stability of the dam. In addition; the data generated through this study may also be utilized by the later researchers intending to work on the same subject or in the same study area. It may also be used by the scientific community.

All efforts are being made to carry out the present study in a systematic way, supported by the actual field data, laboratory tests and the secondary data procured from various sources. However, these efforts were made under the limitations of resources and the financial constraints. All these limitations might have affected the quality of the results, to certain degree of inaccuracy. Therefore, it is strongly recommended that the results and findings of the present study must be considered indicative only. More elaborate systematic studies are required before implementing these findings to the project in question.

## 1.8 Scheme of Presentation

The research project presents systematically the characterization and suitability analysis of embankment material with special consideration to core and filter by taking Dendo dam as a case study. It takes account of the following listed chapters;

**Chapter 1** covers the introduction which discusses about the proper selection of construction material for embankment dam to develop water resources. Additionally, it covers about the problem justification, objectives, significance of the study, location and accessibility, methodologies, application of the results and limitations of the research and finally scheme of presentation.

**Chapter 2** presents a review on previous works on the related topics and around the area of the subject research project.

**Chapter 3** offers the general overview of the study area. It contains; the location of the project area, climate, physiography, vegetation and land use, hydrogeology, regional and local geology, seismicity of the study area and engineering properties of foundation material.

**Chapters 4** discusses about characterization and suitability analysis of embankment material with especial consideration to core and filter material. It includes about construction material for core, filter, shell and riprap, index and engineering properties of core material, mineralogical composition of core material, dynamic property of core material, engineering and mineralogical properties of the filter material and engineering properties of shell and riprap.

Finally, **Chapter 5** presents the conclusions and recommendations that include the researchers' scientific and logical recommendations.

# CHAPTER-II LITERATURE REVIEW

## 2.1 Embankment Dam

### 2.1.1 General

Depending on the predominant fill material used, the two principal types of embankment dams are earth and rock-fill dams. When plenty of materials are convenient to the site, embankments can usually be built for considerably less cost than any form of concrete gravity dam. The use of this type, however, is often limited by the necessity of providing a more suitable spillway for the passage of floods.

Earth and rock fill dams use natural materials with minimum of processing; therefore availability of usable material at or near to the site influences the choice of the type of dam. However; the construction material found within economic distance from the dam site should be sufficient in quantity and should satisfy the engineering properties of the construction material. Therefore, before the actual design of the embankment dam proper field and laboratory identification of these materials is critically essential. To determine the quantity of construction material surface and subsurface investigation of material available from local borrow pits, and from required excavation for the foundation, outlet works and spillway should be done. During field investigation appropriate samples from borrow area and excavation for the foundations should be collected for laboratory test and the study must incorporate test results.

Based on the test result the material locally available can be used either in their natural state or by blending construction material of two different physical and/or chemical properties like clays and rock/gravel are mixed to use the advantages of both materials concurrently.

Using locally available material as it is or in their natural state is more economical as minimizes construction cost. However, blending of material will highly improves engineering properties of construction material. In such a case the embankment zone will have high strength of rock/gravel material and low permeability value of clayey material.

According to Sherard (1967), as sited in Singh, B. and Varshney, R.S. (1995) more efficient developing mechanism should be selected for material available as layered deposit and the

property of such blended mixture can be controlled by varying excavation sequence or by varying mix proportion to obtain different percentage of the two soils.

### 2.1.2 Overview of Embankment material

Most of the time locally available embankment material governs the type of embankment dam. If the site is dominated by only one type of material (soil) the design will consist of a homogeneous embankment. If it is impervious soil, a homogeneous embankment with only small amount of pervious material to control the internal erosion will be selected. If it is pervious material (sand or gravel), a dam with a very thin core may be used where enough impervious material is available to make a core; otherwise an impervious facing may be constructed.

In homogeneous fill dams the slopes are flattened, which contributes to the seepage control by descending the velocity of the percolating water. These dams are often of low to moderate height, otherwise their construction would be unduly complicated (Cendergren, 1977).

For the case where varied material is available at the site a zoned dam which incorporates the material available on the site into the embankment will be selected. A zoned dam is a rolled fill dam composed of several zones that increases in permeability from the core towards the outer slopes. The number of zones depends on the availability and the type of borrow material. Stability of zonal dam is mostly due to the weight of the heavy outer zone. Zones of lower permeability can be formed in homogeneous embankment by using either more compaction or higher water content during construction. In this case the material for zones like: core, Filter, Shell and Riprap should be checked individually (Sherard, 1967).

### 2.1.3 Core Material

The first essential requirement for core material is the availability of suitable material at an economical distance from the dam site. Later it has to be investigated for available quantity and relevant soil properties. The important soil properties to be considered are; permeability, compacted density, shear strength, compressibility, flexibility and erosion resistance. Various types of materials with a permeability of $10^{-5}$ cm/s or lower have been used in cores of the embankment dams (Bharat Singh, 1995).

Bharat Singh, (1995) states that soils of higher compressibility should be avoided as excessive settlement, cracking and high construction pore pressures can take place. Two desirable properties to be looked for core material are the flexibility (ability to deform without cracking) and erosion resistance. Flexibility increases with an increase in Plasticity Index (PI). However, very high values of PI may be associated with high compressibility. According to Bharat Singh

(1995) erosion resistance is the ability of the soil to withstand the erosive action of water leaking through possible cracks. Erosive resistance is mainly derived from two sources cohesion of the fines and the resistive action of coarse particles to the flowing water and their tendency to wedge-up in the leakage channel. This effect is best obtained in a well graded sand gravel mixture with enough finer particles to provide imperviousness (Table 2.1). In such a material the coarser particles within the crack obstruct the flow and prevent development of high velocities. In tough plastic clay the resistance to erosion is provided by the strong interparticle adhesion.

Sherard (1963) classify material according to their erosion resistance and an experimental investigation carried out for fine grained soils indicates that erosion resistance normally increases with plasticity index. Erosion resistance also increases with compacted density.

The type of material selected for core also dictates the thickness of core design. As per U.S Army corps of engineers (1994), the core thickness should depend on the type of material available, the design of transition filters and the seismicity of the area. If the available material have a high erosion resistance as well as good flexibility, smaller thickness of the core can be used. For a given type of material, the thickness can be kept less if the filter or transition zone material fully meets the specifications and is of adequate thickness. Larger thickness has to be used in seismic areas where there is a greater chance of cracking (Sherard, 1963).

**Table 2. 1** Suitability of Soil for Construction of Dams (after Brahat Singh, 1995)

| Relative Suitability | Homogeneous Dams | Impervious Core | Pervious Shells | Impervious Blanket |
|---|---|---|---|---|
| Very suitable | GC | GC | SW, GW | GC |
| Suitable | CL-CI | CL, CI | GM | CL, CI |
| Fairly suitable | SP, SM<br>CH | GM, GC<br>SM,SC,CH | SP, GP | CH, SM<br>SC,GC |
| Poor | -- | ML, MI, MH | -- | -- |
| Not suitable | -- | OL, OI, OH, Pt | -- | -- |

### 2.1.4 Transition Filters/Drains

The objective of filters and drains used as seepage control measures for embankments is to efficiently control the movement of water within and about the embankment. In order to meet this objective, filters and drains must, for the project life and with the minimum maintenance, retain the protected materials, allow relatively free movement of water, and have sufficient discharge capacity. The term filters and drains are sometimes used interchangeably. Some definitions classify filters and drains by function. In this case, filers must retain the protected soil but have a permeability greater than the protected soil but do not need to have a particular flow or drainage capacity since flow will be perpendicular to the interface between the protected soil and filter. Drains, however, while meeting the requirement of filters, must have an adequate discharge capacity since drains collect seepage and conduct it to a discharge point or area (Cendergren, 1977)

The filter design for the drainage layers and internal zoning of a dam is a critical part of the embankment design. It is essential that the individual particles in the foundation and embankment are held in place and do not move as a result of seepage forces. Transition filters are the most important component part of the dam section which is provided in between core and shells on either side to protect it from piping failure. Filters and drains can provide permanent security against the damage section of seepage and ground water, however; certain fundamental requirements must be strictly enforced. The first requirement of filters and drains is that they must be safe with respect to erosion and clogging. The second requirement, which can be equally important, is they must have sufficient discharge capacities to remove seepage quickly, without inducing high seepage forces or hydrostatic pressure. In addition, if filters and drains are required to serve their intended purpose, the materials used in their construction must have the correct gradation and they must be handled and placed with care to avoid contamination and segregation (Cendergren,1977);. Although naturally occurring gravel and sands some times can be used for filters and drains with little or no processing, drainage aggregates usually need to be treated. Efforts to save money by using untreated local materials almost always produce marginal or unsatisfactory filters and drains. Most natural sand and gravel deposits are highly variable in grading from point to point in a borrow area, or they are covered or interbeded with silt and clay which is difficult to remove. In such case it is more economic to crush the required sizes of the material from suitable rock, available at the site. There are various filter selection criteria proposed by different authors. The most prominent filter criteria are proposed by Terzaghi, USBR, and Sherard.

**Terzaghi's Filter Selection Criteria (1930)**

For the design of filters Terzaghi proposed the following criteria;

1) The 15% size of the filter material, $D_{15}$, must not be more than 4 or 5 times the 85% size, $D_{85}$ of the protected soil to prevent the piping, i.e

$$\frac{D_{15}\ of\ filter}{D_{85}\ of\ \mathrm{Pr}otected\ Layer} < 4\ to\ 5$$

2) The 15% size of the filter material, $D_{15}$, must be at least 4 or 5 times the 15% size, $D_{15}$ of the protected soil, to ensure adequate permeability or,

$$\frac{D_{15}\ of\ filter}{D_{15}\ of\ \text{Pr}otected\ Layer} > 4\ to\ 5$$

Other requirements for a good filter are;

i) Its gradation curve should be approximately parallel to the gradation curve of the protected soil, especially in the finer range.

ii) Filters should not contain more than 5% fines (-0.075 mm) and fines should be cohesion less. This is to ensure that filter remains adequately pervious and does not sustain a crack.

iii) The filter does not have particles larger than 75 mm so as to minimize segregation.

iv) If the base material ranges from gravel (over 10% > 4.75 mm) to silt (over 10% passing 75μ), the base material should be analyzed on the basis of gradation of fraction smaller than 4.75 mm.

<u>Filter Selection as per Indian standard (IS) code</u>

The recommendations for filter selection as per IS code are as follows;

i) $$\frac{D_{15}\ of\ filter}{D_{85}\ of\ base} < 5$$

ii) $$\frac{D_{15}\ of\ filter}{D_{15}\ of\ base} > 4\ and < 20$$

iii) $$\frac{D_{50}\ of\ filter}{D_{50}\ of\ base} < 25$$

iv) The gradation curve of filter material should be nearly parallel to the gradation curve of the base material.

**<u>Filter selection as per U.S. Army Corps of Engineers criteria (1955)</u>**

i) $$\frac{D_{15}\ of\ filter}{D_{85}\ of\ base} \leq 5$$

ii) $$\frac{D_{50}\ of\ filter}{D_{50}\ of\ base} \leq 25$$

**Sherard's Recommendations For Filter Design**

i) The filter is successful in its function of arresting particles migration if;

$$\frac{D_{15}\ of\ filter}{D_{85}\ of\ base} < 9$$

ii) The size of the pore channel, which governs permeability is determined by the size of finer filter particles and will be represented by $D_{15}$ size.

iii) The filter gradation curve need not necessarily be parallel to the base material.

Horizontal Filter

It collects the seepage from the inclined/vertical filter or from the body of the dam. It also collects seepage from the foundation and minimizes possibility of piping along the dam seat. The horizontal is to be provided on stripped ground. Depending on downstream topography, the slope of the horizontal filter towards the toe drain is to be decided.

The horizontal filter must satisfy the following three requirements:

i) Gradation must be such that particles of soil from the foundation are prevented from entering the filter.

ii) Capacity of the filter must be such that it adequately handles the seepage flow from both the foundation and the embankment.

iii) Permeability must be great enough to provide easy access of seepage water in order to reduce seepage uplift forces.

### 2.1.5 Shell Material

The shell is the bulk mass of the embankment dam, which is primarily required to provide the stability to the dam and to withstand the horizontal thrust exerted by the impounded water behind the dam. The first essential requirement for the shell material is the availability of suitable material at an economic distance from the dam site. The borrow areas for the shell have to be located near the dam site. Later it has to be investigated for available quantity and relevant soil properties. In a common type of earth fill embankment a central impervious core is flanked by much more pervious shells that support the core. The upstream shell affords stability against end of construction, rapid drawdown, earthquake, and other loading conditions. The downstream shell acts as a drain that controls the line of seepage and provides stability under high reservoir levels and during earthquakes. For the most effective control of through seepage and seepage during reservoir drawdown, the permeability should increase progressively from the core out toward each slope.

### 2.1.6 Slope Protection (Riprap)

There is no material superior to good stone riprap for the protection of the upstream face of an earth dam from wave action. Stone riprap is of two classes, random riprap and hand-placed. The former consists of stones dumped in place from cars or tracks or tossed in to place by hand. It is dumped in place from car or tracks, the individual stones may be any size the capacity of stream shovel, such material sometimes being termed cyclopean riprap or derrick stone riprap.

Hand-placed riprap consists of one-man stones laid on edge on a gravel bed that has been prepared and graded. An effort is made to break joints as much as possible, and the voids are filled with smaller stones. Not all rocks are use as riprap. Stone for riprap should be hard and durable should not break down rapidly on long exposure to water, frost, and air. (William et al., 1945).

The extent of the treatment required at the upstream face will depend on the operational regimen, the size and the shape of the reservoir, the climate and the typical wind patterns (Jansen, 1988). In estimating the characteristics and the effect of waves that may have an impact on the dam, consideration must be given to the wind velocity, duration, and direction, the reservoir configuration, and the orientation and the slope of the embankment.

According to USBR the factors which influence Riprap design are the availability of the suitable material and embankment design. Bulk specific gravity and unit weight of the riprap material are the parameters used in computation of riprap design. However, adequate riprap design and specifications must consider other measures of the rock quality to ensure riprap stability and the integrity of the riprap throughout the service life of the embankment. This includes petrographic examination and physical property testing to evaluate the physical and chemical quality of the rock in conjunction.

The downstream slope requires protection against erosion by rain water and sometimes by wind also. If the downstream face is made up of rock fill or boulder gravel, no protection would be required.

### 2.1.7 Dynamic property of the embankment material

The destructive potential of an earthquake of a given magnitude depends on amplitude, frequency and duration of the ground vibration and the site conditions. High amplitude corresponds to large magnitude earthquakes. However, it does not alone determine the damage potential, as these also depends on frequency characteristics of the ground motion and its duration. For earthquake of the given magnitude duration is responsible for degree of destruction. According to Seed and Chan (1967) a very high acceleration developed for a very short period of time will cause little damage to many structures. An intermediate magnitude with long duration more severe than high magnitude with low duration taking all the other factors uniform particularly at resonance condition.

Resonance is a condition in which the period of vibration of the earthquake induced ground shaking is equal to the natural period of vibration of the engineering structure. When resonance occurs, the shaking response of the structure is enhanced, and the amplitude of vibration of the structure rapidly increases. As a result at resonance the structure will experience the maximum horizontal displacement. It is among the force that dam is designed to resist.

According to Attewell and Farmer (1976) resonance in low dams up to 100 ft is not usually taken into account since the vibration period of the dam is normally much less than the range of 0.2 to 1 second, of the period associated with severe earthquake shocks

The dam design in the earthquake prone area must include resistance capacity to the dynamic forces which can be applied during earthquake. The seismic coefficient of the embankment varies with the height of the embankment, predominant frequency of the force cycles and the natural period of the embankment (Table 2.2).

**Table 2. 2** Dynamic seismic coefficient of embankment of different height (after USBR design of small dams 1960)

| **Equivalent seismic force series** | | **Vs=(G/S)1/2=91.5 m/s G=155N/cm²** | | | **Vs=(G/S)1/2=305 m/s G=155N/cm²** | | |
|---|---|---|---|---|---|---|---|
| | | **Height of Dam in m** | | | **Height of Dam in m** | | |
| | | **30.5** | **91.5** | **183** | **30.5** | **91.5** | **183** |
| Number of signicicant force cycles | | 10 | 5 | 3 | 15 | 12 | 7 |
| Perdominant frequency of force cycles | | 1.25 | 0.4 | 0.3 | 3.3 | 1.25 | 0.7 |
| Equvalent max. seismic coefficient k cooperative over different portion of the embankment | Top quarter | 0.35 | 0.20 | 0.10 | 0.40 | 0.36 | 0.24 |
| | Top half | 0.33 | 0.15 | 0.07 | 0.35 | 0.28 | 0.16 |
| | Top three quarter | 0.22 | 0.10 | 0.04 | 0.30 | 0.22 | 0.11 |
| | Full height | 0.16 | 0.08 | 0.03 | 0.25 | 0.16 | 0.08 |
| Natural period of Embankments | | 0.87 | 2.61 | 5.22 | 0.26 | 0.78 | 1.57 |

*(Source: Bhrahat Singh et al., 1995)*

These control the time distribution of the inertial forces. If these forces are low, the dam will tend to respond in reasonably elastic manner. According to Attwell et al. (1976), under moderate earthquake attack, some earthquake dams have settled between 0.5 % and 1.0 % of their height (Lane et al. 1976).

If the soils are unlikely vulnerable (either because of the nature of the soil or because the anticipated level of shaking is too small) then the pseudo static method of analysis should provide a reasonably adequate design procedure.

For soils that are likely to be vulnerable to major strength loss or to the development of excess pore pressure, the dynamic method of analysis offers a more realistic approach. This method can be used for all type of soil (Jansen, 1988). In the dynamic method of analysis, assessment of the dynamic behavior of the soil comprising the dam and the foundation such as shear modulus, damping characteristics, bulk modulus or Poisson ratio that influence the earth quake excitation should be made (Jansen, 1988).

# CHAPTER-III GENERAL OVERVIEW OF THE STUDY AREA

## 3.1 Location of the project area

The Dendo dam site is located in Southern National and Nationality People Region accessed by 32km dry road from Alaba Kulito to left abutment and 58km from Welayta Sodo town to the right abutment and construction material sites accessed through gravel and dry weathered road. Alaba Kulito and Welayta Sodo are around 315km and 380km south of Addis Ababa, respectively, which are connected through asphalt road. The dam site is bounded by geographic coordinates of 395800-399000E and 780200-782800N. The Dendo (Bilate) dam project is one of the Projects undertaken by Water Works Design and Supervision Enterprise (WWDSE). The Gelana, Gidabo and Bilate irrigation projects are proposed development projects, aimed to irrigate a total net irrigation command area of 31, 900 ha. Of which, 47% is for Bilate irrigation command area. This command area is situated in the northern part of Lake Abaya, southern part of Ethiopia. The northern Lake Abaya area, which is located in the southern part of the Main Ethiopian Rift (MER), encloses irrigable lands at different places. It indicates the existence of economically exploitable agricultural land (Bilate irrigation project main report, 2008a).

To provide irrigation facilities to the Lower Bilate and Delta region, two alternative dam sites viz. Ropi and Dendo have been identified on the Bilate River. Rock sources for rip rap, masonry works and crushed aggregate exist in Dendo hill and other small hills south of it. The proposed quarry site for rock source is located 800m-1200m down stream of the dam axis, which is west of Dendo mountain/hills. The borrow area for sand, to be used for fine aggregate and transition filters, are collected along the main river course of Bilate and Cherake rivers; upstream and down stream of the dam axis. This sand is the result of point par deposits, which is characterized by fine to coarse grained sand with very minor gravel. The proposed borrow site for core material is at dam site including material excavated from dam foundation, spillway and outlet structure (GGI final feasibility report, 2008b).

## 3.2 Previous works

As sited in the Geological and Geotechnical Investigation final feasibility report, 2008 by Water Works Design and Supervision Enterprise (WWDSE); the regional studies which have been carried in the project area previously include; Development prospects in the Southern Ethiopian Rift valley (Markin et. al., 1974), contains geological map of the southern Ethiopian Rift valley, scale 1:1, 250,000 (Kazmin 1973, revised by King 1973), Geological map of Ethiopia, scale 1:2,000,000 (Mengesha et. al., 1996), Late Eocene - recent volcanism and faulting in the southern main Ethiopian Rift valley (Ebinger et. al, 1993), Patterns of faulting in the Ethiopian rift valley (Mohr, 1987), Rift structure in southern Ethiopia (Moore and Davison, 1978), Quaternary oblique extensional tectonics in the Ethiopian Rift (Boccaleti et al, 1998), Geology, geochronology and rift basin development in the central sector of the main Ethiopian rift valley (Wolde Gabriel et. al., 1991) and investigation of Geothermal Resources for Power Development, (UNDP, 1973).

The following are relatively relevant studies for the Bilate (including Dendo dam site) Irrigation project area:

- Geothermal Resource Exploration in the Abaya and Tulu Moye Geothermal Prospects, Main Ethiopian Rift, by Hydrogeology, Engineering Geology and Geothermal Department of Geological Survey of Ethiopia, Addis Ababa, 2002.
- Hydrogeology of the Bilate River Basin, by Girum Lissanu, Geological Survey of Ethiopia, 1981.
- Reconnaissance engineering geological studies of Bilate dam sites, particularly Ropi and Dendo, Abebe Abate, 1985.
- A feasibility study of Geological and geotechnical investigation of Dendo dam site by Water Works Design and Supervision Enterprise in association with Consulting Engineering service (India) Pvt. Ltd., 2007.

From the above regional and local studies the study by Water Works Design and Supervision Enterprise (WWDSE), as the feasibility study and detail design; shows a basic work on construction material assessment for the selected dam site for determination of the suitability and its available quantity. This work provides a basic setting on type of the embankment material available at the site, its distribution, and the engineering properties of the selected materials.

The studies identified construction materials for the embankment dam namely; Silty clay and silty fine soils for core material, Gravel from highly weathered and fractured rocks for shell, Fine Sand for filter and fine aggregate material, rock for various engineering construction purpose such as; crushed rock or coarser aggregate, masonry works and riprap.

All above mentioned construction materials are at economic distance from the proposed dam site. In addition, the laboratory tests on construction materials have also been carried out. Representative construction material samples collected from the dam site were submitted to different laboratories for the required tests. The laboratories, the representative construction materials samples sent to, include Construction design Share Company (CDSCo) and Geological survey of Ethiopia.

The laboratory tests on soils consist of both index and engineering property tests. Various engineering and index test were done and interpreted in accordance with the latest ASTM and USBR standards.
From the laboratory tests conducted: natural moisture content (NMC) (ASTMD22 16) Gradation/ grain size distribution (ASTMD1140 and D422 specific gravity, dispersion potential test, direct shear test, unconfined compressive strength (Remolded) (ASTM D2166) are included.

As per the above said project office report from the test result of the soil collected from various borrow areas; it is found that in general the soil samples are mostly silty clay and/or clayey silt. Compressibility expected to be medium to high and permeability is low. However, the physical and chemical properties of the construction material need a detailed investigation. The chemical composition of the material affects the suitability of clay for core, sand for transition filter, rock for aggregate, and riprap.

### 3.3 Dendo Dam project

The dam is earth / rock fill dam of 42m in height with reservoir capacity of 52 million $m^3$ to irrigate agricultural land, which is mainly characterized by plain land (flood plain) and gentle slope forming lands with three hills. Dendo dam site falls in the two small hills.

In case of Dendo dam site, the Dead Storage Level (DSL) of the reservoir is going to be very high due to 29m of sedimentation above deepest river bed (as per previous survey) after 50 years. From the geotechnical investigation carried out, the river banks in general are found to be geologically poor and fresh rock is not met with even deeper depth.

A saddle dam is however found much beyond the proposed left abutment and a chute spillway is planned to be taken through that saddle. The saddle in question is found wide open. As such it is to be narrowed down by constructing saddle dam from both end of the saddle to make it 105m wide (gross width) only for spillway flow. The proposed spillway section is an ungated ogee shaped wire where crest is to be kept with FRL i.e EL 1595. The chute spillways are very commonly used with earth dam or earth and rock fill dam for the simplicity of construction and its adaptability with almost any foundation condition. In this context it may be mentioned that a gated spillway could probably cause overtopping of the dam resulting into failure. Considering the fact that the site is in a very remote area and timely operation of the gates may not be possible all the time, an ungated chute spillway is provided. In case of an ungated spillway, no surveillance of the flood is required. The spillway comes in to operation once reservoir level starts rising over the crest of the spillway. The axis of saddle dam is kept aligned with the axis of spillway. The zoning, internal seepage etc is similar to that of main dam. The dam being of small height and comparatively on a better foundation condition as compared to the main dam, no instrumentation is suggested. (Dam and appurtenant structures of Dendo dam report, 2008d)

### 3.3.1 The outlet structure

Present peak irrigation is estimated to be 11.20m$^3$/sec. However; the outlet is designed for 14m$^3$/sec keeping in view future irrigation prospect. The outlet in question is designed as a double barrel rectangular R.C.C conduit. Size of each barrel is 1.4m x 1.8m in the pressure flow portion i.e. in the upstream of the service gate and of size 1.4m x 2.4m in the free flow portion so that it never flows more than 75% full so as guarantee against sealing of some portion from splashing or surging under different stages of flow. An inclination of 1H:5V slope is provided on external side walls to ensure proper compaction level at the junction of earth fill and outlet structure. Conduit is beyond service gate. There will be two gates (one emergency and another service gate) operable with the help of hydro mechanical system placed on top of the gate well. The top of gate well will be connected with the help of a small bridge with railing. The bottom still of the intake structure of the Outlet is kept at EL1585.0m. (DAS of Dendo dam report, 2008d).

## 3.4 Climate and Physiography

### 3.4.1 Climate

As observed from the meteorological map of Ethiopia, 1979 the project area is classified as 'Woina-Dega' (Temprate) with an effective temperature of 14-20$^o$C (Mild) and most of the time comfortable. The moisture index is from 0.5- 1.0 that is intermediate or moist.

As per the final feasibility report of Water Works Design and Supervision Enterprise (WWDSE) the climate in the high lands of the Bilate basin like Hossana, the mean annual temperature varies from 15°C in March/April while the temperature variation in the lower of Bilate generally is higher and ranges between 20°C in July to 24°C in January and March. In addition the lower reach of basin does not exhibit significant temperature changes from month to month. This large variation in the magnitude of temperature between the upper and lower reaches of the basin has direct implication in the estimates of the open water evaporation and evapotranspiration magnitude.

**Table 3. 1** Mean monthly climatic data at Bilate near the northern tip of Abaya

| Parameter | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RF(mm) | 28.2 | 35.4 | 58.2 | 105.6 | 95.2 | 86.2 | 103.2 | 82.5 | 30.9 | 79.6 | 33.8 | 29.1 | **818.0** |
| Tmax (°C ) | 32.3 | 32.9 | 33.1 | 31.6 | 29.8 | 28.3 | 27.3 | 27.8 | 29.0 | 30.0 | 31.3 | 31.5 | **30.4** |
| Tmin (°C ) | 15.2 | 15.4 | 15.4 | 15.2 | 15.4 | 15.1 | 15.3 | 15.5 | 15.1 | 14.4 | 13.6 | 14.0 | **15.0** |
| SSH(hrs) | 7.8 | 8.4 | 7.8 | 6.4 | 7.6 | 6.1 | 4.8 | 5.4 | 6.3 | 7.0 | 3.8 | 3.5 | **15.0** |
| Wind (m/s) | 1.4 | 1.5 | 1.2 | 1.0 | 1.1 | 1.1 | 1.1 | 0.9 | 0.8 | 0.7 | 0.9 | 1.4 | **1.1** |
| RH-06 (%) | 7.8 | 74.3 | 84.5 | 91.4 | 93.4 | 92.3 | 90.9 | 91.3 | 93.1 | 85.3 | 72.8 | 68.5 | **84.1** |
| RH-12 (%) | 41.1 | 42.8 | 48.3 | 56.1 | 60.7 | 62.7 | 64.5 | 60.2 | 55.5 | 50.8 | 47.9 | 43.0 | **52.8** |
| Rh-08 (%) | 39.3 | 41.1 | 50.1 | 60.8 | 62.5 | 62.1 | 63.8 | 60.4 | 64.3 | 61.7 | 52.2 | 45.0 | **55.3** |
| Mean RH | 49.9 | 51.0 | 59.2 | 68.5 | 72.3 | 71.6 | 71.8 | 70.0 | 69.8 | 63.9 | 53.0 | 49.9 | **62.6** |
| **ETo(mm/mon)** | **139.5** | **140** | **145.7** | **123** | **127.1** | **108** | **102.3** | **108.5** | **114** | **117.8** | **126** | **136.4** | **1488.3** |
| **Eo(mm/m** | **192.2** | **193.2** | **201.5** | **162** | **171** | **144** | **136.4** | **146** | **153** | **164.3** | **177** | **189.1** | **2029.7** |

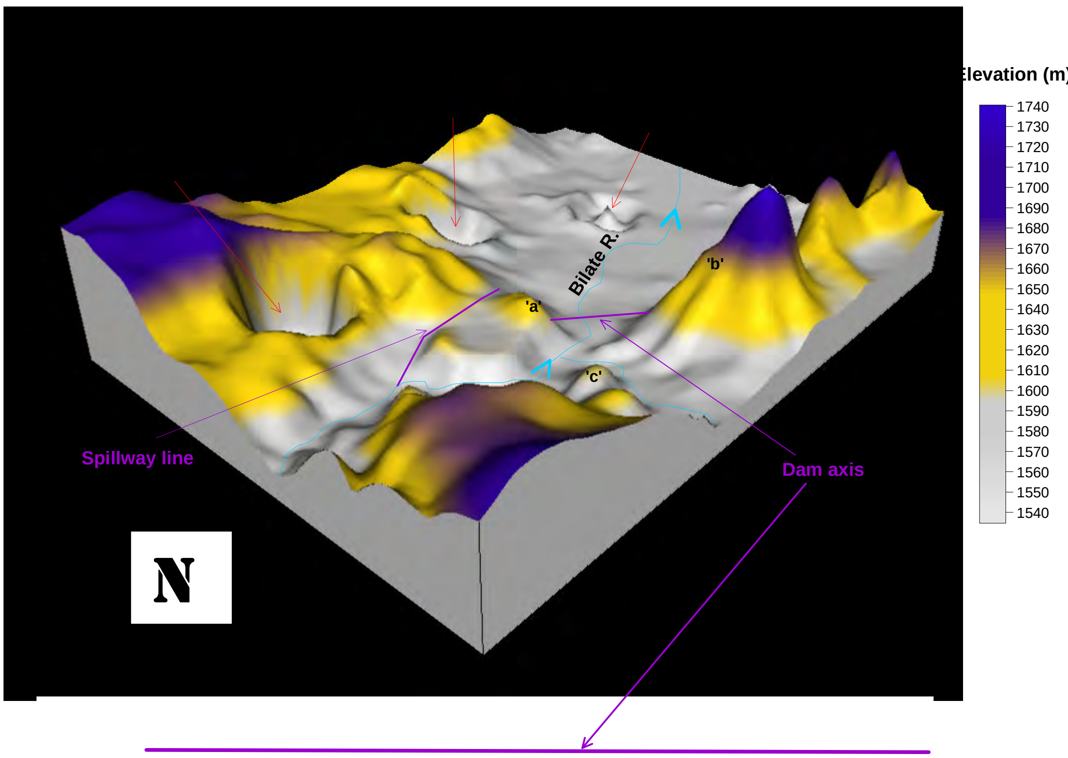
According to penman-Monthieth estimation method, the estimated ETo in this station is 1488mm and the open water evaporation is estimated about 2029mm. In both cases the evaporation loss is consistently greater than the monthly rainfall distribution which indicates the essentiality of irrigation in most or all of the months in the project area (Bilate irrigation project main report, 2008a).

### 3.4.2 Physiography

The physiography around Dendo Dam site is the result of volcano-tectonic, sedimentary and erosion processes. The site is mainly characterized by plain land (flood plain) and gentle slope forming lands with hills. Surfacially, the physiography is covered by pyroclastic fall (lithic tuff) deposit, which is commonly covered by thin residual soil layer. Exceptionally the steep slope forming and top of Dendo Mountain/hill is covered by rhyolitic rocks. This hill is crossed by surfacially recognized normal fault and lineament. River channel and plain land around the dam axis is covered by flood plain and point bar deposits (silt, sand and minor gravel and clay). As observed during the geological and geotechnical investigation by WWDSE, Bilate River and its near-by tributary Cherake rivers transport huge sediments (mainly sand and silt) during the rainy season. With one day peak flooding, more than 1m thick point bar sand deposit is observed on the left bank of the dam axis. (GGI final feasibility report, 2008b)

### 3.4.3 Vegetation and Land use

The reservoir and downstream of the dam area has moderate forest with moderate tree growth and vegetation of shrubs and bushes. Out of the available gross command area of 9790 ha. in Bilate command, the land use for agriculture so far developed is 3015 ha. and other areas are dependent on rain-fed agriculture. The land use being enhanced to irrigate a net area of 6729 ha. by implementing Dendo (Bilate) Irrigation project.(Bilate irrigation project main report, 2008a)




*(Source: Study and Design of Bilate irrigation project, 2008)*

**Figure 3. 1** Geomorphologic map of Dendo dam site area

## 3.5 Hydrogeology

The project office during feasibility study has carried out landsat imagery interpretation to assess the hydrogeological set up and the geological features existing under the study area. The study discovered that both orientations of faulting i.e. NS and NNE-SSW are clearly observed in the area which can serve as conduits for groundwater recharge and that contribute for the occurrence of groundwater.

The physiography of irrigable land of the study area mainly comprises low lying plain. The Bilate River and its tributaries flow from the neighboring elevated ridges towards these plains and from alluvium and fan deposits, and the form of the groundwater movement also follow the topography.

As per the study most of the Bilate river basin is covered by young volcanic rocks, so that the groundwater of the area is contained in weathered volcanic horizons between successive lava flows and in fractured, fissured and jointed rocks. Perched water which occurs in patches of alluvium that overlay impervious volcanics is also not uncommon in the area. Thus, the ground water in the Bilate river basin occurs both in an unconfined and confined condition. Besides, the study also identified that high level springs and the low-level springs are the other sources of groundwater in the area.

The high level springs occur above 1750m a.s.l. close to either the major or minor water divides and are cold, small discharge and perennial where as the low level springs occur below 1750m altitude and are mostly the result of tectonic fractures and perennial, thermal and have high discharge. The thermal springs are saline, and occur along the west bank of the Bilate River, from just north of the Bilate tena southwards to the delta and concentrated in 3 foci of activity; the north abaya lake area, the dugna-chericho, and the duta-teza volcano area.

Suitability of the water for irrigation has been checked by analyzing the water quality test results of sampled water. The test result of Bilate river water shows very low Electrical Conductivity and sodium hazard index which makes the water suitability for irrigation to be excellent according to the USDA chart. The result further indicates that the water quality of the thermal springs of the area falls in the range of high to very high Electrical Conductivity and SAR values. This result holds for Hand-dug wells and deep wells of the area, which exhibits very high SAR index with medium to high electrical conductivity (Hydrogeological Study of Bilate irrigation project report, 2008c).

## 3.6 Regional Geology and Seismicity

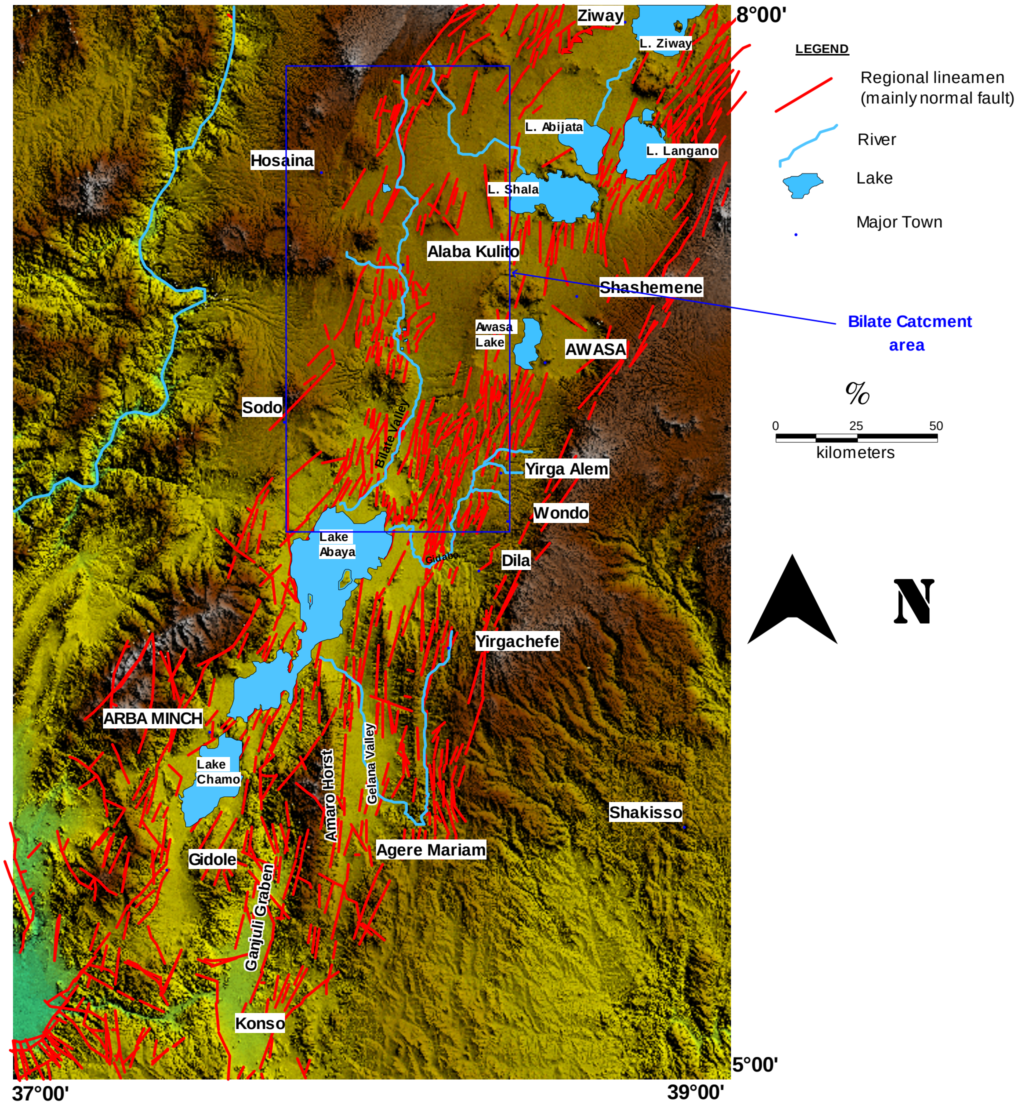
### 3.6.1 Structural set-up

The Dendo dam and Irrigation Project area is situated in the rift zone of Ethiopia, Main Ethiopian Rift (MER). This part of the Ethiopian rift, which has an average width of 80km, is a complex trench trending North-North-East and separating the Ethiopian plateau on the west and the Somalian plateau on the east (GGI final feasibility report, 2008b).

As sited in the Study and Design of Bilate irrigation Project final feasibility Report, 2008; Volcano-tectonic activity during the evolution of the MER migrated from the north to south and confirms the observation made by Zanettine et.al. 1978 regarding evidence that showed movements along the escarpment of Ganjuli Graben that is now occupied by Abaya Lake as young as the Pleistocene (Solomon et al.,2001). The style of faulting within the rift is especial interest; it is dominated by North-North-East trending swarms of en-echelon tensional faults that commonly produce horsts and grabens.

After the development of the Main Ethiopian Rift, the Quaternary episodes of tectonics were formed, and active spreading axis, along the center of the rift, that is known as Wonji Fault Belt (WFB) is developed. The WFB is an intense zone of normal faulting and volcanism, which forms rift-in-rift structures and consists of several segments disposed en echelon fashion along the center of MER. It is the presence active axis of extensional in the MER (Abebe et. al., 2002). As per the above said study, in general, two main fault systems have been distinguished in the MER: N30°E-N40E° and N20°E trending fault systems, which mainly characterizes the rift margins and WFB (rift floor), respectively.

Bilate River is the major river that is found in the rift floor and draining into Lake Abaya. It flows parallel to the major NNE-SSW structural fabric of the rift (WFB). A series of intense normal faulting and quaternary volcanism observed in Bilate river basin is believed to represent the southern sector of the WFB (GGI final feasibility report, Appril 2008b).




*(Source: Study and Design of Bilate irrigation project, 2008)*

**Figure 3. 2** Regional geological structural view of the project area

### 3.6.2 Stratigraphy

According to Geological and Geotechnical Investigation of final feasibility report, 2008; based on previous regional geological mapping or studies (Kazmin & Berhe, 1981, UNDP, 1987, Mengesha et. al., 1996, Solomon et. al., 2002), the regional stratigraphy of the Bilate river valley is discussed and summarized below.

Pre-rift flood basaltic successions with minor sialic members (Jimma Volcanics-Tertiary volcanic) are well exposed on the plateau and escarpments adjoining the Bilate river valley

which rest unconformable on the Precambrian basement. Tertiary volcanic succession has been down faulted into rift floor which in part is covered by the rift valley lakes like Lake Abaya.
This pre-rift volcanism (volcanic basement) is overlain by a Mio-Pliocene (9-2 my) succession comprised predominantly of ignimbrite, trachytic and rhyolitic lava flows & domes (Nazereth Group). The Nazereth Group volcanic products are exposed over the surrounding areas along the rift margins and escarpments. In the rift floor, the Nazereth Group is overlain by succession of flood basalts of Pliocene age (Bofa Basalt). This succession is in-turn overlain by the Quaternary bimodal transitional basalt/peralkaline felsic volcanic products of the Wonji Group. The volcanic products of the Wonji Group (including those from axial volcanic centers) are intimately associated with lacustrine sediments related to ancestral lakes in the rift floor (in the fluvial periods of the Pleistocene). With the formation of the Wonji Fault Belt during the Upper Pliocene-Quaternary times tectonic movement and volcanic activity occurred in the MER, which produced step-like structures and related volcanic activity, represented mainly by basaltic lava fields together with aligned scoria and spatter cones. The fault zone is frequently marked by central volcanoes, which erupted significant amount of felsic product. The surface geology of Dendo dam site and surrounding area is probably belonging to such volcanic product (Wonji Group of Mohr, 1967a) (GGI final feasibility report, 2008b).

### 3.6.3 Regional Seismicity of the area

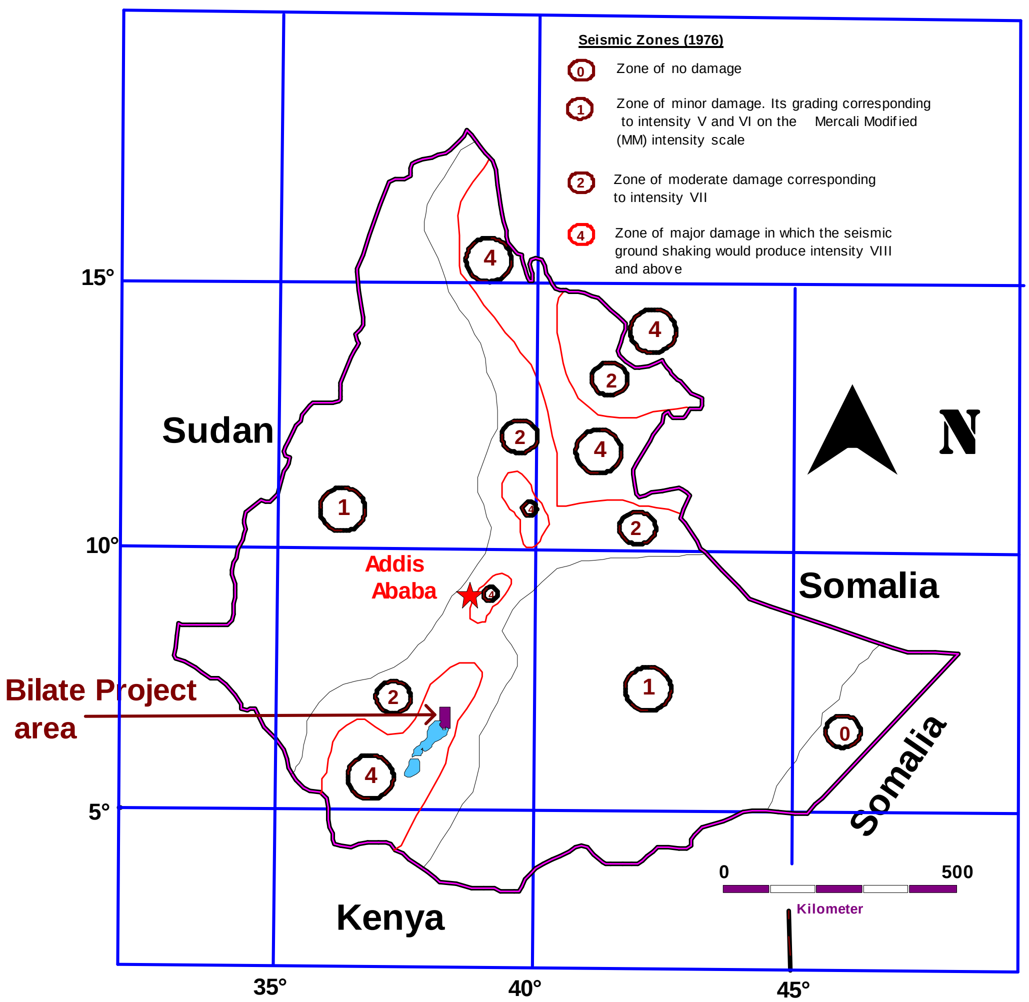
The Bilate project area is located on the southern portion of Main Ethiopian Rift (MER), which is part of the northern part of the African Rift Valley. The geological structure of the study area is controlled by tectonic events that lead to the development of the rift system. One point worth mentioning in relation to the geological structure of the area is seismicity. In terms of regional ground movement and acceleration, the project area can be discussed as follow:

### 3.6.4 Ground Movements/ Displacements

According to WWDSE final feasibility report, 2008 there is no systematic monitoring of ground motion or crystal deformations in Ethiopia in general and the site in particular. To estimate ground displacements the study therefore referred to global observations of satellite geodesy, which suggests plate movements in the order of 3 -5 cm per year. Thus, averaging and extrapolating these observations may derive to lateral movements (diversion of plates), vertical movements (faulting) or oblique movements in the order of up to 1m per 20 years.

### 3.6.5 Ground Acceleration

As the above said report, detail analysis of seismicity has not been completed. Assessment of the seismicity around the site was made based on regional seismic hazard map of Ethiopia produced by Geophysical Observatory of the Addis Ababa University. Based on this study (Intensity map and Zoning map of Ethiopia), the Dendo dam site area is found within the area having 20% ground acceleration and VIII intensity with 100 years return period and probably of 0.01 per annum of being exceeded and the site falls under zone IV with a corresponding major damage.




*(Source: WWDSE final feasibility study report, 2008b)*

**Figure 3. 3** Seismic zoning map of Ethiopia

In general the study report concluded that the site is situated in seismically very active locations of the country.

## 3.7 Local Stratigraphy

Massive, bedded, compact pyroclastic deposit that dips at very low angles towards the river in both sides of the abutments forms the foundation in the Dendo dam site and spillway portion. However, it is commonly covered by residual soil in most part of the dam, spillway and reservoir areas. Moreover, in exposed section of Budameda Crater Lake, this lithology is interbedded with ash layer that is susceptible for weathering and erosion. At the stage of the geological mapping and study by WWDSE; core drilling is suggested in order to confirm whether such rock sequence is found at depth and, confirmed that the same compact pyroclastic material covers most of the reaches of the reservoir.

As stated in WWDSE final feasibility report, 2008 and confirmed during present study the exposed lithological units around Dendo Dam, spillway and reservoir areas are Rock units and Soil units. The rock units are Tuff with local interbedded of ash, Scoria, and Rhyolitic rocks and; the Soil units are River channel and/or point bar deposits, Flood-plain and Lacustrine Deposits, Residual Deposit and Colluvial Deposits.

### 3.7.1 Tuff with locally inter-bedded ash

Though this unit is very recent product of the Main Ethiopia Rift, it is the oldest exposed rock around Dendo Dam site. Both right and left abutments, margins of the reservoir areas and spillway portion are covered with this lithologic unit, but commonly covered by soil deposits. This soil deposits are the result of partial weathering of the underlying bed rock (tuff) and commonly less than 1m in thickness. But, in some area it is more than 1m thick so it is mapped as pyroclastic fall deposits (WWDSE final feasibility report, 2008). As Such lithological unit is represented by thinly bedded, fresh to moderately weathered lithic tuff. It is dull gray to light dark gray, moderate to highly strong (fresh rock) rock and commonly containing felsic rock fragment with minor scoraceous basaltic rock fragments. Locally, this lithologic unit is inter-bedded with ash layer (particularly seen on the northern bottom part of Budameda Crater Lake) and soil materials that might be derived from ash falls, as ash deposits. In few localities, pumiceous tuff is seen. The typical area of pumiceous tuff deposit is around the area where Cherake River, tributary to Bilate River emerges from two cliff forming hills. The reservoir margin around Cherake River, especially the southern part is covered by these rocks.

### 3.7.2 Scoria

This unit is found further south of the Dam site, 3-3.5km downstream-right flank. It forms a collapsed cone shape, faced towards NE. It is a friable pyroclastic fall and differs from the pyroclastic falls (pumice, tuff and ash) by its basic composition. But, in the study area, it is totally oxidized and its darker color is changed to red/reddish brown. Its grain size varies from gravel to block forming aggregate.

### 3.7.3 Rhyolitic rocks

It is represented by rhyolite, rhyolitic ignimbrite, obsidian rich rhyolite and minor ignimbritic tuff. Such stratigraphic unit is exposed mainly on Dendo mountain/hill and small hills south of this mountain. Rhyolite and rhyolitic ignimbrite are the dominant lithologies on Dendo mountain and the surrounding, which characterized by gray to light greenish gray color, fresh to moderately weathered and moderate to high strength. The rocks have a porphritic texture (fine grained ground mass with larger crystals), in which phenocrysts are commonly aligned parallel to flow banding and probably feldspar.

The rhyolitic rock unit is highly dissected by young NNE-SSW & N-S trending faults in which recent obsidian rich felsic rock extrude on it. It forms an elongated ridge, in the direction of N-S.

### 3.7.4 Alluvial deposits (river channel and/or point bar deposits)

These are sand, silt and minor gravel unit which are deposited on the channels and around margins of both Bilate and Cherake Rivers. River channel deposits are commonly seen on the center of the river, which is dominated by sand and gravel with minor silt impurity. Where as the point bar deposits occur above this deposit on the inside of the river bends with their upper surfaces in the form of migrating dunes. The cross bedding seen in the bar deposits results from preservation of some dunes.

### 3.7.5 Flood-plain and Lacustrine Deposits

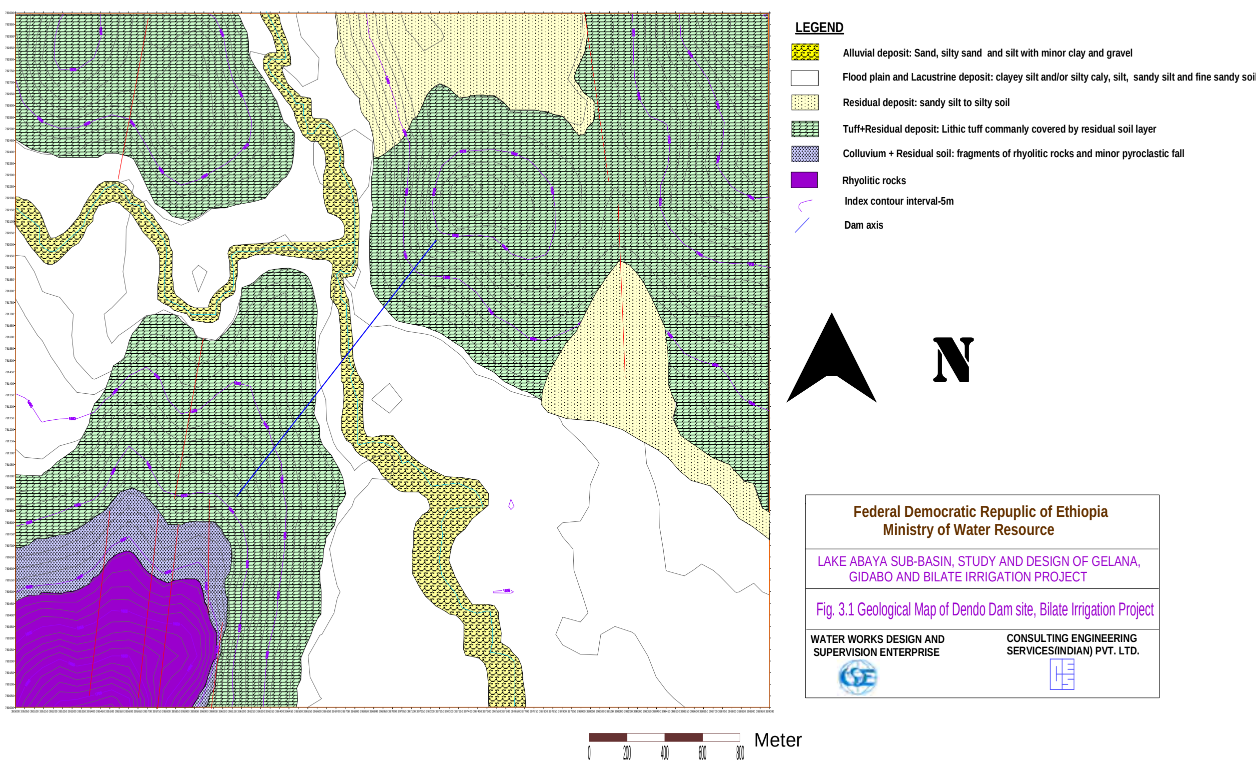
Such deposits are found on plain and gentle slope forming part of the dam site area, especially on the valley of Bilate and Cherake Rivers. These are silt, sand and minor clayey silt or silty clay and gravely sand. Fine sand and silt deposit on thin horizontal layers during floods is mainly observed on both the flats, right and left bank of the rivers. Surfacially clay containing soils have been observed on marshy area around the confluence of Bilate and Cherake rivers.

### 3.7.6 Residual Deposit

Residual deposits ranging in size from silt to sand are observed on gentle slope forming part of tuffaceous hill (abutments) and often on the top of hills. This unit has no uniform thickness and distinct lateral extent to map separately with exception of few areas.

### 3.7.7 Colluvial and Slip wash Deposit

Colluvial deposits are not common on the dam portion, but they occur on the slope of Dendo mountain and surrounding hills around south of it. It covers the area between exposed rock (occasionally thin residual soil) and alluvial deposits and mainly observed at the eastern and southern part of Dendo Mountains. Colluviums around Dendo hills are characterized by gravel to boulder, sized rock of felsic volcanic product with minor silty sandy gravelly soils. Slope wash and colluvial deposits intermingle with lacustrine deposits along the bottom of the valley slopes around the dam site and the reservoir area has been observed. The slope wash include mainly fine sand, silt, and clay that moves down the slope and due to precipitation that moves over the surface during heavy rains.




*(Source: WWDSE final feasibility study report, 2008b)*

**Figure 3. 4** Geological map of Dendo Dam site, Bilate Irrigation Project

### 3.8 Geology of the Dam Site, Reservoir and Spillway Area

The Dendo dam site, reservoir and spillway areas lay within the Southern Main Ethiopian Rift (SMER) characterized by active extensional tectonics that produced series of horst and graben structures.

The area around Dendo Dam site is covered by recent volcanic-tectonic events and fluvial deposits, in which the former (volcano-tectonic events with some water action) are an essential part of the area. As stated in regional geology part, the Dendo dam site and the near-by surrounding area are located in southern sectors of the Main Ethiopia Rift System (MERS) running generally in NE-SW directions, particularly in Wonji Fault Belt (WFB). WFB is an active spreading axis along the center of the MER, resulted from the quaternary episode of tectonism after the development of the MER.

The Wonji Fault Belt around the project area is intense zone of normal faulting and volcanism, which forms rift in rift structures and consists of segments disposed en echelon fashion along the center of the MER. Each segment of the wonji Fault belt hosts at least one major felsic central volcanic complex of Quaternary age. The main felsic volcanic products around the project area (dam site area) are Dugna Fango (most known major Felsic Central Volcanic Complex) and Dendo felsic volcanic mountains.

#### 3.8.1 Geology of the right and left abutments

The right and left abutments are composed of weakly weathered tuff which is hardened and relatively fresh towards the bottom; based on trenches. The compacted tuff in the abutment hills show bedding, dipping towards the river in both sides. However, thin layers of residual soils commonly cover both the abutments. It is dull brown to yellowish brown sandy and silty soil having a thickness of <1m to more than this. It is very difficult to set the lateral extent and to map separately due to thickness variation and exposed tuff. Slope wash deposits are also seen on relatively gentle slope forming part of the abutments consisting of sandy and silty material. In the surrounding geology, this tuff is inter-bedded with ash layers, susceptible for weathering and erosion, the core drilling geotechnical investigation by WWDSE would confirm this.

#### 3.8.2 Geology of the foundation

The foundation is the valley bottom (river course and terrace) of Bilate River. This portion of the dam is characterized by river channel and/or point bar deposits and Flood-plain and/or Lacustrine Deposits. These are silt, sand and minor clayey silt or silty clay and gravely sand. The Flood-plain and/or lacustrine sedimentation in the Bilate valley is the result of deposition of finer materials in still water conditions. Except near the edges of the deposit where alluvial influences are important, the materials are very fine-grained silt and fine sand with clay. The stratification is so fine that the materials appear to be massive in structure. The stream channel deposits consist of sand and sandy clay. The clayey alluvium represents over bank deposits along the meanders in the present stream channel. Flood plain deposits consist of fine and stratified silt and clay also occur along the river channel.

### 3.8.3 Geology of the reservoir area

Either side of the lower part of the reservoir does not show much rock exposure, but the marginal part of the reservoir is characterized by weakly weathered tuff covered by residual soil at some places. Towards the narrow valley of Cherake river, the reservoir margins are characterized by cliff/steep slope forming/ pumiceaous tuff deposits having sedimentary rock features.

The river valleys around the reservoir area are covered by channel, lacustrine and/or flood plain deposits like the area around dam axis. The river sand, silt, gravely sand and flood plain deposits: fine sand, silt with clayey soil, around the reservoir area might be thicker and not determined at this level study.

Slope wash and colluvial deposits inter-finger with the lacustrine deposit are commonly seen in the gentle slope forming part of the reservoir margins. The colluviums consist of sand weathered from the volcanic bedrock. The slope wash includes fine sand, silt, and clayey- silty soil mixed with colluviums and soils to form a heterogeneous deposit with variable thickness.

### 3.8.4 Geology of the spillway portion

The spillway is located in the left side of Bilate River, north east of the left abutment. Its geology is characterized by pyroclastic fall deposit (Lithic tuff) residual and slope wash deposits. The pyroclastic fall deposits are dull gray, weak to moderately weathered lithic tuff and commonly covered by residual soils.

# CHAPTER -IV CHARACTERIZATION AND SUITABILITY ANALYSIS OF EMBANKMENT MATERIAL

## 4.1 Introduction

The embankment dam type is selected based on existing geological conditions at the proposed dam site and the availability of usable construction material at the site or within the economic distance from the dam site. The main objective of the dam is to obtain the optimum quantity of water for desired purpose. To fulfill this, the dam must be impervious enough to hold back the stored water and at the same time it must be stable enough to withstand all static and dynamic forces, to which it will be subjected. For stability against shear failure, the shear strength of the material has to be within the allowable limit particularly for outer parts of zoned dam. The impervious zone and the reservoir area should be water tight to obtain the optimum quantity of water for desired purpose. Therefore, the embankment has to be broadly zoned into central impervious core and the outer pervious material shell, or a rock fill or homogeneous type, where uniform material is used throughout the embankment. For the safe functioning of the dam project selection of an appropriate construction material for various zones of an embankment is an important consideration. Therefore, to identify locally available construction material, proper investigation and systematic study of engineering properties of the construction material for both, existing and anticipated adverse conditions is essential to assess its suitability of material for the desired purpose. For this, appropriate in-situ and laboratory tests have to be performed on the representative samples. Further, mineralogy has a significant influence on the engineering properties of the construction material. Proper mineralogical analysis of the construction material is advantageous in understanding the engineering behavior of the material. Moreover, the site condition also has significant effect on the performance of the selected material. Therefore, it is important to discuss the anticipated conditions in relation with the engineering, mineralogical and dynamic properties of the construction material. For present study based on the test results conducted in the laboratory on soil samples, collected from the borrow area, during present study and; various tests conducted on soil and rock samples during previous study; characterization and suitability of embankment material has been made. In the course of the work, particular attention was given to study the suitability of the core material. Due to the limitations on resources it was not possible to cover the characterization and suitability analysis for other zones in a similar manner as it is done for the core material. More emphasis was given to the core material as it is a critical zone from the stability and performance point of view for an embankment dam.

## 4.2 Construction Material for Dendo Dam

Based on previous studies conducted by the Water Works Design and Supervision Enterprise (WWDSE) for Dendo Dam Project, there are in total 6 major potential sites (Fig. 4.1 & 4.2) which were identified for various types of construction materials required for the embankment Dam (GGI of final feasibility report, 2008). The construction material available from these sites includes; material for central core, fine filter, shell/ rock fill, and riprap. From these identified sites, one borrow site (left and right sides of Bilate River) and excavated material from spillway will provide material for core. Sand can be collected along the main river course of Bilate and Cherake rivers; upstream and down stream of the dam axis. This sand is the result of point bar deposits, which is characterized by fine to coarse grained sand with very minor gravel. It is deposited inside the bends in both rivers, dominant at Bilate River and may provide sufficient material for fine filter. Rock sources for shell/rock fill, riprap, masonry and crushed aggregate exists in Dendo hill, other small hills south of it and from Ropi which is 15km from the dam site.

## 4.3 Construction Material for Core

During the geological and geotechnical investigation by Water Works Design and Supervision Enterprise (WWDSE) an investigation using test pits was made in selected borrow sites to determine suitability and its available quantity of the potential sources for construction material of earth fill material. A total of 12 test pits upstream, downstream and along dam foundation of the dam site and, 2 test pits in spillway portion were excavated manually in selected borrow areas. (Fig.4.1). The depths of the test pits excavated varied between 3.0m to 5.4m. Based on this investigation report, the dominant soil material around Dendo dam site belongs to light brown silt, sandy silt and clayey silt.

Availability of construction material at economic distance from the dam site is one of the primary advantages of this site. However; as per the report of previous study by WWDSE and confirmed during present study the problem with earth fill material is the availability of clay. Clayey material is in general rare. Further, available quantities with relevant soil properties, are the other suitability factors and this needs proper investigation. In order to establish the suitability of the construction material for impervious core the important soil properties that have to be considered during the study are; permeability, compacted density, shear strength, compressibility, flexibility and erosion resistance. These properties are mainly affected by index properties of the soils. (Singh and Varshney, 1995).

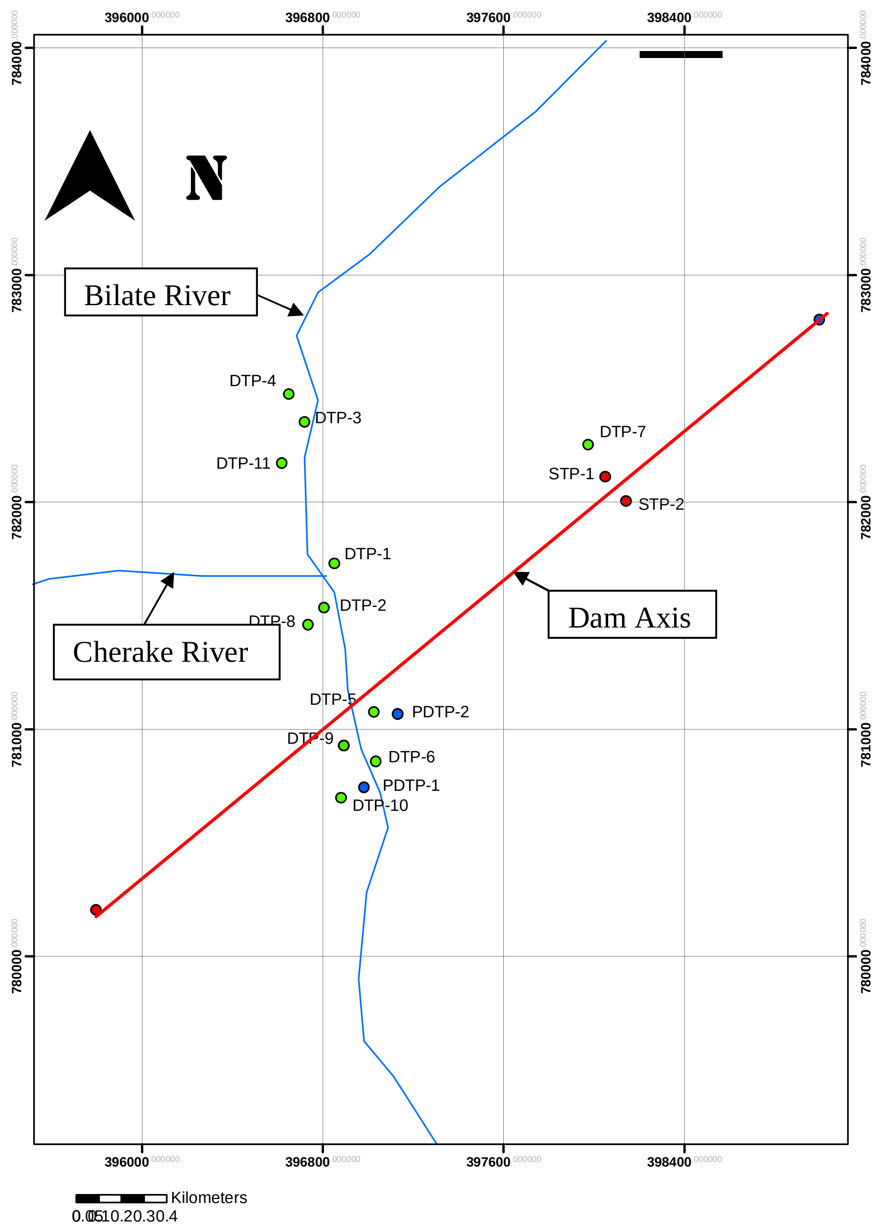
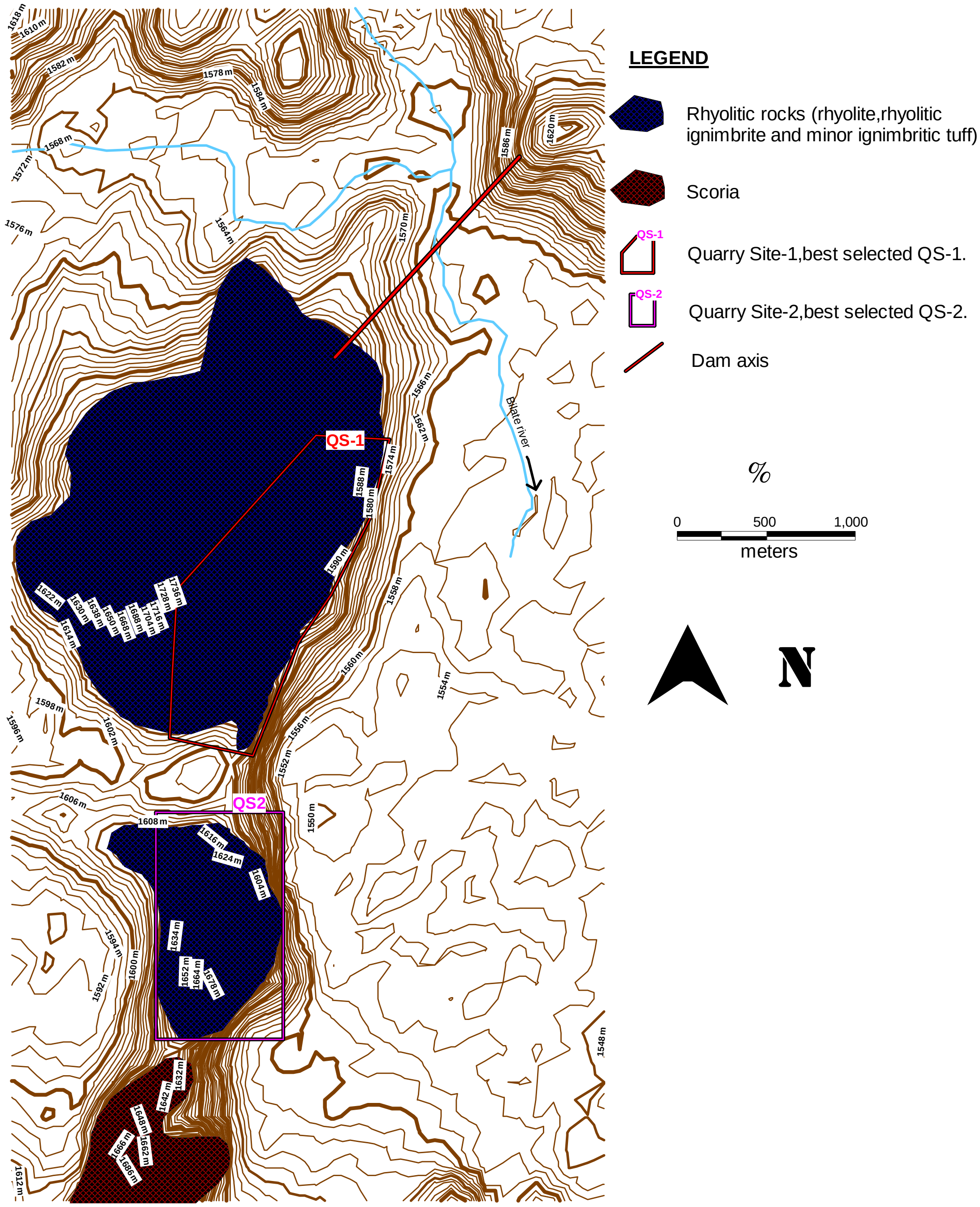



**Figure 4. 1** Map showing relative locations for core material w.r.t dam axis

### 4.3.1 Index properties

The properties of soils which are not of primary interest but which are indicative of the engineering properties are known as index properties. Simple test, which are required to determine the index properties are known as classification test. The soils are classified and identified based on their index properties. The main index properties of coarse-grained soils are particle size and the relative density. However, for fine grained soils, the main index properties are Atterberg's limits and consistency. The index properties give some information about the engineering properties. However, design of large, important structures should be done only after determination of engineering properties (Arora, 1997).




(S*ource GGI final feasibility report, April 2008)*

**Figure 4. 2** Relative location map of rock quarry sites

**Table 4. 1** Location details and other relevant information for identified potential material source sites

| Test pit Name | Depth (m) | Coordinates | | Elevation (m), a.s.l. | Relative location | Description |
|---|---|---|---|---|---|---|
| | | Easting(m) | Northing(m) | | | |
| DTP-1 | 3.25 | 396855 | 781726 | 1558 | Left abutment b/n DDBH1 & DDBH2) | Light brownish gray sandy silt with thin layer (band) of fine sand. |
| DTP-2 | 4.75 | 396808 | 781532 | 1558 | Left abutment (b/n DDBH2 & river course) | Light brownish gray, loose, fine sand with thin layer of moderately compacted clayey silt towards the top. |
| DTP-3 | 4.0 | 396723 | 782349 | 1568 | Around 850m downstream, left bank | Gray to dark brownish gray, poorly dense/compacted/weakly wet, moderately porous clayey silt. |
| DTP-4 | 4.25 | 396653 | 782472 | 1562 | Around 1000m downstream, left bank | Dry, light gray, weakly dense, slightly porous silt with minor bands of clayey silt. |
| DTP-5 | 5.1 | 397030 | 781072 | 1556 | Around 500m downstream, left bank | Hard/compacted compacted clayey silt with clayey sandy silt-thin layer. |
| DTP-6 | 5.4 | 397038 | 780854 | 1553 | Around 700m downstream, left bank | Light brownish gray, weakly compacted sandy silt to silt contains thin bands of clayey silt. |
| DTP-7 | 3.0 | 397977 | 782249 | 1600 | right abutment b/n DDBH4 & DDBH5) | Dull yellowish gray, porous, moderately compacted sandy silt. |
| DTP-8 | 4.9 | 396738 | 781456 | 1556 | right abutment b/n DDBH3 & DDBH4) | Very wet, light brown clayey silt and/or silty clay. Very wet-due to flooding of Bilate river. |
| DTP-9 | 4.5 | 396897 | 780924 | | Around 575m downstream, right bank | Very wet, light grayish brown silty clay to clayey silt, having minor dry patches of silty soil. |
| DTP-10 | 3.25 | 396884 | 780695 | 1556 | Around 800m downstream, right bank | Light brownish gray, loose sandy silt with thin bands of sandy soil. |
| DTP-11 | 3.0 | 396622 | 782168 | 1561 | Around 750m upstream, right bank | Dull to dark Brown, wet to slightly dry, moderately dense silty clay and/ or clayey silt. |
| DTP-12 | 4.5 | 396897 | 780924 | 1557 | Around1kmupstream, right bank | Light brown to brown very wet silty clay and/or clayey silt. |
| STP-1 | 3.0 | 398053 | 782108 | 1594 | Spillway portion | Light yellowish brown to light yellow ,loose, dry sandy silt. |
| STP-2 | 4.6 | 398145 | 782001 | 1590 | Spillway portion | Light brown, slightly porous weak to moderately compacted sandy silt; contains minor coarse grained rock fragments. |

(*Source GGI final feasibility report, April 2008)*

**Table 4. 2** Grain Size distribution and Specific gravity of core material

| S.No. | Test Pit No. | Depth (m) | Coordinates (UTM) | | Specific gravity | Grain size distribution (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Easting | Northing | | 4.75 | 2.0 | 1.18 | 0.475 | 0.30 | 0.075 |
| 1* | TP3 | 3.15-4.00 | 396723 | 781349 | 2.51 | - | - | - | - | 100 | 99 |
| 2* | TP5 | 2.8-3.85 | 397030 | 781072 | 2.88 | 100 | 46 | 33 | 24 | 23 | 20 |
| 3* | TP6 | 1.2-2.75 | 397038 | 780854 | 2.57 | - | - | 100 | 99 | 98 | 96 |
| 4* | TP10 | 0.0-1.10 | 396884 | 780695 | 2.51 | - | - | 100 | 96 | 91 | 42 |
| 5* | TP10 | 1.1-3.1 | 396884 | 780695 | 2.54 | - | - | 100 | 99 | 98 | 75 |
| 6** | PDTP-1 | 2.5-3.5 | 396985 | 780740 | 2.6 | 100 | 84.1 | 78.63 | 63.5 | 57.6 | 39.27 |
| 7** | PDTP-2 | 2.0-3.0 | 397135 | 781063 | 2.62 | 100 | 100 | 100 | 100 | 100 | 100 |

* Test data from previous study (GGI of final feasibility report, 2008)
** Data generated during present study

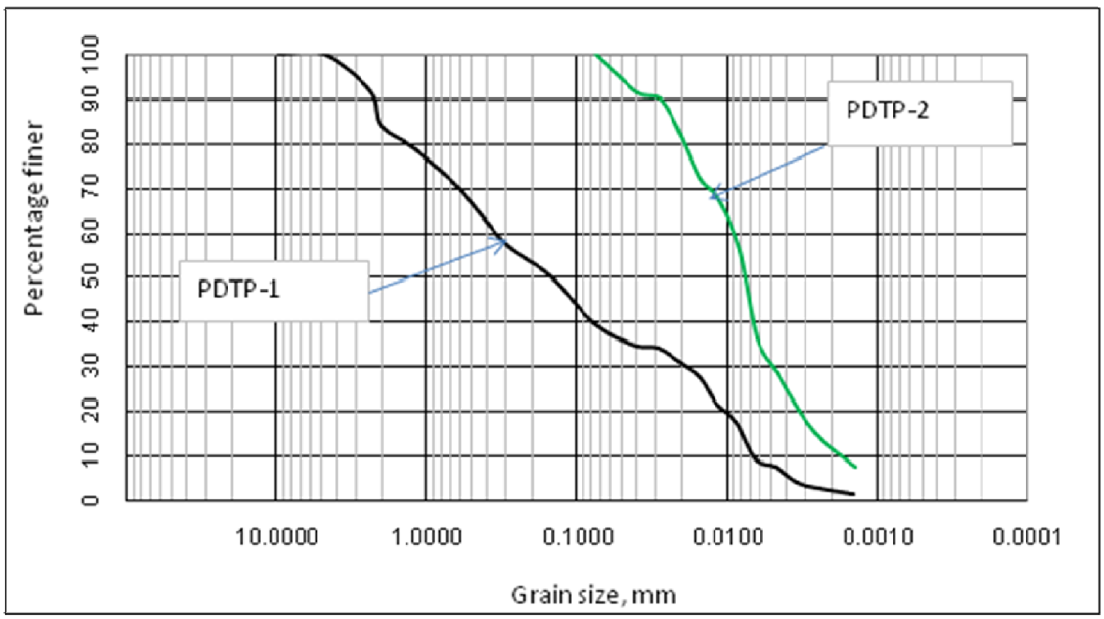



**Figure 4. 3** Gradation curve for core material of PDTP-1 and PDTP-2

**Particle size analysis**

The size analysis also known as mechanical or gradation analysis; is a method of separation of soils in to different fractions based on the particle size. It expresses quantitatively the proportions, by mass, of various sizes of particles present in a soil (Arora, 1997). For present study a combined grain size analysis and hydrometric test were performed on two samples collected from test pits (PDTP1 and PDTP2) from the borrow area (Table 4.2).

A perusal of Table 4.2 and Fig. 4.3 indicates that core material from PDTP-1 is fine grained material with particle size ranging from coarser sand to clay particles in which more than 50% of the particles are of sand fraction. However, grain size distribution analysis for PDTP-2 shows that the soil is clayey silt with no coarse particle. In general, the grain size distribution of core material from borrows area, presented in Table 4.2, indicates that there is no gravel fraction and most of the samples are clayey silt. Therefore, when grain size distribution of Dendo dam core material is concerned addition of coarser material is necessary as it locks the propagation of crack of different size through the core of the dam depending on the size of the coarser material. Cracks that usually affect the core are measurable in millimeter to centimeter scales. However, it originates from microscopic scale (grain to grain detachment). In severe case, it may leads to piping phenomena for embankment dams. Once the piping initiates it becomes progressively worst with increasing rate. It results into loss of huge volume of the embankment. Therefore, it must be prevented from the source through possible defensive measures during the planning or construction stage of the embankment. After the crack initiate it grows through propagation; micro crack grow to small visible cracks and interconnection of small cracks leads to a larger crack. In a core of dam constructed from uniform fine grained soil, the micro crack glide easily to develop into a larger scale which may endanger the stability of the dam and permit high velocity flow of seepage water through the crack. However, if there is significant proportion of coarser gravelly material, it limits the propagation and interconnection of the cracks. Further, it obstructs the flow and prevents development of high velocities within the crack and improves the shear strength of the core material (Singh and Varshney, 1995).

**Consistency Limits**

The consistency of a fine grained soil is the physical state in which it exists. It is used to denote the degree of firmness of a soil. Consistency of a soil is indicated by such terms as soft, firm or hard. In 1911, a Swedish agriculture engineer Atterberg mentioned that a fine grained soil can exist in four states; namely, liquid, plastic, semi-solid or solid-state. The water contents at which the soil changes from one state to the other are known as consistency limits or Atterberg limits. The Atterberg limit such as liquid and plastic limit can be determined numerically in the laboratory. Based on the consistency the soils can be classified into various engineering classes and thus, a fair idea can be obtained for its engineering performance (Arora, 1997).

To determine the consistency of the soils of the borrow area, disturbed samples were collected during present and previous field investigation and, the tests were performed in the laboratory. The tests were performed to determine the liquid limit and the plastic limits of the core material of the borrow areas. Based on the liquid limit ($W_L$) and plastic limit ($W_P$), the plasticity index is determined as the difference of liquid limit and plastic limit;

Plasticity Index, $I_p = W_L - W_P$ …......................................................eq. 4.1

The test results on consistency of soils from borrow area are presented in Table 4.3

Perusal of Table 4.3 and fig 4.4 indicates that the representative soil samples collected for core of the embankment during previous study by WWDSE fall in CH, CI and MI or OI group of unified soil classification system. According to Sherard, 1967 and Indian Standard (IS: 8826-1978) as sited in Singh, B. and Varshney, R.S. (1995) CH (highly plastic tough clay) with PI greater than 20 is suggested as good material for core, however, the soils found in CI (clay with medium plasticity index) group of unified soil classification system with PI greater than 12 is considered as fair material and those fall in MI (silts of medium plasticity with plasticity index greater than 12) are considered as poor material for construction of core and soils those are in OI and OH group are not suitable for impervious core. Based on this the suitability of soil for impervious core is analyzed.

**Table 4. 3** Consistency of core material from borrow area

| Sample No. | Depth(m) | Atterberg limits | | | Unified soil classification | Suitability for impervious core as suggested by USBR |
|---|---|---|---|---|---|---|
| | | Liquid limit($W_L$) | Plastic limit($W_P$) | Plasticity index($I_P$) | | |
| DTP-3 | 3.15-4.0 | 54 | 25 | 29 | CH | Not suitable |
| DTP-5 | 2.8-3.85 | 38 | 21 | 17 | CI | Suitable |
| DTP-6 | 1.2-2.75 | 47 | 32 | 15 | MI or OI | Not suitable |
| DTP-10 | 0.0 -1.1 | 55 | 23 | 32 | CH | Not suitable |
| DTP-10 | 1.1-3.10 | 41 | 29 | 12 | MI or OI | Not suitable |
| DTP-12 | 3-4.5 | 55 | 36 | 19 | CH | Not suitable |
| STP-1 | 1-2.25 | 43 | 26 | 17 | CI | Not suitable |
| PDTP-1 | 2.5-3.5 | 54 | 31 | 23 | MH or OH | Not suitable |
| PDTP-2 | 2.0-3.0 | 58 | 31 | 27 | MH or OH | Not suitable |

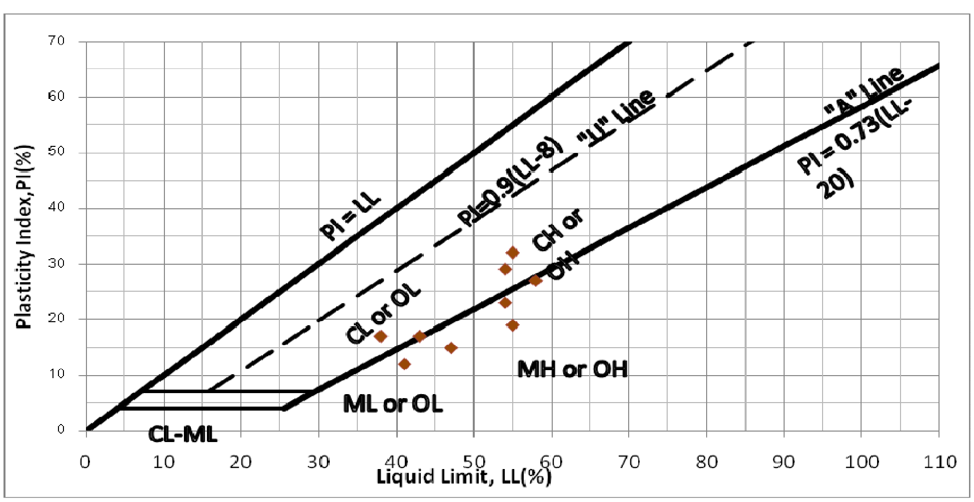



**Figure 4. 4** Core material properties on casagrande·s plasticity chart

During present study two soil samples were collected from borrow area and Atterberg limit test was conducted. The test result indicates the liquid limits of both samples are greater than 50 and their plasticity index are greater than 20. Therefore, as per unified soil classification system, the soils are grouped as MH or OH (inorganic/organic silts of medium to high plasticity respectively). According to Singh, B. and Varshney, R.S. (1995) the soil is considered as poor (MH) or unsuitable (OH) material for impervious core. Moreover, according to Sherard, 1967 and Indian Standard (IS: 8826-1978) among the samples collected during previous study only CI (clay with medium plasticity index) type of soil is suitable for impervious core.

**Activity of the soil**

The amount of water in the soil depends on the type of clay minerals. Skempton (1953) showed that for soils with a particular mineralogy, the plasticity index is linearly related to the amount of the clay fraction. He coined a term called activity (A) to describe the importance of the clay fractions on the plasticity index. The equation for A is;

Activity (A) = Plasticity index ($I_P$)/ % finer than 2 micron (or clay fraction)

**Table 4. 4** Activity of the core material

| Test pit No. | Depth (m) | Clay proportion | Plasticity Index (Ip) | Activity Number (Ac) | Activity classification |
|---|---|---|---|---|---|
| **DTP-6** | 1.2-2.75 | 35 | 15 | 0.43 | Inactive |
| **DTP-10** | 1.10-3.10 | 19 | 12 | 0.63 | Inactive |
| **DTP-12** | 3.0-4.5 | 37 | 19 | 0.51 | Inactive |
| **PDTP-1** | 2.5-3.5 | 7.47 | 27 | 3.6 | Active |
| **PDTP-2** | 2.0-3.0 | 13.91 | 23 | 1.65 | Active |

Activity of the soils may be classified as;

| Activity | Classification |
|---|---|
| <0.75 | Inactive |
| 0.75-1.25 | Normal |
| >1.25 | Active |

For the core material of the borrow area, activity was thus, determined and is presented in Table 4.4. Perusal of Table 4.4 indicates that the soil samples DTP-6, DTP-10, and DTP-12 are inactive and soil samples from PDTP-1 and PDTP-2 are actives thus it may show swelling characteristic. The calculated swelling potential values of the representative borrow area soil samples are presented in the Table 4.5 and as the calculated value indicates that the swelling potential of the core material is varying from low to high with most of the samples are in medium range. Therefore the result indicates that some of the soil samples show swelling characteristics.

**Volume change characteristics**

Change in strength and deformation characteristics of soil is highly affected by volume change of soils. Stability of the engineering structures founded or constructed from those soils will also be affected. According to Bowels (1984) if plasticity index of soils is greater or equal to twenty (PI $\geq$ 20), there will be a volume change problem which require some kind of precautionary measures.

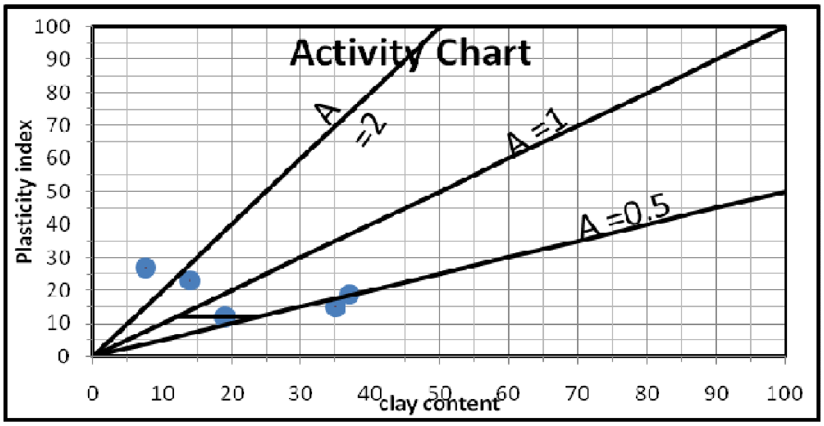



**Figure 4. 5** activity chart of core material

Depending on the type of selected construction material volume change (swelling and shrinkage) is expected in core of the embankment dam during reservoir level fluctuation. Swell potential is one of the essential properties of the soil that has to be considered when clayey soils are desired to be used in the embankment.

For Dendo embankment dam few soil samples are identified for swell potential during previous study by WWDSE (GGI of final feasibility report, 2008). The test results show that, the swell index values of soils ranges between 7.86 to 30%. During present study to determine the swelling potential of the core material equations proposed by Seed et al. (1962(b)) and Chen (1988) are used. The equations are simple model using plasticity index parameters to assess the swelling potential of clay soils and are given as eq.4.2 and eq.4.3, respectively.

For Natural soils; $SP = 60\,K\,[(PI)^{2.44}]$ ………. *eq. 4.2*

$SP = B\,[e^{A}\,(PI)]$ ……….*eq4.3*

Where, SP is swelling potential, Where, 'K' is a constant which is given as 3.6 x $10^{-5}$ for soils having clay content between 8 and 65%.

A = 0.0838, B = 0.2558 are constants, and PI is plasticity index. Using equation (4.2), the swelling potential for the core material is ranging between 0.93 and 6.7 with an average value of 3.8%, and using eq.4.3, it ranges between 2.2 and 7.5 with average value of 5.1%.

**Table 4. 5** Swelling potential of core material for eq. 4.1

| Sample No | Depth (m) | Plasticity Index ($I_P$) | Swelling Potential (Sp) | Expansivity |
|---|---|---|---|---|
| PDTP-2 | 2.0-3.0 | 23 | 4.54 | Medium |
| PDTP-6 | 1.2-2.75 | 15 | 1.6 | Medium |
| DTP-10 | 1.10-3.10 | 12 | 0.93 | Low |
| DTP-12 | 3.0-4.5 | 19 | 2.85 | Medium |
| DTP-1 | 2.5-3.5 | 27 | 6.7 | High |

| Swelling potential(Sp) | Expansivity |
|---|---|
| > 25 | Very High |
| 5 – 25 | High |
| 1.5 – 5 | Medium |
| < 1.5 | Low |

It is observed that the values of the swelling potential computed by the two equations show slight variation. For eq. 4.2 expansivity of soil ranges from low to high while for eq. 4.3 it varies from medium to high. Therefore, as far as volume change characteristics is considered, it needs proper control during construction for soils which fall in range from medium to high expansivity.

### 4.3.2 Engineering Properties of core material

The main engineering properties of soils are permeability, compressibility and shear strength. During previous study by WWDSE borrow area for core material of Dendo dam has been identified and different laboratory tests were carried out. Atterburg Limits, Procter Compaction, Free Swell tests, Shrinkage Limit, Permeability, Consolidation, Direct Shear and Triaxial (CU) tests were conducted on the selected samples.

Based on the test results; as per Unified Classification, the soils are classified as CH, CI, MI or OI group by the above said enterprise (GGI of final feasibility study, April 2008). During the present study also systematic study is carried out to determine engineering properties of the core material. To do this two representative soil samples of core material were collected from borrow area and laboratory tests were conducted. According to laboratory test results; as per Unified soil Classification, the soils are classified as MH or OH (Table 4.3).

**Permeability**

The property of a soil, which permits flow of water through it, is called permeability. The knowledge of the permeability of soils, as expressed by the coefficient k, is of considerable importance for many practical engineering problems, such as the water-retaining capacity of earth dams because water lost through the soil may result into removal of soluble solids or may cause internal erosion called piping.

The previous geological and geotechnical investigation by WWDSE laboratory tests were conducted on representative soil samples collected from the borrow area, dam axis (dam foundation) and spillway. As the test result shows most samples falls in the range of $10^{-6}$ to $10^{-2}$ cm/sec with two samples having the result in the order of $10^{-2}$ and one sample in order of $10^{-7}$. During present study also two soil samples were collected from borrow area (PDTP-1and PDTP-2) and submitted to geotechnical laboratory of the Faculty of Technology; Addis Ababa University for permeability test and the test result shows that the soil is in the order of $10^{-6}$ cm/sec.

**Table 4. 6** Permeability of core material

| No. | Test Pit No. | Depth (m) | Permeability (cm/sec) | Unified soil classification | Permissible limits for impervious core as per USBR |
|---|---|---|---|---|---|
| 1 | TP1 | 0-3.10 | $1.49 \times 10^{-6}$ | NP | --- |
| 2 | TP2 | 0.0-3.20 | $2..93 \times 10^{-6}$ | CH | $(0.05\pm0.05) \times10^{-6}$ |
| 3 | TP2 | 3.1-4.75 | $2.42 \times 10^{-2}$ | NP | --- |
| 4 | TP3 | 2.0-4.0 | $1.96 \times 10^{-6}$ | CI | $(0.08\pm0.03) \times10^{-6}$ |
| 5 | TP5 | 1.4-3.85 | $3.26 \times 10^{-2}$ | MI or OI | $(0.57 \pm 0.22) \times10^{-6}$ |
| 6 | TP6 | 1.2-2.75 | $2.45 \times 10^{-6}$ | MI or OI | $(0.57 \pm 0.22) \times10^{-6}$ |
| 7 | TP10 | 1.10-3.1 | $9.76 \times 10^{-7}$ | MI or OI | $(0.57 \pm 0.22) \times10^{-6}$ |
| Present study | PDTP-1 | 2.5-3.5 | $2.67 \times 10^{-6}$ | MH or OH | $(0.06\pm0.0.10) \times10^{-6}$ |
| | PTDP-2 | 2.0-3.0 | $4.67 \times 10^{-6}$ | MH or OH | $(0.06\pm0.0.10) \times10^{-6}$ |

NP: Non plastic material

Perusal of Table of 4.6 indicates that permeability of most materials collected from borrow area is in the higher side of the permissible limit of $(0.06\pm0.0.10) \times10^{-6}$ for MH or OH type soil and $(0.05\pm0.05) \times10^{-6}$ for CH type of soil except for CI type of soil which is in the permissible limit of $(0.08\pm0.03) \times10^{-6}$, as suggested by USBR. Moreover, as observed in the Table 4.6 two samples of borrow material are non plastic. However, materials (very fine sand and silts mixtures of both with clay) with a permeability of $10^{-4}$cm/s to $10^{-7}$ and clayey soil can be used in cores of the earth dam (Tschebotarioff, 1955). Therefore, as far as permeability of core material is concerned, the soils that fall in CI, CH, and MI group of Unified Soil Classification System can be used for the impervious core of the embankment dam with proper control depending on the design requirement of the dam. But, as per the engineering use chart for compacted soil after USBR, 1974 indicates that the workability of MI and CH group of soils is fair to poor and graded as $6^{th}$ and $7^{th}$ place for core of rolled earth dam. Therefore, for Dendo dam it is recommended that either identification of another borrow site with in economic distance from dam site with suitable gravely clay soil or blending of materials is necessary to meet out the desired properties.

**Shear strength Properties**

Shear strength of a soil is its maximum resistance to shear stresses just before the failure. It is the principal engineering property, which determines the stability of slopes, bearing capacity of the soil and the earth pressure on retaining structures. Almost all the problems of soil engineering are related in one way or other with the shear strength of the soil (Earth manual).

For the present study because of the limitation of resources and financial constraints it was beyond the reach of the present study to conduct the elaborate shear strength test on the soils of the core material. However, an attempt has been made to evaluate the shear strength property of the core material based on the classification tests and the secondary data from the Ministry of Water resources. The test results as per the Project office are presented in Table 4.7. As observed from Table 4.7 the shear strength parameter values vary in the range, Cohesion 'C' (10-24 KN/$m^2$) and angle of shearing resistance 'ϕ' ($24^0$ –$40^0$). According to USBR 'C' value is on the higher side of the permissible range of (7-1.38kg/$cm^2$) with only one sample in permissible range. Whereas, the 'ϕ' value is on the higher side of the permissible range of ($14.15^0$ – $24.43^0$).

**Table 4. 7** Direct and Tri-axial Shear Test Result of core material

| **Test pit ID** | **Depth (m)** | **Direct Shear Test** | | **Test pit ID** | **Depth (m)** | **Tri-axial Shear Test (UU)** | |
|---|---|---|---|---|---|---|---|
| | | **C' (KN/$m^2$)** | **ϕ($c^o$)** | | | **C'** | **ϕ($c^o$)** |
| DTP-3 | 2-4.0 | 17 | 29 | DTP-5 | 3.85-5.1 | 86 | 30 |
| DTP-5 | 1.4-3.85 | 10 | 40 | DTP-10 | 1.1-3.10 | 56 | 35 |
| DTP-10 | 1.1-3.10 | 24 | 27 | | | | |
| DTP-10 | 0.0-1.10 | 22 | 24 | | | | |
| DTP-6 | 1.2-2.75 | 18 | 30 | | | | |

*(Source: Ministry of Water Resources)*

**Compressibility**

When a soil mass is subjected to a compressive force its volume decreases. The property of the soil due to which a decrease in volume occurs under compressive forces is known as the compressibility of soil. Construction often involves the use of soil to make a structure or the placement of a structure made of other materials on a soil foundation. In either case the compressibility of the soil used is an important consideration as higher compressibility of material is associated with high settlement which may lead to differential settlement that ultimately results into development of cracks. For the present study, based on the liquid limit and plasticity index value, attempt has been made to determine compressibility of core material.

According to Sherard (1995) the compressibility of material with plasticity index between 10 & 20 is medium and for those with the value having more than 20 is high to very high. As the test result (Table 4.3) indicates that the plasticity index value of the core material ranges from 12-32, in which 55.5% is below 20. Thus, compressibility for most of the samples for core material is in medium range. However, the test result of present study showed that liquid limit of both samples are greater than 50 and their plasticity index is above 20. So, according to Sherard (1995) the compressibility of both samples is high. Therefore, compressibility of Dendo core material falls in the range of medium to high and need proper control before construction.

**Compaction**

Compaction is the densification of soils by the application of mechanical energy. It may also involve a modification of the water content as well as the gradation of the soil (Holtz, 1981). Air during compaction is expelled from the void space in the soil mass and therefore, the mass and density increase. Compaction of a soil is done to improve its engineering properties. Compaction generally increase the shear strength of the soil, it means that the stability and the bearing capacity of the soil will improve. It is also useful in reducing the compressibility and permeability of the soil. Core material compacted at moisture content wet of optimum will have lower permeability, high flexibility or capacity to deform without cracking and lesser compressibility on saturation. However, USBR practice is to place the fill at 1 to 3% below optimum. As per US Army Corps Practice, Compaction is done at or above optimum moisture content.

According to Middlebrooks the core material should satisfy the following criteria;

i) It must be placed at a density or moisture, which will not allow further consolidation on saturation.

ii) It must be sufficiently plastic so that differential settlement will not cause cracks to develop through it.

In the previous study both standard test and modified Procter tests were conducted on soil samples collected from borrow area as per the procedures of AASHTO T-99 standards and presented in Table 4.8

During the present study also two representative soil samples were collected from the borrow area. The test was conducted in Addis Ababa University by using standard Procter test and modified proctor test as per the procedures of ASTM standards. The results thus obtained are presented in Table 4.8 and Fig. 4.6

The USBR dams have been built with compaction moisture content for impervious zone ranging from 0.7 to 2.5% dry of optimum (Singh and Varshney, 1995).

**Table 4. 8** Compaction Test Results of the Core Material from Borrow Area

| | | **Tests conducted by Project Office** | | | | | | **Test conducted during Present Study** | |
|---|---|---|---|---|---|---|---|---|---|
| **Sample No.** | | **DTP-5** | **DTP-6** | **DTP-10** | **DTP-10** | **DTP-12** | **DTP-3** | **TP-1** | **TP-2** |
| **Depth (m)** | | 1.4-3.85 | 1.2-2.75 | 0.0-1.10 | 1.1-3.10 | 3.0-4.5 | 2 .0-4.0 | 2.5-3.5 | 2.0-3.0 |
| **Properties** | | | | | | | | | |
| Classification (USC) | | CI | MI or OI | CH | MI or OI | CH | CH | MH or OH | MH or OH |
| Compaction | MDD | 1.52 | 1.23 | 1.43 | 1.27 | 1.24 | 1.28 | 1.55 | 1.5 |
| | OMC | 22 | 32 | 25 | 27 | 26 | 34 | 17.7 | 20.5 |
| MDD – Maximum dry density, OMC – Optimum moisture content, USC – Unified Soil Classification | | | | | | | | | |

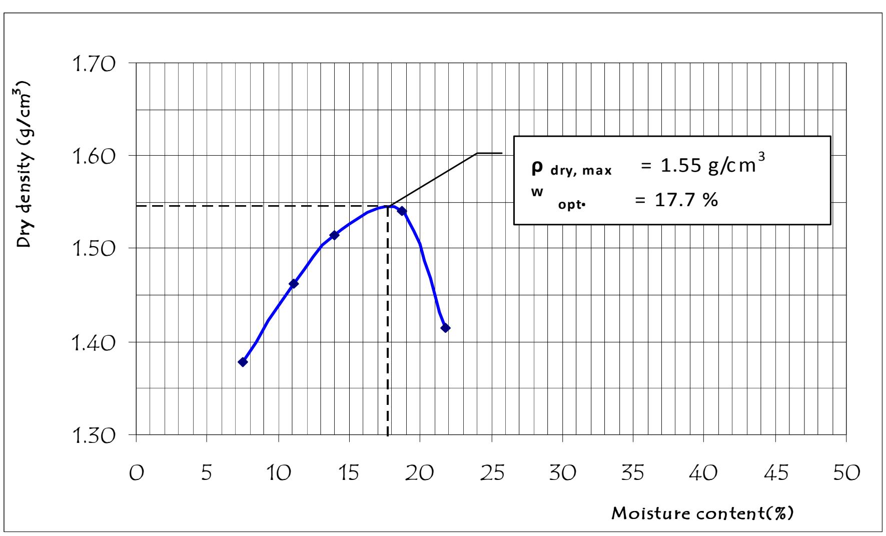



**Figure 4. 6** Modified compaction curve for core material of PDTP-

Based on the Table 4.8 and Fig.4.5 the maximum dry density (MDD) at the optimum moisture content (OMC) of the soil is lower or not in permissible limits as suggested by USBR (discussion under Table 4.9).

**Flexibility and Erosion Resistance**

Two desirable properties to be looked for core material are the flexibility and erosion resistance. Flexibility means ability to deform without cracking. Non cohesive granular material cannot retain open cracks but such materials are very pervious therefore they cannot be used in core. Flexibility increases with an increase in Plasticity Index (PI). However, very high values of PI may be associated with high compressibility. Erosive resistance is the ability of soil to withstand the erosive action of water leaking through possible cracks. Erosive resistance is mainly derived from two sources cohesion of the fines and the resistive action of coarse particles to the flowing water and their tendency to wedge up in the leakage channel. This effect is best obtained in a well graded sand gravel mixture with enough finer particles to provide imperviousness. In such a material the coarser particles within the crack obstruct the flow and prevent development of high velocities. In tough plastic clay the resistance to erosion is provided by the strong interparticle adhesion. A filter plays a very important role in safeguarding against failure by leakage. The eroded particles of the core flowing within the crack cannot pass through to the downstream filter, which gradually seal up the crack (Singh and Varshney, 1995).

For the present study an attempt has been made to estimate the erosion resistance based on the plasticity index of the material. As per Sherard (1967) highly plastic tough clay (CH) with plasticity index greater than 20 are considered ‘good material’ as far as erosion resistance of core material is concerned. However, very high values of PI may be associated with high compressibility. The plasticity index of CH type of soil samples tested by the Project Office is ranging in between 19 and 32 (Table 4.3). The test result implies that the soil is erosion resistant however, the soils those have high plasticity index are compressible. For the other type of available core material at borrow area (MI or OI, CI, MH or OH), the analysis show that the material does not satisfy the criteria suggested by Sherard (1967) and Indian Standard (IS: 8826-1978) erosion resistance of core material is concerned. Moreover, the core materials do not contain sufficient quantity of coarse material, as can be noticed from the gradation of the material (Table 4.2 and Fig. 4.3). The core material varies in the range of clay to sand fraction only. As such no gravel fraction is noticed in any of the samples tested by the Project Office. Even under the present study the two samples collected from borrow area does not show any gravel fraction. As can be noticed from gradation of material from PDTP-1, the particles ranging from clay to sand fraction; however, gradation of material from PDTP-2 indicates that the material is clayey silt with no gravel or sand fraction. Thus, in the absence of coarse fraction the core material may be less resistant to the erosion and chances of piping will be increased. Therefore, there is a necessity to blend the material with appropriate proportion of coarse fraction.

**Table 4. 9** Summery of Procter, Free Swell, Permeability, and Direct and Tri-axial **Shear test results**

| No. | Test Pit No. | Depth (m) | Free Swell (%) | Procter (std) | | Permeab. (cm/sec) | Direct Shear | | Triaxial/UU | | Unified soil classification |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | OMC ( % ) | MDD (g/cm$^3$ ) | | C (KN/m$^2$) | Φ (Deg.) | C (KPa) | Φ (Deg.) | |
| 1 | TP1 | 0-3.10 | 10 | | | $1.49 \times 10^{-6}$ | 16 | 30 | | | |
| 2 | TP2 | 0.0-3.20 | | | | 2..93 x $10^{-6}$ | 24 | 30 | | | |
| 3 | TP2 | 3.1-4.75 | | | | $2.42 \times 10^{-2}$ | 8 | 40 | | | |
| 4 | TP3 | 2.0-4.0 | | 27 | 1.41 | $1.96 \times 10^{-6}$ | 17 | 29 | | | CH |
| 5 | TP5 | 3.85-5.1 | | | | | | | 86 | 30 | |
| 6 | TP5 | 1.4-3.85 | | 22 | 1..52 | $3.26 \times 10^{-2}$ | 10 | 40 | | | CI |
| 7 | TP6 | 1.2-2.75 | 30 | 32 | 1.23 | $2.45 \times 10^{-6}$ | 18 | 30 | | | MI/ OI |
| 8 | TP10 | 1.10-3.1 | 25 | 27 | 1..27 | $9.76 \times 10^{-7}$ | 24 | 27 | | | CH |
| 9 | TP10 | 0.0-1.0 | | 25 | 1.43 | | 22 | 24 | | | MI / OI |
| 10 | TP10 | 1.1-3.10 | | | | | | | 56 | 35 | |
| 11 | TP12 | 3.0-4.5 | 20 | 29 | 1.41 | - | | | | | CH |
| Present study | PTP1 | 2.5-3.5 | | 20 | 1.49 | $2.67 \times 10^{-6}$ | | | | | MH/ OH |
| | PTP2 | 2.0-3.0 | | 29.7 | 1.42 | $4.67 \times 10^{-6}$ | | | | | MH/ OH |

A perusal of Table 4.9 indicates that the 'Maximum dry density' (MDD) for CH type of soils varies in the range of 1.27– 1.41 t/m$^3$ in which two soil samples are within the permissible limits of 1.35 – 1.5 t/m$^3$ and one sample is in lower side. Also, 'Optimum Moisture Content' (OMC) varies from 27 to 29% which is in higher side of the permissible limits of 24.3 – 26.7 %, as suggested by USBR. For MI type of soil Maximum dry density (MDD) varies in the rage of 1.23-1.43 t/m$^3$ which is in lower side of the permissible limit of 1.634-1.666 t/m$^3$, and its Optimum moisture content (OMC) varies 25-32% which is in higher side of the permissible limit of 18.5-19.9%.

For CI type of soil Maximum dry density is 1.52 which is in lower side of the permissible limit of 1.724-1.746 t/m$^3$ and its Optimum moisture content is 22 which is in the higher side of the permissible limit of 17-17.6%. For present study also tests were conducted on two soil samples. Based on the test results, the soils are grouped as MH or OH type soil as unified soil classification. The Maximum dry density of these soils varies in the range of 1.42-1.49 t/m$^3$ which is in the higher side of the permissible limit of 1.26-1.36 t/m$^3$ and the Optimum moisture of these soils varies in the range of 20-29.7% which is in the lower side of the permissible limit of 33.1-39.5%, as suggested by USBR.

### 4.3.3 Mineralogical Composition of core material

Clay minerals are very tiny crystalline substances evolved primarily from chemical weathering of certain rock-forming minerals. Chemically they are hydrous aluminosilicates plus other metallic ions. All clay minerals are very small, colloidal-sized crystals (diameter less than 1 micron), and they can be only seen with an electronic microscope. The individual crystals look like tiny plates or flakes, and from X-ray diffraction studies scientists have determined that these flakes consist of many crystal sheets which have a repeating atomic structure. In fact, there are only two fundamental crystal sheets, the tetrahedral or silica, and the octahedral or alumina, sheets. (R.D.Holtz, 1981).

Clayey soils are composed of an aggregate of clay mineral and non clay minerals (Atwell, 1976). The presence of even a small amount of clay minerals in a soil mass can markedly affect the engineering properties of that mass. The behavior of clay mineral is governed by electrical and internal surface forces, which can be analyzed by the fundamental nature of the particles and clay water interaction. Therefore, identification of the type of clay mineral is essential to understand the behavior of the soil.

**Mineralogical identification**

The mineralogical composition of clayey soils has an important bearing on the swelling potential. The negative electric charges on the surface of the clay minerals, the strength of the interlayer bonding, and the cation exchange capacity all contribute to the swelling potential of the clay. Hence, it is claimed by the clay mineralogist that the swelling potential of any clay can be evaluated by identification of the constituent mineral of this clay. The following five techniques are used to identify minerals in clay soils.

i) X- ray diffraction
ii) Differential thermal analysis
iii) Dye adsorption
iv) Chemical analysis, and
v) Electron microscope resolution

Out of the above techniques XRD is the most widely used method for identification of clay minerals and to study their crystal structure. This method is used in determining the proportion of the various minerals present in colloidal clay consists essentially of comparing the ratio of the intensities of lines from standard substance. Brindley claimed that the use of self-recording counter spectrometers in lieu of photographic techniques increases considerably both the accuracy and the convenience of the X-ray method. The X-ray method for quantitative determination should be applied with considerable circumspection and that in favorable cases the possibility of identifying species by X-ray analysis can be regarded with restrained optimism. (Chen, 1975)

For most application, in many instances, a semi-quantitative analysis is sufficient. This may be done as follows; the silt and sand fraction can be examined by microscope and the approximate proportion of non-clay minerals is determined. The clay size material (2μm) can be determined by grain size distribution analysis. As the $1^{st}$ approximation, it may be assumed that the amount of clay minerals equals to at least the amount of clay size. For most soils, the amount of clay minerals exceeds the amount of clay size. This most probable result is from cementation of clay particles into aggregates larger than 2μm in diameter (Mitchell, 1976).

**Mineralogy and Activity**

Clay mineralogy varies with location and not all clay soils exhibit shrink/swell potential. Montmorillonite for example is a clay mineral which produces large volume changes in response to moisture whereas Kaolinite produces negligible volume change.

Skempton's Activity value introduced in 1953 gives an indirect method of clay mineral identification. The Activity value PI / C is the ratio of PI (plasticity index) divided by C (percentage of 0.002mm clay particle size). The Activity value is specific to the clay fraction and therefore a distillation of the Atterberg limit. A value of less than 0.75 is classed as inactive indicating a clay mineral with little shrink/swell potential.

Figure 4.7 shows the standard plasticity (Casagrande) chart in use today with the principal clay groups superimposed. It can be seen that montmorillonite clay minerals are present if the Atterburg limit of the clay sample is close to the U-line. The A-line separates the illite from the kaolinite groups and other inactive clay minerals are below. Most soils contain more than one mineral however hence the Atterburg limit may not coincide with a specific shaded area on the chart. The chart demonstrates that soils plotting below the A line are likely to contain stable clay minerals with no significant shrinkage potential. Soils plotting between the A-line and the U-line should be possible to further differentiate by reference to their Activity value.

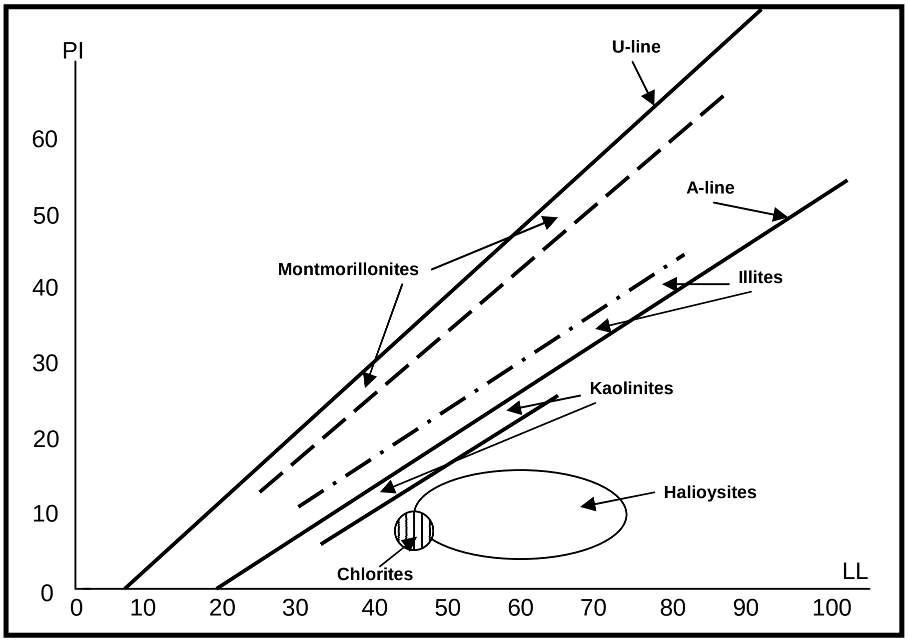



**Figure 4. 7** Casagrande plasticity chart showing Atterburg limits for principal clay minerals (from Holtz and Kovacs 1981) Illustrative only.

For the present study both direct and indirect mineralogical identification methods were used. For the direct method XRD analysis was conducted on two soil samples of the core material. Results of the analysis of the soil samples collected from PDTP-1 shows that the clay minerals (Kaolinite, Nacrite, Illite and, Hematite) are observed, where as from the soil sample collected from PDTP-2 (Kaolinite, Nacrite, Quartz and, Borax) are observed. The summery of XRD results are shown in Table 4.10. From the test results, the minerals expected to have significance in the desired properties of the core material have been identified. Based on the minerals, identified in XRD mineralogical analysis, there is no Na-montimorillonite that is commonly known for its dispersive potential in clay soils. In addition the minerals (like calcite) that affect/causes the suitability of the core material during operation through solubility has not been identified. Solubility of material is undesirable for embankment, particularly for core and filter zones. While considering the soil for the proposed embankment zone, the quantity of soluble solids present in soil may be an essential factor for its suitability.

**Table 4. 10** X-ray diffraction mineralogical analysis

| No | Sample name | Atterberg Limits | | Minerals identified Using XRD in order of decreasing. |
|---|---|---|---|---|
| | | **Liquid Limit** | **Plastic Limit** | |
| 1 | DPTP-1 | 54 | 31 | Kaolinite $Al_2Si_2O_5(OH)_4$<br>Illite, trioctahedral-K0.5$(Al,Fe,Mg)_3$ $(Si,Al)_4$O10$(OH)_2$<br>Hematite $Fe_2O_3$<br>Nacrite $Al_2Si_2O_5(OH)_4$ |
| 2 | DPTP-2 | 58 | 31 | Kaolinite $Al_2Si_2$O5$(OH)_4$<br>Borax $Na_2B_4$05(OH)4$(H_2O)_8$<br>Nacrite $Al_2Si_2$O5$(OH)_4$<br>Quartz $SiO_2$ |

Fell et al., (2005) stated that the effect of soluble solids on embankment depends on;

- Temperature,
- Minerals present in the soil and their solubility characteristics in water,
- Coefficient of permeability (the amount of water passing through the soil)
- Chemical characteristics of the water, and other factors.

Geological materials are selectively soluble in water. Calcite readily dissolves in low PH rain water than other rock forming minerals. The solubility of most rock forming minerals increase with temperature, on the other hand the solubility of calcite and other crystal form of calcium carbonate ($CaCO_3$) in pure water decrease somewhat as the temperature rises. This is opposite to most rock forming minerals (Krauskopf and Bird, 1995).

Peccerillo (1996) also stated that calcite is very poorly dissolved in pure water however, it dissolve readily in acid rain water containing $H_2SO_4$ , as increase in temperature generally results in higher solubility, however a number of carbonates and sulfates are exceptions. In addition to this the solubility of $CaCO_3$ in natural water decreases at higher temperature because $CO_2$, like any other gas, is less soluble in hot water than in cold water.

For the Dendo dam core material case the dominant minerals are kaolinite, illite, and quartz, as observed in XRD results (Table 4.10) and there is no calcite mineral that affect the suitability of the core material during operation through solubility. The solubility of silica which is one of the dominant minerals observed increases with temperature, over burden pressure and ph**.** However, the site condition, temperature, over burden pressure and ph values of surface and groundwater do not favor solubility of silica in case of Dendo dam core material.

### 4.3.4 Dynamic property of the core material

Earthquakes can cause failure of earth dams in a number of ways, of which the following are considered the most important (sherard et al., 1963; Seed, 1973):

(i) Piping failure through cracks formed in the dam, its foundation, or its abutments.
(ii) Overtopping caused by loss of freeboard from compression the foundation or the embankment induced by shaking.
(iii) Collapse of embankment because of liquefaction of loose embankment material caused by the shaking.
(iv) Shear slides in the embankment caused by shaking.
(v) Overtopping caused by large waves (seiches) in the reservoir, uplifting of the reservoir bottom, major reservoir slope collapse, or blockage of the spillway or outlet works.

Among these five ways cracking is the most dangerous from the standpoint of piping failure and the most directly controllable by designing(self-healing) drainage features and zones that will slough in to any opening and slow down any through-seepage and possibly prevent piping failures. Collapse failures from liquefaction are also at least controllable by drainage systems that keep saturated zones to the minimum sizes possible. (Cedergren, 1977)

The type of construction material used for embankment dam controls the response of the embankment dam to the ground vibration in two ways. The first is flexibility or the resistance of the material to the induced dynamic forces without shear failure or excessive settlement. The second is the potential of the material to amplify or de-amplify the amplitude of the ground vibration at the bed rock on which the embankment dam is founded which is on the density and the shear wave velocity contrast between the foundation rock/soil and embankment material. Therefore, reasonable selection of the materials particularly in seismically active region is necessary.

The response of the embankment for the imposed dynamic load is highly influenced by the dynamic behavior of the embankment material. Seed and Chan (1967) carried out studies on the dynamic strength of soils. They indicated the superimposing pulsating load; the dynamic strength is lower than normal static strength for sensitive clays or for cohesive clay of low density, especially at higher water content (Singh, 1995). The reduction in strength may be 10 to 25%. On the other hand, for soils with moderately high to high density the dynamic strength is found to be 10 to 20% higher than normal strength. The difference between the two is small at 5% strain. In view of individual characteristics of cohesive soil used in construction of embankment dams, it would be preferable to perform dynamic shear test on the actual soil in seismically active regions.

Conducting cyclic tests on the representative samples of the embankment material is important to measure the combined effect of the initial static stresses and superimposed dynamic stresses. It also helps in determination of the generation of pore water pressures and the development of strain (deformation) in the soil for evaluation of the cyclic resistance of the soil.

Liquefaction is an extreme case of shear strength loss due to pore pressure development. It is commonly reported in loose fine to medium sand deposits. Considering liquefaction potential of core material, cohesive soils commonly are not susceptible to liquefaction condition during cyclic loading of earthquake. However, there will be a considerable untrained shear strength loss due to the seismic shaking. In order to liquefy, cohesive soils must meet the following criteria (Day, 2006):

(i) The soil must have less than 15 % of the particles, based on dry weight, that are finer than 0.005 mm (i.e., percent finer at 0.005 mm < 15 %).
(ii) The soil must have a liquid limit (LL) that is less than 35 (that is, LL < 35).
(iii) The water content '*w*' of the soil must be greater than 0.9 of the liquid limit [that is, w> 0.9 (LL)].

If the core material does not satisfy the above said criteria it is generally considered that it is not susceptible to liquefaction.

For the present study because of the limitation of resources and financial constraints it was beyond the reach of the present study to conduct cyclic direct shear test to determine dynamic behavior/ property of the core material. However, an attempt has been made to evaluate dynamic behavior/ property of the core material based on the classification tests and literature reviews. In case of core material for Dendo dam only CI (clay of intermediate plasticity) type of soil is fairly suitable and, there will be differential settlement may take place under the proposed height of the dam if the other identified soils (CH, MH.etc) are dominate/use in the core material. Under dynamic shaking the total settlement is increased and result into rapid increase of differential settlement that may cause piping. Therefore, blending of the available borrow material with gravel in proper ratio is advisable to improve the dynamic property of the core material.

## 4.4 Construction Material for Transition filters and drains

All earth and rock-fill dams are subjected to seepage through the embankment, foundation, and abutments. Seepage control is necessary to prevent excessive uplift pressure, instability of the down stream slope, piping through the embankment and/or foundation and erosion of material by migration in to open joints in the foundation and abutments (Earth Manual). Placement of more pervious material in the outer zones in the embankment is one of the methods to control seepage. For this filters are essential to control seepage and for the safe functioning of any embankment dam. It should be placed inside the embankment where it will be more effective in controlling seepage and reducing pore pressure. Safe interception and passage of seepage are necessary to ensure vital embankment performance Sherard (1963). Moreover, the filter drains ensures foundation material not to be washed away with the seeping water and transition filters check the development of destructive internal water pressures. Therefore, the zone immediately downstream of the core is designed to serve as filter which prevents the migration of particles from the core into the downstream shell. The design of drainage system is primarily governed by height of the dam, cost and availability of the pervious material, nature of pervious material and foundation conditions (Jansen, 1988).

Proper testing has to be done to ensure durable particles that will not be unacceptably altered or changed during excavation, hauling, placement and compaction or by long term weathering and erosion. Testing should include grain size distribution, hardness, mechanical breakdown, design stress, density, abrasion, chemical resistance and freeze thaw (USBR, 1987).

**<u>Filter Criteria</u>**

The filter design for the drainage layer and internal zoning of a dam is a critical part of the embankment design. It is essential that the individual particles in the foundation and embankment are held in place and do not move as a result of seepage forces. This is accomplished by ensuring that the zones of material meet “filter criteria” with respect to adjacent materials. (Earth manual)

The particle sizes which are commonly used for filter selection criteria are $D_{15}$, $D_{50}$ and $D_{85}$ of the filters and the protected layers. These particle sizes of the base and filter material, which are deduced from the gradation curve, are presented in Table 4.12.

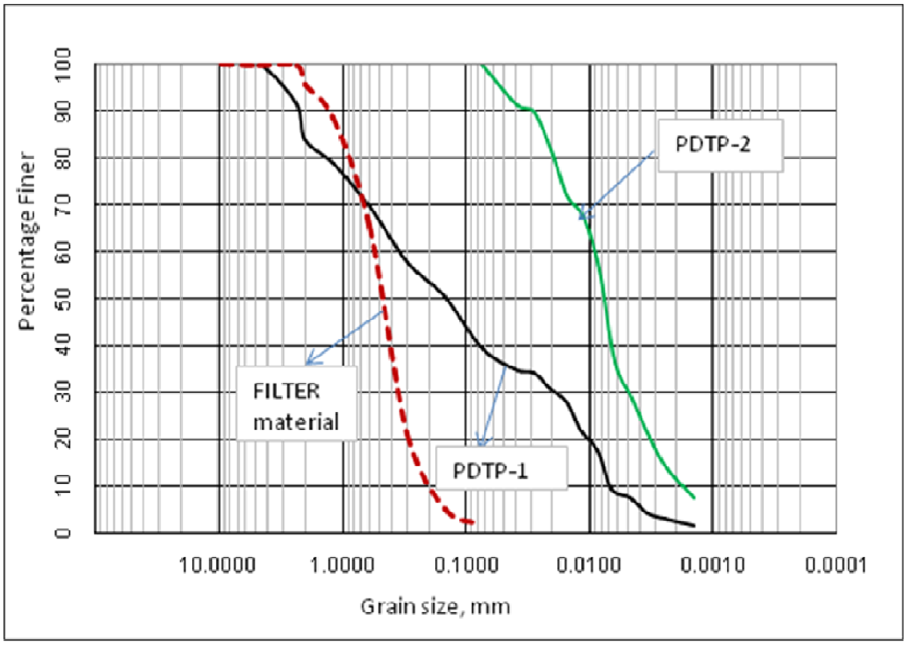



**Figure 4. 8** Grain size distribution curve for filter and core materials

Different criteria give varied emphasis to a certain particle sizes. A perusal of Fig. 4.8 and Table 4.12 indicates that the available material for filter 'FI' satisfy the criteria partially when core material from DPTP-1 is used as the base material (Table 4.12). However the base material which is MH or OH type of soil for which suitability analysis done is not suitable for embankment core as it is discussed in flexibility and erosion section. Therefore, further suitability analysis of filter material after blending or after identification of more suitable base material from locally available material is necessary.

### 4.4.1 Engineering properties of transitions filters

For the proposed Dendo dam the suitable construction material for fine filter is obtained from Cherake and Bilate River deposits upstream and downstream of the dam axis. It is characterized by fine to medium size sand with rounded to sub-rounded grain shape. The quantity is sufficient to cover the entire volume required for fine filter. In addition, the suitability of the sand as fine filter for the core material was also checked. Due to limitation on resources tests to determine its engineering property has not been done; however, the chemical test (presented in table 4.11) during previous study shows that both samples are suitable for the desired purpose.

**Table 4. 11** Sand Test Result

| **Source** | **Sample no.** | **Chloride content(mg/l)** | **Sulfate content(mg/l)** | **Fineness modulus** | **Clay content%** |
|---|---|---|---|---|---|
| Cherake River | 1 | 28.5 | Nil | 2.81 | 2.10 |
| Bilate River | 1 | 30.6 | Nil | 2.8 | 2.60 |

**Table 4. 12** Results of filter criteria

| Criteria | **Requirement** | **Core Material Sites** | **Result** | **Criteria** |
|---|---|---|---|---|
| Indian | $\frac{D_{15}\ of\ filter}{D_{85}\ of\ base} < 5$ | **DPTP1** | 0.075<5 | Satisfied |
| | | **DPTP2** | 7.5>5 | Satisfied |
| | $\frac{D_{15}\ of\ filter}{D_{15}\ of\ base} > 4\ and\ < 20$ | **DPTP1** | 21.4>20 | Not Satisfied |
| | | **DPT2** | 62.5>20 | Not Satisfied |
| | $\frac{D_{50}\ of\ filter}{D_{50}\ of\ base} < 25$ | **DPTP1** | 2<25 | Satisfied |
| | | **DPTP2** | 47.25>25 | Not Satisfied |
| US Army Corps of Engineers (1995) | $\frac{D_{15}\ of\ filter}{D_{85}\ of\ base} \leq 5$ | **DPTP1** | 0.075<5 | Satisfied |
| | | **DPTP2** | 7.5>5 | Not Satisfied |
| | $\frac{D_{50}\ of\ filter}{D_{50}\ of\ base} \leq 25$ | **DPTP1** | 2<25 | Satisfied |
| | | **DPTP2** | 47.6>25 | Not Satisfied |
| Terzagi | $\frac{D_{15}\ of\ filter}{D_{85}\ of\ base} < 4$ | **DPTP1** | 0.075<4 | Satisfied |
| | | **DPTP2** | 7.5<4 | Not Satisfied |
| | $\frac{D_{15}\ of\ filter}{D_{15}\ of\ base} > 4$ | **DPTP1** | 21.4>5 | Not Satisfied |
| | | **DPTP2** | 20>5 | Not Satisfied |
| Sherad's | $\frac{D_{15}\ of\ filter}{D_{85}\ of\ base} < 9$ | **DPTP1** | 7.5<9 | Satisfied |
| | | **DPTP2** | 7.5<9 | Satisfied |

Further, referring Terzaghi's Other requirements for good filter such as:

v) Its gradation curve should be approximately parallel to the gradation curve of the protected soil, especially in the finer range.

vi) Filters should not contain more than 5% fines (-0.075 mm) and fines should be cohesion less. This is to ensure that filter remains adequately pervious and does not sustain a crack.

vii) The filter does not have particles larger than 75 mm so as to minimize segregation.

viii) If the base material ranges from gravel (over 10% > 4.75 mm) to silt (over 10% passing 75μ), the base material should be analyzed on the basis of gradation of fraction smaller than 4.75 mm.

The identified Cherake sand satisfies the above requirements set by Terzaghi when PDTP-2 is used as base material. ( fig. 4.8). However, as observed in Table 4.12 it fails to satisfy the main criteria set by Terzaghi. For PDTP-1 base material also it fails to satisfy the first requirement for good filter and it satisfied other requirements partially.

### 4.4.2 Mineralogical properties of transitions filters

Although naturally occurring gravel and sands some times can be used for filters and drains with little or no processing, drainage aggregates usually need to be treated. Most natural sand and gravel deposits are highly variable in grading from point to point in a borrow area, or they are covered or interbeded with silt and clay which is difficult to remove (Cendergren, 1977). The quantity required for filters and drains is usually small; however, quality requirements are high. Sand, which satisfy the quality requirement for concrete aggregate in terms of chemical composition, also satisfy compositional requirement as filter. However, minerals contained in filter materials must be evaluated for potential degradation as water percolates through the filter material.

Sand is derived from physical disintegration or weathering of rocks of different mechanical properties and varying mineralogical composition. The mineralogical composition of fragmentary materials is formed from polymineral rocks and must also be the polymineral kind. Monomineral rock is turned to monomineral fragmentary material, such as limestone, quartz, Gypsum and other sands (Shestoperov, 1983).

The predominant minerals in sands are quartz and feldspar in addition it may contain a certain quantity of mica or sands may contain only quartz. Because of the temperature at which Quartz forms, it is the most resistant mineral to surface weathering. According to Goldish (1967) mineral stability series, igneous minerals have the following order of decreasing stability;

*Quartz > Alkali feldspar > Muscovite >Amphibole > Na-Ca Plagioclase > Pyroxines and Ca-plagioclases > Olivine (*Peccerillo et al 1996)

There are various crystalline forms of silica found in nature like α-quartz, β-quartz, tridymite etc. Chert is impure form of microcrystalline α-quartz, often described as mineral chalcedony; Opal is also amorphous form of silica which contains some water. Presence of Amorphous silica in significant proportion in sand can cause major problems in case of using this sand for concrete aggregate. As shown by numerous experimental studies, temperature and pressure have an effect on the solubility of quartz. According to Krauskopf and Bird (1995), the solubility of α-quartz (at PH< 9 at $25^{o}$c and 1 bar pressure) increases with increasing pressure at constant temperature. It also increases with increasing temperature at constant pressure. Low PH favors precipitation of silica, where as high PH determines high solubility for $SiO_2$ (Peccerillo et al., 1996).

On the other hand, feldspars are relatively easily breakdown and decompose by wetting. According to Michell (1976) feldspars are silicate minerals with three dimensional frame work structure where in part silicon is replaced by aluminium. The excess negative charge resulting from this replacement is balanced by cations such as potassium, calcium, sodium, strontium, and barium, as this cation are relatively larger, and their coordination number is also large. These result in the formation of open structure and low bound strength. As a consequence there are cleavage plane, the hardness is only moderate and feldspars can easily be break down. Therefore, in filter sand, presence of feldspar in large quantity may affect the performance of the filter. For the Dendo dam site case even, the presence of weak quartz variety like α-quartz or deleterious minerals in the sand may not cause significant problem as the temperature, ph, and over burden pressure is moderate in Dendo dam site.

To identify the filter material mineralogically it requires detailed analysis on sufficient number of samples. However, due to resource limitation mineralogical identification was not conducted during the present study.

### 4.5 Construction Material for Shell

The shell is the bulk mass of the embankment dam, which is primarily required to provide the stability to the dam and to withstand the horizontal thrust exerted by the impounded water behind the dam. The first essential requirement for the shell material is the availability of suitable material at an economic distance from the dam site. The borrow areas for the shell have to be located near the dam site. Later it has to be investigated for available quantity and relevant soil properties.

As per the requirement for shell section of the dam it is recommended to use sound and resistant to erosion rock fragments, gravels and cobbles are available around the dam site above and below the dam axis. According to geological and geotechnical investigation report by WWDSE on construction material; in addition to gravels and cobbles, quarry sites( Fig. 4.2) has been identified as potential source for the construction material for shell and other rock fill material. It is suitable site with respect to its accessibility and close proximity to the dam site. In addition it can also be obtained either from the same part of Dendo hills, or from Ropi area (15km up stream). The later rock source area is already a quarry site for local construction.

### 4.5.1 Engineering properties of Shell Material

Primary purpose of shell is to provide the stability to the main dam by virtue of its weight and to withstand the thrust of the impounded water. This function will only be performed effectively if the construction material, to be used for the shell, has desirable engineering properties**.** The important engineering properties, which influences the performance of the shell material are permeability, compacted density and shear strength.

For Dendo dam during previous study only potential site has been identified and no engineering property test was conducted on identified material. During present study also due to financial constraint it was beyond the reach of the present study. Therefore, it is recommended that engineering and index properties should be done on identified shell material to determine its suitability for the desired purpose.

## 4.6 Riprap

Adequate slope protection must be provided for all earth and rock fill dams to protect against wind and wave erosion, weathering, ice damage, potential damage from floating debris. (Earth manual, 1968). The upstream slope of embankment dam needs protection against erosion by wave action. The material used to protect the upstream slope of embankment should be sound, resistant to erosion and sufficiently large to withstand the wave action from the reservoir. On the downstream slope, only erosion from rain fall, surface runoff and/or wind erosion must be considered except for sections that may be affected by wave action in the tail water pool (US Army Crops of Engineers, 1994).

Methods of protecting slopes include dumped riprap, precast and cast-in-place concrete pavements, soil cement, bituminous soil stabilization, sodding and planting, but the main protection measures are; Dumped stone Riprap, Hand placed Riprap and Soil cement slope protections. However, the type of protection provided is governed by available materials and economics.

### 4.6.1 Engineering properties of riprap

The rock fragment used for riprap should be composed of dense, sound durable rock with acceptable shape factor and sufficiently large to withstand the wave action from the reservoir. The riprap must be underlain by bedding layers of fine material to act as filter to prevent the embankment material from being washed through the interstices in the riprap. In order to meet the design requirements riprap protection requires good quality rock and bedding of sufficient size. Consideration should be given to materials available from required excavations as well as from the nearby quarry sources. Adequate riprap design and specifications must consider other measures of the rock quality to ensure riprap stability and the integrity of the riprap throughout the service life of the embankment. This includes petrographic examination and physical property testing to evaluate the physical and chemical quality of the rock in conjunction.

According to Study and design of Bilate irrigation project report (2008b), rock sources for riprap, masonry works and crushed aggregate exist in Dendo hills and small hills south of it. Rock in this area is light gray and variable in size but of the same origin (felsic volcanic rocks). These are rhyolitic and ignimbrite rocks (rhyolite, rhyolitic ignimbrite, and obsidian rich felsic rock). It is moderately weathered to fresh rhyolitic and ignimbritic rocks having Unite Weight of 2481 kg/m$^3$ on an average and Unconfined Compression Strength (UCS) is 111.2 Mpa.

### 4.6.2 Mineralogy of riprap material

Mineralogy of the riprap material is one of the important factors which must be considered during construction material assessment. The required engineering property is resulted from mineralogical composition of the rock.

The resistance to degradation under anticipated site conditions is essential for functional requirement of the Riprap layer. Degradation has an effect of reducing block integrity average weight and angularity, modifying the mass distribution and interlocking property of the Riprap. Rapid degradation process can significantly impair the performance of the protection layer during the design life of the structure.

On the basis of petrographical analysis the rocks are light gray, porphyritic rhyolite. The constituted in this rock samples CRS-1 and CRS-3, are sanidine, 57-58%, quartz 20-25%, opaque(Ferrous oxide) 3-5% and pyroxene 2-5%.

**Table 4. 13** Quarry rock sample test result

| Source | Porosity (%) | Specific gravity (Gs) | Water absorption | Point load(Mpa) | Unit weight Kg/m$^3$ | Unconfined compression strength (Mpa) |
|---|---|---|---|---|---|---|
| CRS-3 | 4.9 | 2.531 | 1.979 | 4.468 | 2531 | 107.2 |
| CRS-1 | 12.63 | 2.432 | 4.413 | 4.799 | 2432 | 115.2 |

*(Source Bilate dam and irrigation project report, 2008b)*

## 4.7 Engineering Properties of Foundation Material

During feasibility study by Water Works Design and Supervision Enterprise (WWDSE) engineering properties of dam foundation, spillway portion and abutments were carried out. The foundation is the valley bottom (river course and terrace) of Bilate River. This portion of the dam is characterized by river channel and/or point bar deposits and Flood-plain and/or Lacustrine Deposits. These are silt, sand and minor clayey silt or silty clay and gravely sand. Seven bore holes were drilled around Dendo dam site for the investigation of the sub surface geology. As per the study in-situ test result, the thickness of the overburden at the foundation is ranging from 9.0m to 15.0m, where as on the abutments it is ranging 2.0 to 3.0m thick. This overburden is mainly characterized by weakly compacted to loose silty to sandy soil (silt, sandy silt, clayey silt and fine sand).

Volcanic rock (tuff) is common in all drilled borehole at certain depth, below overburden and residual soil. Thick and relatively good bed rock is only found in the left bank of the foundation having thickness ranges of 16-24m with inter layers of soil and weathered rocks. Based on one drilled borehole in the spillway portion, the subsurface geology is similar with that of the dam site. To study the engineering properties of the dam foundation and the spillway potion in-situ field test and laboratory test has been carried out by WWDSE during feasibility study.

### 4.7.1 Standard Penetration Test (SPT) Result Interpretation

One of the in-situ field test carried out during the geotechnical core drilling is SPT tests. This test is used to determine foundation strength or bearing capacity of the soil or weathered rock. SPT data can also be used to evaluate the liquefaction potential of a material and generally, the data have been used for predicting triggered by earthquake loading.

As per the report during the tests, the number of blows per 15cm penetration was recorded for 3 times and the last two readings were taken as N value. Based on the test results the majority of the SPT, N values in the case of Dendo dam site is more than 10 (10-45). So, the soil can be grouped as medium to very dense with minor exception of loose soil having less than 10 N values.

### 4.7.2 Permeability of Main Dam and Spillway

According to variable /falling head/ test results conducted in most of the bore hole sections (both on overburden and rock) the coefficient of permeability (K) of Dendo dam and spillway sites varies between 2.65x $10^{-4}$ cm/sec and 3.79 x $10^{-6}$cm/sec. Most of the coefficient of permeability values is generally in the range of $10^{-6}$ to $10^{-5}$. Therefore, most of the subsurface section can be considered as impervious. However, foundation properties are quite irregular and heterogeneous would require proper foundation treatment. Pockets with total water loss as found the foundation calls for further foundation investigation before taking up construction and appropriate treatment would be necessary. The foundation properties reveal that no liquefaction of foundation soils is expected during earthquake.

**Table 4. 14** Packer Permeability test results of foundation Material

| Borehole ID | Depth (m) | Average Lugeon |
|---|---|---|
| DDBH-2 | 0.0-5.2 | 1.28 x $10^{-5}$ |
| DDBH-3 | 5.0-9.2 | 2.01 x $10^{-5}$ |
| DDBH-1 | 5.0-10.55 | 2.92 x $10^{-5}$ |

**Table 4. 15** Falling Head Permeability test result of Foundation Material

| Borehole ID | Depth (m) | Permeability (K) cm/sec |
|---|---|---|
| DDBH-1 | 0 to 5.0 | 1.28 x $10^{-5}$ |
| | 5 to 10 | 1.1 x $10^{-5}$ |
| | 10 to 15 | 1.7 x $10^{-5}$ |
| | 15 to 20 | 1.15 x $10^{-5}$ |
| DDBH-3 | 5.0 to 9.2 | 2.01 x $10^{-5}$ |
| | 9.2 to 15.0 | 2.05 x $10^{-5}$ |
| | 15.0 to 20.0 | 1.22 x $10^{-5}$ |
| | 20.0 to 25 | 2.47 x $10^{-6}$ |
| | 30.35 to 35.35 | 2.49 x $10^{-6}$ |
| DDBH-4 | 5.0 to 10.55 | 2.92 x $10^{-5}$ |
| | 10.55 to 15.0 | 2.63 x $10^{-4}$ |
| | 20.0 to 25.25 | 2.69 x $10^{-6}$ |
| | 25.25 to 30.5 | 2.06 x $10^{-6}$ |
| DDBH-5 | 5.0 to 10.0 | 6.95 x $10^{-6}$ |
| | 10.0 to 15.0 | 5.72 x $10^{-6}$ |
| | 15 to 21.5 | 5.45 x $10^{-6}$ |
| DDBH-6 | 5.0 to 10.5 | 5.28 x $10^{-6}$ |
| | 10.5 to 20.0 | 4.43 x $10^{-6}$ |
| | 15.0 to 20.0 | 4.21 x $10^{-6}$ |
| | 20.0 to 24.5 | 5.35 x $10^{-6}$ |
| | 24.5 to 30.5 | 1.63 x $10^{-5}$ |

*(Source Bilate dam and irrigation project report, 2008b)*

### 4.7.3 Shear strength of the foundation materials

The shear strength of soil is a most important aspect of geotechnical engineering. In geotechnical engineering, we are generally concerned with the shear strength of soils because, most of our problems in foundation and earthwork engineering, failure results from excessive applied shear stresses. The bearing capacity of shallow or deep foundation, slope stability, retaining wall design and, indirectly, pavement design are all affected by the shear strength of soil in a slope, behind a retaining wall, or supporting a foundation or pavement.

**Table 4. 16** Direct and Tri-axial Shear Test Result of foundation material

| Test pit ID | Depth (m) | Direct shear test | | Test pit ID | Depth (m) | Tri-axial shear test (cu) | |
|---|---|---|---|---|---|---|---|
| | | C ($KN/M^2$) | Φ (deg.) | | | C ($KN/M^2$) | Φ (deg.) |
| DTP-2 | 3.1-4.75 | 8 | 40 | DBH-3 | | 35 | 31 |
| DTP-1 | 0.0-3.10 | 16 | 30 | - | - | - | - |
| DTP-2 | 0.0-3.2 | 24 | 30 | - | - | - | - |

*(Source Bilate dam and irrigation project report, 2008b)*

### 4.7.4 Reservoir Water Tightness

The Dendo reservoir area is mainly characterized by flat to gentle slope forming flood plain of Bilate River and slightly steep slope forming on both banks. The alluvial deposits (silt, sandy silt, fine sand and silty clay and/clayey silt with minor gravel) on the flood plain and slope wash and residual soils and minor colluviums on the gentle slope forming part of reservoir margin seems to be impermeable. The laboratory permeability test results on soil samples those are taken from test pits excavated around reservoir bottom also confirm the impermeability nature of the soils, which is mainly in the order of $10^{-6}$cm/sec. However, the geological structures those are crossing the Dendo reservoir through dam axis should be given due consideration during the design work with special treatment recommendation, though they are commonly covered by soil lair.

As it was discussed in the local geological setting there are normal faults trending N-S, NNE-SSW crossing both the Dendo dam site and reservoir area. As reported in GGI final feasibility report by WWDSE these faults are easily recognized by aerial photograph and satellite imagery interpretation, especially in the area where exposed rocks are found. Few of the faults are also observed and identified at the site during the geological mapping and construction material assessment, particularly those are found around the Dendo hill. These geological structures are commonly hidden by sediment deposit on the reservoir bottom of Dendo. Therefore, geological structure consideration for water tightness of the reservoir is an important factor.

## 4.8 Overall Characterization and suitability the Embankment Material

Construction material for embankment was characterized based on engineering, mineralogical and dynamic behavior/ property of the material. For this various tests have been conducted on core material during the present study and, tests conducted by WWDSE during previous study are used.

The tests that have been conducted during both previous and present study are; classification, Procter compaction, permeability, consolidation, free swell, volumetric shrinkage, direct shear, and triaxial (CU) test. In addition, XRD mineralogical analysis has been made for the core material. All the available secondary data on construction material were also analyzed for better characterization.

### 4.8.1 Core Material

The previous study by WWDSE identified core material for Dendo embankment dam. According to the study the soil materials collected for impervious core are, classified as CI, CH, MI, OI, as per Unified soil classification system. Among these soils CI (clayey soils of intermediate plasticity) are considered as suitable and MI soil is recommended to be used with proper control. During present study using all available secondary data and test results of the present study, the core material of borrow sites are characterized. Based on the study the soil in the borrow area are classified as, CI, MI or OI, CH, and MH or OH as per Unified Soil Classification System. Out of the identified soils only CI type of soil is with in permissible limits suggested by USBR. However, the other types of soils show medium to high compressibility, high shear strength and low dry density, and slight variation of permeability that is in higher side of the permissible limit as suggested by USBR. Moreover, as per the engineering use chart for compacted soil after USBR, 1974 indicates that the workability of MI and CH group of soils is fair to poor and graded as $6^{th}$ and $7^{th}$ place for core of rolled earth dam.

Referring to the mineralogical analysis; kaolinite, illite, quartz, nacrite, borax and haematite, are the minerals identified in both samples tested. The common mineral identified in both samples is kaolinite. Therefore the identified dominant mineral in Dendo core material may not cause significant problem as far as solubility and other related conditions are concerned. However, referring to the dynamic behavior/ property, slight differential settlement under dynamic condition is expected when the identified soils are used as core material.

### 4.8.2 Filter Material

Proximity to the dam site and availability in sufficient quantity of filter material for Dendo dam project is the main advantages of the project. Two borrow sites (Bilate River and Cherake River) are identified as potential source for fine filter F1. For Cherake River sand as filter material and MH (sility clay of high plasticity) soil from PDTP-1 as base material partially satisfies Terzaghi and Sherard criteria. However, for soil from PDTP-2 the filter material does not satisfy the criteria set by USBR, US Army Corps of Engineers, Indian standard, and Terzaghi. Moreover, the filter material does not fully satisfy the requirements set by Terzaghi for good filter when either of the core material is used as base material.

### 4.8.3 Shell Material

According to geological and geotechnical investigation report by WWDSE on construction material; in addition to gravels and cobbles, quarry sites( Fig. 4.2) has been identified as potential source for the construction material for shell and other rock fill material. It is suitable site with respect to its accessibility and close proximity to the dam site. In addition it can also be obtained either from the same part of Dendo hills, or from Ropi area (15km up stream). The later rock source area is already a quarry site for local construction. However, no index or engineering property test has been done to determine its suitability for the desired purpose. Therefore, engineering, chemical and mineralogical test should be done on the identified shell material as the unwanted quality affects the safe functioning of the zone. Moreover, the shell/rock fill material will be free from disintegration during saturation with reservoir water.

### 4.8.4 Riprap Material

Sources for riprap material exist in Dendo hill and other small hills south of the Dendo hill. Rock quarry/exposure towards west of the Dendo hill and quarry site-1 are also suitable sites with respect to its accessibility and close proximity to the dam site. The materials from these sites is rhyolitic and ignimbrite rocks in composition and possess specific gravity of 2.48(Gs), unconfined compression strength (UCS) of 111.2Mpa, and water absorption ratio of about 3.196. According to USBR, 1992 it is suitable in terms of UCS and classed as poor to marginal in terms of specific gravity and water absorption ratio.

# CHAPTER-V CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

The Dendo dam site is located about 347km south of Addis Ababa and bounded by geographic coordinates of 395800-399000E and 780200-782800N. The dam is earth / rock fill dam of 42m in height with reservoir capacity of 52 million $m^3$ to irrigate agricultural land, which is mainly characterized by plain land. For the success of this project identification of the material based on: engineering, mineralogical, and dynamic property and the site conditions have substantial impact on the long term stability and economic feasibility of a given Embankment project. Moreover, identification of suitable construction material play great role in design requirement to be constructed. Therefore, the present study focused on Characterization and suitability analysis of embankment materials with special consideration to core and filter material.

The embankment material for Dendo dam has been characterized in terms of engineering, mineralogical composition, dynamic behavior and its relative response to the site condition. In addition, general suitability of the material has been analyzed with giving especial emphasis to core and filter material. This is done based on detailed literature review, scrutinizing previous works and various field and laboratory tests. The previous study has been conducted geological and geotechnical investigation at the dam site to evaluate the foundation condition and to determine the availability of suitable construction material. During present study also the construction material for different zones (core, filter, shell and riprap) of the embankment dam has been identified based on previous and present work.

Based on the laboratory test results of soil samples generated during the previous and present study; the identified core material in Dendo borrow area has been classified as CH, MI or OI, CI, MH or OH as per USCS. Proximity to the dam site was the main advantages of using this material for the core of the dam. However, in terms of index and engineering properties the identified core material showed drawbacks. The combined grain size analysis and hydrometric test performed on core material showed that the core material from borrow area has no gravel fraction and most of the samples are clayey silt. Therefore, when grain size distribution of Dendo dam core material is concerned addition of coarser material to the fine material is necessary as it locks the propagation of crack of different size through the core of the dam depending on the size of the coarser material. Further; the addition of coarser material improves the shear strength of the core material. In addition, consistency limits tests conducted on soil samples indicate that the liquid limit and plasticity index of most samples are high which is associated with high compressibility. Moreover; two samples of the previous study fall in MI/OI group of unified soil classification system, which are considered as poor/unsuitable for impervious core according to USBR. During present study also consistency limit tests conducted on two soil samples. The test result showed that both samples fall in MH/OH group of USCS, which are not suitable for impervious core according to USBR. The engineering properties of the core material are analyzed. For this secondary data obtained from Ministry of Water Resources and data generated during present study has been used. As observed from the test results of soil samples, the identified core material for Dendo dam has low dry density, medium to high swell potential and medium to high volumetric shrinkage were the major drawbacks.

Further, the mineralogical composition of the core material has been analyzed using XRD. Based on the analysis, kaolinite, illite, quartz, nacrite, borax and haematite, are the minerals identified in both samples tested. The common mineral identified in both samples is kaolinite. Therefore the identified dominant mineral in Dendo core material may not cause significant problem as far as solubility and other related conditions are concerned. However, referring to the dynamic behavior/ property, slight differential settlement under dynamic condition is expected when the identified soils are dominantly used as core material.

Filters are also one of critical part as it is used to control seepage and for the safe functioning of any embankment dam. It is essential that the individual particles in the foundation and embankment are held in place and do not move as a result of seepage forces and, used to prevent the development of cracks in core material. For Dendo dam case availability of sufficient quantity of filter material, at dam site is one of the major advantages. At Dendo dam site two borrow area (namely: Cherake and Bilate) are identified as potential source of fine filter material (F1). However; for present study the suitability analysis was done on filter material collected from Cherake River. As the analysis indicates that the Cherake sand satisfies the Sherard's criteria for filter selection when PDTP-1 or PDTP-2 core material is taken as a base material but it does not satisfy the criteria set by USBR, US Army Corps of Engineers and Indian standard. However, the base materials used for the suitability analysis of filter material is unsuitable. Therefore, before the suitability analysis of filter material, identification of suitable core material is essential.

Further, in addition to gravels and cobbles, quarry site has been identified as potential source for the construction material for shell and other rock fill materials. It is suitable site in respect to its accessibility and close proximity to the dam site. However, index and engineering property tests have not been done (especially for shell) to determine its suitability for the desired purpose. Therefore, engineering, chemical and mineralogical test should be done on the identified shell material as the unwanted quality affects the safe functioning of the zone. Moreover, the shell/rock fill material will be free from disintegration during saturation with reservoir water.

Rock sources for riprap, masonry works and crushed aggregate exist in Dendo hills and small hills south of it. Rock in this area is light gray and variable in size but of the same origin (felsic volcanic rocks). These are rhyolitic and ignimbrite rocks (rhyolite, rhyolitic ignimbrite, and obsidian rich felsic rock). It is moderately weathered to fresh rhyolitic and ignimbritic rocks having Unite Weight of 2481 $kg/m^3$ on an average and Unconfined Compression Strength (UCS) is 111.2 Mpa. In terms of quality of the riprap material, durability of the material is highly required for the stability of the layer. The durability of the rock to retain its physical and mechanical properties without degradation in engineering service is the function of rock property (mineralogical composition) and engineering environment or site conditions. The rhyolitic and ignimbrite rocks, selected for riprap, is classed as suitable in terms of UCS is concerned (Balkema, 1995). Based on water absorption ratio and in terms of specific gravity of the material, it is classed as marginal as per USBR, 1992.

## 5.2 Recommendations

Almost all construction materials for Dendo dam project are available with in economic distance. However, as the present study shows most of the identified materials for different zones of the embankment (especially core) have major drawbacks. Therefore, before construction it is necessary to conduct detail study in engineering, and chemical properties of the identified material. Further, based on the test results and analysis of previous and present study the following recommendations are forwarded;

- As observed from the present and previous study the dominant core material is clayey silt and fine sand with clay. Therefore, it is necessary either identification of another borrow area with suitable gravely clay material with in reasonable distance or blending of the available material with an appropriate ratio is necessary.
- Blending of material is necessary;
  - To reduce compressibility, swelling potential, crack potential due to shrinkage crack or differential settlement, undesired stiffness contrast with shell material.
  - To improve plasticity index (IP), maximum dry density and optimum water content.

- To increase in erosion resistance of core material without losing flexibility and to improve the workability of the core material as the identified core material contains no gravel material.

Moreover, the identified borrow site for core material is one i.e left and right bank of the Bilate River. However, the index and engineering properties of the material varies highly from test pit to test pit. Therefore, it is necessary to conduct detail study to determine its index and engineering property.

The availability of sufficient amount of filter material from both Cherake and Bilate River with in economic distance is one of the advantages. However, as observed from the present analysis it fails to satisfy most of the criteria set by different authors. Therefore, before filter design, it is necessary to get suitable base material. In addition to this, for Dendo dam case no engineering and mineralogical test is conducted in filter material. So as the engineering and mineralogical properties of the filter material affect the performance and safe functioning of the embankment dam, it is highly recommended that to conduct engineering and mineralogical test on identified filter material before construction. Moreover, as the Dendo dam site is found in seismic prone area, analysis for dynamic property is also essential.

The previous study conducted no test on shell material. During present study also due to limitation in resources and financial constraints it was beyond the reach of the study. Therefore, as the shell material is highly necessary to provide the stability to the main dam by virtue of its weight and to withstand the thrust of the impounded water, it should have desirable engineering properties. Moreover, its effective performance is determined based on its index property and mineralogical composition of the material. Therefore, before construction phase conducting engineering, index, chemical and mineralogical tests are necessary.

All efforts were made to conduct the present study in a systematic manner, well supported by actual test results and scientific observations made at the site. The findings and recommendations made through this study should be considered as indicative only as the study was performed under limitations of time and resources. Moreover, the Dendo dam project is under feasibility study. So the data generated during previous study, which is used for present study is not sufficient. Thus, the quality of results may be affected to certain degree of inaccuracy. Therefore, it is strongly recommended to conduct more elaborate scientific study on various aspects before adopting the findings of the present study for implementation.

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# Annex

**ADDIS ABABA UNIVERSITY**
**Faculty of Technology**

**Department of Civil Engineering**

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E - Mail : dceng@ceng.aau.edu.et
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Date: 3-Jul-09

**SUMMARY OF TEST RESULTS**

Project: Msc. Thesis Work
Client: Ato Mulatu Tumoro Rashe

**1-Grain Size Analysis**

See Attachment 1 for grain size distribution Curves

**2-Atterberg Limits & Specific Gravity**

| Sample No. | Liquid Limit,% | Plastic Limit,% | Plastic index,% | Shrinkage Limit,% | Linear Shrinkage,% | Specific Gravity |
|---|---|---|---|---|---|---|
| 1 | 54 | 31 | 23 | 15 | 11.43 | 2.60 |
| 2 | 58 | 31 | 27 | 19 | 14.29 | 2.62 |

See Attachment 2-1 & 2-2 for details

**3-Standard Proctor Compaction & Permeability based on Standard proctor Compaction**

| Sample No. | Existing Moisture Content,% | Optimum Moisture Content, $\omega_{opt}$, [%] | Maximum Dry Density, $\rho_{dry, max}$, [g/cm³] | Maximum Dry Density, $\rho_{dry, max}$, [kN/m³] | Coefficient of Permeability, K [cm/s] |
|---|---|---|---|---|---|
| 1 | 7.91 | 20 | 1.49 | 14.62 | 2.67E-06 |
| 2 | 11.82 | 29.70 | 1.42 | 13.93 | 4.87E-06 |

See Attachment 3 for details

**4-Modified Compaction**

| Sample No. | Existing Moisture Content,% | Optimum Moisture Content, $\omega_{opt}$, [%] | Maximum Dry Density, $\rho_{dry, max}$, [g/cm³] | Maximum Dry Density, $\rho_{dry, max}$, [kN/m³] |
|---|---|---|---|---|
| 1 | 8.39 | 17.7 | 1.55 | 15.21 |
| 2 | 10.91 | 20.50 | 1.50 | 14.72 |

See Attachment 4 for details

Tested by
Yonas Mekonnen

Verified by
Amsalu Gashaye

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**FACULTY OF TECHNOLOGY**
**CIVIL ENGINEERING DEPARTMENT**
**GEOTECHNICAL ENGINEERING LABORATORY**

Attachment 1 = Grain Size Analysis

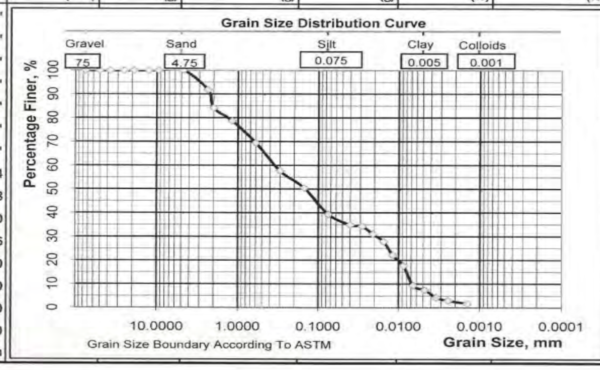
Project: Msc. Thesis Work
Client: Ato Mulatu Tumoro Rashe

Sample No : 1

Wet Sieve Analysis

Total mass of sample, g 2050

| Sieve No | Sieve Opening (mm) | Mass of Sieve (g) | Mass of sieve + Retained soil (g) | Mass of Retained soil (g) | Percentage Retained (%) | Cum. Percentage Retained (%) | Perc. Passing (%) |
|---|---|---|---|---|---|---|---|
| 3'' | | | | | | | 100.0 |
| 2'' | | | | | | | 100.0 |
| 1.5" | | | | | | | 100.0 |
| 1" | | | | | | | 100.0 |
| 3/4'' | | | | | | | 100.0 |
| 1/2" | | | | | | | 100.0 |
| 3.8" | | | | | | | 100.0 |
| No 4 | | | | | | | 100.0 |
| No 8 | | | | | | | 91.8 |
| No 10 | | | | | | | 84.1 |
| No 16 | | | | | | | 78.6 |
| No 30 | | | | | | | 69.4 |
| No 50 | | | | | | | 57.6 |
| No 100 | | | | | | | 50.4 |
| No 200 | | | | | | | 39.3 |
| pan | | | | | | | ------- |




Hydrometer Analysis

Specific Gravity of soil 2.60

Test Temperature, deg.c 20

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 3/4 | 1.0300 | -0.0027 | 1.0273 | 8.36 | 0.01386 | 0.0401 | 88.73 | 34.84 |
| 1 | 1.0295 | -0.0027 | 1.0268 | 8.50 | 0.01386 | 0.0286 | 87.10 | 34.20 |
| 2 | 1.0270 | -0.0027 | 1.0243 | 9.16 | 0.01386 | 0.0210 | 78.98 | 31.01 |
| 4 | 1.0245 | -0.0027 | 1.0218 | 9.82 | 0.01386 | 0.0154 | 70.85 | 27.82 |
| 8 | 1.0200 | -0.0027 | 1.0173 | 11.01 | 0.01386 | 0.0119 | 56.23 | 22.08 |
| 15 | 1.0165 | -0.0027 | 1.0138 | 11.94 | 0.01386 | 0.0087 | 44.85 | 17.61 |
| 30 | 1.0120 | -0.0027 | 1.0093 | 13.13 | 0.01386 | 0.0065 | 30.23 | 11.87 |
| 60 | 1.0100 | -0.0027 | 1.0073 | 13.65 | 0.01386 | 0.0066 | 23.73 | 9.32 |
| 120 | 1.0085 | -0.0027 | 1.0058 | 14.05 | 0.01386 | 0.0047 | 18.85 | 7.40 |
| 240 | 1.0060 | -0.0027 | 1.0033 | 14.71 | 0.01386 | 0.0034 | 10.73 | 4.21 |
| 480 | 1.0050 | -0.0027 | 1.0023 | 14.98 | 0.01386 | 0.0024 | 7.47 | 2.94 |
| 1440 | 1.0040 | -0.0027 | 1.0013 | 15.24 | 0.01386 | 0.0014 | 4.23 | 1.66 |

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Attachment 1 = Grain Size Analysis

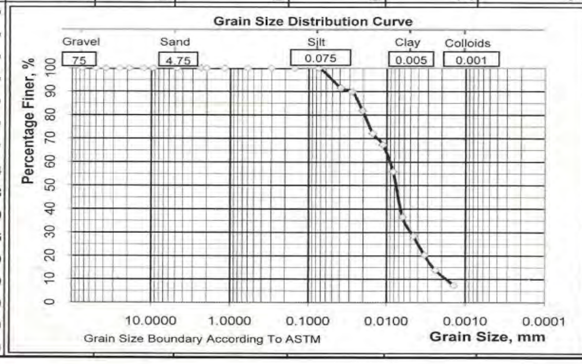
Project: Msc. Thesis Work
Client: Ato Mulatu Tumoro Rashe

Sample No : 2

Wet Sieve Analysis

Total mass of sample, g 500

| Sieve No | Sieve Opening (mm) | Mass of Sieve (g) | Mass of sieve + Retained soil (g) | Mass of Retained soil (g) | Percentage Retained (%) | Cum. Percentage Retained (%) | Perc. Passing (%) |
|---|---|---|---|---|---|---|---|
| 3'' | | | | | | | 100.0 |
| 2'' | | | | | | | 100.0 |
| 1.5" | | | | | | | 100.0 |
| 1" | | | | | | | 100.0 |
| 3/4'' | | | | | | | 100.0 |
| 1/2" | | | | | | | 100.0 |
| 3.8" | | | | | | | 100.0 |
| No 4 | | | | | | | 100.0 |
| No 8 | | | | | | | 100.0 |
| No 10 | | | | | | | 100.0 |
| No 16 | | | | | | | 100.0 |
| No 30 | | | | | | | 100.0 |
| No 50 | | | | | | | 100.0 |
| No 100 | | | | | | | 100.0 |
| No 200 | | | | | | | 100.0 |
| pan | | | | | | | ------- |




Hydrometer Analysis

Specific Gravity of soil 2.62

Test Temperature, deg.c 20

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 3/4 | 1.0310 | -0.0027 | 1.0283 | 8.10 | 0.01376 | 0.0392 | 91.54 | 91.54 |
| 1 | 1.0305 | -0.0027 | 1.0278 | 8.23 | 0.01376 | 0.0279 | 89.92 | 89.92 |
| 2 | 1.0280 | -0.0027 | 1.0253 | 8.89 | 0.01376 | 0.0205 | 81.83 | 81.83 |
| 4 | 1.0250 | -0.0027 | 1.0223 | 9.69 | 0.01376 | 0.0151 | 72.13 | 72.13 |
| 8 | 1.0235 | -0.0027 | 1.0208 | 10.08 | 0.01376 | 0.0113 | 67.28 | 67.28 |
| 15 | 1.0200 | -0.0027 | 1.0173 | 11.01 | 0.01376 | 0.0083 | 55.96 | 55.96 |
| 30 | 1.0165 | -0.0027 | 1.0138 | 11.94 | 0.01376 | 0.0061 | 44.64 | 44.64 |
| 60 | 1.0140 | -0.0027 | 1.0113 | 12.60 | 0.01376 | 0.0063 | 36.55 | 36.55 |
| 120 | 1.0115 | -0.0027 | 1.0088 | 13.26 | 0.01376 | 0.0046 | 28.46 | 28.46 |
| 240 | 1.0090 | -0.0027 | 1.0063 | 13.92 | 0.01376 | 0.0033 | 20.38 | 20.38 |
| 480 | 1.0070 | -0.0027 | 1.0043 | 14.45 | 0.01376 | 0.0024 | 13.91 | 13.91 |
| 1440 | 1.0050 | -0.0027 | 1.0023 | 14.98 | 0.01376 | 0.0014 | 7.44 | 7.44 |

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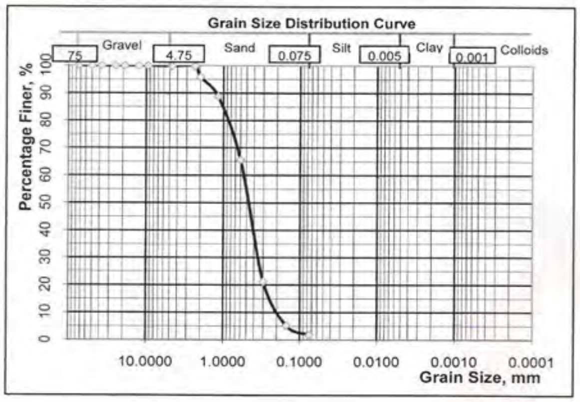
Attachment 1 = Grain Size Analysis

Project: Msc. Thesis Work
Client: Ato Mulatu Tumoro Rashe

Sample No : 3 (Sand)

**Sieve Analysis** *Total mass of sample, g* ***500***

| Sieve No | Sieve Opening (mm) | Mass of Sieve (g) | Mass of sieve + Retained soil (g) | Mass of Retained soil (g) | Percentage Retained (%) | Cum. Percentage Retained (%) | Percentage Passing (%) |
|---|---|---|---|---|---|---|---|
| 3" | 75.0 | 1057.0 | 1057.0 | 0.0 | 0.00 | 0.00 | 100.00 |
| 2" | 50.0 | 1199.0 | 1199.0 | 0.0 | 0.00 | 0.00 | 100.00 |
| 1.5" | 37.5 | 1084.0 | 1084.0 | 0.0 | 0.00 | 0.00 | 100.00 |
| 1" | 25.0 | 1186.0 | 1186.0 | 0.0 | 0.00 | 0.00 | 100.00 |
| 3/4" | 19.0 | 1419.0 | 1419.0 | 0.0 | 0.00 | 0.00 | 100.00 |
| 1/2" | 12.5 | 1185.0 | 1185.0 | 0.0 | 0.00 | 0.00 | 100.00 |
| 3.8" | 9.5 | 1171.0 | 1171.0 | 0.0 | 0.00 | 0.00 | 100.00 |
| No 4 | 4.75 | 567.0 | 568.0 | 1.0 | 0.20 | 0.20 | 99.80 |
| No 8 | 2.36 | 521.0 | 521.0 | 0.0 | 0.00 | 0.20 | 99.80 |
| No 10 | 2 | 558.0 | 578.0 | 20.0 | 4.00 | 4.20 | 95.80 |
| No 16 | 1.18 | 527.0 | 562.0 | 35.0 | 7.00 | 11.20 | 88.80 |
| No 30 | 0.6 | 506.0 | 622.0 | 116.0 | 23.20 | 34.40 | 65.60 |
| No 50 | 0.3 | 478.0 | 700.0 | 222.0 | 44.40 | 78.80 | 21.20 |
| No 100 | 0.15 | 461.0 | 541.0 | 80.0 | 16.00 | 94.80 | 5.20 |
| No 200 | 0.075 | 258.0 | 275.0 | 17.0 | 3.40 | 98.20 | 1.80 |

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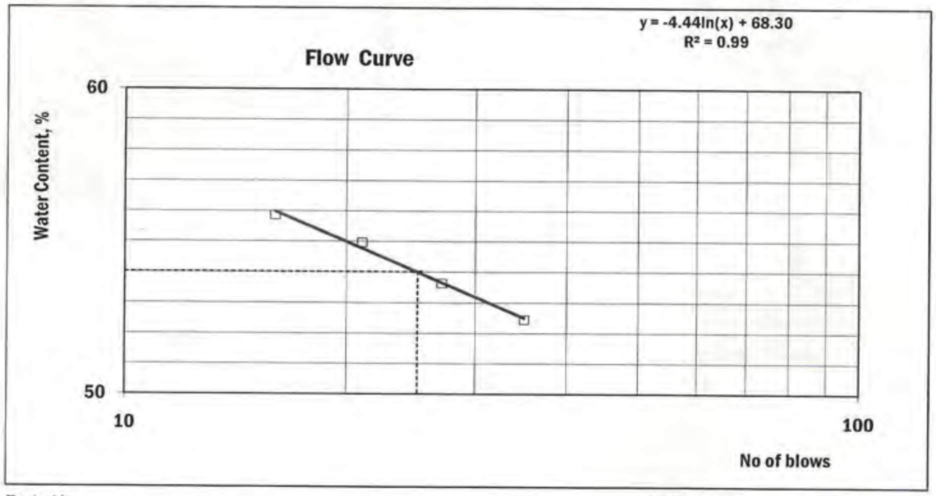
Attachment 2-1 = Liquid Limit and Plastic Limit Test

Project: Msc. Thesis Work
Client: Ato Mulatu Tumoro Rashe

Sample No : 1

| | Liquid Limit | | | | Plastic Limit | |
|---|---|---|---|---|---|---|
| Trial No | 1 | 2 | 3 | 4 | 1 | 2 |
| Container No | C21 | 45 | C2 | D29 | 47 | 32 |
| Mass of container, g | 14.16 | 15.42 | 13.70 | 15.45 | 15.38 | 15.60 |
| Mass of container + Wet soil, g | 35.99 | 32.35 | 34.48 | 32.08 | 16.60 | 17.55 |
| Mass of container + Dry soil, g | 28.48 | 26.44 | 27.11 | 26.12 | 16.31 | 17.08 |
| Mass of water, g | 7.51 | 5.91 | 7.37 | 5.96 | 0.29 | 0.47 |
| Mass of dry soil, g | 14.32 | 11.02 | 13.41 | 10.67 | 0.93 | 1.48 |
| Water content, % | 52.44 | 53.63 | 54.96 | 55.86 | 31.18 | 31.76 |
| No of blows | 35 | 27 | 21 | 16 | ------ | ------ |

Liquid Limit, % = 54 Plastic Limit, % = 31 PI, %= 23

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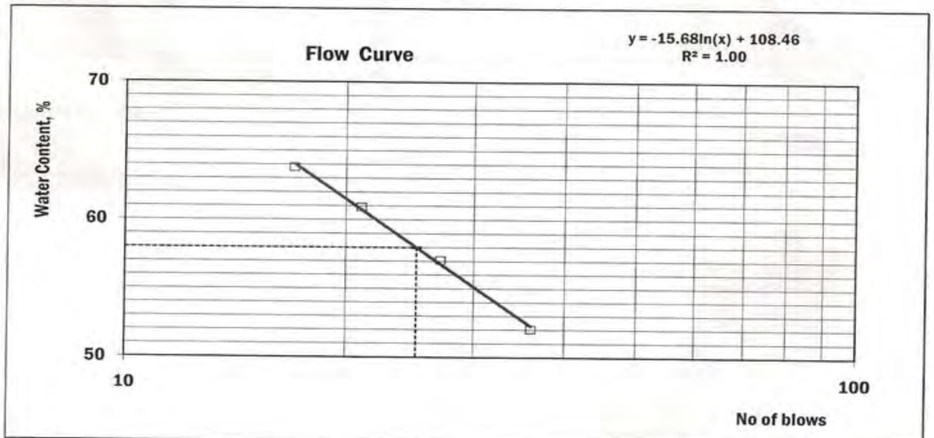
Attachment 2-1 = Liquid Limit and Plastic Limit Test

Project: Msc. Thesis Work
Client: Ato Mulatu Tumoro Rashe

Sample No : 2

| | Liquid Limit | | | | Plastic Limit | |
|---|---|---|---|---|---|---|
| Trial No | 1 | 2 | 3 | 4 | 1 | 2 |
| Container No | 53 | 56 | 26 | D33 | 72 | 35 |
| Mass of container, g | 13.68 | 15.76 | 15.67 | 15.49 | 15.66 | 15.60 |
| Mass of container + Wet soil, g | 29.98 | 34.56 | 36.83 | 34.90 | 17.19 | 17.02 |
| Mass of container + Dry soil, g | 24.40 | 27.73 | 28.82 | 27.34 | 16.83 | 16.69 |
| Mass of water, g | 5.58 | 6.83 | 8.01 | 7.56 | 0.36 | 0.33 |
| Mass of dry soil, g | 10.72 | 11.97 | 13.15 | 11.85 | 1.17 | 1.09 |
| Water content, % | 52.05 | 57.06 | 60.91 | 63.80 | 30.77 | 30.28 |
| No of blows | 36 | 27 | 21 | 17 | ------ | ------ |

Liquid Limit, % = 58 Plastic Limit, % = 31 PI, %= 27

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**Attachment 2-2 =Shrinkage Limit & Linear shrinkageTest**

| | |
|---|---|
| Project: | Msc. Thesis Work |
| Client: | Ato Mulatu Tumoro Rashe |

**Test Pit No:** 1

**Shrinkage Limit**

| Determination No. | 1 | 2 | 3 |
|---|---|---|---|
| Dish No | 1A | 2A | 3A |
| Mass of dish coated with petroleum jelly ,(g) | 24.31 | 24.13 | 24.50 |
| Mass of dish coated with petroleum jelly + wet pat,(g) | 94.67 | 94.79 | 97.37 |
| Mass of dish coated with petroleum + oven-dried soil pat,(g) | 71.24 | 69.53 | 72.58 |
| Mass of oven-dried soil sample,(g) | 46.93 | 45.40 | 48.08 |
| Mass of water in wet soil,(g) | 23.43 | 25.26 | 24.79 |
| Water content of wet soil pat | 0.50 | 0.56 | 0.52 |
| Volume of wet pat ,($cm^3$) | 45.88 | 45.82 | 46.75 |
| Volume of oven-dried soil pat ,($cm^3$) | 28.93 | 28.78 | 28.71 |
| Shrinkage limit,% | 13.81 | 18.11 | 14.03 |
| Average Shrinkage limit,% | | 15 | |

**Linear shrinkage**

Length of semi-cylinderical trough =140mm.

| Determination No. | 1 |
|---|---|
| Semi cylinderical trough No. | A |
| Initial wet legth of soil $L_o$,(mm) | 140 |
| Dry length of soil $L_d$ ,(mm) | 124 |
| Linear Shrinkage LS ,% | 11.43 |

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*Verified by*
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Attachment 2-2 =Shrinkage Limit & Linear shrinkageTest

| | |
|---|---|
| Project: | Msc. Thesis Work |
| Client: | Ato Mulatu Tumoro Rashe |

Test Pit No: 2

Shrinkage Limit

| Determination No. | 1 | 2 | 3 |
|---|---|---|---|
| Dish No | M18 | M3A | M3B |
| Mass of dish coated with petroleum jelly ,(g) | 25.39 | 24.96 | 24.34 |
| Mass of dish coated with petroleum jelly + wet pat,(g) | 96.88 | 98.99 | 99.57 |
| Mass of dish coated with petroleum + oven-dried soil pat,(g) | 70.79 | 72.30 | 71.27 |
| Mass of oven-dried soil sample,(g) | 45.40 | 47.34 | 46.93 |
| Mass of water in wet soil,(g) | 26.09 | 26.69 | 28.30 |
| Water content of wet soil pat | 0.57 | 0.56 | 0.60 |
| Volume of wet pat ,($cm^3$) | 45.28 | 45.69 | 46.84 |
| Volume of oven-dried soil pat ,($cm^3$) | 27.75 | 28.34 | 27.16 |
| Shrinkage limit,% | 18.84 | 19.74 | 18.37 |
| Average Shrinkage limit,% | | 19 | |

Linear shrinkage

Length of semi-cylinderical trough =140mm.

| Determination No. | 1 |
|---|---|
| Semi cylinderical trough No. | A |
| Initial wet legth of soil $L_o$,(mm) | 140 |
| Dry length of soil $L_d$ ,(mm) | 120 |
| Linear Shrinkage LS ,% | 14.29 |

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**Attachment 3 =OMC&MDD Determination**

**Test Method: ASTM D698-91[Using Standard Effort of 600kN-m/m$^3$]**

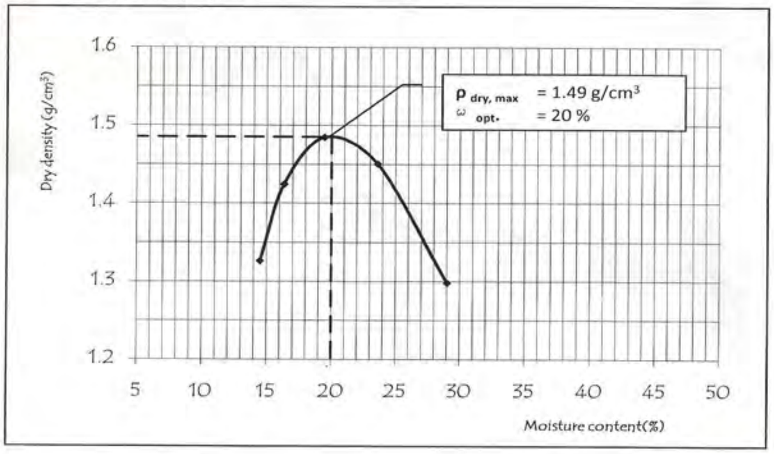
| | |
|---|---|
| Project: | Msc. Thesis Work |
| Client: | Ato Mulatu Tumoro Rashe |

**Sample No. 1**

**Moisture content Vs dry density computation table**

| Determination No. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Mass of Mold, g | 5616 | 5616 | 5616 | 5616 | 5616 |
| Mass of mold + Compacted Soil, g | 7049 | 7180 | 7290 | 7310 | 7200 |
| Mass of Compacted soil, g | 1433 | 1564 | 1674 | 1694 | 1584 |
| Volume of Mold, cm3 | 944 | 944 | 944 | 945 | 946 |
| Bulk density, g/cm3 | 1.52 | 1.66 | 1.77 | 1.79 | 1.67 |
| Water Contenet, % | 14.48 | 16.34 | 19.44 | 23.59 | 29.02 |
| Dry density, g/cm3 | 1.33 | 1.42 | 1.48 | 1.45 | 1.30 |

| | |
|---|---|
| Exsisting Water Content | 7.91 |
| Opt. moisture content, (%)= | 20.0 |
| Max.dry dernsity, (g/cm$^3$) = | 1.49 |

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Attachment 3 =OMC&MDD Determination
Test Method: ASTM D698-91[Using Standard Effort of 600kN-m/m$^3$]

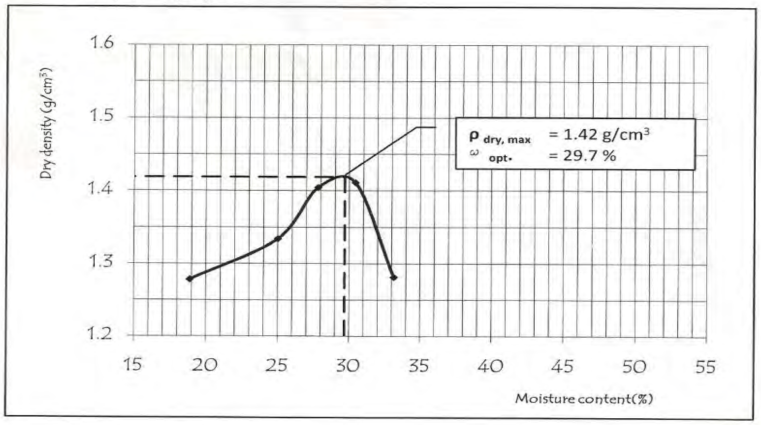
Project: Msc. Thesis Work
Client: Ato Mulatu Tumoro Rashe

Sample No. 2

Moisture content Vs dry density computation table

| Determination No. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Mass of Mold, g | 5616 | 5616 | 5616 | 5616 | 5616 |
| Mass of mold + Compacted Soil, g | 7050 | 7190 | 7310 | 7355 | 7230 |
| Mass of Compacted soil, g | 1434 | 1574 | 1694 | 1739 | 1614 |
| Volume of Mold, cm3 | 944 | 944 | 944 | 945 | 946 |
| Bulk density, g/cm3 | 1.52 | 1.67 | 1.79 | 1.84 | 1.71 |
| Water Contenet, % | 18.87 | 25.00 | 27.80 | 30.43 | 33.16 |
| Dry density, g/cm3 | 1.28 | 1.33 | 1.40 | 1.41 | 1.28 |

Exsisting Water Content 11.82
Opt. moisture content, (%)= 29.7
Max.dry dernsity, (g/cm$^3$) = 1.42




Tested by

Yonas Mekonnen

Verified by

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**Attachment 4 =OMC&MDD Determination**
**Test Method: ASTM D1557-91 [Using Modified Effort of 2700kN-m/m$^3$]**

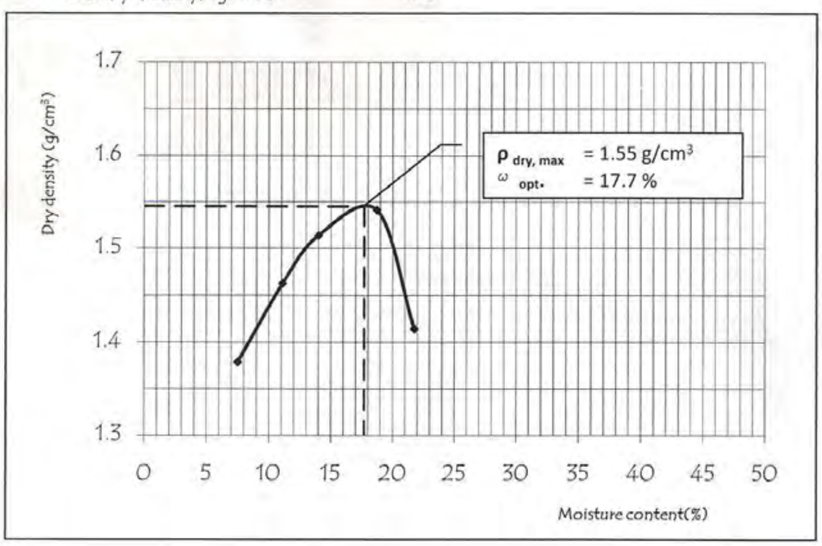
| | |
|---|---|
| Project: | **Msc. Thesis Work** |
| Client: | **Ato Mulatu Tumoro Rashe** |

**Sample No. 1**

**Moisture content Vs dry density computation table**

| Determination No. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Mass of Mold, g | 5641 | 5641 | 5641 | 5641 | 5641 |
| Mass of mold + Compacted Soil, g | 7040 | 7175 | 7270 | 7370 | 7270 |
| Mass of Compacted soil, g | 1399 | 1534 | 1629 | 1729 | 1629 |
| Volume of Mold, cm3 | 944 | 944 | 944 | 945 | 946 |
| Bulk density, g/cm3 | 1.48 | 1.63 | 1.73 | 1.83 | 1.72 |
| Water Contenet, % | 7.50 | 11.11 | 13.99 | 18.72 | 21.76 |
| Dry density, g/cm3 | 1.38 | 1.46 | 1.51 | 1.54 | 1.41 |

| | |
|---|---|
| Exsisting Water Content | 8.39 |
| Opt. moisture content, (%)= | 17.7 |
| Max.dry dernsity, (g/cm$^3$) = | 1.55 |




Tested by

Yonas Mekonnen

Verified by

Amsalu Gashaye

ADDIS ABABA UNIVERSITY
FACULTY OF TECHNOLOGY
CIVIL ENGINEERING DEPARTMENT
GEOTECHNICAL ENGINEERING LABORATORY

Attachment 4 =OMC&MDD Determination
Test Method: ASTM D1557-91 [Using Modified Effort of 2700kN-m/m$^3$]

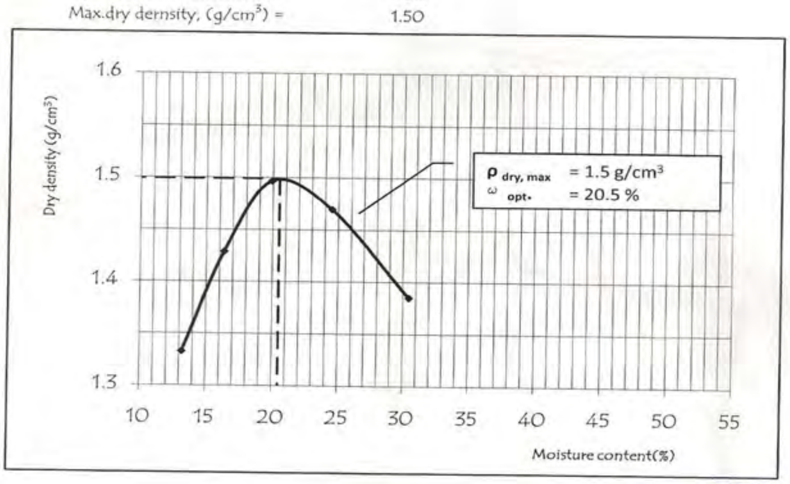
Project: Msc. Thesis Work
Client: Ato Mulatu Tumoro Rashe

Sample No. 2

Moisture content Vs dry density computation table

| Determination No. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Mass of Mold, g | 5641 | 5641 | 5641 | 5641 | 5641 |
| Mass of mold + Compacted Soil, g | 7065 | 7210 | 7335 | 7370 | 7350 |
| Mass of Compacted soil, g | 1424 | 1569 | 1694 | 1729 | 1709 |
| Volume of Mold, cm3 | 944 | 944 | 944 | 945 | 946 |
| Bulk density, g/cm3 | 1.51 | 1.66 | 1.79 | 1.83 | 1.81 |
| Water Contenet, % | 13.21 | 16.36 | 19.91 | 24.52 | 30.46 |
| Dry density, g/cm3 | 1.33 | 1.43 | 1.50 | 1.47 | 1.38 |

Exsisting Water Content 10.91
Opt. moisture content, (%)= 20.5
Max.dry dernsity, (g/cm$^3$) = 1.50




Tested by

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Verified by

Amsalu Gashaye

# DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any university and that all sources of materials used for the thesis have been duly acknowledged.

Candidate: Mulatu Tumoro Rashe

Signature: ____________________

Date of Submisson: ____________________

The thesis has been submitted for examination with my approval as university advisor.

Advisor: Tarun K.Raghuvanshi (Ph.D)

Signature: ____________________

Date of Approval: ____________________