Addis Ababa University
school of Graduate Studies,
Faculty of Science

Engineering Geological Assessment of Granular Material from Weathered Adigrat Sandstone as Filter Material - Special Consideration to Shumbrit Dam, Western Amhara

A Thesis Submitted to
The School of Graduate Studies of Addis Ababa University
In Partial Fulfillment of the Requirements for the
Degree of Master of Science in
Engineering Geology

By

Tamiru Kebede

July 2009

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Abstract

Granular filters are used in embankment dams to prevent impermeable materials from internal erosion, while draining seepage water to prevent saturation of the downstream embankment. Such materials are usually assessed from courses of rivers or streams that contain alluvial sand and gravel materials and their suitability or performance has been evaluated using existing filter design criteria based on particle size ratios. During this work same assessment of a granular material which derived from weathering of the Lower Sandstone unit of the Mesozoic Rock Formation of Ethiopia in protecting red tropical clayey silt soil has been done. Its overall characteristics, especially those relevant to filter design, have been studied. It is also compared with respect to an alluvial source, found at relatively distant place from research site. The geometrical criteria have been mainly checked using the formulas and recommendations proposed by many scholars and standards. In addition to this, the final gradation or grain size distribution of a suitable filter material has been prepared based on the gradation of the base material following the design procedures prepared by United States Soil Conservation Service (USSCS).

The residual granular material, which was sampled and analyzed for grain size distribution, nearly satisfies most of the filter criteria, but it is a little bit finer. Of the various criteria available, the USSCS method and Sherard recommendations have been given more emphasis as they consider the type of base material and accordingly proposed different approaches and ratios for design of the filter. The gradation curve for the average residual filter (averaging three samples from different localities) prepared and also checked with the empirical criteria and design rules together with one alluvial soil from the distant source. The assessment result (especially USSCS method) indicates that the residual material almost satisfies the geometrical criteria, except it becomes a little bit finer. Whereas, the average residual soil and the alluvial sediment satisfies completely both requirements of filtration and draining. As to the other characteristics of the filter, all materials (residual and alluvial) have satisfactory quality; the grains of the residual sand are dominated with quartz, while the alluvial is fragments of basaltic rocks.

The behaviour of the base soil, which is related to its dispersive nature, also examined in a laboratory test. The result indicates that the base soil can be categorized as non-dispersive.

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Chapter I - Introduction

1.1 Background

Systematic study, design and construction of embankment dams for water harvesting purposes requires a thorough understanding of the geological, engineering geological and geotechnical properties of foundation and construction soils/rocks. Soils are the main natural construction materials used for the various zones of the embankment dam body, more than any other natural or fabricated ones like rock, concrete, iron bars, etc. Naturally, soils are formed from insitu weathering of rocks that underlain a given geological environment. These soils may either remain where they are formed (residual soils) or transported by various agents (water, wind, or glaciers).

Embankment dams are generally of two types depending on the dominant materials used for their construction. These are earth fill and rock-fill dams. Further, earth fill dams are classified in to homogeneous and zoned types based on whether they are made up of mainly one kind or various kinds of materials placed systematically, respectively. In the design and ultimately for safety and stability of embankment dams, suitable quality and properly placed or designed natural construction materials are two of the basic considerations. It is; however, equally important to consider or assess sufficient quantity of the various required materials within economic distance from the proposed dam site (Bharat Singh, 1995).

For safe design of embankment dams certain criteria must be satisfied. These criteria have evolved from the study of the causes of failures of dams, elsewhere, in past. An exhaustive list of dams which had suffered damage or had failed up to 1950 was prepared by Middlebrooks in 1953 and has been cited by Sherard (Bharat Singh, 1995).

According to the list, the causes of failure could be overtopping (30%), seepage effects, piping and softening (25%), slope slides (15%), conduit leakage (13%), damage to slope paving (5%), miscellaneous (7%) and other unknown reasons (5%). The criteria for safe design have to be specified that they cover all possible causes of failure. The main criteria that are commonly accepted for safe design of embankment dams include;

- There should be no risk of overtopping. The most important aspect of this criterion is estimation of the design flood and provision of adequate spillway.

- The seepage line should be well within the downstream face of the dam section. If the dam section is homogeneous and no drainage arrangements are made, seepage through dam body is going to emerge on the downstream face. This results in ósloughingô or softening of the downstream face and may lead to local toe failure. The failure may progressively develop upwards. This can be safeguarded against by providing a free draining zone on the downstream face or by intercepting the seepage inside the dam section by internal drainage.
- There should be no possibility of piping through the embankment or foundations. In the dam section the main protection against piping is provided by filters which prevent migration of soil particles with seepage water. In the case of pervious foundations, seepage control measures comprising curtailment of seepage on the one hand and a safe, filter - protected exist on the other are used to safeguard against piping failure.

As indicated in the previous paragraphs, one of the main aspect that require due considerations in the design consideration of embankment dams is seepage and its control mechanisms. A sufficiently large percentage of earth dam failures reported by Sherard et al. (1984) was due to seepage. Water seeping under pressure through soil voids is accompanied by a mechanical drag on the soil particles. When these drag forces exceed the resistive forces of the soil grains, movement of the grains may take place. It is of fundamental importance to limit the seepage through earth dams not only to keep the water loss within acceptable limits, but also to take adequate control measures to ensure the safety of the dam. The adverse effects of seepage can be divided into two categories: migration of soil particles resulting in piping, and embankment failure caused by saturation forces. The first category is due to lack of filter protection or faulty filter through which soil grains can pass. Some other reasons may be poor compaction, cracks in impermeable soil due to differential settlements, and leaching of dispersive soils leading to deflocculation.

Seepage through embankments and its foundations can be controlled by either preventive or curative approaches. Usually these approaches are combined in earth dam design practice. The former approach involves keeping the water out in so far as possible or reduction in quantity of seepage. Some of the methods in the approach are impermeable zone for embankment and cut-off trenches and grout curtains in foundation. The second approach strives to provide a safe outlet to water which has entered in spite of the measures taken in the first approach. The most known method in this category is a drainage system such that seepage forces will not be able to cause soil migration (filters). In addition, the position or direction of the drainage systems will be such that they cannot cause embankment sliding or foundation blow out (Bharat Singh, 1995).

Accordingly, filter materials that can be used for seepage control within the embankment and/or foundation need to be explored. Generally, in the engineering geological exploration of required natural construction materials for embankment dam, both quantity and quality considerations are important. In case of filter materials; however, the quality aspect is more important than the quantity as the stability of the dam depends mainly on seepage force control mechanisms.

Many engineering structures require granular filters to control erosion due to the damaging action of seepage and groundwater. Filters are provided to prevent erosion of base soils, to provide adequate drainage without excessive build-up pressure and eliminate the occurrence of clogging and piping. Base soil is defined as a layer of soil within an embankment dam to form an impermeable zone. It may be of natural materials such as clay or silt or prepared materials such as cement, asphaltic concrete, plastic or rubber. A granular filter is typically sand or sandy gravel. It is generally considered that failure of a dam can be prevented if filters are provided according to modern design criteria and well constructed practicies (Sherard and Dunnigan 1989; Peck, 1990).

In other words, almost all dams have some seepage as the impounded water seeks paths of least resistance through the dam and its foundation. Most of current granular dam filters design guidelines in practice are based on the experimental investigations and empirical reasoning. Filters fail when such criteria are often too coarse or too fine (over conservative). If filters are too coarse, erosion will continue which may result in failure. Over-conservative filters on the other hand result in uneconomical design. There may be other problems in filter performance if the materials are segregated during placement or construction.

Filters are used in different locations within a dam, the downstream filter being the most critical. The filters control internal erosion by retaining eroded particles from the dam impermeable fill, while controlling the seepage flow and forming a drainage layer for the purpose of preventing saturation of downstream fill.

For filters having an impermeable fill (base) of cohesive soils, designers have applied design principles originally developed for cohesionless soils. This has resulted in over- conservative design, as cohesive soils provide resistance to erosion (Sherard et al. 1984). Vaughan (2000) on the other hand suggested that design rules applicable for cohesionless soils were not conservative for use in cohesive soils for two reasons. The cohesive force in clays does not prevent filter failure; instead it allows cracks to stay open while their walls are eroded, sometimes even by a small flow of water. Moreover, due to segregation, self-filtration does not protect loss of materials and fine fraction gets washed through the filter.

In order to investigate the variation of filter performance, two different conditions in cohesive impermeable fill base soil can be considered; the base is intact and no cracks present, and the soil has developed a settlement crack. In this study, the first condition is considered as the dam is founded almost entirely on uniform rock foundation (see Chapter 4). In the case of intact base soil, the required seepage condition (hydraulic gradient) is significantly high for erosion to occur. In this situation filter design becomes over-conservative if carried out in line with the criteria for cohesionless soils. However, filter performance varies significantly when a crack develops in cohesive base soil as a result of either foundation settlement, or shrinkage due to the presence of vegetation. It takes a smaller seepage force (lower hydraulic gradient) to erode particles through filter pores, resulting in piping failure. Sometimes in cases where segregation occurs, coarse particles settle near the walls of cracks and only finer particles arrive at the base filter interface, which does not allow self-filtration to activate.

1.2 Research Area

In this particular research the suitability or quality of sand obtained from both slightly weathered sandstone and conventional streambed will be assessed for filter material of an earth fill dam identified in East Gojam zone of Amhara National Regional State. The area is relatively elevated part of the Western Highlands of Ethiopia, where sand from streams/ rivers is scarce. Most of the nearby streams in the area are at their upper or younger stages that it is difficult to get sufficient quantity and quality of granular (sand and gravels) sediments that can be used for filter materials and even for fine aggregate within their beds. The streamøs bed is covered either with rock outcrops or boulders. Due to this nature of the streams, the local people engaged in small scale construction activities are also using sand from weathered and crushed sandstone, which is exposed in the nearby areas. The sandstone is part of the Mesozoic litho-stratigraphy of Ethiopia classified as Adigrat or Lower Sandstone unit. It covers sufficiently large areas in the vicinity of the research site. It is believed that this sandstone can be one option for source for filter material that can be used in the embankment section of the homogeneous earth fill dam proposed within the zone at

Debre Eliase Woreda.

The dam is proposed on a stream called Shumbrit found within the Lower Jedeb basin, which is one of the main rivers in the zone that drains to Abay (Blue Nile) River. For this particular dam and probably for any other sites identified in the area, source areas for sand and gravel materials have been proposed from the weathered Sandstone unit and stream bed. The first source area is found at relatively closer distance to the dam site than any stream/ river source areas that could also be used. Here the material is found as residual soil and/or crushed soil/aggregate from the weathered sandstone. Streams that can deliver filter material are, on the other hand, located at distant areas and their quantity is limited as shared by many construction demands in the area. The alluvial sediment grains are originated from mainly volcanic rocks, particularly from basaltic rocks, which are part of the Cenozoic Formation of the Central Western Highlands of Ethiopia. On the other hand, quartz or silica minerals dominate the sand grains from the weathered sandstone unit.

1.3 Significance of the Research

In this research the two sources for filter materials will be investigated, particularly for quality by various empirical and mainly geometrical filter criteria, like Terzaghi, USBR, India Standard and others with respect to the homogeneous fill material. In addition to this the filter materials would be evaluated for their physical and chemical properties that may contribute for deterioration during the filter service times. On the other hand the physical, chemical and other geotechnical properties of the fill material that may play important role in relation to erosion resistance would also be evaluated. Finally, the chemistry of the water that will be stored in the reservoir and expected to seep through the embankment/ foundation, and have contact to the filter, will be analyzed for its influence on the degradation of the filter material and influence on the impermeable fill material.

This research has two basic significances, particularly for design engineers and geologists/ engineering geologists who are involved in the design and exploration activities of embankment dams in the region. The first is to give general idea about the relative suitability or quality of the filter material obtained from two source areas; firstly, from in-situ weathered Sandstone/ crushed sandstone and secondly alluvial sediment. The second is to generate actual design input data with respect to filter material quality and core material gradation or soil class for this particular project. In addition to this, the result of the research can be used as an initial guide for the selection of which one of the two types of filter materials for a particular project proposed or planned in the vicinity of the area and any other similar places of the region.

1.4 Research Objectives

The main objective of the research is to characterize the Lower Sandstone unit exposed nearby to the study area from its degree of weathering and resulting soil type(s), and their consequent quality for filter material for dominant fine soil (reddish brown silty clay soil). Its quality is compared with alluvial origin sand soil, which can also be used as filter material, located/ proposed at relatively distant source area(s). Besides, the engineering geological/ geotechnical characterization, relevant to filter design, of the impermeable homogeneous fill soil and foundation material will be done so as to apply various filter criteria or design.

This research project has the following specific objectives:-

- Generate a general textural, gradational and mineralogical characteristic data of soils derived from the weathered (at various degrees) or crushed portion of the lower Sandstone Formation of the study area.

- Characterize, similarly, the alluvial sediments or sand deposits found in the beds of some streams/ rivers of the area which could be proposed as source to filter or sand material.

- Generate some design input data for the particular research project site about filter and homogeneous fill material, and recommend some solutions for their deficient quality (if any).

- Characterize the impervious fill zone material and the foundation material (soil part) of the dam for its gradation, index and engineering properties, and relation to the proposed filter material(s).

- Besides attempts will also be made to assess the mineralogical and chemical properties of the proposed filter material, fill soil and foundation material, so as to assess their general suitability in relation to filter design.

1.5 Research Methodology and Approach

To fulfill the objectives of this study, the following systematic research methodology has been followed;

1.5.1 Data Collection

Both secondary and primary data have been used to characterize the Lower Sandstone unit. Various available secondary data sources related to the rock unit and also resulting soils and other soils types (found in the study area and the vicinity) required for embankment construction has been collected. In addition data sources that reveal the general condition of the study area have been gathered. These include the following sources;

- Geological Maps of the area of scale 1: 2, 000,000
- Geological reports, dam design documents, drawings and existing laboratory reports about the research area and nearby places
- Topographic map of the area at 1: 50,000 scale
- Books, journals, articles, and other unpublished documents related to filter materials and design procedures, and geological condition of the area

Primary data have been collected and results generated concerning the required engineering and index properties of the various soil types derived from the Lower Sandstone and stream/ river sediments that can be possible sources for filter, and from impermeable embankment soils. For these the following investigation techniques have been implemented:-

- Test pitting and auguring at dam site and borrow areas for impermeable embankment fill soil
- Disturbed sampling from the proposed borrow areas for the fill and filter/fine aggregate materials
- Geotechnical laboratory testing of soils secured from proposed borrow areas
- Mineralogical studies (visual) of Soils and Rocks
- Chemical studies of soils and water

Concerning subsurface explorations at the dam site, about four hand-dug test pits (usually helpful to investigate to maximum depth of 5m) and an auger hole using an augur (which is capable of boring to depth of 4.5 m in fine moist soil) were excavated and bored along the proposed dam axis of the projects. The designation or description of these exploratory holes can be referred in Table1.1 below.

On the contrary, only augur holes were utilized to characterize borrow areas for the impermeable fill soil. A total of thirteen augur holes were bored within two proposed borrow areas (Borrow Area -1 and -2) located within the reservoir area of the project. The first eleven holes were bored in the Borrow Area-1, main source (See Chapter 4), and they were located in rectangular grid system on the right side of the reservoir area. Whereas, the last two were bored randomly within second borrow area proposed at left portion of the reservoir. The general description of the holes is presented in Table 1.2.

Table 1.1 General Designations of Subsurface Exploratory Holes at Dam Site

S/N	Exploratory Hole Name	Depth(m)	Location	Remark
1	SHFOTP-1	3.5	Right Abutment slope,	Test Pit
2	SHFOTP-2	3	Right Abutment feet	Test Pit
3	SHFOTP-3	1.5	Left Abutment feet	Test Pit
4	SHFOTP-4	1	Left Abutment slope	Test Pit
5	SHFOAH-1	2	Left valley floor	Augur Hole

Table 1.2 General description of Exploratory Augur Holes Bored at Fill Material Borrow Areas

S/N	Augur Hole Name	Depth (m)	Location	Remark
1	SHBOAH-1	4.3	Borrow Area 1, right portion of the reservoir area	Located in rectangular grid system of 70 by 50meter interval commencing from 50m upstream of the right peak point of dam axis.
2	SHBOAH-2	2.2		
3	SHBOAH-3	3.5		
4	SHBOAH-4	3.0		
5	SHBOAH-5	2.5		
6	SHBOAH-6	4.3		
7	SHBOAH-7	3.6		
8	SHBOAH-8	3.0		
9	SHBOAH-9	3.5		
10	SHBOAH-10	3.2		
11	SHBOAH-11	3.4		
12	SHBOAH-12	3.0	Borrow area-2, left portion of the reservoir	Randomly spaced
13	SHBOAH-13	3.2		

The geological logs of all exploratory holes are presented as Annexure ï 1.

1.5.2 Soil Sampling and Laboratory Testing

To achieve the main objective of the research, soil samples were collected and analyzed in laboratory to determine relevant geotechnical properties or parameters. The samples were taken from proposed borrow areas for homogeneous fill and filter zones. Two samples were from the former and four from the later borrow areas were taken. In addition to soil, a water sample was secured from the stream flow for laboratory analysis. The relevant designation of the samples along with requested and performed laboratory tests is presented in Table-1.3.

The test results of all samples are presented as Annexure-2.

Table 1.3 Soil and Water Samples Designations

S/N	Sample No.	Sample Type	Location	Test Requested/Performed	Remark
1	SHHO-1	Fine Soil	Homogeneous Borrow Area-1, left Reservoir	Grain Size Analysis Atterberg Limits Dispersivity	
2	SHHO-2	Fine Soil	Homogeneous Borrow Area-2, right Reservoir	Grain Size Analysis Atterberg Limits Dispersivity	
3	SHFL-1	Granular Soil	Residual filter source area-1	Grain Size Analysis	
4	SHFL-2	Granular Soil	Residual filter source area-2	Grain Size Analysis	
5	SHFL-3	Granular Soil	Residual filter source area-3	Grain Size Analysis	
6	SHFL-4B	Granular Soil	Alluvial filter source area	Grain Size Analysis	

1.5.3 Data Analysis and Synthesis/ Interpretation

For the analysis of the collected data, two basic methods or procedures have been implemented to define the quality of the various sources of filter materials and homogeneous fill soil. These are;

i. Grain size and gradation analysis for both filter and protected soil;
ii. Preparation of filter limits based on the gradation of the homogeneous fill material or base soil (according to USSCS design procedures);
iii. Checking with the various spot filter criteria like Terzaghi;s, USBR, Indian Standard, US Soil Conservation Services (SCS) and, Sherard criteria and recommendations;
iv. Characterize the mineralogical and chemical composition or suitability of the filter, fill and foundation material (soil portion) with appropriate standards.

v. Finally, the ground water and river water chemistry particularly for exchangeable sodium percentageô and corrosivity will be analyzed and the impact on filter material deterioration described.

vi. Prepare a report about all research activities and results.

1.6 Limitation of the Research

Conducting this research requires thorough understanding of the theoretical or empirical or any other experimental activities regarding filter design for impermeable cohesive base soil. Availability and access to such previous works is main constraint, especially recent design procedures or standards. Most of the available literatures or previous works in the area of filter characterizations and design are based on experiments conducted in other countries, and totally there is no local material or existing works in this respect. It is hence the research which is based on totally on available literatures and criteria developed in other countries, like United States of America. In addition to absence of domestic design criteria, there is other limitation regarding data analysis and interpretation. This research mainly focuses on characterization of the granular soil derived from the Lower Sandstone unit for its relative suitability as filter to alluvial granular sediment. The characterization is mainly based on geometrical, physical and chemical factors, and not includes the hydraulic factors due to lack of well indicated relevant information or data.

1.7 Presentation Schemes

The results of the research work are presented in this report. The chapter outlines of the report and main issues discussed are indicated as follow:-

Chapter 2 is dedicated to give an overview about the project area. Here the area is described in terms of its location & accessibility, type of proposed engineering structure & design considerations and other salient features of the research project.

Chapter 3 presents the geological, structural and physiographical setting of the region and the area. In the section, the general stratigraphy of the various rock formations underlying the region is discussed. In addition to this, the main rock units that cover and underlain the specific project area are described.

Chapter 4 describes all engineering geological aspects of the project site. The foundation condition of the dam site is defined and all observed/explored rock and/or soil units are explained in and their geotechnical characteristics are determined. In addition to these, all required natural construction materials are described for their quantity, quality and accessibility & location.

Chapter 5 is a review of literatures about filtration of cohesive soil through granular filters, and it contains a summary of available or existing filter design guidelines (empirical) applicable to cohesive soils. Factors influencing filter effectiveness are discussed. In addition to this other factors that are recommended to be considered while designing filters for embankment base soil are also described. These include the geometrical, physical, chemical and compaction characteristics of the filter, and also the protected base soil.

Chapter 6 presents data collections, test results, synthesis and interpretations pertaining to filter material, base soil, and both surface & groundwater in relation to filter design for the project site. Here, all data required for the physical, chemical, and geotechnical characterization of the proposed filter materials are well indicated. The protected base soil is described for its index and dispersivity properties. Surface water from stream flow and groundwater from nearby springs are also analyzed for chemical and physical properties and their impact on the deterioration or long time effect on filter materials are emphasized.

Chapter 7 Sets Out conclusions and recommendations based on the findings of the current study. The chapter also describes limitations and recommendations for further investigations of filter design with respect to other types of cohesive soils. References used for the completion of this study are listed thereafter.

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Chapter II - Overview of the Project Area

2.1 Preamble

Food security in the country is presently a major challenge. Tackling this problem is considered as main goal for the Amhara National Regional State (ANRS). To achieve the goal one of the strategies followed by the government is water harvesting at different scales; from household level storage ponds/ tanks to small scale or micro earth dams that benefit a community, and presently even larger projects. Since 1995 GC (1988EC), several such small earth dams have been studied, designed and implemented in the various woredas of the region. These dams range from 10 to 25 m in height and 200 to 500 m crest length. Similar types of micro earth fill dams are also being studied, designed and implemented in present in the different areas of the region, and the research project, Shumbrit homogeneous fill dam, is one of them.

2.2 Location and Accessibility

The research area is located in East Gojam zone, in Debre Elias woreda of ANRS. The dam site is found within the Blue Nile river basin at the lower part of Jedeb river, which is one of the main tributaries of Abay (Blue Nile) in the zone. Specifically, the dam is proposed along a small stream called Shumbrit, left tributary of Jedeb River. The dam site and reservoir area lie at borderline between three peasant association (PA) kebeles namely Yegedad, Densee and Yewober PA. The project area is defined by Geographic co-ordinates (UTM) of 11473000m N and 0324999.95m E, at damsite. The project site is found at about 270 Km from Bahir Dar city, capital of ANRS. Of this, 255 Km is all weather asphalt and gravel road until Elias town (woreda capital). From the town it is necessary to follow a dry weather clay road in the North West for about 13 Km that leads to a locality called Yegedad Micheal church. Finally, to reach the dam site one has to walk through a foot path for about 2 km along gentle to moderate slope or topography (Fig.2.1).

2.3 Proposed Engineering Structure

Based on the types and quantity of locally available natural construction materials, especially embankment fill soils, homogeneous earth fill dam type is proposed. In the immediate vicinity of the site there is relatively large quantity of impervious fine soil (clay to silty clay texture). Here, granular and free draining soil that can be used for shell or casing material is very scarce that zoned type of dam is uneconomical. The dam has crest length of about 312.5 m and maximum height of about 13 m with a free board of 2 m (Fig.2.2). With these dimensions, the dam will inundate (reservoir area) a land of about 35 hectare, which is almost entirely grazing and bush land.

Fig. 2.1 Location Map of Research Project Site

For removal of surplus run off that is excess of the reservoir capacity, a spillway is also proposed on the left abutment side of the dam. It is an Ogee type spillway at the control section and with natural ground control of the left side and guide wall at the right part.

The dam is proposed mainly for irrigation purpose, though it may help also for watering livestock. In this project a net of about 425 hectare of farmland is going to be irrigated.

The project stream watershed size above the dam axis is estimated to be about 15 Km^2. The stream drainage basin has longest length of about 5 km. It has slope range of 0.4 to 2.84% (Biruk Alemayhu, 2008).

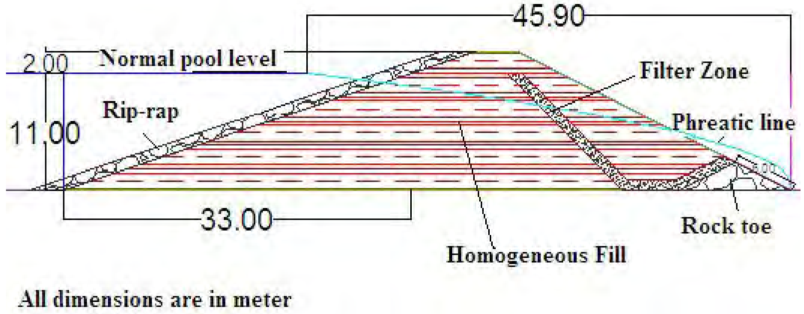

Fig. 2.2 Proposed Dam Section

2.4 Physiography and Climate

Ethiopia can be, widely, divided into four major physiographic regions. These are the Northwestern plateau, Southeastern Plateau, the Main Ethiopia Rift, and Afar Depression. The research area is found near to the central portion of the Northwestern plateau. This landmass is characterized mainly by rolling mountains associated with deep valleys at some places, like the Blue Nile Gorge. It is highly dissected at many places with surface drainages, which generally shows dendritic patterns. The drainage system of the area is dominantly part of the Blue Nile basin, though there is minor portion of the Awash basin in the extreme east. Wide flat plains bounded by the rolling mountains are not uncommon, forming wide farmlands and grazing fields.

The north western plateau of the country is characterized by having relatively heavy rainfall. This area has a mean annual rainfall up to 1200 mm, though it is variable, becomes higher in the south western portion. The central portion of the plateau receives mean annual rainfall of about 1000 mm. The area is categorized into hot and dry environment, which has a daily mean temperature that ranges from 20^0 C to 25^0 C.

The research project stream has a catchment area of about 15 km^2. Most part of the watershed has gentle to moderate slope. It is covered mainly with farmlands, though wide grazing lands and swamps are not uncommon especially following the drainage boarders. Beside to these major land covers, limited extent natural bush lands and areas covered with homestead eucalyptus trees are observed. There are three drainage lines above the dam site, which form nearly denderitic pattern.

Chapter 3 - Geological Setting

3.1 Regional Geology

The bedrock geology of Ethiopia embraces a great variety of rock types within a wide age range (Mohr 1971, Kazmin 1972, Mengesh et al. 1996). Precambrian metamorphic and igneous rocks cover 23% of the country and include rocks such as gneiss, schist, marbles, granitoids and soapstone. Thick successions of Palaeozoic and Mesozoic sediments (25%) overlie the Precambrian. These include limestone and sandstone. A large part of the country is covered by Tertiary and Quaternary volcanic rocks (44%), and in these areas, basalts, tuffs and ignimbrites are extensively observed. The Precambrian rocks can be divided into a Lower, Middle and Upper Complex (Kazmin 1972). The Lower Complex comprises possibly Archaean gneisses, migmatites and granitoids, forming a basement to the volcano-sedimentary successions of the Middle and Upper Proterozoic Complexes.

The Late Palaeozoic(?) to Mesozoic sedimentary rocks of Ethiopia were deposited during a regional transgression of the Indian Ocean, followed by Late Mesozoic uplift and erosion (Kazmin 1972). In the western-central part of the country, the lower portion of the Mesozoic succession is represented by the *Adigrat Sandstone* of Triassic to Jurassic age. This rests unconformably on the Precambrian basement, or slightly unconformably on locally developed Palaeozoic sedimentary rocks. The Adigrat sandstone varies in thickness from a few to 800 m, and consists essentially of red to yellow, well-sorted quartz sandstone. The upper part, however, is in places calcareous, particularly close to the transition to the overlying limestones of the *Antalo Group*. Thick limestones are developed in the middle part of this group. These vary from near-shore, oolithic limestones, through fossiliferous, pale limestone and marl to black limestones deposited in deeper water.

A large portion of Central Ethiopia is covered by volcanic rocks, ranging from the extensive plateau basalts within the Early to Middle Tertiary Trap Series, to Quaternary lavas, tuffs and ignimbrite.

The Blue Nile Gorge (the river Abay Gorge as locally known) contains a complete stratigraphy of the Ethiopian geology starting with a Precambrian rock unit at the base overlain by a thick sequence of Mesozoic sediments caped by the tertiary trap basalts making up the Ethiopian plateau (A. Mogessie, and et. als, 2001).

The basement up on which all younger formation were deposited contains the oldest rocks in the country, the Precambrian, with ages of over 600million years. The Precambrian contains a wide variety of sedimentary, volcanic and intrusive rocks which have been metamorphosed to varying degrees. At the end of the Precambrian time uplift occurred, which was followed by a long period of degradation (weathering), erosion and deposition. Sediments which were deposited during the palaeozoic time interval, which lasted 375 million years, have been largely removed by erosion, except for shales and deposits partly of glacial origin laid down in northern Ethiopia towards the end of this period. Subsidence occurred in the Mesozoic, which began some 225 million years ago, and a shallow sea spread initially over the south east part of Ethiopia and then extended farther north and west as the land continued to subside. As a consequence sandstone was deposited. Deposition of mudstone and limestone followed as the depth of water increased.

In western Ethiopia sedimentation ended with the deposition of clay, silt, sand and conglomerate brought in from the land as the sea receded due to due to uplift of the land mass. In the southeast gypsum and anhydrite were precipitated on inter tidal flats. Again there was a fresh invasion of the sea in the south-east in Late Mesozoic times during which the sequence of sedimentation was repeated in the south east in the Ogaden during the Tertiary period. It ended with the deposition of conglomerates, sandstones and mudstones with some interbeded marls, and finally erosion as the area was uplifted.

Extensive fracturing occurred early in the Cenozoic, the earliest rocks of which are dated 65 million years, although major displacement along the fault systems which approximates to the alignment of the Red Sea, Gulf of Aden and East African rift system did not occur until later in the Tertiary. Faulting was accompanied by widespread volcanic activity and the two processes, which are partly related, have largely determined the form of the landscape in the western half of Ethiopia and in the Afar Depression.

The outpouring of vast quantities of basaltic lave over the western half of the country was accompanied by, and alternated with, the eruption of large amounts of ash and coarser fragmental material, forming the Trap Series (Kazmin, 1975).

The Northwestern and Southeastern plateaus of Ethiopia are separated by the Rift Valley. Along the western margin of the Northwestern Plateau in the Blue Nile Gorge, a 2000m section of Mesozoic strata capped by massive Tertiary volcanic is exposed. The altitude of the plateau ranges from 3000 to 4000m in the northeast and around 1500m in the south west, with an average height between 1800 to 2500m. Between the Ordovician and Early Mesozoic a system of northerly as well as northwesterly trending troughs were filled with continental sediments. Early Jurassic marine sediments filled these troughs and at Late Jurassic time, the transgressive sea was widespread over a part of Ethiopia. Regression happened at the end of the Jurassic (Getaneh, 1991).

Mesozoic sediments are widely deposited in Ethiopia during a continuous subsiding period of the land and migration of the sea from east, in the Ogaden towards the west and north covering the central part and northern areas of the country. Today a large part of these Mesozoic sediments are exposed on the Eastern Ogaden, central dissected plateau areas in the Blue Nile river basin and in northern Tigray around Mekele.

As part of the Northwestern Plateau, the Blue Nile Basin covers 204000 square kilometers. The typical Mesozoic succession of the basin is about 1200m thick and includes from bottom to top five formations:-

(i) Lower Sandstone or Adigrat Sandstone (Triassic),
(ii) Gohatsion Formation or Abay Beds,
(iii) Antalo Limestone (Jurassic),
(iv) Muddy Sandstone (Mugher Sandstone) and
(v) Upper Sandstone (Cretaceous)

The sediments are overlain by thick massive flood lavas, mainly basalt, which are generally Post-Oligocene in age and reach a maximum thickness of 5500 meters. (Scan the Stratigraphic column of this document at page 48, File: Mesozoic Units)

The Lower Sandstone unit unconformably overlies the basement and in some places Paleozoic continental sediments. The thickness ranges from about 100m to 700m; in the Abay river Basin. This unit is formed by several layers with the thickness of the layers varying from 30cm at the bottom to 1m near the top. They appear as fine grained sandstones intercalated with reddish shales and siltstones, mudstones and beds of conglomerates. Medium-to coarse-grained sandstone including planar cross-bedding structures are characteristic. The boundary with the overlaying gypsum-shale unit is transitional, and consists of inter-bedded sandstone, siltstone, mudstone and shales at its lower part.

Gohatsion Formation, at its lower part represented by greenish, grey or brown colored dolostones and shales. The dolostones are characterized by flute casts at the base of beds, ripples and falser bedding at the lower part and parallel lamination at the top. Probably they represent deposits in shallow ponds and lagoons. At the top occur mudstones with thin layers of angular quartz.

The bottom of Antalo Limestone unit is characterized by fossiliferous and burrowed mudstone and oolitic limestone. Silty limestone with very thin marl layers follow. The upper part is formed massive limestone. Total thickness reaches about 180 m.

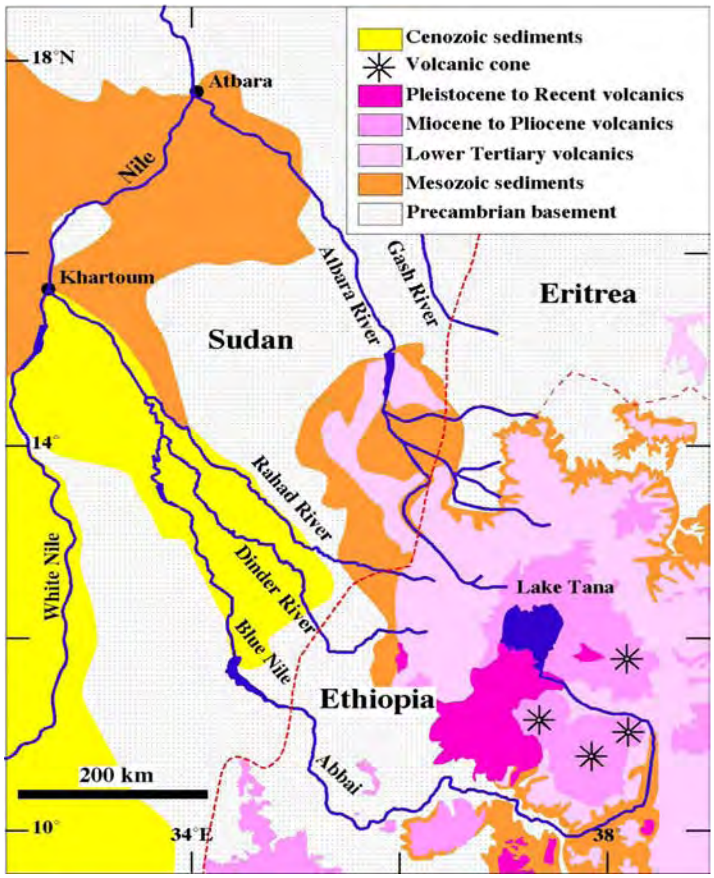

Fig. 3.1 Regional Geology Map of North Western Plateau of Ethiopia

The Muddy Sandstone Formation is not found in the Abay section, but is exposed in the canyons of Mugher, Ega, Wodem, Dersena, Beressa, Adabai, Zhema, Wenchit and Chennli rivers. Alternating gypsum, dolomite and shale make up the lower part. The upper part of the unit is composed of thick vari-colored mudstone.

The Upper Sandstone consists of mainly gray, brown and red sandstone with intercalated lenses of conglomerate and claystone.

The rocks of the Trap series are the earliest group of volcanic rocks, which were erupted from fissures during early Tertiary. They consist of piles of flood basalts and ignimbrites which are overlain by shield volcanoes and mainly consist of porphyritic olivine basalt. The basalts are transitional from alkaline to tholeiitic.

3.2 Local Geology and Structure

The solid geology of the project site is characterized by uniform or one kind of rock. The rock unit is a volcanic rock of basic composition. It is named as basalt, based on field observation. Out crops of the rock are observed mainly along the stream beds, banks and nearby sloppy or hilly terrains.

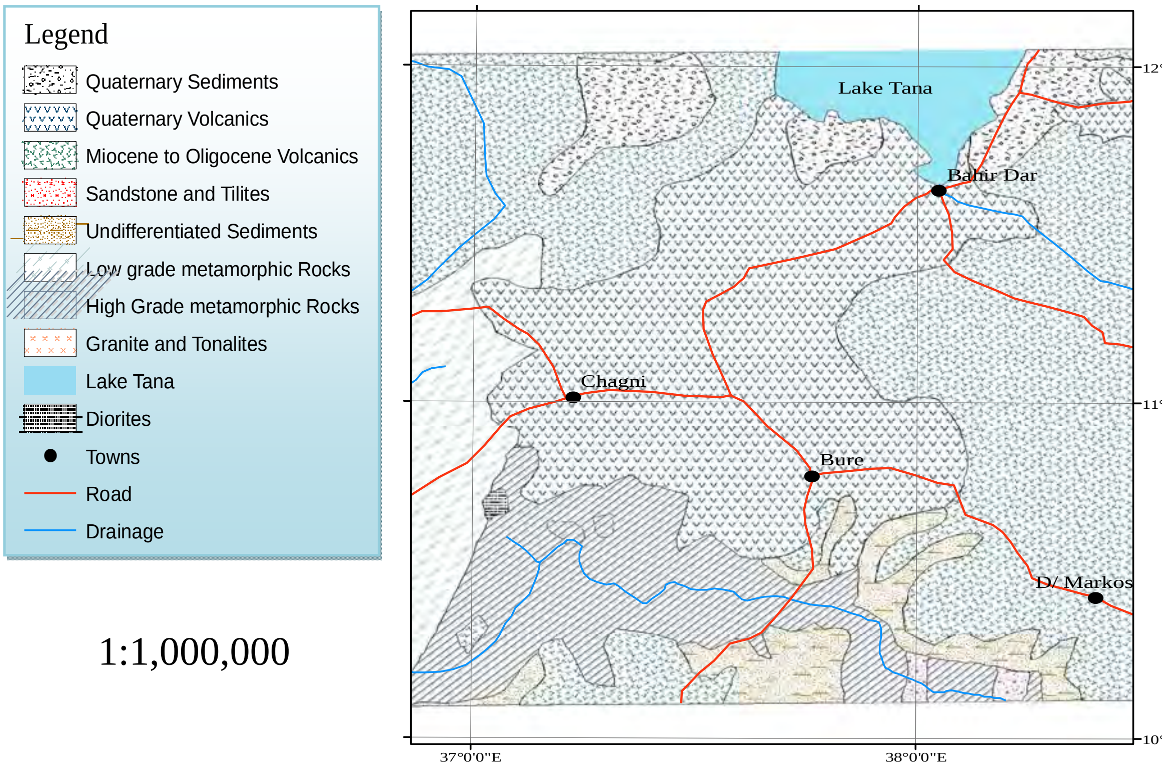

Fig. 3.2 Geology of the Research and Surrounding Areas

It has dark gray color, and fine texture. Characteristically, the rock unit shows a primary structure of columnar jointing having well developed rectangular to hexagonal shape top surfaces. Except along the stream bed, the rock out crops reveal some degree of physical weathering that is defined also by development of secondary joint sets. These joints are dominantly developed along the existing primary structure. The secondary joints are observed for some limited depth (not more than a meter), especially near to the stream banks and beds. At nearby sloppy terrain the depth to joint penetration is relatively high (may reach more than 2 to 3m at some places). The joints result in fragmentation of the rock unit in to boulders to pebbles that cover the surface of many areas of the sloppy terrains bounding the stream course.

The majority of uphill and gentle valley areas are covered by superficial soils. Based on origin there are two types of soil in the project area. These are residual and alluvial/ floodplain deposit. The residual soil is formed from in situ chemical weathering of the local rock unit. It is observed at relatively elevated areas and upslope or upper parts of hill sides. It is characteristic reddish brown in color. The soil is clay to silty clay in texture, but at restricted areas it is laterized. The alluvial soil is found along the gentle and curve areas following the stream banks. It is a soil deposited by the stream during flood times. It is dark brown in color having dominantly silt to clayey silt texture.

3.3 Geology of the dam site and Reservoir Area

The damsite and reservoir area are made up of three engineering geological materials (Fig. 3.3). These are; (i) Residual Fine Grained Soil, (ii) Alluvial Fine Grained Soil and (iii) Basalt Rock.

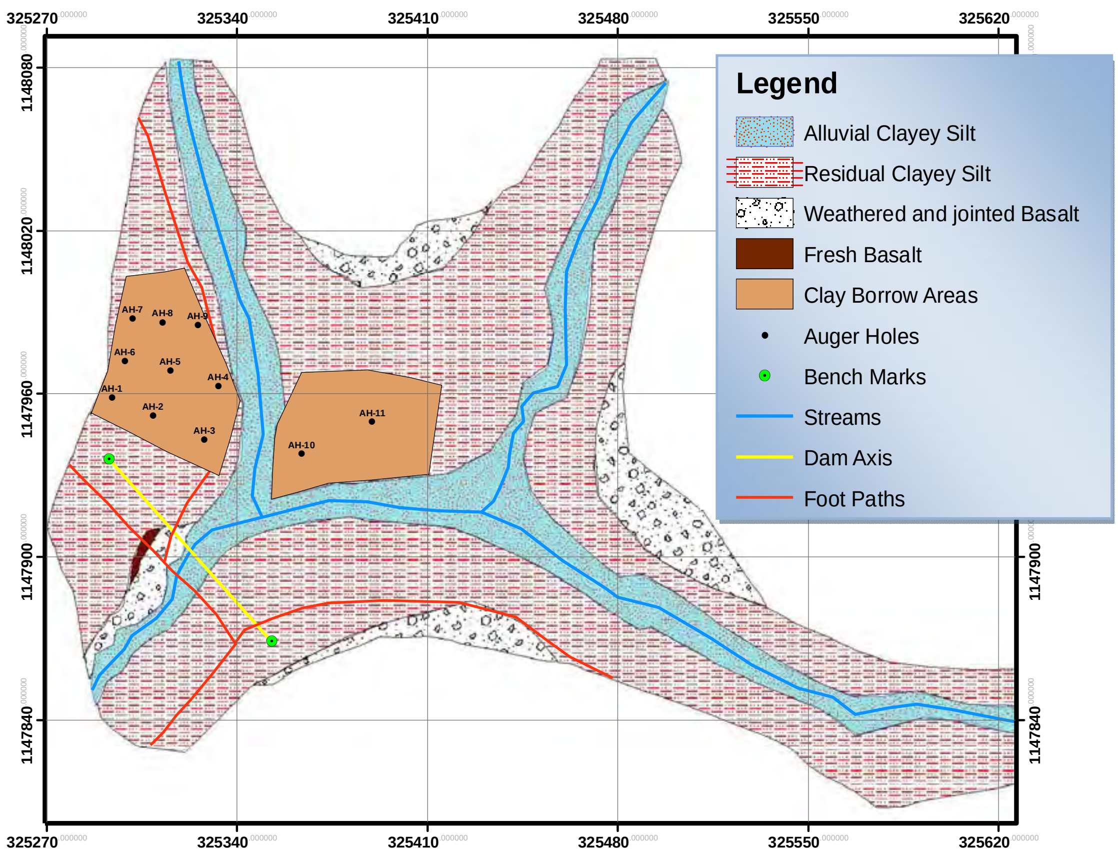

Fig. 3.3 Engineering Geological Map of Damsite and Reservoir Area

(i) Residual Fine Grained Soil

This soil unit covers most part of the damsite and reservoir area, which are away from the streams bed and nearby gentle flood plains. The slope and rim or peripheries of the reservoir area and abutments of the damsite are entirely covered with the residual soil. Naturally, the soil is developed from the underlying local geology (Basalt) through chemical weathering. It has characteristic reddish brown color. It is clay to silty clay soil. This soil is normally underlain by weathered (mainly physical) bedrock, the basalt unit (Fig. 3.4).

(ii) Alluvial Fine Grained Soil

This soil unit is observed along the flood plain areas, banks, and at some places on beds of the streams (Fig 3.3). It is alluvial sediment that is transported and deposited by the streams flood for several years. It has dark to reddish brown color, and similar clay to silty clay grain size.. From the natural stream bank cuts, the thickness of this soil ranges from 1.5 m to about 4 m. It is also underlain by the basalt bedrock unit (Fig.3.4).

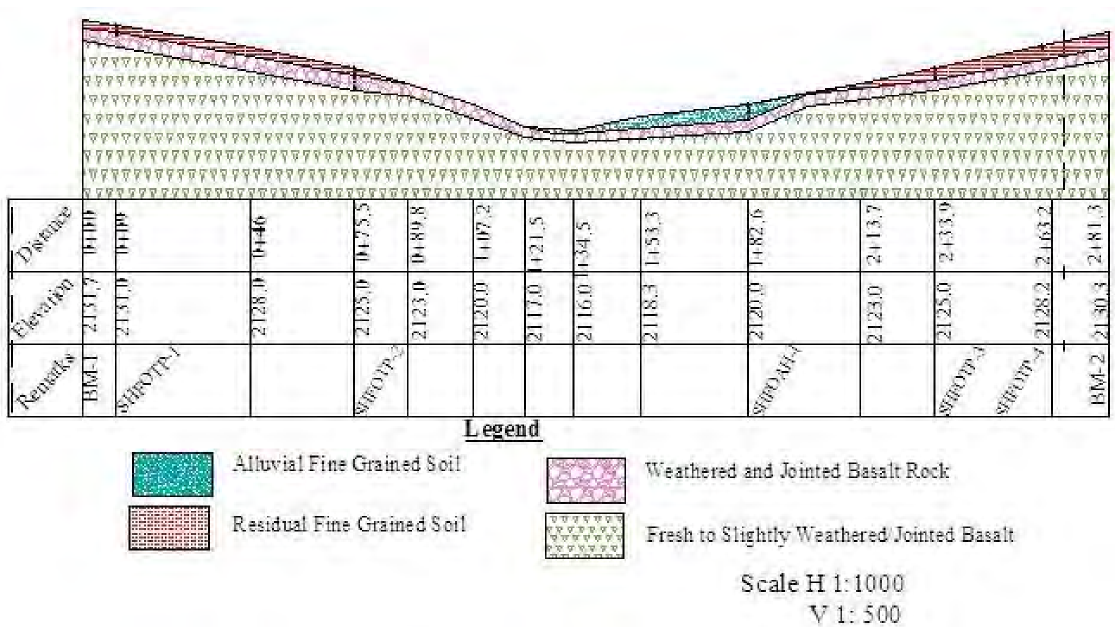

Fig. 3.4 General Geological cross Section along the proposed dam axis.

(iii) Basalt Rock

Some portions of the streams bed found in the reservoir and dam site (right side) are covered by the underlying bedrock, basalt. Elsewhere, the rock is covered with variably thick either the residual or alluvial soil horizons. It has dark gray color, and fine grains.

Chapter IV - Engineering Geological Setup of the Dam Site

4.1 Preamble

To collect engineering geological data that are required for the safe design of the dam, both surface and subsurface explorations have been performed. The data were collected from both foundation and borrow areas/ quarry sites. At the foundation of the dam site, information related to overburden soil and bedrock were collected. These include thickness, index and engineering properties, and surface extent of overburden soil, and depth to and nature of the bedrock. To get these data, outcrops and cuts of stream banks were visually examined, and exploratory holes (test pits and augur holes) were implemented. About four test pits and an augur hole have been dug/ bored manually along the proposed dam axis, and their detail description or logs are presented in the coming sections.

Within the main proposed homogeneous fill borrow areas and also examination of natural cuts and augur holes have been carried out to determine the quantity and quality of the soil. About 11 augur holes were bored in a grid along the lines. For further study and determination of required engineering properties/ or various design parameters with laboratory testing of the soil of the borrow area, representative disturbed sample has been taken. In addition to these activities, source areas for granular filter material and fine aggregate were investigated and sampled for laboratory testing. In this field, quarry site(s) for rock are identified and examined for the rockȏs quality, quantity and other relevant information. To characterize the quality of the stream water, samples were also taken for laboratory physical and chemical testing. During the field work emphasis was given on collecting data, mainly related to or required for the design of filter zone for the embankment.

4.2 Foundation Investigation of Dam Site

4.2.1 Valley Floor Area

The valley floor area includes the streambed and gentle areas until abutment feet on both sides. It is covered and made up of either the basalt rock unit or the alluvial sediment. The stream bed and right side of the valley are totally made up of the rock unit, whereas the surface of left portion is covered by the alluvial sediment. The rock is columnar basalt. It is dark gray in color and fine grained. It is affected by shallow depth physical weathering that result in secondary joints. The joints have shallow depth, maximum of 1m. Such joints are not observed within the stream bed, rather seen at nearby gently sloping side. These are dominantly oriented across the stream flow, though there are few joints parallel to the flow. At many places these are filled by secondary materials, like fine soils. Due to the physical weathering surface fragments of the rock are observed in some amount. Here the rock is not affected by chemical weathering, and it is strong.

On the other hand the left bank of the stream and nearby gentle valley portion is covered with the alluvial soil. It has dark brown color and dominantly silty to clayey silt texture. To define its thickness and some of the geotechnical properties, an augur hole has been bored. From the holes log (Annexure - 1), the soil has thickness of about 1.5 m. It is dry at top, but gets moist to wet to depth. It is underlain by the basalt rock unit. It is stiff and impermeable fine soil.

4.2.2 Left Abutment

The left abutment of the dam site has moderate slope. It is covered uniformly by the residual soil with variable thickness. To explore the nature and thickness of the soil, and depth to the bedrock, two hand - dug test pits were excavated (Annexure - 1).

The pits are located near the abutment foot (SHFOTP-3) and upper slope (SHFOTP-4) areas. The first pit has depth of about 1.5 m. The pit profile reveals that the top 1.5 m is residual fine soil with few rock fragments of pebble to boulder size. The soil is dry to moist, stiff and impermeable. The bottom of the pit is covered by un-excavatable, strong basalt rock that underlies the local geology.

4.2.3 Right Abutment

The right abutment has relatively steeper slope. Unlike the left abutment, it is covered with variable soil types (grain size or texture), though all are residual in origin. Here also two test pits, one (SHFOTP-2) near to the foot and the other (SHFOTP-1) to peak, were dug.

Test pit number SHFOTP-1 has depth of about 3 m. Its profile (Annexure -1) shows that the first 1 m is the residual fine soil. It has reddish brown color, and clay to silty clay texture. This soil has medium to low plasticity. It is dry to moist, stiff and impermeable. It is underlain by a lateritic hard pan zone of thickness 2 m. This horizon has dark gray to reddish to yellowish brown variegated colors. It is not easily workable or excavatable, and limits the depth of the pit. From local, geological observations of outcrops, the lateritic zone overlies the bedrock. Here, the depth to bedrock is expected within 4 m from the surface.

4.2.4 Spill Way

The spillway site is selected or proposed on the left abutment side by considering the relative suitability in terms of topography and geology. Naturally, the spillway route has moderate downstream slope starting from the control point, near the abutment, till it joins the streambed. From surface observation and nearby test pits profile, the route is covered by the residual and alluvial soils at near initial portions and where it is joining the stream, respectively. The soils thickness is variable, but not more than 1.5m (near to stream bank). Below the soil horizon the underlying basalt rock is found. It is strong and only affected by shallow depth of physical weathering. If the required depth of excavation is beyond the soils thickness (maximum 1.5m), there will be workability problem and special rock excavating equipments (like Jack hammers) are required (Plate 4.1).

Plate 4.1 The Dam Site

Based on the surface and subsurface investigation results at the dam site, an engineering geological cross-section along the proposed dam axis is prepared (Fig. 4.1).

4.2 Reservoir Area Condition

The reservoir area, where the run-off will be impounded, has nearly circular to ellipsoidal shape. It is covered with bush and grazing lands, with small extent of farmland. The slope of the reservoir is moderate. It is covered and made up of three engineering geological materials.

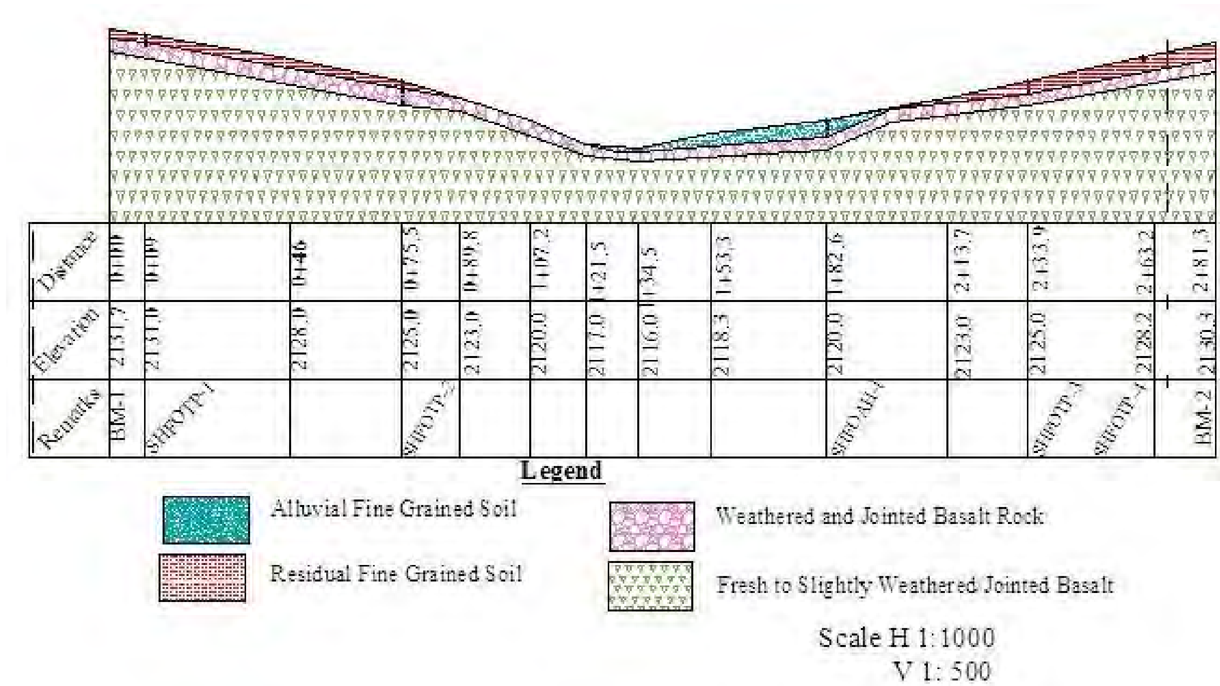

Figure 4.1 Generalized Geological Cross-sections along the Dam Axis

These are;

(i) Residual Fine Grained Soil

(ii) Alluvial Fine Grained Soil

(iii) Basalt Rock

Residual Fine Grained Soil

This soil unit covers most part of the reservoir area, which is away from the stream bed and nearby gentle flood plains. The slope and rim or peripheries of the reservoir area are entirely covered with the residual soil (Fig. 4.2). Naturally, the soil is developed from the underlying local geology (Basalt) through chemical weathering. It has characteristic reddish brown color. It is clay to silty clay soil, having dry to moist water content, stiff consistency and low permeability. From natural gully cuts and performed visual and subsurface investigations/ explorations, the thickness of the soil is variable; ranges from a meter to more than 4m (see next section). This soil is normally underlain by weathered (mainly physical) bedrock, the basalt unit.

Alluvial Fine Grained Soil

This soil unit is observed along the flood plain areas, banks, and at some places on beds of the streams (Fig. 4.2). It is alluvial sediment that is transported and deposited by the streams flood for several years. It has dark to reddish brown color, and similar clay to silty clay grain size. It is also dry to most, stiff and impermeable. From the natural stream bank cuts, the thickness of this soil ranges from 1.5m to about 4m. It is also underlain by the basalt bedrock unit.

Both the residual and alluvial fine soils found in the reservoir are proposed for the homogeneous impermeable fill material for the dam. These have been sampled and laboratory tested for the required index and engineering properties (See next section).

Basalt Rock

Some portions of the streams bed found in the reservoir, especially near to the dam site, are covered by the underlying bedrock, basalt. Elsewhere, the rock is covered with variably thick either the residual or alluvial soil horizons (Fig. 4.2). It has dark gray color, and fine grains. The top surface of the rock at some places shows both columnar (primary) and secondary joints (due to the physical weathering). The joints are believed to have shallow depth as massive part also exposed in nearby areas (at dam site). This top jointed section of the rock unit is pervious and need to be stripped to a depth to massive rock surfaces.

The reservoir is covered with mainly impermeable soil and rock units, except at few places near to the dam site where jointed rock section observed. The areas covered with the jointed basalt rock needs proper remedial measures to avoid leakage from the reservoir water. At these places the top jointed rock sections must be either stripped out or need to be blanketed.

4.3 Natural Construction Materials

4.3.1 Impervious Fill

The proposed dam section has large size impervious homogeneous fill. This section is selected because there is no free draining coarse material, which can be used as shell or casing zone, at an economical distance from the dam site.

On the other hand, impermeable fine grained soil is found as ample quantity within less than a kilometer radius. For the present project borrow areas for homogeneous fill material are proposed within the reservoir and nearby areas. Two borrow areas are selected. The first (Borrow Area 1) and main one is located in the right portion of the reservoir and immediate nearby areas, whereas the second (Borrow Area 2) or supplemental source is proposed on the left side (Fig. 4.2).

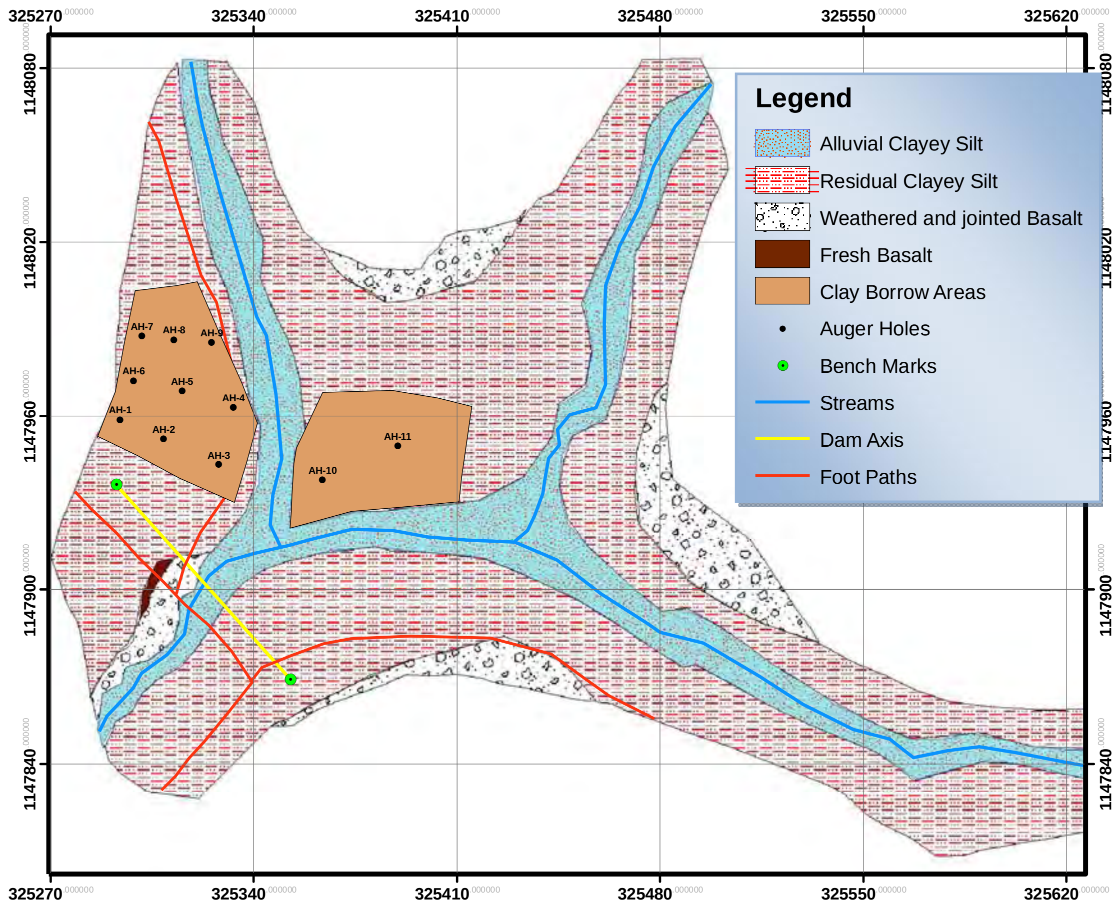

Fig. 4.2 Engineering Geological Map of Reservoir Area

To explore the quantity and quality of the soil found in the borrow areas both surface and subsurface methods were implemented. Small gully cuts were examined and about 13 augur holes (named as AH-1 to AH-11) were bored (Annexure -1 & Fig. 4.2) within the areas. The holes were bored nearly on grids of four by four lines in the first borrow area. The second area is mainly explored from stream and gully cuts, but also two augur holes were bored at its central portions (Fig. 4.2). The investigation shows that, the soils has variable depth within the reservoir area and borrow sites. It ranges from 2.2 to more than 4m and their bottom is marked by the underlying bedrock. Areas having more than 1.5m thick soil is delineated as borrow areas for the impermeable fill section and indicated in Fig.4.2. By considering the surface areal extent, average depth of the soil, and porosity of 30%, available quantity of the soil has been estimated. In the first borrow area about 77700 m^3 of soil is expected, whereas at the second area about 28900 m^3 impermeable soil is estimated. Totally, about 106,500 m^3 of impermeable fill material is expected from the two borrow areas.

Almost the augursô profiles reveal nearly similar soil type above the bedrock. The soil is residual that develops from the bedrock through in situ chemical weathering. It has characteristic reddish brown color. From visual examination and simple field index tests, the soil has silt to clayey silt texture with medium to high plasticity. It is dry to moist to depth, stiff to very stiff and impermeable soil. To determine the required soil parameters by laboratory testing, representative samples have been taken from two portions of the borrow areas. The samples were taken, one (SHHO-1) from the first borrow area and one (SHHO-2) from the second one. The test results are summarized in Table 4.1.

Table 4.1 Laboratory Test Result Summary for Impervious Fill Material

S/N	Test Types	Test Results		Remark
		SHHO-1	SHHO-2	
1	Sand Content (%)	4	3.8	Annexure - 2
2	Silt Content (%)	51	51	
3	Clay Content (%)	45	44.8	
4	Liquid Limits (%)	55.51	54.48	
5	Plastic Limits (%)	30.69	31.56	
6	Plasticity Index (%)	24.82	22.92	
7	USCS Soil Class	MH	MH	Using Plasticity Chart
8	Maximum Proctor Dry Density (g/cc)	1.25 ï 1.37	1.25 ï 1.37	Average properties based on soil class (Baharat Singh, 1995)
9	Optimum Moisture Content (%)	33.1 -39.5	33.1 -39.5	
10	Cohesion (Kg/cm^2)	0.44 -1.4	0.44 -1.4	
11	Angle of Internal Friction (Degree)	6 - 41	6 - 41	
12	Permeability (Cm/s)	2.6 x10^{-5} to 6 x 10^{-4} (impermeable)	2.6 x10^{-5} to 6 x 10^{-4} (impermeable)	

4.3.2 Granular filter and Fine aggregate

Critical filters with a simple but effective job is one of the principal parts in an embankment dam which is able to immune the dam against erosion, prevent water escape and seal unfavorable cracks that may occur through the impermeable fill. In addition to assess source areas with economical aspects, choosing a proper, optimum and fit ï to-need filter should be taken into account. Gradation curve and its properties, relative density of filter, soil compaction, grain shape, hydraulic head, physic-chemical properties, fine content, problematic soils, etc. are some of the factors that influence suitability of filter materials.

For this particular project two possible sources, from mode of origin point of view, for granular filter materials were proposed. The first source area is located at about 30km south east of the dam site. It is found in the same woreda, but in a different PA named as Jabi Genet or simply Genet, which is located at about 15Km south of Debre Elias town. The site is accessed by dry weather clay road. This source area is an existing borrow area for sand/ fine aggregate for local construction activities. Presently, three specific legal production sites are operating which are 2 to 3km far each other. In this particular investigation, the nearer one is named as Borrow area 1 and the middle as Borrow area 2, and the farthest as Borrow area 3. At these sites, the sand is obtained from similar geological unit that is classified as Mesozoic Lower or Adigrat Sandstone unit (Getanh, 1989). It is being excavated from the slightly weathered portion of the unit after uncovering the top fine soil, which has thickness ranges of few centimeters to about 2m (Plate 4.2). The rock unit at these particular areas exposed on the surface in large surface extent, a total sum of about 10 hectare. By considering/estimating the weathered section, from which granular soil can be extracted, as having thickness of about 4 to 5m, the quantity of residual in the area is calculated. From these existing borrow areas; hence, about 200,000 to 300,000m3 of residual sand soil can be exploited. Here, the porosity of sand is taken as 40%.


Plate 4.2 Residual Sand from Adigrat Sandstone Unit

Visual examination of this residual sand at these sources reveals different grain size. Borrow area 1 is dominated by fine to medium grained sand with significant amount of fines (mainly silts), whereas Borrow area 2 is characterized by medium sand with relatively some fines. At Borrow area 3, medium to coarser sand grains are dominant, with relatively lower fines. The sand grains at all sites are dominated by quartz or silica minerals, which are coated or stained with reddish to yellowish secondary minerals (probably oxides of iron).

To define the important geotechnical properties of the sand source in the laboratory, representative samples, one from each source area, were taken. The sample taken from Borrow area 1 is designated as SHFL-1 and that from Borrow area 2 as SHFL-2, and that of from Borrow area 3 as SHFL-3. The various important laboratory conducted tests required for filter design and specifications, and test results on the three samples are summarized in Table- 4.2 (Annexure- 2).

Based on the laboratory test results of both the filter and impervious soil, the design criteria and specifications of the filter zone are determined in Chapter 6. The second alternative source area for granular soil that can be used for filter material is proposed in different zone and woreda to the project site. It is located in West Gojam zone, in Jabi Tena/ Korit woredas boarder, near to Genete Abo village. The source is found inside the bed of a stream called őTaliaö. It is situated at about 90Km North West of the dam site. From Debre Elias town, this stream sediment source is accessed by dry weather gravel and asphalt roads that connect small towns like Amanuel ï Dembecha ï Jiga ï and to finally Genete Abo Village. The village is located (at about 17km) alongside a road (under upgrading during the study) that connects Jiga to Koarit towns. The specific source area is found at about a kilometer from the village in south west direction.

The granular material at this site is found as stream sediment within bed of őTaliaô stream (Plate -3). The deposit is observed as isolated patches along restricted portion of the streambed where such materials are subjected to deposition due to change in bed slope, become relatively gentler (Plate 4.2). This source area covers the demand of constructions in many of the towns or small cities like Debre Markos and Fenot Selam.

Plate 4.3 Alluvial Granular Sediment from 'Talia' Stream

The stream sediment has been examined visually during this field trip. It is dominated by medium to coarse sand, with some extent of fines and oversize (gravels) materials. The individual grains are dominated by fragments of basaltic rock that gives characteristic dark gray color to the sediment. Similarly, a representative sample (SHFL-4B) was taken from this source area to determine the important geotechnical properties of the sediment with laboratory testing. The tests and results are also summarized in Table 4.2 (Annexture-2).

In the same manner, the suitability or quality of this granular material as filter material for the impervious fill soil has been evaluated using appropriate methods (Chapter 6).

Table 4.2 Laboratory Test Results for Granular Filter Material (Residual Sand)

S/N	Test Types	Test Results				Remark
		SHFL-1	SHFL-2	SHFL-3	SHFL-4B	
1	Gravel Content (%)	0.6	0.39	3.5	6.2	
2	Sand Content (%)	99.17	99.4	96.8	93.62	
3	Fine Percentage (%)	<1	<1	<1	<1	
4	USCS Soil Class	SP	SP	SP	SP	Poorly graded Sand
5	Permeability (Cm/s)	0.78×10^{-1}	0.9×10^{-1}	1.5×10^{-1}	1.0×10^{-1}	Determined by Hazen method, and all are classed as pervious
7	Mineralogy (Major)	Quartz	Quartz	Quartz	Basaltic liths	

Finally, the two main proposed source areas for filter material can also be used for fine aggregate in mortar and concrete works.

4.3.3 Coarse Aggregate

Coarse aggregate source areas that are readily available as natural deposit are not found in the vicinity of the project area. The field exploration rather identified another option for source for coarse aggregate used in concrete works. Such materials can be easily produced by crushing the local rock type as there is sufficiently large quantities of fragments of the rock is available within economic distance (not more than 2km downstream of the dam site).

The fragments are result of in situ physical weathering of the columnar basalt. The weathering results in various size fragments that range mainly from pebbles to cobbles, but there are also some boulders and gravels. The individual fragments are sufficiently strong as they are affected by very slight chemical weathering discerned as surface coating of oxides of copper or iron that can be removed during crushing. The rock type possesses the quality required for coarse aggregate.

4.3.4 Masonry Stone, Rock Toe and Rip Rap

The rock type exposed and found as field fragments in the project area (mainly within 2km radius downstream of the dam site) is very suitable for masonry work, rip rap and rock toe as far as its natural quality is concerned. This is because the rock is basalt, which is one of the strongest volcanic rocks. The nature of occurrence of the rock unit; however, is not suitable to develop or acquire sufficient quantity of appropriate size that can be used for these purposes. The observed primary and secondary joints result in dominantly pebble to cobble sizes, and even finer fragments. The amount of boulders suitable for the intended works are limited and found mainly as disseminated manner in the area.

One such quarry site is proposed at about 200m downstream of the dam axis in the left side, near to a relatively smaller stream (left tributary of Shumbrite) named as ôDeber Minchö. Here some limited amount of rock that can be used for the itended purposes can be quarried out. Similarly, the downstream valley slopes of Shumbrit stream, until it join to the main river (Jedeb) can also be used as quarry areas for rock, but the required size fragments are limited. As a result of this nature of the country rock, other relatively distant source area is proposed to supplement or as an alternative source. The alternative quarry site is located at about 25km from the dam site in south east direction or at about 7km south of Debre Elias town, alongside to the road to Genet Kebele near to a stream called ôTishetö. The rock type is the same basalt, but here sufficiently large fragments can be easily quarried out (Plate 4.4). The quantity is also sufficient.

Plate 4.4 Rock Quarry Site

4.3.5 Water

Water that can be used for compaction and concrete/ mortar works can be found from the project stream. The stream is a perennial one that has base flow of more than 10 liter per second. From visual observation during the field work (mid March, 2009), the stream water looks clear, except at few places where it is turbid due to animal contamination while drinking.

The water quality of the stream flow can be attributed by a groundwater that comes out from the volcanic rocks of the north western plateau of Ethiopia. It does not have substantial quality problem which endangers the construction activities, and overall stability of the dam (Dorsh Consult, 2006).

4.4 Overall Engineering Geological Assessment

The study area can be defined by a rock type, which is part of the Cenozoic volcanic rocks of Ethiopia geology. From examination of the outcrops along the stream course and banks at and nearby areas of the proposed dam site, the underlying rock is basalt. It is one of the rocks having good quality as far as its engineering properties are concerned, if it is unaffected by secondary processes like physical and chemical weathering. At the proposed dam site the rock; however, is affected by different degree of weathering and jointing that its original geotechnical properties are somehow reduced. The depth of influence of these secondary processes is variable along the dam axis, and generally it is shallow that it is not be beyond 3m from the surface. Fresh part of rock is exposed few meters downstream of the dam axis in the right side of the stream course. This indicates the ultimate strong rock is expected at shallow depth, especially at valley floor area.

The effect of weathering, especially chemical weathering, on the rock is pronounced that most part of the dam site are covered by variably thick (a few centimeters to about 2m) clayey silt residual soil. This soil is impermeable, but has low strength. On the other hand the valley floor area, particularly the left side, is covered with alluvial silt to clayey silt soil of maximum 2m thickness, overlying directly on the basalt rock. This alluvial soil has nearly similar texture and permeability with the residual soil, but it has relatively lower stiffness.

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Chapter V - Literature Review

5.1 Preamble

Granular filters are used in embankment dams to prevent erosion of base and simultaneously to allow seepage. One of the first approaches to filter design was probably made by PRINZ in 1923 (Brauns et al, 1993), who idealized a filter as a regular packing of spheres and on the basis of geometrical considerations. He derived a rule where the filter particles (represented by the diameter d_{50F}, for which 50% by weight are smaller) should not exceed the size of base particles (represented by the diameter d50B) smaller with a factor 4.42.

Terzaghi (1922) was the next to specify the requirements for selecting filter materials. He proposed design criteria based on cohesionless base soils. Two basic requirements he identified were related to particle distribution of base and filter materials: retention ratio ($D_{15}/d_{85} <= 4\text{-}5$) and permeability ratio ($D_{15}/d_{15} >= 4\text{-}5$), where D_{15} is the diameter of filter particles for which 15% by mass is finer , d_{15} and d_{85} are the diameters of base particles for which 15% and 85% by mass respectively finer.

Developments in filter design continued and Bertram (1940), United States Army of Civil Engineers (USACE) (1953), Karpoff (1955), Zweck and Davidenkoff (1957), Sherard et al. (1984b) greatly contribute to the filter requirements related to Particle Size Distribution. Extensive laboratory testing programs were done, beginning with work by Bertram (1940) who worked under the direction of Terzaghi and Casagrande, followed by the work of United States Bureau of Reclamation (USBR) and US Corps of Engineers (1941). These experiments showed that the basic requirements could best be met by designing the particle size of the granular filters in relation to the particle size of the soil being protected (Fell et al. 1992). The USBR method which has been modified from time to time, for example USBR (1977) has been used widely and successfully for design of filters. Most recently further experiments have been carried out by the United States Soil Conservation Service (Sherard et al. 1984a, b and Sherard and Dunnigan 1985) and by Kenney and Lau (1985).

In many cases filter design rules originally developed for cohesionless soils have been used for dam sections made up of cohesive soil. The studies involving cohesive soils are relatively few in number and are mostly empirical. Although it has been generally recognized that retention ratio is an effective criterion, some doubts have been expressed (Vaughan and

Soares, 1982; Sherard et al., 1984b; International Commission on Large Dams (ICOLD), 1994). As relevant factors cannot be determined directly, various design criteria for safe filters have been developed considering different approaches. Various factors such as retention ratio, permeability of filters, hydraulic gradient, erosion resistance, particle sizes and shapes are not treated with equal importance. For example, traditional filter design has involved the retention ratio (i.e. Terzaghiǿs criteria), while filter permeability has been considered as the main design factor by some researchers (Vaughan and Soares, 1982; Vaugham, 2000). According to Mullner (1993), most available filter rules neglected hydraulic parameters, which influenced erosion of cohesive soils.

5.2 Granular Filters in Embankment Dams

In embankment dams, pervious materials are generally used as filters to dissipate excess pore pressures, and to eliminate wash out of fine base particles under piping conditions. If filters are improperly design, particles from base layers might penetrate them.

Progressive accumulation of fines may result in the clogging of filters thus considerably affecting the drainage, which leads to build up of excessive pore pressures and consequently to instability of earth structures.

To minimize crack and piping failure, Sherard and Dunnigan in 1985 (Fell et. al., 1992) proposed multiple lines of defense to guard against leaks in cracks. These include reducing differential settlement cracking and sealing concentrated leaks. Measures for reducing settlement include the following;

- Using rock abutments to achieve flatter slopes instead of sharp slopes
- Reducing the compressibility of impervious fill material by compacting the bottom half at lower water content
- Compacting the upper half of the fill at a higher water content to provide both flexibility and the capability to take an imposed load without cracking
- Improving flexibility by using plastic clay instead of silty sand and others

Measures to seal concentrated leaks include the following;

- Using conservative downstream filters to prevent leaks
- Using plastic clay for greater erosion resistance and others

5.3 Factors Influencing Granular Filter Performance

The process of filtration, which includes prevention of base soil erosion and permitting controlled seepage, is not a simple but a complex phenomenon. Filtration is considered as particle migration in porous medium, where all involved factors such as particle sizes, pore sizes and seepage and other forces vary in wide ranges as stated by Schuler and Brauns, in 1993. Contributing factors are divided into five different groups: Geometrical, physical, hydraulic, chemical and biological factors.

Geometrical filter criteria determine whether mobilized (detached) soil particles will pass through filter openings. If the geometrical filter criterion is not met by a grain size distribution, no erosion will occur until seepage forces exceed the resisting forces. For cohesive soils, the resisting force is generally represented by cohesion, which plays a significant role in filtration. Geometrical factors include particle size distribution (PSD), shape of grains of both base and filter materials. The uniformity coefficient and internal stability of base and filter materials are described below. The constriction size distribution (CSD) and non-homogeneity (Segregations) of filter materials during placement are also included as geometrical factors (Schuler and Brauns, 1993; Mullner, 1993).

Sherard et al. in 1984 had conducted filter tests for cohesive base soils considering filter action only (properties of filters needed to prevent erosion of base soils) but not considering permeability factors (properties needed for a filter to act as a drain). Base soils consisting of silts and clays were tested by three different methods;

(i) Conventional filter tests with compacted base,

(ii) Slot test with a central pinhole, and

(iii) Slurry tests mixing a known amount of clay with water about2.5 times of liquid limit.

Identical results were reported for each method tested. Although there was a general correlation between d_{85} and D_{15}, there was a wider scatter. For all kinds of cohesive base soils, ratio $\mathbf{D_{15}/d_{85}}$ was in excess of 9, for some clay the ratio was 25 and for some, it even exceeds 50. For typical clays without content of sand sized particles, with d_{85} = 30 to 80µm, the retention ratio, D_{15}/d_{85} ranges from 19 ï 56, and this indicates that the requirements of filter design for cohesive soils do not correlate with general criteria used for cohesionless soils, where $D_{15}/d_{85} <= 4$ ï 5.

According to Sherard et al. the slot and slurry tests are very severe in the sense that the velocity of the initial concentrated leak imposed on base (10m/s) is much larger than that occur in leak through a dam. Vaughan and Soares in 1982 stated that due to slow leak, only fine particles reached the filter face and silt- sized particles were left behind as debris in the leakage channel. Contradicting the concepts of perfect filter, Sherard et al. (1984b) noted that the perfect filter approach was unduly conservative; the main reason being that nearly all clay soils contain a considerable amount of silt sized particles with diameter 50- 80μm and these particles are easily available to the filter face, even for a slow flow. It is not necessary to provide a filter to protect clay flocs of 10μm. They summarized that for fine ï grained clays, a sand filter with D15<= 0.5mm was conservative. For sandy clays and silts, a filter criterion $D_{15}/d_{85} <= 5$ is conservative and reasonable.

A soil is said to be internally stable when its finer particles do not move through pores of coarse particles (Kovacs, 1981). Internal stability of soils has great effect on clogging. It is generally considered that coarse broadly graded soils are internally unstable. Lafler et al. (1989) showed that internally unstable soils, which were safely protected by fine filters, might self-clog. Particles move from base layers, accumulate at interface, and produce a layer of very low permeability thereby initiating clogging. This finally results in an increase of pore pressures at interface. A further problem associated with broadly graded soils is that they are very difficult to place without segregation (Milligan, 2003).

Indraratna et al. in 1990 reported a relationship between the coefficient of uniformity and clogging. They studied the effectiveness of cohesionless granular filters for protection of lateritic residual soils. Several series of tests were conducted in fine to medium sand filters, and a clogging filter was detected with uniformity coefficient Cu = 3.8. It is summarized that fine to medium sand filters are effective for lateritic soils and clogging only occurs when the uniformity coefficient is close to 4.

The following are considered as physical factors that affect filter performances;

(i) Base soils- cohesion, weight of grains, particle surface roughness, density, and specific gravity,
(ii) Filter particles fines content and surface roughness.

For the base soils, among all other physical factors, cohesion plays the major role in filtration performance. It is generally recognized that when conventional filter design criteria based on

PSD are used for cohesive dam fill sections, it ignores the resistance to erosion owing to cohesive forces. A small quantity of water seeps through compacted clay soils, which has little energy and subsequent little chance for fine clay particles to enter into filter pores as indicated in Sherard et al., in 1984. Kassif et al. in 1965 also mentioned that the flux was small through the clay layers, hence design criteria may be less stringent and range of possible filter materials becomes wider.

Kassiff in 1965 carried out experimental investigation of filtration of cohesive soils through coarse granular filters. Their experimental results were compared with the results of the analytical model of Zaslavsky and Kassiff in 1965. The critical hydraulic gradient (i_{cr}) from both methods showed surprisingly high values. Tests had been carried out for compacted clays in contact with actual filter materials as well as perforated plate simulating filter materials. Experimental results indicated that a fair coarse filter could protect fat clay. Higher average gradients were required to cause failure, even when clay was allowed to swell under zero pressure.

Theoretical analysis of piping in cohesive soils by Zaslavasky and Kassiff in 1965 revealed that pore sizes of filter had no influence on erosion behavior of cohesive soils, and the soil layers would not fail entirely , but aggregate clay particles would start to move. Their theoretical model thus related directly to the floc size of soils, which was separated from the clay surface. Such aggregates influenced filtration performance significantly.

Wolski in 1970 examined erosion resistance of silty clay at base-filter interface by measuring the changes in porosity and pore pressures through x-ray examination. The results were reported in two stages. In the first stage, at relatively low hydraulic gradient, removal of base particles at filter interface was observed until arching of several small particles over the filter pores stopped erosion. Later on, at higher hydraulic gradients, breakdowns of arches and further erosion were reported trough progressive particle loss and formation of piping failure. Thus, it was recommended that filter design based on PSD was conservative if used for intact soils. However, there were two problems with filter design for cohesive soils: the formation of cracks, and the dispersion of clays with flow water.

Filters should be given minimal compaction. Excessive compaction, particularly of crushed rock, can lead to the criterion of fines to result the filters susceptible to cracking.

When there is a crack in a cohesive soil fill, a filter, to become effective must be non-cohesive. A filter with cohesive properties may sustain an open crack without collapse and thus fail to prevent the base material crack. The inclusion of more fines might result in a more cohesive filter. Mantz in 1977 found that quartz particles possessed surface attraction at sizes less than 50microns (coarse silt). However, provided that filters do not contain surface-active clay minerals, filter cohesion is very small compared to cohesion in the base impermeable zone as mentioned by Vaughan and Soares in 1982. Milligan in 2003 reported that when a core cracked, a downstream filter became a secondary interface. If both base and filter crack, it is inevitable that piping and subsequent erosion will occur. To avoid filter materials becoming cohesive, there is a maximum limit of fines content of 8%.

The chemical composition of both seepage water and soil, which influence particle sizes (dispersion and flocculation), are chemical factors. These are ionic strength, pH, and temperature of flowing fluid. Likewise the moisture content of base soil greatly influences dispersion and flocculation. It has an important effect on permeability, which was discussed by Aitchison and Wood in 1965. Compactions at 2% dry of optimum moisture content result in permeability 50% higher than when compaction is carried out at different levels of moisture content. Permeability and flocculation (dispersivity) of clay soils can be reduced exceedingly when compaction is carried out on the wet side of optimum moisture content.

The main hydraulic factors that have influence on filter design are total hydraulic head, hydraulic gradient, pore fluid velocity, and the angle between direction of flow and gravity. Mullner in 1993 pointed out that the well- known filter rules neglected hydraulic parameters, which are influenced by the erosion resistance of cohesive soils. If hydraulic factors are not taken into consideration, this leads to an economical design of filters. Water flowing through porous media may cause the destabilization of soil structures, if the filter is not geometrically stable. Stability is also affected by changes in hydraulic load conditions. Variation in seepage pressure due to a sudden change in hydraulic head has a great impact on particle movement. Compressibility of filter media due to sudden increase in hydraulic load affects particle movement too. Transport of moveable soil particles is greatly dependent on the hydraulic gradient.

The US Army of Corps of Engineers (USACE, 1971) performed extensive filtration experiments varying hydraulic gradient. At higher gradients, susceptibility to piping increases when the filter is subjected to vibrations.

Kenny and Lau in1985 their study of granular filters stated that stability based on grading curve basically depended on three factors: PSD, porosity and the severity of seepage and vibration.

5.4 Focus of Current Study

The current research focuses on engineering geological assessment of the various proposed granular materials as filter/drain for the reddish brown fine soil that will be used for homogeneous embankment fill. This quality performance assessment is based mainly on the geometrical, physical and chemical factors or criteria proposed by the various scholars. All proposed granular filters are examined for their relative suitability and analyzed accordingly. In addition to this, the impermeable fill soil also examined to its chemical nature, especially whether it is dispersive or not. To do this samples of the soil are analyzed in laboratory for dispersion by dispersion test, by double hydrometer test.

In the geometrical suitability analysis or criteria checking the following most popular empirical criteria have been used;

A. USDA-SCS Method

The geometrical suitability of the granular soils suggested for filter is analyzed using basically the USDA-SCS, Engineering Division 1986 design procedures. It is based on the type of base soil in terms of its grain size or gradation. These showed that the basic requirements could best be met by designing the particle size of the granular filters in relation to the particle size of the soil being protected. There are about 12 steps to design the lower and upper limits or envelops of filter gradations for a certain base soil category. This procedure determines the filtration capacity or base soil retention suitability of the granular soils or the piping requirement. The second important function of the soils, i.e. the permeability criteria or the requirement that seepage move more quickly through the filter than through the protected soil, is again analyzed by a grain-size relationship criterion based on experience.

The design manual presents criteria for determining the grain size distribution (gradation) of sand and gravel filters needed to prevent internal erosion or piping of soil in embankments or foundations of hydraulic structures. These criteria are based on results of an extensive laboratory filter study carried out by the Soil Conservation Service at the Soil Mechanics

Laboratory in Lincoln, Nebraska, from 1980 to 1985 (USDA National Engineering Handbook, 1994).

B. USBR (1977) Method

The USBR method or criteria used here is as follows (Fell et al.1992);

(i) D_{15F}/d_{15B} = 5 to 40, provided that the filter does not contain more than 5% passing 0.075mm. This criterion ensures that the filter is more permeable than the base soil.

(ii) D_{15F}/d_{85B} <= 5, and the grain Size of the filter should be roughly parallel to that of the base material. This criterion ensures that the filter is sufficiently fine to control erosion of the base.

(iii) Maximum size particles in filter equal to 75mm to prevent segregation during placement.

(iv) For base materials which include gravel particles, the base material d_{15B}, d_{85B}, etc. should be analyzed on the basis of the gradation of the soil finer than 4.75mm.

C. Terzaghi Criteria

These criteria have been used since 1930 for the design of filters for dams and other works. Although known to be conservative and originally developed for cohensionless uniform base soil and filter materials, the well known Terzaghi retention criteria are given by (Baharat Singh, 1995);

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,

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

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 75 μm), the base material should be analyzed on the basis of gradation of fraction smaller than 4.75 mm.

D. Recommendations as Per Indian Standard

The recommendations for filter selection as per IS code are as follows (Baharat Singh, 1995);

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.

E. Sherard's Recommendations

Experiments conducted at the Soil Mechanics Laboratory, in USDA-SCS on different soils revealed the following criteria (Baharat Singh, 1995);

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

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

This shows that Terzaghiꞌs criterion includes a factor of safety of 2 and conservative.

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 coefficient of permeability (K) of dense filters is generally in the range of K = 0.2 to 0.6 D^2_{15} with average 0.35 D^2_{15} (K in cm/s and D_{15} in mm)

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

Comparing the various indicated filter design criteria, an emphasis is given on the USSCS and related Sherard and Dunnigan recommendations for this particular research work. This is because the methods considers to the type of base soil to be protected, and accordingly proposes unique procedures for the filter design or criteria.

Filters are required to be constructed of sand and gravel which is sufficiently durable so as not to breakdown excessively during mechanical action of placement in the dam, under the chemical action of seepage water, or under wetting and drying within the dam (Fell et. al 1992). The Los Angeles abrasion and wet strength, wet/ dry strength variations largely assess the susceptibility to breakdown during the placement. The sodium sulphate soundness test assesses the susceptibility to breakdown under wetting and drying, with the added involvement of sodium sulphate in the solution used for soaking. These tests and recommended standards are likely to be more rigorous for high hazard dams, and dams with seepage water which is highly acidic or has high salt content (example, some tailings dams).

The other mineralogical consideration is proportion of carbonate minerals in the filter material. It is probably not suitable for use in filter zones because of susceptibility to solution and redeposition as cement between the particles. Filters from rocks containing significant amount of gypsums are highly susceptible to the same solution problem.

In the light of the above it is recommended that (Fell et. al. 1992) the following should always be considered in characterizing the proposed filter material;

- The mineral composition of the particles should be determined,
- If the material is found to contain even small amounts (e.g. 1-5%) of carbonate, gypsum or sulphide minerals, then care has to be taken while designing the filters.

In the field the proposed filter materials should be visually examined for their constituting minerals, especially the above indicated, and in the laboratory the mineralogy of the grains need to be determined.

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Chapter VI - Data Collection, Analysis and Interpretation

6.1 Preamble

Nearly every fill dam or embankment contains filters and drainage elements as elements for controlling seepage and for preventing erosion of soil due to the drag forces of seeping water. As these elements are very important for the safety of the structure in question and as the interaction between seeping water and soil still remains an element of uncertainty, great efforts have been made in the past to understand the complicated filtration phenomenon. Thus a large number of filter criteria have been derived in the past, including the well known criterion by Terzaghi.

Various filter criteria are known to determine the dimension of granular filters. Filter rules are mainly derived from experiments or laboratory test results. As a consequence of this empirical approach, various influences have to be considered due to different test set-ups and evaluations of experiments, and therefore the rules are applicable only in connection with the respective test conditions. Many parameters influence the dimensioning of a granular filter. Therefore it is necessary to set-up filter rules to determine certain basic assumptions concerning suffusion, granular curve and range of grain sizes, grain shape, density of packing of base and filter, and finally condition of seepage flow (direction, gradient, laminar or turbulent) in the considered filter range. This indicates the necessity to use different filter criteria depending on conditions of those basic parameters, mainly gradation curve of the protected soil (Brauns et. al. 1993).

Filtration phenomena exist in various forms. Ground surface forms a very important interface as far as the condition of filter stability is concerned. Above ground surface, the dam body is a structure built with selected materials according to appropriate rules including filter criteria. On the contrary, below ground surface, it is accepted what nature has prepared as a foundation for any structure intended to build.

As long as there is well defined soils both in the embankment and foundations, simple geometrical filter criteria may serve the needs well. Hence, data concerning embankment soils and foundation materials need to be secured before any criteria checking or design of filters.

The next step is to identify possible sources of filter materials that satisfy the requirements defined for both foundation and embankment sections. The purpose of a filter in earth dams is to protect soil against erosion, while being permeable to seepage. As simple as the desired effect may be, as complex is the process of filtration. This is not astonishing, when considering that filtration can be compared with particle migration in a porous medium, where all involved factors (particle size, pore sizes and acting forces) vary in wide ranges. Filtration or effective retaining of base material can occur due to geometrical conditions, i.e. filter openings smaller than base particles, or due to static conditions, i.e. retaining forces stronger than driving forces, while geometrical conditions allow particles to pass through, (U.Schuier & J. Brauns, 1993). Filter criteria, that take into consideration a geometrical comparison of base and filter material, are called geometrical filter criteria. The involved parameters for these criteria or geometrical properties for the base soil are grain sizes and their distributions, and shape of grains. For filter materials, the properties are constriction sizes of the pores and their distribution, and shape of constriction, which are in turn depend on particle size and its distribution. In addition to these, homogeneity of both materials is also one of the influencing parameters in geometrical filter criteria.

On the other hand, criteria that are based on static conditions are called physical and hydraulic filter criteria. In these criteria, the influencing properties include; soil cohesion, effective stress, and weight of grains of the base soil. For the filter, internal stability is the influencing one. In addition to these, hydraulic gradient, pore flow velocity and angle between direction of flow and gravity are also parameters in the physical and hydraulic criteria (Brauns et al, 1993). For certain reasons, geometrical criteria are preferable: they provide the highest degree of safety, because they are independent of flow conditions (Brauns et al, 1993). In this research project, hence, only the phenomena of filters/ drains of granular masses with special regard to geometrical aspects will be considered.

For procedural design of filter for the main impermeable homogeneous embankment fill soil of the project dam, both existing secondary and new primary data have been collected. The data were collected from the various parts or components of the project, which are directly related to filter design. These components include, dam foundation, borrow areas for the fill soil and proposed filter materials, and stream surface water flow. These data consists mainly of index and engineering properties of the various soils units/ horizons found at the dam foundation, and borrow areas for various zones of the embankment. The properties of the soils have been determined by visual field observation, laboratory tests and with some empirical relationships. The results of these identification methods of soil have been analyzed and interpreted using various existing geometrical design procedures/ criteria that are related to filter design for cohesive embankment fill soil.

6.2 Data Collection

6.2.1 Dam Foundation Condition

Both surface and subsurface investigations have been conducted along the proposed dam axis or site to define and characterize the foundation geological materials (soil and rock). Outcrops of rocks, and soil cuts along stream banks were visually examined for their extent, index and general engineering properties. To understand the subsurface condition along the dam site, both hand dug test pits and an augur hole were dug and bored along the assumed axis of the dam (Plate - 6.1). All performed explorations and results have already been indicated/ discussed in chapter 4. In this particular section foundation data related to filter design are presented and discussed.

Plate - 6.1 Dam Site with its Components

The central valley floor area (especially the right side of the stream) is covered mainly with jointed basalt rock, occasionally covered with thin top fine residual soil. From close observation of outcrops of the rock unit, the origin of the joints are related mainly to physical weathering though there are some primary ones (columnar joints) formed during the cooling of the lava (Plate - 6.2). Here, the depth of influence of the joints is believed to be shallow, not more than a meter or one and half a meter, as there are also nearly massive outcrops in the vicinity (Plate - 6.2). This jointed portion of the bedrock is considered to be pervious, whereas the underlying massive basalt is impermeable. Both sections of the rock unit are strong enough to support the proposed embankment without shear failure and pronounced settlement. It is hence, necessary to design an impervious cut off trench with impervious soil that will be in contact with the lower massive part of the bedrock (Fig 6.1).

For this segment of the dam, minor seepage through the cut-off wall is expected and may erode some soil grains from the trench material to the jointed foundation rock, which is pervious, and in addition it should be drained safely to the downstream toe or relief well of the dam. For these functions, a horizontal filter and drain zone is necessary to be designed between the downstream cut-off wall/ embankment base and jointed rock.

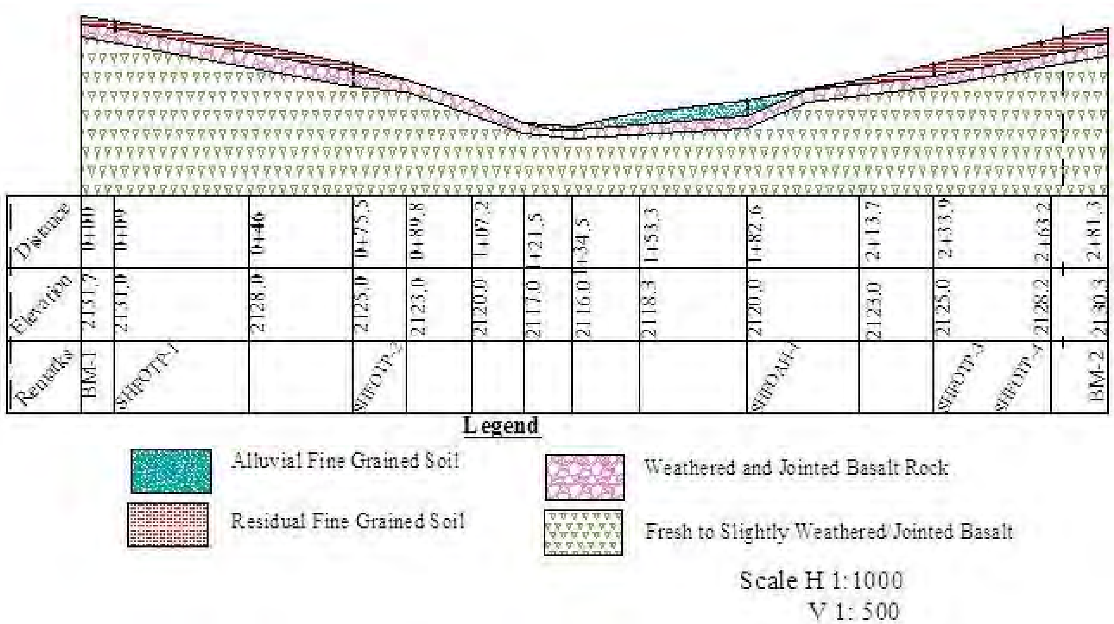


Fig. 6.1 Geological Cross-sections along the Dam Axis

The left valley floor area of the dam site, on the other hand, is covered relatively by significantly thick soil. From nearby stream bank cut observation and an augur hole boring (SHFOAH-1), the thickness of the soil unit reaches to maximum of 2m, decreases toward the stream left bank (Plate 6.3). It is an alluvial soil deposited by the stream during flood times (flood plain deposit). It has dark brown color. It is fine grained soil of high to medium plasticity, having stiff consistency and dry to moist moisture content. It is impermeable soil

(Chapter 4). This soil layer is underlain by the basalt bedrock encountered at depth of 2m (from the augur hole). The top part of the bedrock (1 to 1.5 m) is jointed below which it is massive (similar to the right valley side).


Plate 6.2 Top Jointed and Underlying Massive Foundation Basalt Rock (at right valley floor)

Though the area is covered with the impermeable alluvial soil having maximum of 2m thickness, some seepage is expected through the soil and underlying jointed rock zone. Here also, a cut-off trench connected to the underlying massive portion of the bedrock and made up of impermeable soil need to be designed. To control seepage water through foundation both inclined and horizontal filter/ drain sections are necessary.

Samples from proposed soil borrow areas (SHHO-1) for cut of trench, and the alluvial soil foundation (SHHO-2) at the dam site, and also samples (SHFL-1, SHFL-2, SHFL-3 and SHFL-4B) from proposed source areas for filter material were taken to secure required data for the design of the filter. The respective data from both protected and filter materials are already presented in Chapter 4 and restated in the coming sections. The engineering geological foundation conditions at both abutments are nearly similar, except variation in extent or dimensions of the various soil/ rock units. The surfaces of both abutments are covered with variably thick (ranges from some centimeters to maximum of 1.5 m) residual fine grained soil.

The soil has characteristic reddish brown color, and is dominantly clayey silt in grain size. It is stiff to very stiff, dry to moist to depth, impermeable and locally laterized. At the abutment slopes and foot areas or portions, hand dug test pits were dug to understand the subsurface soil/ rock units underlying the residual fine soil (Chapter 4). The pits show that the top soil is underlain by slightly to moderately weathered, and jointed part of the bedrock, basalt. This weathered and jointed rock part has also variable thickness, which ranges from some centimeters to about 2m. It is particularly thick in the right abutment, where about 2m thickness is observed (log of test pit number SHFOTP-2, Annex-1 and Plate - 6.4). It is dry, dense, strong horizon, though it is believed to be pervious to semi-pervious.

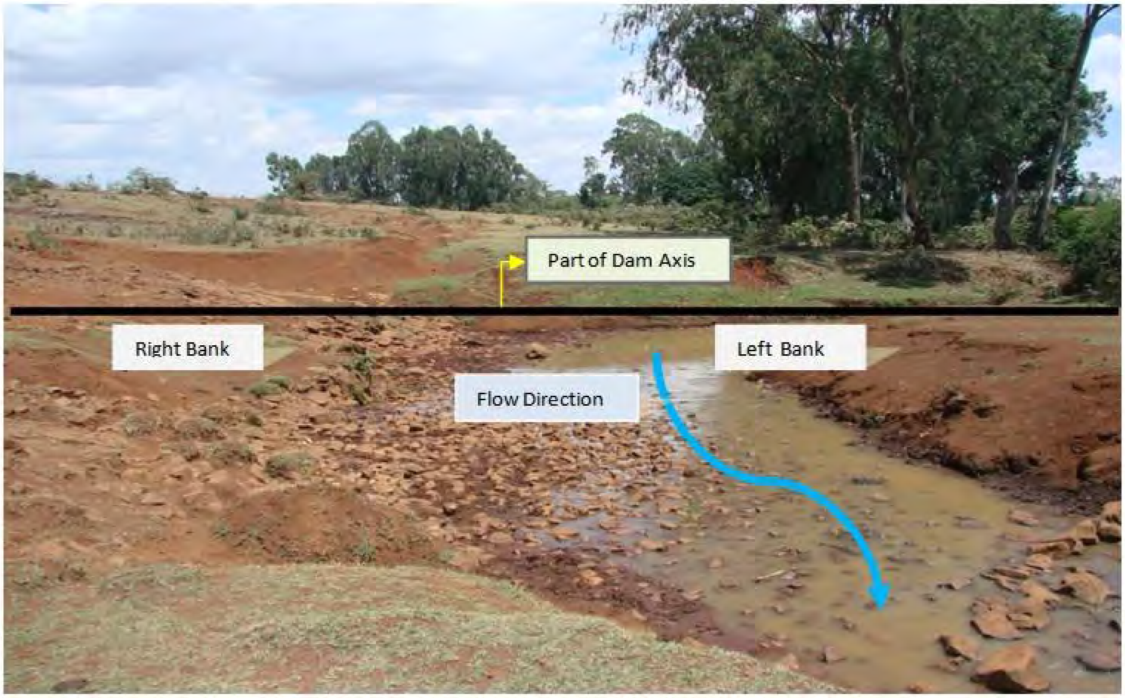


Plate - 6.3 Portion of Alluvial Soil Foundation at the left valley floor area

Plate - 6.4 Soil / Rock Profile at Right Abutment Foundation Area (from pit SHFOTP-2)

Ultimately, the massive part of the bedrock is encountered (hard to dig) under these two horizons, within depth ranges of 1.5 to 3m from the surface (Geological cross-section, Fig 6.1). To avoid seepage of water through the weathered/ jointed foundation horizon, the cut off trench (preventive measure) at both abutments should be keyed with the underlying massive part of the bedrock. In spite of this seepage preventive measure, some amount of water may leak through the foundation soils. This leakage should be safely drained without causing internal erosion (most unlikely), and development of excessive pore pressures within the foundation. In this case, a filter/ drain zone between the foundation and the downstream embankment base is necessary or proposed (Fig. 6.2).

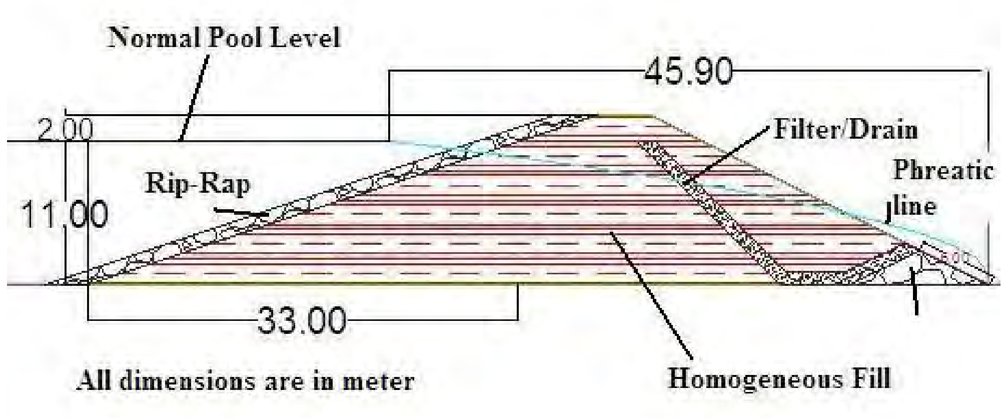


Fig.6.2 Proposed Dam Section

For the design of the filter/ drain that will help to control seepage through foundations, the protected soil is represented by two samples taken from the two proposed borrow areas for the embankment homogeneous fill soil (SHHO-1 and SHHO-2). This is because, the foundation fine soils (both alluvial and residual) found at the dam site has similar origin to these borrow area soils and visually they have similar characteristics. On the other hand, about four possible source areas were identified and sampled for filter material. Three of the samples (SHFL-1, SHFL-2, and SHFL-3) were taken from various portion of the weathered Lower Sandstone unit, whereas the fourth (SHFL-4B) was taken from stream bed sediment (Chapter 4 and Plate ï 6.5).

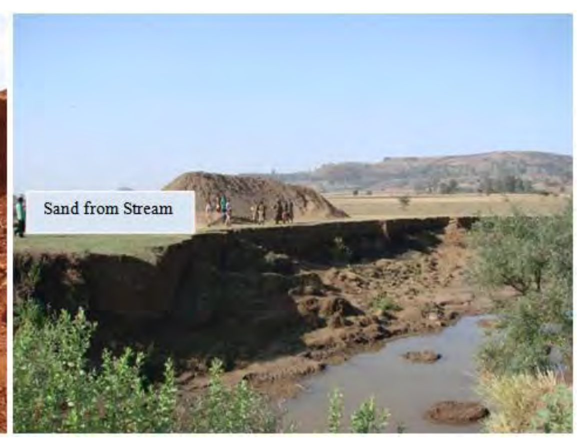


Plate - 6.5 Granular Filter Materials from Lower Sandstone Unit and Stream Sediments

6.2.2 Embankment Condition

The availability, quantity, quality and location within economic distance are main governing criteria regarding the choice of embankment type of any earth fill dam. In this regard, fine grained soils, which are both residual and alluvial flood plain deposit, are available in sufficiently large quantity within short distance from proposed dam sites or stream courses in the project area as a whole (Plate - 6.6 below). These soil units (base soil) have sufficient imperviousness for either impermeable homogeneous fill or core section in the case of zoned dam. On the other hand, natural free draining granular soil, like gravel and/ or sand gravel mixtures with sufficient binders, are found in limited quantity in close range, and if sufficiently available, located at distant places from possible dam sites in the area. Seeing to these, homogeneous impermeable fill type of embankment has been proposed for this particular dam project, and may be any possible similar sites in the zone (Fig. 6.2).

Though the homogeneous fill section is made up of dominantly with impermeable fine grained soils, there are relatively thin seepage control sections within it and at its base in the downstream portion. The control sections/ zones are made up of granular soil; sand and/ or sand ï gravel mixtures, and act as filter/ drains for possible seepage through the main embankment and foundation soils.

For this particular research project, the samples taken from the Borrow areas for impermeable fill soil represent base soil, whereas, those from Lower Sandstone and stream sediments are possible granular filter/ drain materials for the base soil. Accordingly, the filter design procedures and analysis will be done and presented in the succeeding sections. Those data or parameters about both materials (base and filter) obtained directly from laboratory tests and literatures, and derived from empirical relationships that are relevant to the design of the filter and checking of its performance are presented in the next sections (Test results, Annexure - 2).

A. Base Soil Parameters (Red Tropical Soil)

The main embankment soil is part of a general soil category, which is broadly classified as Tropical or African Red Clay Soils (Dumbleton, 1967). The red clay soils are residual soils produced by weathering of rocks at the land surface under relatively high temperature and rainfall and good drainage. Bases and silica are leached, leaving the soil rich in iron and aluminum. In many parts of the tropics, the clay minerals and iron oxides occur respectively as metahalloysite and hematite under dry conditions, and as hydrated halloysite and goethite under moisture conditions (Dumbleton, 1967). The plasticity of the clay minerals is modified by the iron oxide. Black montmorillonitic clays, rich in bases and silica, occur in association with the red clays but on lower ground.

It is very useful to understand the mode of origin and mineralogy of the particles of deposits of engineering importance, like embankment fill material. There are two main reasons for studying these two natures of certain material. The first is to help to distinguish different types of soils, so as to be able to correlate their engineering properties with those of similar soil types occurring in different parts of the country or the world. This will enable engineering techniques developed in one region to be applied to another region where materials and conditions are similar. The second reason is to aid in explanation of the origin of the engineering properties of different types of deposit, and to help to interpret engineering test results.

The Tropical red soils, from which the embankment impermeable fill zone is designed, are formed from many kinds of rocks, if the weathering conditions are suitable. These are formed from rocks like Basalt, phonolite, volcanic lava, volcanic ash and pumice. In the present research area, the soils are developed from basaltic bedrock. The tropical red clay soils are true soils that occur at the surface, except where they have been covered, for instance, by volcanic material, when they mark periods of volcanic inactivity. These are formed in regions of relatively high temperature, under conditions of moderate to high rainfall and good drainage, when the rate of leaching is high. This means, these occur mainly on higher and sloping ground, where drainage conditions are good. Leaching removes the more soluble bases and silica, leaving the soil rich in less soluble components, i.e. iron in the form of iron oxide, and aluminium in the form of clay minerals. The clay minerals are of the kaolin group of halloysite type. The iron oxide in these soils, which accounts for the dark red to red color, occurs in an unhydrated form, hematite, and a hydrated form goethite (Dumbleton, 1967).

Kaolin in the form of halloysite has disordered structure, which gives rise to a material of higher potential plasticity than well ordered kaolinites. This higher plasticity is modified by the iron oxide (Dumbleton, 1967). Soil classification tests have been performed on these tropical red soils in Kenya by P. T. Sherwood 1967 (Sherwood, 1967). The classification test comprises the determination of the particle size distribution and of the liquid and plastic limits of the soils. If these properties are known, a reasonable knowledge of the permeability, compaction properties and several other characteristics can be inferred from data obtained with others soils of similar classification properties. Accordingly, samples from proposed borrow areas were taken and classification tests were done, and thus important engineering properties were determined.

Plate- 6.6 Road Cut Exposure of Fine Grained Residual Soil in the surroundings of the Research Area

Specific source areas, which satisfy the required quantity, for impermeable fill soil have been assessed, identified and delineated. Two possible borrow areas for the fill soil have been selected within the project reservoir area at different or opposite portions. These areas were explored with augur holes, and representative samples (SHHO-1 and SHHO-2) were collected for laboratory classification testing of relevant parameters that can be used for both the dam design, including the filter section (Chapter 4, and Plate - 6.7).

The results of the classification tests and determined important engineering properties are presented in Fig.6.3.

Another important property of the impermeable fill soil that needs to be considered especially in the case of seepage control study and design is its dispersivity. Dispersive clays are a particular type of soil in which the clay fraction erodes in the presence of water by the process of deflocculation (USDA_SCS, 1980).

This occurs when the inter-particle forces of repulsion exceed those of attraction, so that clay particles are detached and it goes in suspension. If water is flowing, as in pores or cracks in earth dams, the detached clay particles are carried away and piping occurs.

Identification of depressiveness is required for earth structures. This cannot be identified by conventional index tests as particle size distribution, Atterberg limits and compaction characteristics. There are four laboratory tests commonly used to identify dispersive clays; Crumb Test, SCS Dispersion Test, Pore Water Chemistry Correlation, and the Pinhole Erosion Test. For the present research project, the fill soil has been tested by using the SCS dispersion test method (double hydrometer). For this the soil was tested in the Federal Water Works Design and Supervision laboratory. The test results are presented as Annexure -2, and in Fig.6.3.

Plate - 6.7 Impermeable Soil Borrow Area1; Sampling and Auguring/ Logging

As mentioned in the previous sections, two samples were taken from the proposed borrow areas for impermeable homogeneous fill soil. The samples have been taken to Bahir Dar University, Civil Engineering Department Soil Laboratory Section for the required tests. The lab tests mainly focused on grain size analysis (sieve and/or hydrometer), though some relevant index tests like Atterberg limits were also conducted. The test results are presented in Annexure-2. Here below, parameters (mainly geometrical) required for the design of filter envelops are presented. These include, grain size (gradation) curves and associated particle sizes with their percentages, and Atterberg limits.

The gradation or grain size analysis table and curve of the two soil samples are presented in Fig.6.3.

Using the gradation curve and determined Atterberg limits, the soils are classified according to Unified Classification System (USCS). For this purpose, the plasticity chart (Fig. 6.4) is used as the percentage of grain sizes greater than 0.075mm (No 200 US standard) is 50%, and the result is presented in Table 6.1 together with other relevant parameters.

Gradation for Fill Material			
SHHO-1		SHHO-2	
Particle Size (mm)	Percent Finer (%)	Particle Size (mm)	Percent Finer (%)
2	100	2	100
1.18	99.8	1.18	99.8
0.6	99	0.6	99.2
0.3	98.2	0.3	98.4
0.15	97.6	0.15	97.4
0.075	69	0.075	96.2
0.03147	58.6	0.02981	52
0.01999	56.4	0.01892	51.2
0.0116	54	0.01095	50.8
0.00822	52	0.00778	50.4
0.00583	49	0.00548	48
0.00412	49	0.00391	46.4
0.00309	48.2	0.00318	46
0.00306	47.6	0.00292	45.2
0.00123	42	0.00267	45.2
		0.00116	42

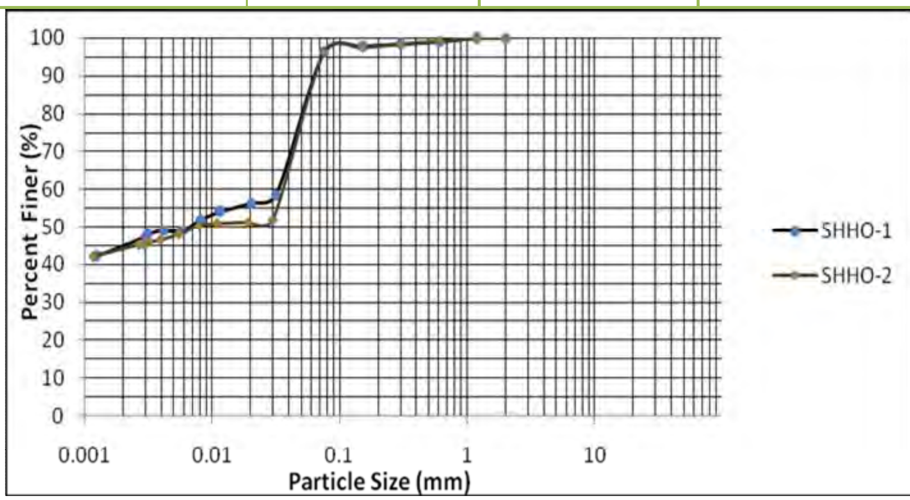


Fig. 6.3 Gradation Curves of Base Soil Samples SHHO-1 and SHHO-2

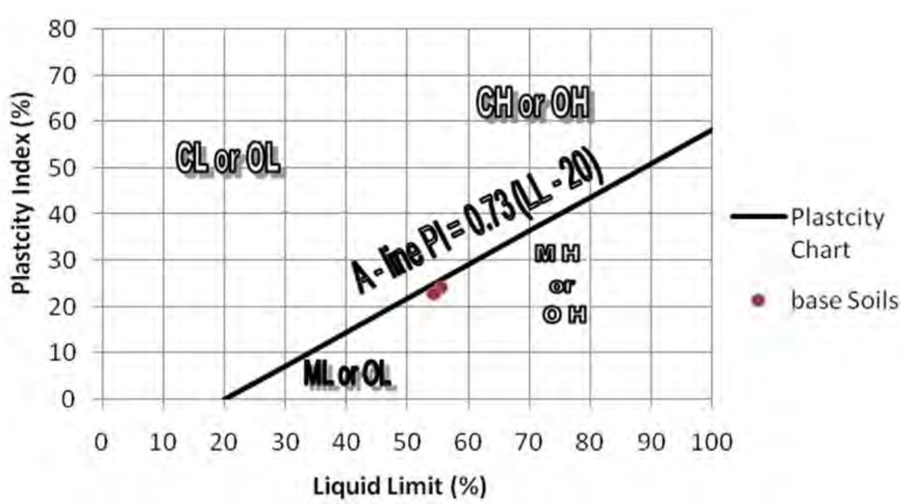


Fig. 6.4 Classfication of Embankment Fill Soils Using Plastcity Chart

Table 6.1 Soil Classification Test Results and Determined Engineering Properties of the Fill Materials

S/N	Classification Test Results and Determined Engineering Properties	Sample Number		Remark
		SHHO-1	SHHO-2	
1	Particle Size Distribution (%):- Gravel Sand Silt Clay	 - 4 51 45	 - 3.8 51 44.8	
2	Atterberg Limits (%):- Liquid Limits Plastic Limits Plasticity Index	 55.51 30.69 24.28	 54.48 31.56 22.92	Plasticity Chart
3	Unified Soil Classification Soil Group	MH (Highly plastic silt)	MH	
4	D_{85B} (mm)	0.059	0.057	
5	D_{15B} (mm)	-	-	No meaningful value
6	Compaction Characteristics:- Maximum Dry Density (g/cc) Optimum Moisture Content (%)	 1.25 to 1.37 33.1 to 39.5	 1.25 to 1.37 33.1 to 39.5	Baharat Singh, 1995
7	Shear Strength Parameters:- Cohesion (kg/cm^2) Angle of Internal Friction (degree)	 0.44 to 1.4 0.11 to 0.29	 0.44 to 1.4 0.11 to 0.29 (tan phi)	
8	Permeability (Cm/s)	2.6 x 10^{-5} to 6 x 10^{-4}	2.6 x 10^{-5} to 6 x 10^{-4}	

* D_{15B}, D_{85B} *are particle size of the base soil finer than 15% and 85% respectively.*

B. Filter Material Parameters (Residual and Alluvial)

Similarly, data on soils, used in the seepage control sections (filters/ drains), have been collected. As indicated in the previous chapters, two possible sources (in terms of mode of origin) have been selected for these filtration and drainage purposes. The first is from in-situ weathering products (residual granular soil) of the Lower Sandstone Unit of the Mesozoic geology of Ethiopia exposed nearby to the research project area. The second source is from alluvial sediment found within a stream/ river located at relatively very distant place. Four possible borrow areas, three for the residual soil and one for the alluvial sediment, have been identified, and representative samples were secured for laboratory tests. Four different samples representing the borrow areas were taken. Three of these samples (SHFL-1 to SHFL-3) were taken from the weathered portion of Lower Sandstone unit; whereas the last sample (SHFL-4B) was taken from the stream sediments (Chapter 4).

In other words, in the research area, there are two main types of granular soils, which can be performing the seepage controls through the base soils. The first is a sand or/ and sand-gravel mixtures that is derived from moderately weathered sandstone, which is the lower stratigraphic unit (Adigrat Sandstone) in the Mesozoic Formations of the Ethiopia geology. This unit is widely exposed in the vicinity of the research area, and its weathered product is being utilized by local construction activities parallel with stream sediment or alluvial sand deposits found at relatively very distant areas (Plate-6.8). The Adigrat Sandstone unit is variegated quartos sandstone of fluvial or littoral origin. It consists typically of yellowish to reddish brown to pink, fine to medium grained non-calcareous, well sorted quartz sandstone (Abay River Basin Master Plan Report, MoWR, 1998).

In the surroundings of the research area, there are several existing borrow areas (owned by licensed local farmers) from which the residual sand is being exploited. Of these, three of them are now active, therefore representative samples were taken from each of them. These borrow areas are located in close proximity to each other and are not more than 2km gap. They are found at about 28 to 30km from the research project site, in south east direction, and accessible by dry weather road. On the contrary, the source area for alluvial sand is located at relatively distant areas of 90 to 95 kms from the project site (Chapter 4).

Plate - 6.8 Residual and Alluvial Sand/ Sand-gravel Mixtures for Local Constructions (in Debre Markos City)

A sample is also secured from this source. All the samples were taken to Amhara National Region State Rural Road Authority Soil Laboratory Section. In this lab, mainly grain size analysis and determination of percentages of fines were conducted (Annexure -2).

The grain size analysis table and curves of the granular soils are summarized and presented in Fig. 6.5. Here the average grain size distribution of the filter materials secured from the weathered sandstone unit is also presented, and suitability analysis is performed on this material.

Gradation for Filter Materials					
	Percent Finer (%)				
Particle Size (mm)	**SHFL-1**	**SHFL-2**	**SHFL-3**	**SHFL-4B**	**Average Residual Sample**
9.5	100	100	100	100	100.00
6.3	99.75	99.86	98.87	97.12	99.49
4.75	99.39	99.61	96.95	93.8	98.65
2	96.84	98.3	79.27	79.57	91.47
1.18	90.45	96.06	56.15	64.37	80.89
0.6	55.92	56.53	26.07	33.57	46.17
0.425	28.07	21.82	13.71	16.97	21.20
0.3	11.67	6.81	7.05	7.49	8.51
0.15	2.12	1.35	1.6	1.12	1.69
0.075	0.22	0.21	0.15	0.18	0.19
pan	0	0	0	0	0.00

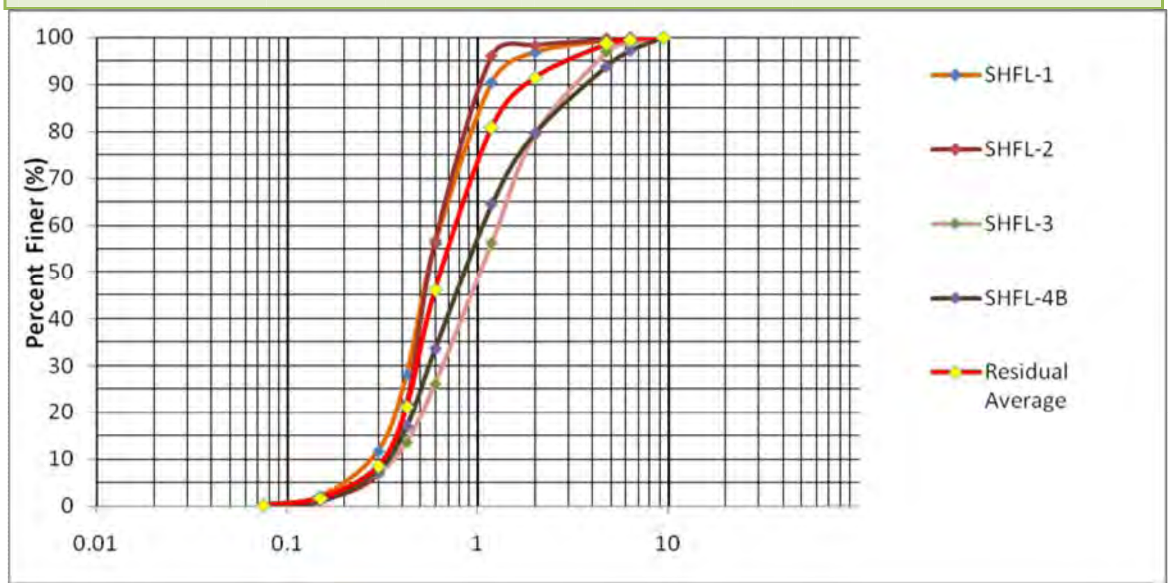


Fig. 6.5 Gradation Curves of the Granular Filter Soils

In addition to the grading characteristics, the filters were examined for mineralogy, physical and chemical composition. From visual observation and previous works, the sand grains are dominated by silica or quartz. These grains, however, are thinly coated with reddish stains, probably iron oxides.

The relevant parameters required for the design or checking of filter are summarized in Table-6.2. These are either determined directly from laboratory tests or derived from empirical relations or taken from standard relevant literatures.

Table 6.2 Summary of the Parameters of the Filter materials

S/N	Required Parameters	Sample Numbers					Remark
		SHFL-1	SHFL-2	SHFL-3	SHFL-4B	Average	
1	D_{15} (mm)	0.32	0.38	0.44	0.4	0.38	
2	D_{10} (mm)	0.28	0.32	0.36	0.34	0.32	
3	D_{60} (mm)	0.66	0.62	1.4	1.1	0.78	
4	D_{30} (mm)	0.41	0.46	0.68	0.56	0.48	
5	Uniformity coefficient (Cu)	2.36	1.93	3.9	3.2	2.4	
6	Coefficient of Curvature (Cc)	0.94	1.06	0.92	0.84	0.92	
7	USCS Soil Group	SP	SP	SP	SP	SP	Poorly graded Sand
8	Permeability (cm/s)	0.7×10^{-1}	0.9×10^{-1}	1.5×10^{-1}	1×10^{-1}	0.9×10^{-1}	Hazen method, classed as pervious
9	Percent fines (%)	< 1	< 1	< 1	< 1	< 1	

6.3 Data Analysis and Interpretations

The basic requirements of filters are that they are sufficiently fine grained to prevent erosion of the soil they are protecting, and are sufficiently permeable to allow drainage of seepage water. Extensive laboratory testing programs, beginning with work by Bertram, 1940, who worked under the direction of Terzaghi and Casagrande, followed by the work of the USBR and others, showed that the basic requirements could best be met by designing the particle size gradation of the filters in relation to the particle size gradation of the soil being protected. More recently further experiments have been carried out by the United States Soil conservation Services (USSCS). These experiments led to recommended modifications of the design rules suggested by USBR (Fell et al, 1992).

Important properties of the filter material are gradation, compacted density, and permeability. Filters are designed to permit free passage of water and prevent migration of fines through the filter. The average in-place relative density of the filter should be at least 85 percent and no portion of the filter should have a relative density less than 80 percent. Special care must be taken to assure that compaction does not degrade the filter material (by grain breakage and/or segregation) and reduce its permeability. When the filter material is sand or contains significant portions of sand sizes, the material should be maintained in as saturated a condition as possible during compaction to prevent bulking. The filter material should pass the 3-in. screen for minimizing particle segregation and bridging during placement. The permeability of sands and gravels varies significantly with the amount and type of fines present (material smaller than the No. 200 sieve). Also, the amount and type of fines present influence the capacity of a filter to self-heal by collapsing any cracks within the filter (USACE Design Manual, 1886).

To analyze the relative suitability of the residual, and also the alluvial sands to filter/ drain material for the base red tropical soil (impermeable homogeneous fill soil), filter design procedures provided by USSCS Engineering Division is basically utilized. In addition to this, design criteria suggested and recommended by other scholars, and various standards available for this purposes are implemented, and analyzed for their applicability. Based on these design procedures and criteria, the relative suitability of the granular soils, obtained from the different proposed source areas, is analyzed and interpreted. In general, all relevant parameters considered during the design of critical granular filter/ drains are analyzed with respective empirical approaches. The granular materials, in this regard, are examined mainly for their geometrical suitability as filter/ drain materials for the base soil.

Filters and drains allow seepage to move out of a protected soil more quickly than the seepage moves within the protected soil. Thus, the filter material must be more open and have a larger grain size than the protected soil. Seepage from the finer soil to the filter can cause movement of the finer soil particles from the protected soil into and through the filter. This movement will endanger the embankment. Destruction of the protected soil structure may occur due to the loss of material. Also, clogging of the filter may occur, causing loss of the filterös ability to remove water from the protected soil. Criteria developed by many years of experience are used to design filters and drains which may prevent the movement of protected soil into the filter.

This criterion, piping or stability criterion, is based on the grain-size relationship between the protected soil and the filter. In the following, the small character ñdò is used to represent the grain size for the protected (or base) material and the large character ñDò for the grain size for the filter material.

6.3.1 Geometrical Factors Analysis

Geometrical factors (filter openings smaller than base particles) are mainly influenced by particle size distribution (PSD) and the shape of grains of both base and filter materials. The constriction size distribution (CSD) and non-homogeneity (segregation) of filter materials during placement are also included as geometrical factors (Schuler and Brauns; Mullner, 1993). Designing, and checking the PSD factors for the materials of the present research project have been done in the coming sections using various known criteria.

A. USDA-SCS Method

The geometrical suitability of the granular soils suggested for filter is analyzed using USDA-SCS, Engineering Division 1986 design procedures. It is based on the type of base soil in terms of its grain size or gradation. This showed that the basic requirements could best be met by designing the particle size of the granular filters in relation to the particle size of the soil being protected. There are about 12 steps to design the lower and upper limits or envelops of filter gradations for a certain base soil category. This procedure determines the filtration capacity or base soil retention suitability of the granular soils or the piping requirement. The second important function of the soils, i.e. the permeability criteria or the requirement that seepage move more quickly through the filter than through the protected soil, is again analyzed by a grain-size relationship criterion based on experience.

The design manual presents criteria for determining the grain size distribution (gradation) of sand and gravel filters needed to prevent internal erosion or piping of soil in embankments or foundations of hydraulic structures. These criteria are based on results of an extensive laboratory filter study carried out by the Soil Conservation Service at the Soil Mechanics Laboratory in Lincoln, Nebraska, from 1980 to 1985 (USDA, 1994).

The first step is to determine the gradation curve (grain-size distribution) of the base soil material, by using enough samples to define the range of grain sizes for the base soil or soils and design the filter gradation based on the base soil that requires the smallest D_{15F} size. For this research work two samples (designated as SHHO-1 and SHHO-2) were used to define the range of grain sizes for the base soil.

They have almost similar gradation curves, and the data analysis or filter design is performed based on one of them, namely SHHO-1. The next step is to determine the base soil category based on the percentage of soil finer than US standard sieve No. 200 (0.075mm) (Table 6.3).

Based on the gradation curves of the two base soil samples (SHHO-1 and SHHO-2), the soils are classified as Category 1(fine silt and clays) as more than 96% of the soils are finer than 0.075mm.

Table 6.3 Base Soil Category

Base Soil Category	% finer than No. 200 Sieve (0.075mm)	Base Soil Description
1	>85	Fine silt and clays
2	40 - 85	Silty and clayey sands
3	15 - 39	Silty and Clayey Sand and gravel
4	<14	Sand and Gravel

Following this procedure, soil categorization is done to determine the maximum allowable D_{15} size of the filter to satisfy the filtration requirement. For this soil category the maximum D_{15} size is less than and equals to 9 times the d_{85}. Using the appropriate value of d_{85} (0.056 mm) of SHHO-1, the maximum D_{15} is calculated as 0.5 mm. Similarly, the minimum allowable size for D_{15} is determined to satisfy the permeability requirement.

For the same soil category, the minimum D_{15} is greater than or equals to 4 times d_{15}, but not less than 0.1. This base soil has no meaningful d_{15} size, and a default value of 0.1mm is used.

The following step focuses on the width of the filter band. The width of the allowable filter design band must be kept relatively narrow to prevent the use of possibly gap-graded filters. To achieve this, two criteria should be considered; the width of the designed filter band should be such that the ratio of the maximum to the minimum diameter at any given percentage passing values less than and equal to 60% is 5 or less.
In addition to this the coarse and fine limits of the filter band should each have a coefficient of uniformity of 6 or less. The first criterion is satisfied for the maximum and minimum D_{15} sizes as their ratio is 5. Here, the maximum D_{10} is determined by dividing the maximum D_{15} by 1.2 by assuming the slope of the line connecting D_{10} and D_{15} should be on a uniformity coefficient of about 6. Hence, the value of maximum D_{10} is 0.42mm. This value enables to determine the maximum allowable D_{60} by multiplying 0.42 with 6, and equals to 2.52mm. In turn, the minimum allowable D_{60} for the fine side of the filter band can be calculated by dividing 2.52 with 5, and equals to 0.5mm.

The next step is to determine the minimum D_5 and maximum D_{100} sizes of the filter. These maximum and minimum particle size criteria are defined, for all base soil categories, as D_5 greater or equal to 0.075mm, and D_{100} less than or equal to 75mm. Following this step, criteria for filter segregation during construction is considered. To minimize segregation during construction the relationship between the maximum D_{90} and the minimum D_{10} of the filter is important. In this step a preliminary minimum D_{10} size is calculated by dividing the minimum D_{15} size by 1.2, and the maximum D_{90} is determined based on range of this calculated D_{10} (Table 6.4). Accordingly, the values of the D_{10} and D_{90} are 0.083mm and 20mm, respectively.

Table 6.4 Segregation Criteria

Base Soil Category	If D_{10} (mm) is:	Then Maximum D_{90} (mm) is:
All Categories	< 0.5	20
	0.5 ï 1.0	25
	1.0 ï 2.0	30
	2.0 ï 5.0	40
	5.0 - 10	50
	> 10	60

Following the rest of the finalizing steps for this category base soil, the gradation limits or envelops of granular filters are designed by connecting respective determined values, and by extrapolating the coarse and fine curves to the 100% finer values. The design filter band limits are presented in Fig.6.6.

After completing the design of both the fine and coarse size bands or envelops of the filter, the relative suitability of the various selected natural filter materials have been inserted or drawn with respect to the envelops (Fig. 6.7). Based on their gradation curve position with respect to the limits, the relative suitability of each of the granular materials is described.

Except filter materials SHFL-1 and SHFL-2, which become a little bit finer than the grading limits, the rest falls within the designed filter grading limits.

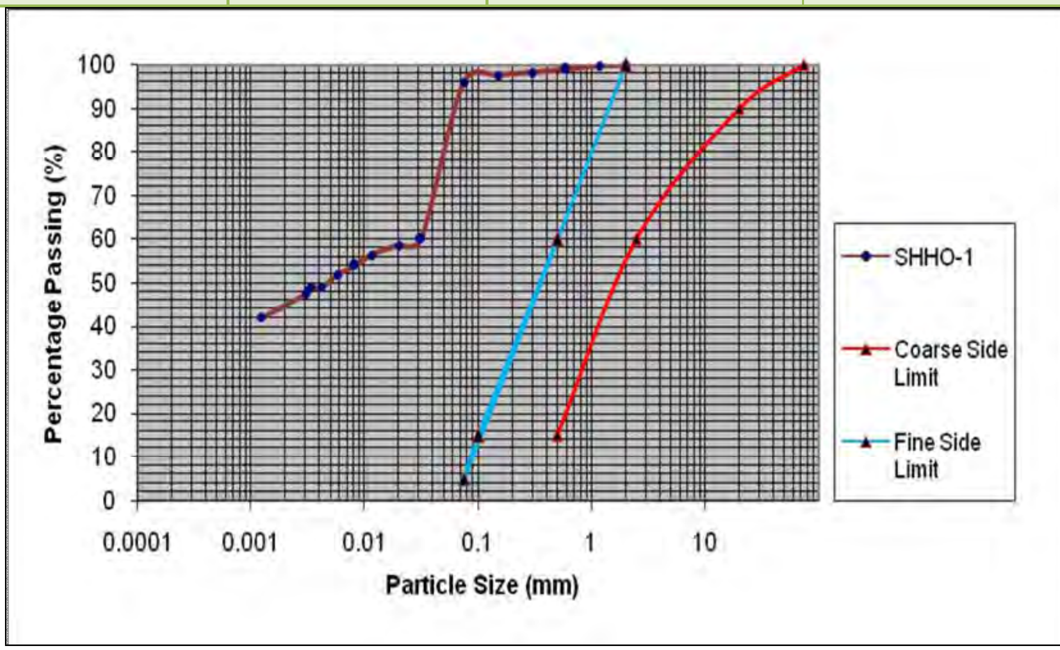
This indicates that for this particlular base soil, filters materials SHFL-3, SHFL-4B, and the average of the residual material, which is derived from the Lower Sandstone unit, can be safely used for the intended purposes.

Filter materials SHFL-1 and SHFL-2 , on the other hand, can be utilized by improving their gradation through mixing with relatively coarser sand from borrow areas of SHFL-3.

The average filter material gradation (indicated as yellow, in Fig.6.8), which is developed from the mean grain size distributions of the materials proposed from the weathered products of the Adigrat Sandstone units, reveled a good result.

This gradation distribution can be specified as suitable filter material for the protection of the base soil and also as appropriate drainage, both as chimmeny and horizontal filters.

Determined Particle Sizes			
Fine side of the filter band		**Coarse side of the filter band**	
Particle Sizes (mm)	**Percent Finer (%)**	**Particle Sizes (mm)**	**Percent Finer (%)**
0.06	0	0.3	0
0.075	5	0.38	5
0.083	10	0.42	10
0.1	15	0.5	15
0.5	60	2.52	60
2	100	20	90
		75	100



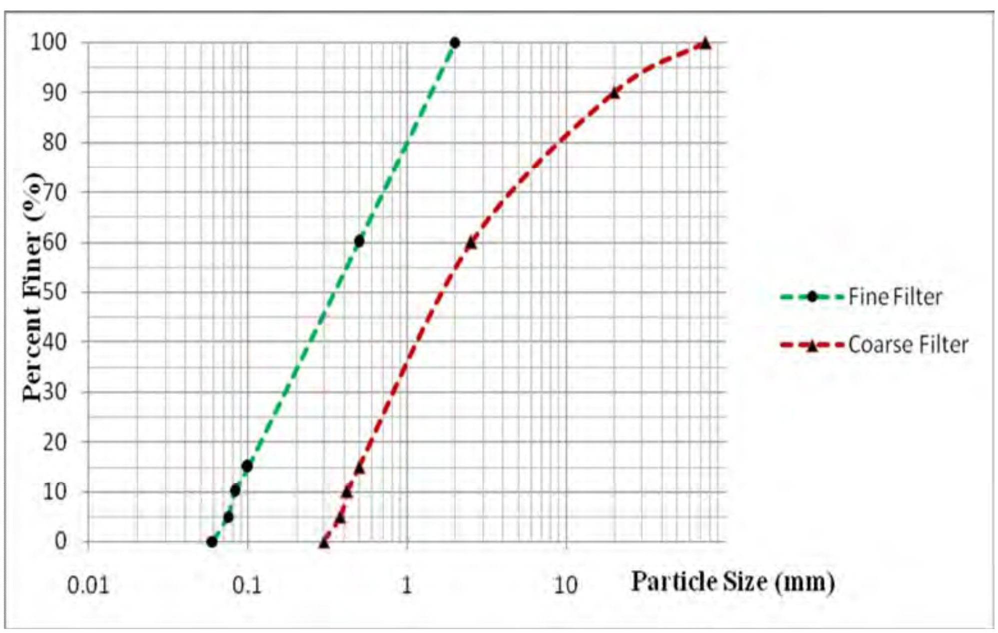


Fig.6.6 Gradation Limits for Filters for Base Soil SHHO-1

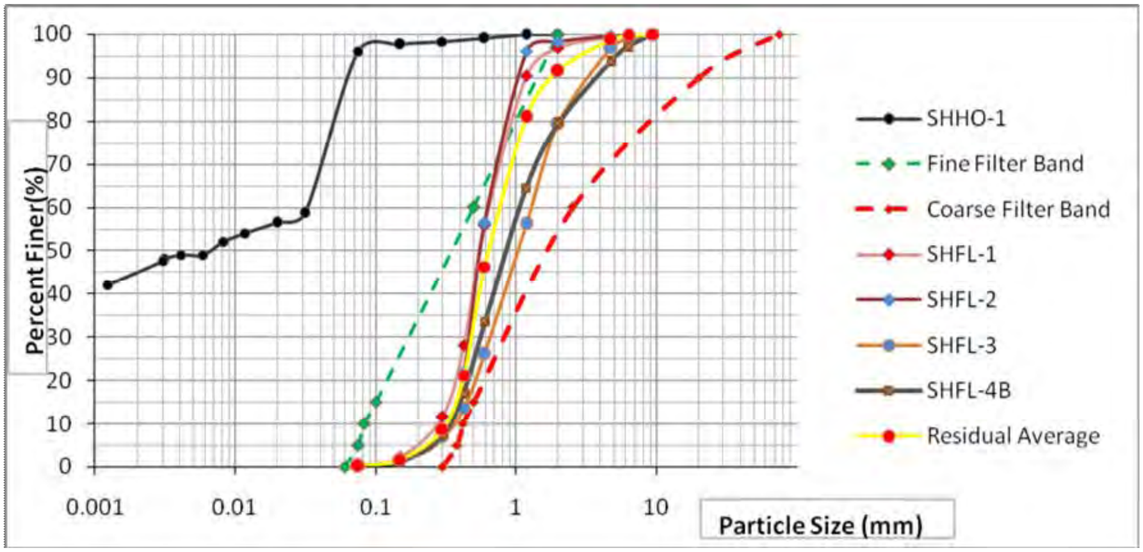


Fig. 6.7 Gradation Curves of Base Soil, Filter Limits and Natural Granular Filters

Similarly, the alluvial sediment filter soil (SHFL-4B) shows good result or satisfy the requirements of filteration and permability for the red fine base soil, proposed for the homogeneous fill for the dam. The borrow area or source of this filter material; however, is very far from this particular research project area and here economical aspects need to be analyzed. The economic question in this regard is that whether it will be economical to blend the residual sands (located within 30Km) according to the specifications or to transport the alluvial sediment from distant source (about 92 to 95Km). It is believed that blending the residual filter materials, especially from the source area for SHFL-3 to the other, will be more economical than transporting from disant places. However, for this a systematic detailed economic analysis is required which is beyond the scope of present study. Through the present study an attempt has been made to highlight some of the facts with following resons;

(i) The gradation curves for SHFL-1 and SHFL-2 shows that these soils are a little bit finer than the specfication, wheras SHFL-3 is coarser. Blending of small amount of SHFL-3 to the two finer sand soils will satisfy the criteria and met the gradation specfication.

(ii) The source area for the alluvial sediment is being under over exploitation, as it satisfies the demands of construction activities in the sorrounding areas. This may limit the available quantity.

B. USBR (1977) Method

The USBR method or criteria used here is as follows (Fell et al.1992);

(i) D_{15F}/d_{15B} = 5 to 40, provided that the filter does not contain more than 5% passing 0.075mm. This criterion ensures that the filter is more permeable than the base soil.

(ii) D_{15F}/d_{85B} <= 5, and the grain Size of the filter should be roughly parallel to that of the base material. This criterion ensures that the filter is sufficiently fine to control erosion of the base.

(iii) Maximum size particles in filter equal to 75mm to prevent segregation during placement.

(iv) For base materials which include gravel particles, the base material d_{15B}, d_{85B}, etc. should be analyzed on the basis of the gradation of the soil finer than 4.75mm.

Average Soil Gradation for Residual Filter Material (Specification)	
Particle Size (mm)	**Percent Finer (%)**
9.5	100.00
6.3	99.49
4.75	98.65
2	91.47
1.18	80.89
0.6	46.17
0.425	21.20
0.3	8.51
0.15	1.69
.075	0.19

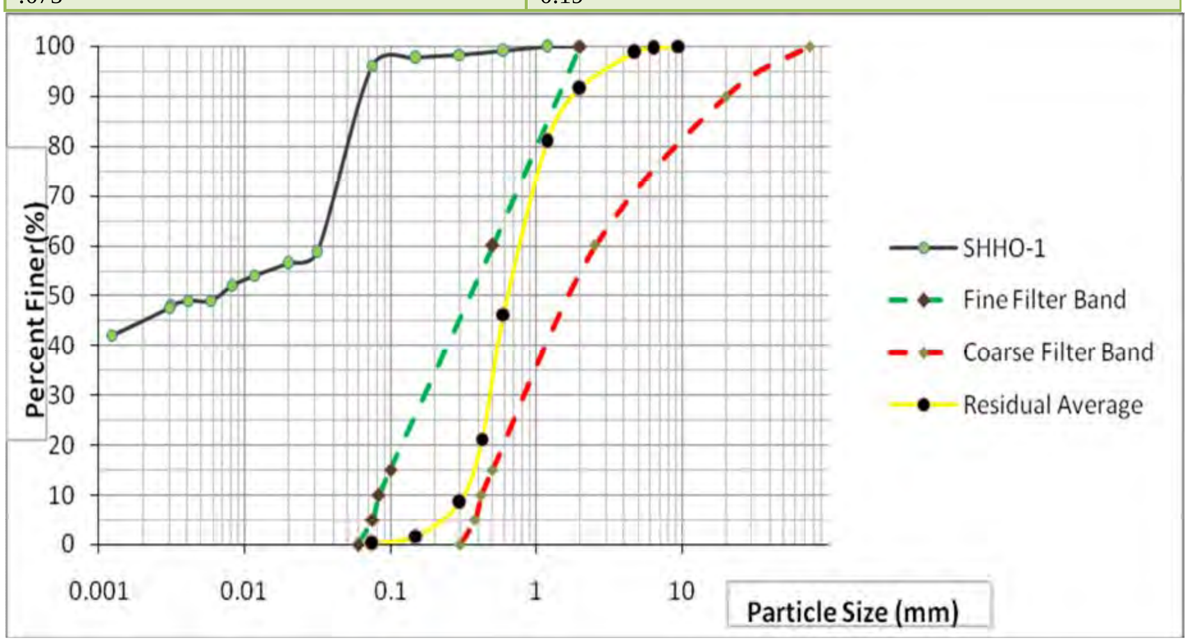


Fig. 6.8 Grain Size Distribution Curve for the Average Residual Filter Material

Accordingly, the criteria are checked for the entire proposed filters/drains used to protect the base soil and drain the seepage safely. The analysis result is presented in Table 6.5.

C. Terzaghi Criteria

These criteria have been used since 1930 for the design of filters for dams and other works. Although known to be conservative and originally developed for cohesion less uniform base soil and filter materials, the well known Terzaghi retention criteria are given by (Baharat Singh, 1995);

Table 6.5 USBR Filter Criteria Checking Result

Soils Sample No	Required Particle Sizes (mm)			Criteria				Remark
	D_{15}	D_{85}	D_{15}	(i)	(ii)	(iii)	(iv)	
SHHO-1	0.1	0.059	-	-	-	-	Nil	
SHFL-1	-	-	0.32	3.2	5.4	10	-	Nearly Satisfied
SHFL-2	-	-	0.38	3.8	6.4	10	-	Nearly Satisfied
SHFL-3	-	-	0.44	4.4	7.5	10	-	Nearly Satisfied
SHFL-4B	-	-	0.40	4.1	6.8	10	-	Nearly Satisfied
Average Residual Soil			0.38	3.8	6.4	10	-	

(i) 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

$$\frac{D_{15}\ of\ filter}{D_{85}\ of\ Protected\ Layer} < 4\ to\ 5$$

(ii) 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,

$$\frac{D_{15}\ of\ filter}{D_{15}\ of\ Protected\ Layer} > 4\ to\ 5$$

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 75 μm), the base material should be analyzed on the basis of gradation of fraction smaller than 4.75 mm.

Accordingly, the proposed filter materials for the present research have been analyzed or checked, and the results are presented in Table - 6.6.

Table 6.6 Summary of Results of Filter Checking Using Terzaghi's Criteria

Criteria	Proposed Filters					Remarks
	SHFL-1	**SHFL-2**	**SHFL-3**	**SHFL-4B**	**Residual Average**	
1	3.2, Not ok!	3.8, Not ok!	4.4, Ok!	4.1, Ok!	3.8, Not ok!	
2	5.4, Not ok!	6.4, Not ok!	7.5, Not ok!	6.8, Not ok!	6.4, Not ok!	
(i)	Nearly Parallel	Nearly Parallel	Nearly Parallel	Nearly Parallel	Nearly Parallel	
(ii)	< 1%, Ok!	< 1%, Ok!	< 1%, Ok!	< 1%, Ok!	< 1%, Ok!	
(iii)	<10mm, Ok!	<10mm, Ok!	<10mm, Ok!	<10mm, Ok!	<10mm, Ok!	
(iv)	Clayey Silt	Clayey Silt	Clayey Silt	Clayey Silt	Clayey Silt	Ok!

The second criterion ensures that the fraction of the protected base soil of size d_{85} or larger cannot pass through the pores of the filter. In this case none of the filters satisfies the requirements, however the values are very near to the values set in criteria. Since this criterion is conservative to cohesive soils like this research fill or base material, it is believed that all of the filters can generally protect the base soil.

The permeability of a soil is approximately proportional to the square of its D_{15} size (Baharat Singh, 1995). The first criterion thus ensures that the filter is 16 to 25 times more pervious than the protected soil and the hydraulic gradient correspondingly smaller.

For the proposed filters, SHFL-3 and SHFL-4B satisfies the requirements, whereas the rest failed with narrow limits.

By the same reasoning, those proposed filter materials that failed to satisfy the requirements, can be used with some level of confidence, at least 80 to 90%.

D. Recommendations as Per Indian Standard

The recommendations for filter selection as per IS code are as follows (Baharat Singh, 1995);

I. $\frac{D_{15} \text{ of filter}}{D_{85} \text{ of base}} < 5$

II. $\frac{D_{15} \text{ of filter}}{D_{15} \text{ of base}} > 4 \text{ and } < 20$

III. $\frac{D_{50} \text{ of filter}}{D_{50} \text{ of base}} < 25$

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

Similarly, the soil samples for the proposed filters and base soils are analyzed with these criteria. The results of filter criteria checking are presented in Table 6.7.

Table 6.7 Filter Criteria Checking Result as Per Indian Standard

Criteria	Proposed Filters					Remarks
	SHFL-1	SHFL-2	SHFL-3	SHFL-4B	Residual Average	
I	5.4, Not ok!	6.4, Not ok!	7.5, Not ok!	6.8, Not ok!	6.4, Not ok!	
II	3.2, Not ok!	3.8, Not ok!	4.4, Ok!	4.1, Ok!	3.8, Not ok!	
III	80, Not ok!	80, Not ok!	157.14, Not ok!	122.86, Not ok!	91.43, Not ok!	
IV	Nearly Parallel	Nearly Parallel	Nearly Parallel	Nearly Parallel	Nearly Parallel	OK!

From the above table, the retention criterion and D50 ratio are not satisfied by all of the filters, whereas the permeability one is met only by SHFL-3 and SHFL-4B. Relaxation in this criteria is recommended for cohesive soils (Baharat Singh, 1995), like this research base soil, which by virtue of cohesion, can withstand higher seepage gradients and resisting piping action. For dams of a height more than 10m (as this project) it is recommended that, the criteria for filters protecting cohesive soils may be relaxed by the designer according to his judgment and experience.

E. Sherard's Recommendations

Experiments conducted at the Soil Mechanics Laboratory, in USDA-SCS on different soils revealed the following criteria (Baharat Singh, 1995);

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

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

This shows that Terzaghiôs criterion includes a factor of safety of 2 and conservative.

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 coefficient of permeability (K) of dense filters is generally in the range of K = 0.2 to 0.6 D^2_{15} with average 0.35 D^2_{15} (K in cm/s and D_{15} in mm)

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

Accordingly the various filter materials proposed for the homogeneous fill base soil have been evaluated by these recommendations, and the results are indicated in the following table (Table 6.8).

Table 6.8 Filter Criteria Checking Result as Per Sherard Recommendations

Criteria	Proposed Filters					Remarks
	SHFL-1	SHFL-2	SHFL-3	SHFL-4B	Residual Average	
I	5.4, Ok!	6.4, Ok!	7.5, Ok!	6.8, Ok!	6.4, Ok!	
II	0.32	0.38	0.44	0.4	0.38	
III	0.03584	0.05054	0.06776	0.056	0.05054	K values
IV	Nearly Parallel	Nearly Parallel	Nearly Parallel	Nearly Parallel	Nearly Parallel	OK!

The first criterion recommended by Sherard is satisfied by all proposed filter materials. In addition to the above recommendations, Sherard came to the following general conclusions for fine grained soils similar to this research base soil:-

a) For fine clays (d_{85B} = 0.03 to 0.1mm), sand or gravelly sand filters with average D_{15} not exceeding about 0.5mm are conservative and reasonable.

b) For fine silts without significant sand content (d_{85B} = 0.03 to 0.1mm) and low plasticity, sand or gravelly sand filters with average D_{15} not exceeding 0.3mm are conservative.

The base soil considered in this particular research work lies in between the soils indicated in the criteria. It is silt with significant clay and very less sand, having D_{85} that ranges from 0.057 to 0.059 mm, with medium to high plasticity.

The proposed filters have D_{15} that ranges from 0.32 to 0.44mm, which almost satisfy the requirements. Since the recommendations have some degree of conservatism or safety factor, the proposed filter can be used safely for the intended purposes according to these Sherardôs recommendations.

6.3.2 Clogging Criteria Analysis

Indraratna et al. (1990) reported a relationship between the coefficient of uniformity and clogging. They studied the effectiveness of cohesionless granular filters for the protection of lateritic residual soils that is similar to this research base soil. Several series of tests were conducted, and in fine to medium sand filters, a clogging filter was detected with uniformity coefficient, Cu, equals to 3.8. It is summarized that fine to medium sand filters are effective for lateritic residual soils and clogging only occurs when the uniformity coefficient is close to 4. Accordingly, the proposed filter materials for this research project have been checked for clogging criteria or problems by determining their Cu values as indicated in Table 6.9.

Table 6.9 Result for Filter Clogging Check for Proposed Filter Materials

Sample No.	D_{60}	D_{10}	Cu Value	Remark
SHFL-1	0.66	0.28	2.36	Except SHFL-3, the rest are well far from 4, and there is no problem of clogging of the filters.
SHFL-2	0.62	0.32	1.93	
SHFL-3	1.4	0.36	3.9	
SHFL-4	1.1	0.34	3.2	

6.3.3 Physical Factors Analysis

The following are considered as physical factors as far as filter materials are concerned; fines content and relative density. When there is a crack in a cohesive soil core, a filter, to become effective must be non-cohesive. A filter with cohesive properties may sustain an open crack without collapse and thus fail to prevent a core crack. Milligan (2003) reported that when a core is cracked, a downstream filter became a secondary interface. If both base and filter crack, it is inevitable that piping and subsequent erosion will occur. To avoid filter materials becoming cohesive, there is a maximum limit of fines content of 5 to 8%. The entire filter materials proposed for this research project, in this regard, satisfies this criterion as the percentage of fines in the materials is less than 1% (Gradation curves of Filters, Annexure-2).

6.4 Dispersivity Analysis of Base Soils

To identify the dispersivity nature of the base soil (represented by sample SHHO-1), the result of the double hydrometer laboratory test has been analyzed. The double hydrometer test or percent dispersion test involves two hydrometer tests on soil sieved through a 2.36mm sieve. The hydrometer tests are carried out with dispersant and without (Fell et.al. 1992). The percent dispersion is equal to:

$$(P/Q) \times 100$$

Where P is percentage of soil finer than 0.005mm for the test without dispersant, and Q is percentage of soil finer than 0.005mm for the test with dispersant. Sherard, in 1976, indicated that soils with a percent dispersion greater than 50% are susceptible to dispersion and piping failure in dams, and those with a percent dispersion less than 15% are not susceptible (Fell et al, 1992). Accordingly, the base soil proposed for this research work has been evaluated. The value of P for this soil is determined to be 6.0, while for Q is 58.5. The calculated percent dispersion; hence, is 10.26. In this regard, the soil is classified as non dispersive.

6.5 Overall Assessment and Interpretation

The various well known criteria have been implemented to check the suitability of the filter material derived from the sandstone unit in comparison to the alluvial sand and gravel deposit, which is found at relatively distant place from the project area. Almost each empirical criterion has their own condition of applicability, and the filter materials are examined accordingly, and a selection of criteria which considers base soil type is found reasonable and so the analysis results from such criteria is used to conclude and recommend for the final design of the filter. Most of the design rules or criteria used for this research do not themselves entirely allow selection of the particle distribution of filters. The emphasis in those rules is on ÷spotô limitations within the grading curve. In this regard the criterion developed by USSCS, which is reported by Sherard and Dunnigan in 1985, is basically implemented.

Based on the first prioritized design rule for filters, the samples from residual sand nearly satisfy or fall within the designed grading limits or envelops. It is; however, found that two of the samples are a little bit finer that the permeability requirement may seem to be a little bit affected. The alluvial and the average residual filter materials, on the other hand, fall totally within the envelops of fine and coarse grading limits designed by USSCS design procedures. The physical characteristics of all proposed filters are in the acceptable quality since the grains are made up of dominantly quartz mineral in the case of residual material, and of basaltic fragments for the alluvial sediment.

Comparison have been made between the residual and alluvial sand based on parameters related to grain size distributions, accessibility, mineralogical compositions and some filter related engineering properties. The comparison result is presented in Table 6.3.

Table 6.10 Filter Related Parameter Comparison Result between Residual and Alluvial Sand

S/N	Compared Parameters	Filter Materials		Remark
		Residual Sand	Alluvial Sand	
1	Particle Size Distribution			
	Gravel	0.4 to 3.5	6	
	Sand	97 to 99	94	
	Fines	< 1	< 1	
2	Uniformity Coefficient (Cu)	1.93 to 3.9	3.2	
3	Coefficient of Curvature (Cc)	0.92 to 1.06	0.84	
4	USCS Soil Group	SP	SP	Poorly Graded Sand
5	Permeability (cm/s)	9×10^{-2} to 1.5×10^{-1}	1×10^{-1}	Hazen Method, both classed as pervious
6	Mineralogical Composition	Dominantly quartz	Dominantly basaltic liths	
	Accessibility	25 to 30Km	90 to 95 Km	From research site
7	Filter/Drain Suitability	The average is very suitable	Suitable	

The sand from the weathered section of the sandstone unit satisfies well the basic requirements of filter for this particular base soil category if an average grain size distribution is able to be produced from the existing borrow areas. This average grain size

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Chapter VII - Conclusions and Recommendations

7.1 Conclusion

The present research work mainly aims at characterizing the residual granular material or soil that results from the in-situ weathering of the lower Sandstone rock unit of the Mesozoic Formation of Ethiopia, exposed in the area. The material is assessed for its suitability as filter/ drain for a red fine grained soil mainly residual soil developed from the volcanic rocks. The sandstone unit is exposed near to the research project area and is being utilized as fine aggregate for local construction activities in the surrounding towns and cities, including Debre Markos, zonal capital. The fine soil, on the other hand, is a residual soil developed from complete weathering of the Cenozoic volcanic rocks, mainly basalt, of the area. The suitability analysis is based on or considers mainly geometrical empirical criteria, which are developed using comparison results of the grain size distribution of the filter and protected base soils.

The various well known criteria have been applied to check the suitability of the filter material derived from the sandstone unit in comparison to the alluvial sand and gravel deposit, which is found at relatively distant place from the project area. Almost each empirical criterion has their own condition of application, and the filter materials are examined accordingly. Selection of criteria, which considers base soil type, is found reasonable and so the analysis results from such criteria is used to conclude and recommend final design of the filter. Most of design rules or criteria used for this research do not entirely allow selection of the particle distribution of filters. The emphasis in those rules is on óspotô limitations within the grading curve. In this regard the criterion developed by USCS, which is reported by Sherard and Dunnigan (1985), is basically implemented.

The available empirical criteria implemented for this research work have been compared to each other to differentiate which one of them are more applicable and practical for the suitability analysis of a filter material for a given base soil. Most of them depend or considers the relationship of spot grain size ratios of the two types of soils; the filter and the base. The USCS method and Sherard et.al. recommendations, on the contrary, considers or aims to design the whole gradation limits, in which a filter need to be bounded based on a give type of base soil category. The proposed filter materials for this particular research project have been analyzed using the filter gradation design procedures of USCS, and their relative suitability in protecting or filtering the base soil, and at the same time draining the seepages (through the foundation and/or embankment) safely have been evaluated. Based on this evaluation the following conclusions have been drawn;

- ❖ In this design procedure the lower or finer, and upper or coarser gradation limits of the filter/drain material suitable for this particular red residual fine (silts and clays) soil have been drawn. Then each proposed filter materials, both the residual and alluvial granular soilsô gradation curves are examined with respect to the limits. In addition to this, an average granular soil for the residual material has been prepared theoretically and its suitability was also checked in the same manner. The result indicates that almost all selected and tested granular materials fall generally within the limits, except two of the residual filter soils (SHFL-1 and SHFL-2) which become a little bit finer.

- ❖ The final output of the design procedure is to define or specify the grain size distribution ranges for the filter/ drain material which successfully protect the base soil and drain seepages safely. It is; hence, specification in respect to the limit of gradation of the filter based on the American Standard for Testing of Materials (ASTM) standard sieve sizes has been prepared. This specification indicates that the proposed residual granular materials can be mixed in some ratios; especially mixing SHFL-3 to the other ones will improve the soils (become coarser) and change the finer filters as successful filter for the base soil.

- ❖ The alluvial soil proposed for filter and used for relative suitability checking as filter totally falls within the grading limits. It is a suitable material as both a filter and drain for this particular soil type. The problem associated to this material is that the source area is located at relatively very distant place. Besides to this the source is now under overexploitation that there may be some shortage of the material in the coming times.

- ❖ The other criteria, other than the gradation limits /geometrical factors, considered in the design of the filter are also well satisfied by both of the proposed type of granular soils. The percentage of fines in the materials is less than 1%. The grains of the residual materials are dominated with quartz minerals which are very strong and durable as a result resistant to deteriorations during the construction and also the life times of the filter. The alluvial material grains are composed mainly of lithe or fragments of basaltic rock. The grains become strong and durable as these have to be transported for some distances and experienced sufficient abrasions, and then durability.

As far as the nature of the base soil is concerned, it is normally important to assess the dispersive property. In this regard, the soil was tested for its dispersive character using double hydrometer laboratory test. The result indicates that the soil is not dispersive.

7.2 Recommendations

The present work has some limitations, especially financial. It is therefore the work focuses mainly on one single issue in the design of filter procedures or considerations, i.e. on the geometrical suitability checking using existing empirical approaches developed for other country cases. The design of filter in embankment needs assessment of several parameters of both the filter and base or protected soil. Considering the limitation, the following recommendations are proposed for further study;

- Since the existing filter design procedure in the country, and also for this research work is based on empirical approach devised for other country cases, it is necessary to conduct a compressive research to come out for local filter criteria. This may comprises categorization of the various engineering soils of the country, and conduct the research for each soil class.

- In the process of filter design there are generally three stages, each of which has its own outcome. These stages are study, design and construction activities. Generally, in the first two stages the filter material is identified and designed or checked with the empirical rules whether it satisfies the basic requirements or not. The third stage, on the other hand focuses on aspects related to the specifications that should be performed in the placement of the filter in the fill section. This includes the placement density measured with relative density. In this research work only the first two stages are considered. It is hence required to conduct a relative density test for the selected filter materials and prepare a suitable specification on the placement density.

- As a source for granular materials that can be used for the intended purpose (filter/drain) and also for fine aggregate, both the residual and alluvial sand can be used. In addition to these sources, there is an alternative material that can be used for similar purposes. This is crushed sand from nearby basaltic rock. Such rock unit is exposed in large quantity within 2 to 3km downstream of the dam site. Here, an economical analysis has to be performed prior to utilizing or choosing the three source areas.

- The physical criteria or requirement for the granular material that has to be considered during filter design, especially the mineralogical composition of the filter, for the residual sand is analyzed based on secondary data. It is; hence, necessary to conduct petrography study of the parent (the sandstone) rock, and also mineralogical examination of the sand grains.

- Other important consideration in filter/drain material is its durability. The materials need to be durable during placement from the action of compaction equipment, water that will have contact with it, and from wet and dry conditions during reservoir operations. For these, there are recommended tests to check the durability of the proposed filter/drain materials. It is necessary to conduct durability test before the utilization of the materials.

- In this research no attempt has been made regarding to determination of the thickness of the filter zone. For this determination the construction requirement is the basic consideration. Based on the type of construction method the thickness has to be fixed.

- Breakdown of particles occurs during placement and compaction. Specifications should apply to the filter after placement in the dam. This means that the contractor may have to manufacture the filters coarser than the specifications.
- It is necessary to sample the stream water together with (if possible) the groundwater in the area, and conduct some important quality tests. This will help to analyze the effect of the seeping water through both the foundation and embankment on the performance of the filter and also on the base soil (especially its dispersive nature). During this research a sample was taken from the stream flow and a quality test was conducted with the limited financial support. The result, however, is not reliable as it indicates high quality water having very low cation and TDS percentages, consequently it is discarded.

- The geological formation (the Adigrat Sandstone) assessed to its weathering product of granular material is exposed at many part of the Ethiopia. The resulting granular material is also being used for different engineering construction purposes at various places. This particular research focuses on characterizing the formation exposed at one specific location, and one specific purpose. It is important to conduct extensive research work that comprising overall engineering geological aspects of the material derived from weathering of the formation and by considering wide geographical and sampling domain.

- Similarly the base soil in this research work was analyzed mainly from grain size distribution and its dispersive nature (using one method of laboratory test). This African red soil (general soil category) need to be examined further for its all engineering geological aspects related to filter design, study and construction requirements.

- The weathering and consequent soil, jointing and the alluvial sediment make the dam site having non-uniform foundation; though seepage problem is only related to the jointed portion of the rock. To make uniform foundation and prevent seepage through the defected rock zone, a cut-off trench having sufficient bottom width and keyed with the underlying fresh basalt rock should be designed.

- The recommendations made through the present study must be considered as indicative only as the study was conducted under the constraints of limited time, restricted resources and financial deficiency. These limitations might have affected the quality of the results marginally. Thus, it is strongly recommended to perform elaborate tests on various aspects before implementing results or findings of the present study.

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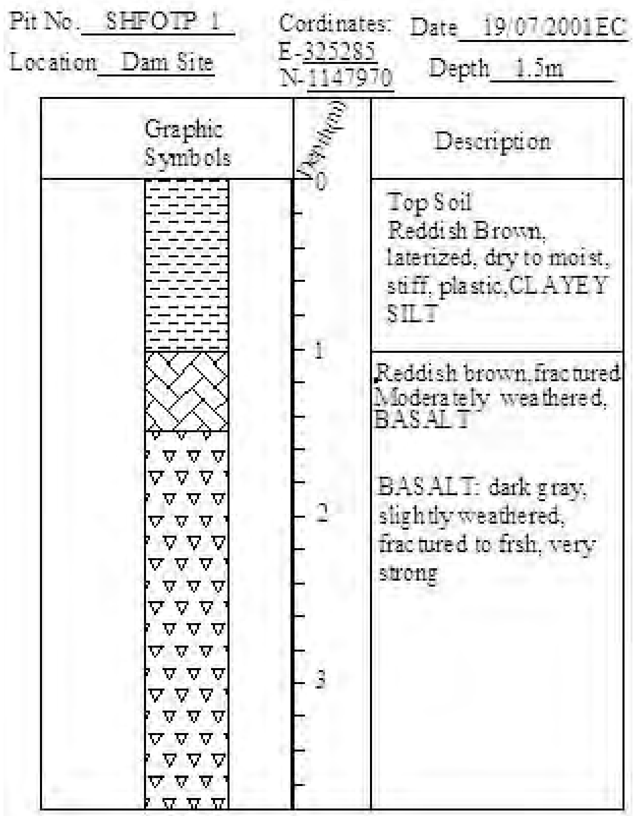
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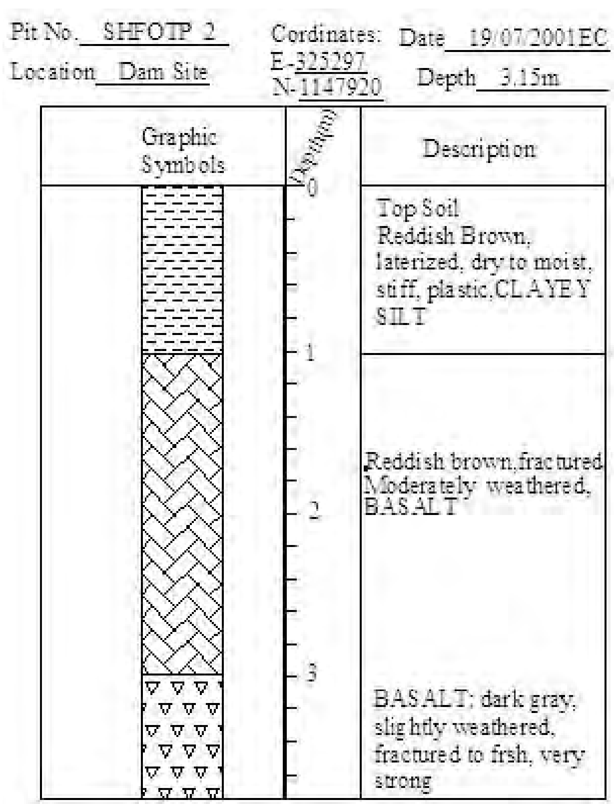
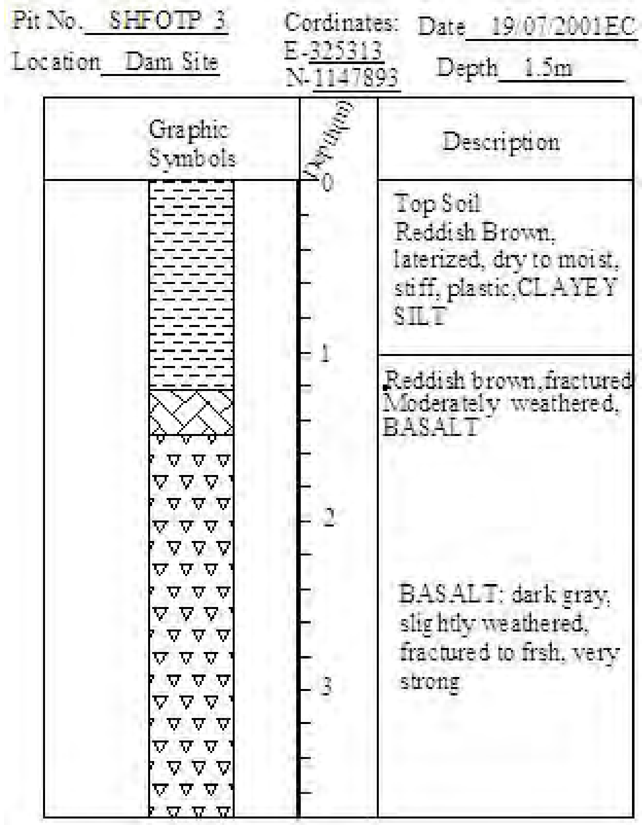
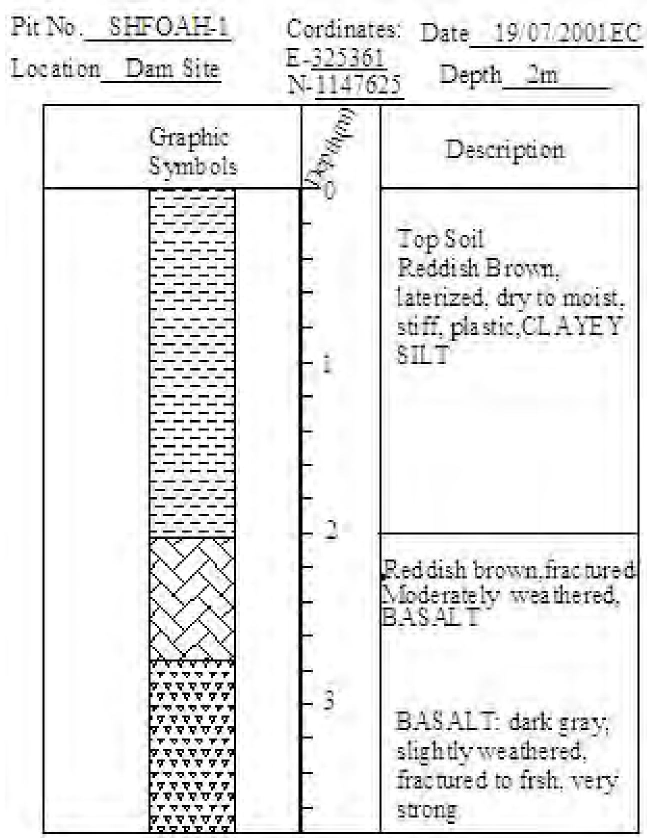
Location Dam Site
Cordinates: E-325285 N-1147970
Date 19/07/2001EC
Depth 1.5m
Graphic Symbols
Depth(m)
Description
0
1
2
3
Top Soil
Reddish Brown, laterized, dry to moist, stiff, plastic, CLAYEY SILT
Reddish brown, fractured Moderately weathered, BASALT
BASALT: dark gray, slightly weathered, fractured to frsh, very strong


Pit No. SHFOTP 2
Location Dam Site
Cordinates: E-325297 N-1147920
Date 19/07/2001EC
Depth 3.15m
Graphic Symbols
Depth(m)
Description
0
1
2
3
Top Soil
Reddish Brown, laterized, dry to moist, stiff, plastic, CLAYEY SILT
Reddish brown, fractured Moderately weathered, BASALT
BASALT: dark gray, slightly weathered, fractured to frsh, very strong


Pit No. SHFOTP 3
Location Dam Site
Cordinates: E-325313 N-1147893
Date 19/07/2001EC
Depth 1.5m
Graphic Symbols
Depth(m)
Description
0
1
2
3
Top Soil
Reddish Brown, laterized, dry to moist, stiff, plastic,CLAYEY SILT
Reddish brown,fractured Moderately weathered, BASALT
BASALT: dark gray, slightly weathered, fractured to frsh, very strong


Pit No. SHFOAH-1
Location Dam Site
Cordinates: E-325361 N-1147625
Date 19/07/2001EC
Depth 2m
Graphic Symbols
Depth(m)
Description
0
1
2
3
Top Soil
Reddish Brown, laterized, dry to moist, stiff, plastic,CLAYEY SILT
Reddish brown,fractured Moderately weathered, BASALT
BASALT: dark gray, slightly weathered, fractured to frsh, very strong

Augur Hole Log Form

Project name: Shumbrit Micro Earth Dam
Location: Clay Borrow Areas
Co-ordinates:
Date: 19/07/2001 EC

Augur Hole No. AH-1 to AH-11
Slope: Gentle
Logged by: Tamiru K.

Symbol	Description	Depth (m)										
- .-. .-.-. -. -. -. -. -. -. -. -. -. -. -. -. -. -. -. -.	Clayey silt soil, medium to highly plastic, reddish to dark brown, impermeable soil	AH-1	AH-2	AH-3	AH-4	AH-5	AH-6	AH-7	AH-8	AH-9	AH-10	AH-11
		4.3	2.2	3.5	3.0	2.5	4.0	3.6	3.0	3.5	3.2	3.4

ANNEXTURE -1

Test Pit/Augur Hole Logs

ANNEXTURE -2

Laboratory Test Results