Characterization of Embankment Material with Special Consideration to Clay Core: A Case Study for Kalid-Dijo Dam in Southern Ethiopia

A Thesis
Submitted to

The School of Graduate Studies of
Addis Ababa University

By
Yosef Tafa

In Partial Fulfillment of the Requirement for the Degree of Masters in Engineering Geology

ADDIS ABABA UNIVERSITY
School of Graduate Studies
Department of Earth Sciences

September 2021

Addis Ababa University

College of Natural and Computational Sciences

School of Earth Sciences

Thesis Approval form

This is to certify that the thesis prepared by Yosef Tafa, entitled: "**Characterization of Embankment Material with special consideration to Clay Core: A Case Study for Kalid-Dijo Dam in Southern Ethiopia**", and submitted in partial fulfillment of the requirements for the degree of Master of Science (Engineering Geology) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Approved by Examining Committee	**Signature**
Dr. --------------------------- Chairman	____________________
Dr. --------------------------- Examiner	____________________
Dr. --------------------------- Examiner	____________________
Dr. Trufat Hailemariam Advisors	____________________

ABSTRACT

The research is assessing the quality of construction material of the Kalid-Dijo irrigation dam, located in Southern part of Ethiopia, Silte Zone. It is a zoned rockfill embankment dam designed using multi criteria analysis, to tolerable the high probable seismicity that involves quality clay material for its central core. However, the project investigation reveals that the available borrow sites do not fully satisfy the prerequisite for core material. Thus, this research aims to characterize further the locally available clay core material and attempts to forward experiment-based alternatives to meet the required quality for core material of the designed zoned rockfill embankment dam.

The previous studies identified MH core clay materials using USCS near to the dam axis; while in this investigation, the same borrow site classified as CH, to have high compressibility, low dry density, low shear strength, high swell potential and high volumetric shrinkage. It fails to satisfy the general design specification criteria and limits for impervious material.

In this research, blending experiments using different ratios are conducted using the available gravelly material to that of the clay from selected borrow sites. Different tests including classification, proctor compaction, consolidation, free swell, volumetric shrinkage, direct shear, dispersion and permeability tests were conducted on the blended ratios to check the improvement on the clay core material. And it is found out that the required improvement was achieved with 50G:50C mix proportions.

Based on results, the blended GC material (50G/50C) has an average of 1.6 maximum dry density (MDD), 24% optimum water content (OMC), plasticity index (PI) 24, 52.33KPa cohesion (C) and 29.38^0 friction angle (Ø), which satisfy the basic requirements of core material. It generally showed shows 40% reduction in PI, 12% improvement in MDD, 5% reduction in OMC, and 18% reduction in compression index. It has also a better shear strength and compressibility characteristics than other mix proportions; however, it needs proper care to manage its segregation potential, likely to be resulted from improper mixing in the field that may lead to continuous leakage path within the core during construction stage.

Based on permeability results, all the blended ratios were classed as low to very low permeability ($\leq 10^{-6}$ cm/sec). Blended ratio of 40G/80C and 30G/70C is preferable in terms of economy; however, the required engineering properties like compressibility and compaction is relatively low. Therefore, the 50G/50C blended proportion can almost satisfy the standard limits set for design for impervious core material.

ACKNOWLEDGEMENTS

First of all, I would like to praise the Sovereign Lord, who provides me with indescribable support during the present research work.

I would like to express my sincere gratitude to my advisor Dr. Trufat Hailemariam for his follow up and support right from the beginning of the thesis period up until now. He has been devoting his precious time and providing all the necessary relevant literature and information that are crucial for the quality of this research.

My special thanks also go to my employer Ethiopian Construction Design and Supervision Corporation (ECDSWC) for allowing me to pursue my postgraduate study and from where I received all secondary data.

I would like to extend my thanks to all staff of Geotechnical Investigation and Geotechnical Design and Supervision process for their valuable advice and courage during research work. I also appreciate ECDSWC laboratory staff for their assistance in provision of necessary data.

My deepest gratitude also goes to Kalid-Dijo dam project especially to Mr. Yahya Ahmed, Kenean Sehale and Temesgen Shomoro for their encouragement, advice and unlimited material support.

I am very grateful to my wife Menen Guesh, my children Raey Yosef and Kidus Yosef and all my families and friends for their priceless and non-ending follow-ups and support. God bless you!

The fear of the **LORD** is the beginning of wisdom. psalms 111:10

Table of Contents

List of Figures

List of Plates

List of Tables

List of Appendix

CHAPTER 1 INTRODUCTION

1.1 General

Development of water resources is one of the basic needs for national economic growth. Efficient utilizations of surface and ground water resources is also essential for the welfare of a community. The major challenge for effective and efficient utilization of water resources is the temporal variation of the resource. There is no doubt that regulating the temporal available water resource plays a central role in any development activities. Moreover, most of the developed world is utilizing their water resources competently. Therefore, the proper and timely utilization of water resources using dams and its conveyances is vital for the economic development of the country. Construction dams are considered as basic infrastructure investment elsewhere.

Dams are structures controlling the flow of a river by completely blocking the valley of a given river. Through the blockage, storage is formed, which can be utilized for various water resources development or flood control purposes. Each dam site has unique characteristics, which require special consideration for effective dam engineering. Topography and geology of dam and reservoir sites, cost and availability of natural construction materials are the most important factors to select the dam type. Stability of the dam foundation and suitability of construction material have an important consideration in the safe functioning of the dam. Before assessing the future demand for any dam site, experience gained from those constructed in the past is essential.

Earth and rock fill dams are relatively more economic and technically feasible for most of the sites. It is possible to engage the nearby natural materials with a minimum of processing for these dams, and gain reasonable haul distance. Further use of materials that are excavated from the dam foundation, spillway, outlet works, and other appurtenant structures also play a role to their economic feasibility. However, the excavated materials' suitability should be properly assessed. The foundation characteristics may have much influence on the design of the embankment. Embankment dams require low capital investment, are much resistant to the earthquake forces in seismic areas and can be completed in a very short period of time with minimum environmental impact, as compared to concrete dams.

A dam must be stable enough to withstand the forces to which it will be subjected and it should be capable of resisting seepage either through the foundation and the structure itself, which will gradually result in internal erosion and ultimately into failure of the dam. Carelessness during the investigation stage and improper use of construction material are among the main causes for engineering related challenges such as excessive seepage, piping, cracking, sliding and settlement (Bell, 1980).

Consequently, it is paramount to conduct detailed investigation of construction material to ensure the availability of the required quality and the quantity of construction material. For the stability and safe functioning of the dam, multi-dimensional characterization of the locally available earth fill material for the embankments will be advantageous. The field investigations must be continued even during the construction stage. It is essential that the prediction of the ground conditions which constitutes the basic design assumption, are checked as construction proceeds and designs should be modified accordingly if conditions are revealed which differ from those predicted (Bell, 1980).

In the light of above discussion, this research tries to characterize the proposed construction material for Kalid-Dijo embankment dam which mainly concerns the engineering properties and site conditions of the recommended construction material sourcing.

1.2 Statement of the Problem

Embankment dams are the most economical and widely constructed type of dams in the world. The Kalid-Dijo dam and irrigation project has selected a rock-fill dam considering different factors. But the geotechnical report of available construction materials revealed that the quarry and borrow sources proposed for the project are from a heterogeneous pyroclastic origin to meet the required quality. Pyroclastic rocks are considered as weak rocks, and when excavated, placed and compacted they produce a dirty rock fill embankment (USSD Materials for Embankment Dams, 2011). Due to the limitations on time and resources, this study give emphasis to the core material as it is a crucial zone from the stability and performance point of view for an embankment dam.

The proposed impervious core material is found to be highly plastic silt which is a residual formation from chemically disintegrated ash and tuff is not suitable. It contains fine grain soils of more than 90% (clay > 56% and silts > 34%) which have a high liquid limit.

A high liquid limit is an indication of a high compressibility which must be avoided to a very limited value in dam construction. The high plasticity index which is more than 35% is also another problem regarding selected core material. Such index property of a soil is associated with less workability during construction. The maximum dry density of the soil is also less than 1.5g/cc. The optimum moisture content is also greater than 25%. Fine particles have an unfavorable character of retaining pore water pressure for a long time. As the optimum moisture content increases this problem gets complicated. The free swell test conducted at feasibility study shows that some material swells more than 100%. Though the clay core of the rockfill dam may be selected at feasibility stage considering multi criteria analysis, improving the unsuitable core material is still a gap which must be addressed. Even though the dam site falls in geologically complex terrain like Kalid-Dijo dam, detail description of construction materials has a great importance. In line with this, this research aims to characterize further the locally available embankment material and attempts to forward alternative solutions that can be used as central core material for zoned embankment dams. It will definitely provide valuable information for the project and also inspire to serve as a guideline for similar projects being constructed elsewhere in the country.

1.3 Objectives

1.3.1 General Objective:

The present study aims to characterize the recommended construction material sources for central core zones of the embankment and to provide a way to improve the qualities of the core material to meet the standards through blending.

1.3.2 Specific Objectives:

The specific objectives of the research include:

- To carry out test pitting and sampling for physical examination and laboratory tastings;
- To characterize clay core material and perform laboratory blending experiments in different proportion; and
- To define the practical blending practice for core material.

1.4 Importance of the Study

Since improper use of construction material is one of the main causes for embankment failure by seepage, piping, cracking, sliding and settlement; so this research study is designed to revise the results of the previous study that constitutes basic design assumption construction materials and how to improve the qualities of construction materials with experimental emphasis of clay core material according to the accepted standards.

Primarily the present study results and findings are expected to be utilized by the Project Authority and will be vital for early inspection of its safe and economic design of the anticipated dam.

The data generated through this study may also be utilized by the later researchers intending to work on the same subject or in the same study area. The present research study may also help in improving the stability of the proposed dam. Besides, it may assist to minimize the risks for unseen defects in construction material. It introduces the means of utilizing locally available construction material in an efficient manner.

*****

CHAPTER 2 LITERATURE REVIEW

2.1 Embankment Dam

2.1.1 General

The availability of natural construction material is one the main factors that may lead to the selection of embankment dam type for a given dam site. The construction material has to be present in sufficient volume and must be within economic distance from the dam site. The design of the embankment dam takes into consideration the engineering properties of the construction material. Proper field and laboratory identification of these materials is the main task before the actual design of the embankment dam. For this initial surface and sub-surface investigations must be directed toward determining the character and quantity of material available from local borrow pits, and from required excavation for the foundation, outlet works and spillway. The field study should be incorporated with appropriate laboratory test results on the sample collected during field investigation.

Sometimes construction materials of two different physical and/or chemical properties like clays and rock/gravel are mixed to use the advantages of both materials concurrently. In such a case the embankment zone will have high strength of rock/gravel material and low permeability value of clayey material. If the properties of the natural material available at a given site may not be ideal, it could be improved by blending, screening, or washing (Li Yong-Hong, 2012)

However, it is usually more economical to utilize material available in their natural state without blending or processing to minimize construction cost. Where two types of materials occur in horizontal layers or close to each other blending can be done more economically with slight rise in cost to obtain the advantage of a material of better quality (Ali, 2008)

According to Sherard (1963), a more efficient developing mechanism should be selected for material available as layered deposit and the property of such blended mixture can be controlled by varying excavation sequence or by varying mix proportion to obtain a different percentage of the two soils.

2.1.2 Overview of Embankment Material

One of the principal economic advantages of the earth dam is that nature has already fabricated the construction material and placed them free of charge at the site (Sherard, 1963). If suitable soils for an earth fill dam can be found within a reasonable haul distance from the site, an earth dam may prove to be more economical. For the case where only one type of material (soil) is readily available on the site, the design will consist of a homogeneous embankment. If it is impervious soil, a homogeneous embankment with only small amounts of pervious material to control the internal erosion will be selected. If it is pervious material (sand or gravel), a dam with a very thin core may be used where enough impervious material is available to make a core; otherwise, an impervious facing may be constructed. For the case where varied material is available at the site a zoned dam which incorporates the material available on the site into the embankment will be selected. In this case the material for zones like: core, Filter, Shell/Rock-fill and Riprap should be checked individually (Sherard, 1967).

2.2 Embankment Dam Material

Inorganic soils generally are divided into two, broadly: fine grained soils and coarse-grained soils. Many embankments are constructed of broadly graded soils (fine or coarse) which do not fit entirely into either category, or exhibit characteristics of both. Fine grained soils are often used in homogeneous dams, and in impervious core sections of zoned embankment dams. Fine grained soils are defined as materials having at least 50 percent by weight of particles finer than 0.075 mm, or the openings of a U.S. Standard No. 200 sieve, according to the Unified Soil Classification System (USCS, 2003).

The principal characteristics that distinguish fine grained soils from coarse grained soils for purposes of embankment dam design are that fine grained soils have lower permeability, lower shear strength, and higher compressibility. Soil plasticity serves as an initial indicator of the potential behavior of a clay or silt when placed in an embankment dam. Consider, for example, clay and silt having the same liquid limit. The clayey soil will be more plastic, that is, it will have a higher PI. It likely will be less permeable than the silty soil. The compressibility of both soils may be nearly the same. If two soils having the same PI are considered, the soil with the higher liquid limit will be more compressible, whether that soil is silt or clay.

Coarse grained soils are used in structural fill zones and shells. It also makes filter and drain zones within embankment dams. Coarse grained soils are also used in core zones, especially when the fine content is greater than 20%. Compressibility is generally of less concern, as these soils are essentially incompressible when compacted to a dense state.

The most important properties of rockfill are as follows; Gradation, Compacted Unit Weight, Permeability, Compressibility, Strength and Deformation

Materials that can be used for embankment dams must fulfill these criteria according to the US Army Corps of Engineers (US Army corps of Engineers,2003).

2.2.1 Earth-fill Materials.

While most soils can be used for earth-fill construction as long as they are insoluble and substantially inorganic, typical rock flours and clays with liquid limits above 80 should generally be avoided (US Army corps of Engineers,2003). The term “soil” as used herein includes such materials as soft sandstone or other rocks that break down into soil during handling and compaction.

If a fine-grained soil can be brought readily within the range of water contents suitable for compaction and for operation of construction equipment, it can be used for embankment construction. Some slow-drying impervious soils may be unusable as embankment fill because of excessive moisture, and the reduction of moisture content would be impracticable in some climatic areas because of anticipated rainfall during construction. In other cases, soils may require additional water to approach optimum water content for compaction. Even ponding or sprinkling in borrow areas may be necessary. The use of fine-grained soils having high water contents may cause high pore water pressures to develop in the embankment under its own weight. Moisture penetration into dry hard borrow material can be aided by ripping or plowing prior to sprinkling or ponding operations (US Army corps of Engineers,2003).

As it is generally difficult to substantially reduce the water content of impervious soils, borrow areas containing impervious soils more than about 2 to 5 percent wet of optimum water content (depending upon their plasticity characteristics) may be difficult to use in an embankment. However, this depends upon local climatic conditions and the size and layout of the work, and must be assessed for each project on an individual basis. The cost of using drier material requiring a longer haul should be compared with the cost of using wetter materials and flatter slopes. Other factors being equal, and if a choice is possible, soils having a wide range of grain sizes (well-graded) are preferable to soils having relatively uniform particle sizes, since the former usually are stronger, less susceptible to piping, erosion, and liquefaction, and less compressible. Cobbles and boulders in soils may add to the cost of construction since stone with maximum dimensions greater than the thickness of the compacted layer must be removed to permit proper compaction. Embankment soils that undergo considerable shrinkage upon drying should be protected by adequate thicknesses of non-shrinking fine-grained soils to reduce evaporation. Clay soils should not be used as backfill in contact with concrete or masonry structures, except in the impervious zone of an embankment (US Army corps of Engineers,2003).

Most earth fill materials suitable for the impervious zone of an earth dam are also suitable for the impervious zone of a rock-fill dam. When water loss must be kept to a minimum (i.e., when the reservoir is used for long-term storage), and fine-grained material is in short supply, resulting in a thin zone, the material used in the core should have a low permeability. Where seepage loss is less important, as in some flood control dams not used for storage, less impervious material may be used in the impervious zone.

2.2.2 Core Material

It generally consists of the most impervious suitable material that is available at an economic distance from the dam site to provide a barrier for seepage flow through the dam. The important soil properties to be considered are; permeability, compacted density, shear strength, compressibility, flexibility and erosion resistance. Various types of materials with a permeability of 10-5 cm/s or lower have been used in cores of the embankment dams (Singh, 1995).

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

According to Singh (1995) erosion resistance is the ability of the soil to withstand the erosive action of water leaking through possible cracks. Erosive resistance is mainly derived from two sources: cohesion of the fines and the resistive action of coarse particles to the flowing water and their tendency to wedge-up in the leakage channel.

This effect is best obtained in a well graded sand gravel mixture with enough finer particles to provide imperviousness (Table 2.1). In such a material the coarser particles within the crack obstruct the flow and prevent development of high velocities. In tough plastic clay the resistance to erosion is provided by the strong inter-particle adhesion.

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

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

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

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

2.2.3 Suitability of Core material

An earth dam may be susceptible to cracking under certain circumstances. All cracking cannot be prevented in the design; however, the design must incorporate provisions to minimize the adverse effect. The transverse crack is of primary concern that may be caused by tension related to embankment differential settlement or differential foundation consolidation. It may also result from shrinkage differential settlement which may be most severe at steep abutments or at adjoining structures where compaction is difficult (Jansen, 1988). Particular attention shall be given to the compressibility of the material selected for the embankment primarily for core material which has a decisive factor for embankment dam differential settlement. Efforts shall be made to identify material of low compressibility where the conditions permit. The embankment materials in different zones having nearly similar stress-strain characteristics are more advantageous to minimize the differential settlement between different zones.

2.2.4 Transition Filters/Drains Material

The objective of filters and drains used as seepage control measures for embankments is to efficiently control the movement of water within and about the embankment. In order to meet this objective, filters and drains must, for the project life and with the minimum maintenance, retain the protected materials, allow relatively free movement of water, and have sufficient discharge capacity.

The filter design for the drainage layers and internal zoning of a dam is a critical part of the embankment design. It is essential that the individual particles in the foundation and embankment are held in place and do not move as a result of seepage forces. Transition filters are the most important component part of the dam section which is provided in between core and shells on either side to protect it from piping failure. Filters and drains can provide permanent security against the damage section of seepage and groundwater, however; certain fundamental requirements must be strictly enforced. The first requirement of filters and drains is that they must be safe with respect to erosion and clogging. The second requirement, which can be equally important, is that they must have sufficient discharge capacities to remove seepage quickly, without inducing high seepage forces or hydrostatic pressure. In addition, if filters and drains are required to serve their intended purpose, the materials used in their construction must have the correct gradation and they must be handled and placed with care to avoid contamination and segregation (Cendergren,1977). There are various filter selection criteria proposed by different authors.

<u>Terzaghi's Filter Selection Criteria (1930)</u>

For the design of filters Terzaghi proposed the following criteria;

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Sherard's Recommendations for Filter Design

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

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

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

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

Horizontal Filter

It collects the seepage from the inclined/vertical filter or from the body of the dam. It also collects seepage from the foundation and minimizes the possibility of piping along the dam seat.

The horizontal is to be provided on stripped ground. Depending on downstream topography, the slope of the horizontal filter towards the toe drain is to be decided.

The horizontal filter must satisfy the following three requirements:

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

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

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

2.3 Embankment Dam Failure

A review of the data from the 1975 and 1988 under the study of ASCE/USCOLD indicates that about 40 percent of failures and accidents to embankment dams are the result of leakage and piping through the dam, foundation, and/or the abutments. Overtopping and washout of the dam are a second major cause of failures and accidents. Slides within the abutments or the embankment slopes caused by a high phreatic surface within the downstream slope, drawdown of the reservoir, or earthquake are another major cause of failures and accidents to embankment dams (USSD, 2011).

The three methods for seepage control in embankments are flat slopes without drains, embankment zonation, and vertical (or inclined) and horizontal drains (USSD, 2011).

According to L.M. Zhang et at. (2007), more than 900 dam failure cases throughout the world excluding China have been collected from the literature and compiled into a database. From reported dam failure cases 66% are earth dams. It is indicated that a dam is most likely to fail within its first five-year service, especially during the first year after construction.

The paper states that most of the dam failures are caused by either overtopping or quality problems. These two causes led to nearly 80% of all failure. From all quality problems 58% are associated with piping in the dam body or foundation. Overall, the most common causes of earth dam failures are overtopping and piping in the dam body or foundation. The principal influence factor on overtopping is insufficiency of spillway capacity. For piping in the dam body or foundation, the most single adverse factor is crack, which can be caused by differential settlement, material shrinkage, foundation defects, and imperfect interface.

2.4 Practical Blending Experiences of Core Material

Fine particles were commonly used as impervious material in earth or rockfill dams before the 1960s. But as observed from practices, fine particles create problems especially in high dams. The problems include large deformation, poor post-crack seepage deformation resistance, high soil moisture content, unavailability of acceptable soil source and construction difficulty (LI Yong-Hong, 2012)

As a solution, spreading gradation gravel material is the most widely used method in the construction of dams. After fulfilling seepage requirements, such materials would improve the core by increasing strength, lowering compressibility, lowering deformation and minimizing core cracking and hydraulic fracturing. This is due to during core cracking, the coarse grain may mitigate seepage erosion and improve self-sealing capability of the cracks due to reversed filter protection. (LI Yong-Hong, 2012)

There are three modifying methods of unsuitable soil: Introducing coarse grained into finer soil, removing coarse grains larger size by screening and blending gravelly soil. In practice, spreading gravelly graded soil, grains larger than 5mm should not exceed 50% and soil grains with 0.1mm must be around 20%. (LI Yong-Hong, 2012)

The major blending methods for earth-rock fill dams are; horizontal spreading and vertical extraction in borrow pit or in blending ground, dumping and blending on filling surface, blending by belt conveyor and blending by mixer. But because of its simplicity, the ‘’horizontal spreading and vertical extraction’’ is widely used.

2.4.1 Experimental Works Done in Blending of Core Material

In recent years, several high embankment dams have been constructed in our country and internationally and a common feature of these dams is the use of clay-gravel mixtures, either natural or artificially blended, as the impervious core materials. Controlling the mass/volume content of gravel plays a central role in controlling the strength, deformation and permeability behavior of the mixtures obtained. For instance, increasing the content of gravel results in an increase in the stiffness of clay-gravel mixtures and it is beneficial to reduce the differential settlement between the core and shoulders. On the other hand, the permeability also tends to increase as the content of gravel increases, which results in a potential risk of seepage failure and unacceptable leakage. A good design practice of blending of core material, therefore, needs a balance between the impermeability and deformation behavior.

In our country Ethiopia, the blending option is not new. A study conducted on Kesem dam, located in Afar region due to the acknowledged core material demonstrate poor engineering properties consider as drawback to be used as impervious core material; these are high compressibility, low dry density, low shear strength, high swell potential and high volumetric shrinkage of the natural CH and CL type of soil. The methods adopted for selection of blending is based on availability and proximity of blending material and desirable engineering characteristics of the blending material. For these various tests include; classification, Proctor compaction, consolidation, free swell, volumetric shrinkage, direct shear, and triaxial (CU) tests were conducted on normal clay and on 20G/80C to 50G/50C blending proportions of the natural clay and the gravelly material. The GC material (USCS) has been obtained at a mix proportion of 40G/ 60C and 50G/50C. Based on results, from an economic and engineering point of view the GC material with blending ratio 40G/60C is recommended for the specific site.

This blended core material (40G/60C) shows 17% reduction in PI, 19% improvement in MDD, 37.5% reduction in OMC, and 23% reduction in Cc. It reduces the swelling potential and shrinkage crack, stronger and stiffer than the natural clay and the Stress-Strain graph improved to minimize undesired stiffness contrast between the shell and core zones, locks or stops propagation and interconnection of cracks and prevents development of high velocities within the crack (Ali, 2008).

As well as a study conducted on Tendaho dam, the main reasons to conduct experimental blending design on impervious core material is due to the recognition of the unsuitable high plasticity character clay soil proposed for core material. The material is a source of problems related to high compressibility, high swelling, slow rate of construction and large difference in stiffness with the surrounding shell material which could lead to differential settlement. In the research, a study had been conducted on the effects of blending the CH soils with naturally available gravelly sand materials using several laboratory tests on blending ratio ranging from 10S/90C to 50S/50C. The test results clearly revealed that blending with granular soils significantly improves the physical and mechanical behaviors of the CH soils and it reduced the swelling potential, compressibility behavior, workability conditions and increased the freedom of selection and/or production ranges of the filter materials. In conclusion, from the standpoint of permeability, the optimum mixture percentage in which neither the material becomes too permeable nor remains too soft, the blending mix ratio recommended is 40S/60C and its improvements were 48.91% reduction of PI, 20.15% improvements in MDD, 48.25% reduction in OMC, 21.21% reduction in Cc, and 25% reduction in Cr. However, the blending ratio 50S/50C also satisfied all requirements but its production would be more costly, besides it classified as SM which is less desirable to be used as an impervious core. (Wuletaw, 2007).

According to Zhongzhi Fu, et al*, (2020), Using Clay-Gravel Mixtures as the Impervious Core Materials in Rockfill Dams*, four cases in China are reviewed, with attention focused on the engineering properties of clay-gravel mixtures and the construction and field quality control aspects. The four dams considered are PuBuGou (PBG), ChangHeBa (CHB), NuoZhaDu (NZD), and LiangHeKou (LHK).

During construction the impervious system of an Earth Core Rockfill dam usually needs a large volume of clay that may exhaust a huge area of farmland. One way to reduce the volume of clay to be filled is to use natural clay-gravel mixtures or to add an appropriate percent of gravel materials into the clay and use the artificial clay-gravel mixtures as the impervious core materials. Using clay-gravel mixtures effectively increase the modulus of the core and reduce the differential settlement between the core and its adjacent rockfill shoulders, and thus alleviate the risk of occurrence of potential cracks within the core wall. The impermeability behavior of the compacted clay-gravel mixtures, however, has to be carefully investigated and verified. The detailed findings of the engineering properties of clay-gravel mixtures are;

Compaction characteristics: - in this review it shows that, the influence of the mass percentage of soil particles larger than 5 mm (P5) on the maximum dry density (ρdmax) and the optimum water content (ωopt). Different compaction efforts were used for different cases. Note for the NZD dam P_5 was evaluated after compaction tests and for the rest three dams it was evaluated before compaction tests. Particle breakage may occur during compaction and the two approaches may give slightly different results. Nevertheless, common trends can be observed from figure 2-2: an increase in P5 from zero results in a steady increase in ρ_{dmax} until a threshold value is achieved, beyond which a further increase in P_5 leads to a rapid decrease in ρ_{dmax}. The value of this threshold is around 60–70% for the reviewed cases. As it is observed in figure 2-2, the optimum water content decreases almost linearly when the gravel content increases.

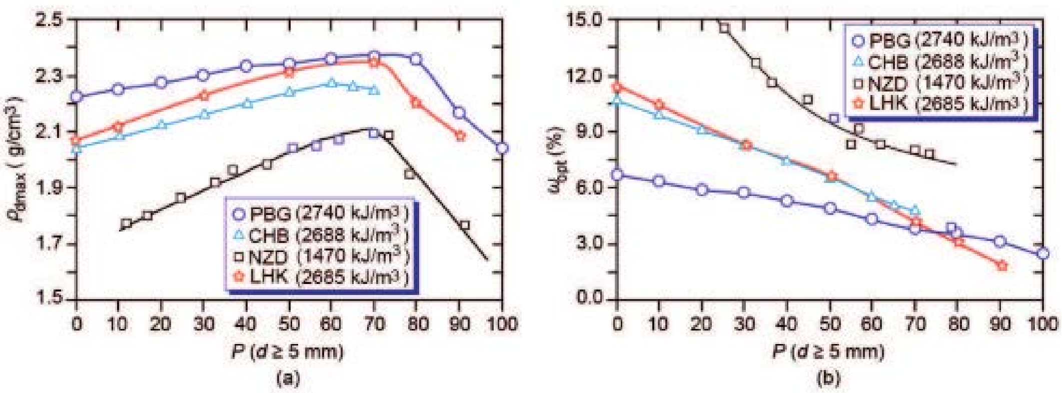


Figure 2-2: *Compaction test results on clay-gravel mixtures. (a) Maximum dry density and (b) optimum water content, (Zhongzhi Fu, et al, 2020).*

Permeability: - this review also tries to show the influence of gravel content on the permeability coefficient. The seepage experiments on the material for the LHK dam is performed with a low percent compaction so that particle breakage was not evident.

A common feature of the approximating curves in figure 2-3 is almost constant or a slight decrease of the permeability when the P5 is increased from zero to about 30%. The lowest permeability can be achieved when P5 is around 30%. Beyond this amount, the permeability coefficient increases rapidly with a further increase in P5.

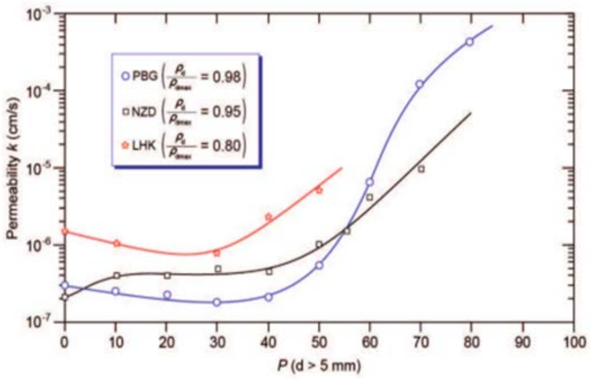


Figure 2-3 *Influence of gravel content on the permeability, (Zhongzhi Fu, et al, 2020).*

When the clay-gravel mixtures are embedding an increased amount of gravel particles leads to a decreased percent compaction of the fine fraction. This tends to increase the permeability of the mixture. On the other hand, the embedded particles serve as seepage barriers as the permeability of gravel particles is considerably lower than the fine fraction. These two competitive effects control the dependence of the permeability of the total material upon the gravel content.

Initial water content also has an influence on the permeability of compacted clay-gravel mixtures. Figure 2-4 shows typical results obtained from laboratory experiments with PBG CGM. For a given grain size distribution and water content, the coefficient of permeability (k), decreases when the dry density of the total material is increased. However, the rate of decrease in permeability also decreases when the dry density is increased, indicating an increasing difficulty in reducing the permeability. For the given compaction effort applied, the maximum dry density of the total material was achieved when ω = 4.625%. However, the permeability coefficient does not reach the minimum at this optimum water content: compacting the clay-gravel mixtures slightly wet of optimum results in a lower permeability although the resultant dry density is also lower than the maximum one (figure 2-4(b)).

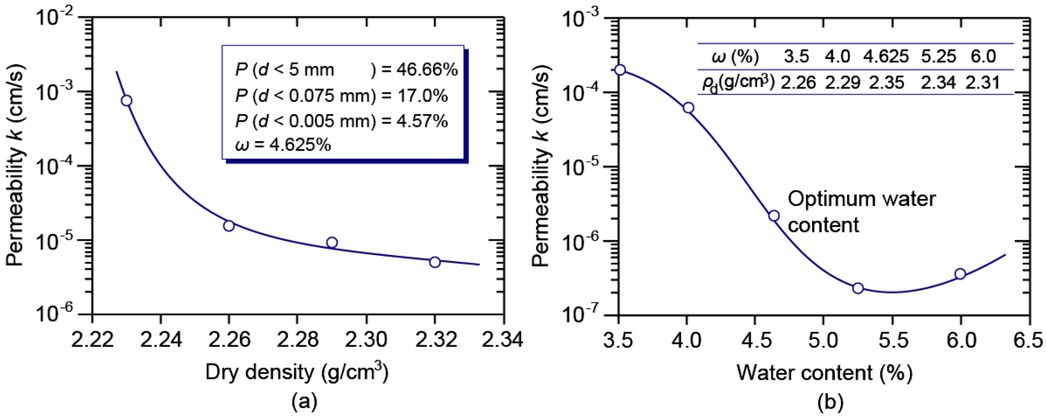


Figure 2-4: *Influence of dry density and water content on permeability. (a) Influence of dry density and (b) influence of water content, (Zhongzhi Fu, et al, 2020).*

Strength: - the shear strength is important for slope stability analyses. The clay-gravel mixtures used in the CHB dam and investigated the influences of the gravel content on the strength components, i.e., the cohesion (c) and the friction angle (φ). The results are shown in figure 2-5. Note each soil specimen was compacted to its maximum dry density under its optimum water content. The cohesion decreases steadily as a result of an increase in gravel content. On the contrary, the friction angle increases when the gravel content is increased. The clay-gravel mixture changes from a cohesive soil to a granular soil when the gravel content is gradually increased.

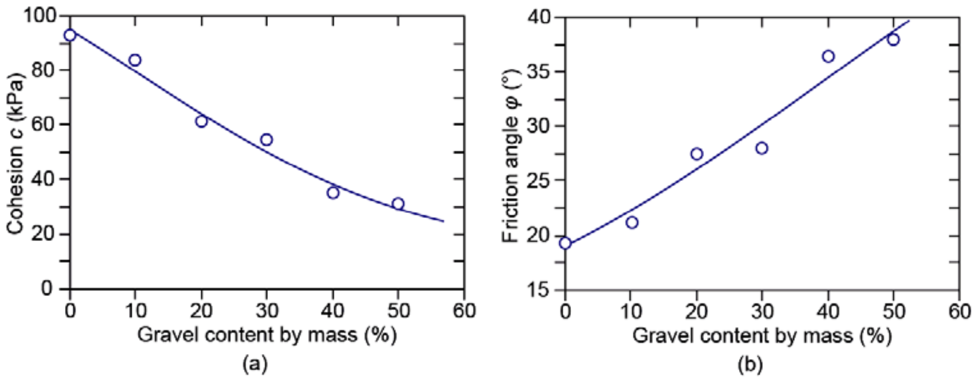


Figure 2-5: *Influence of gravel content on the shear strength. (a) Cohesion and (b) friction angle, (Zhongzhi Fu, et al, 2020).*

2.5 Dynamic property of the embankment material in seismically active area

The destructive potential of an earthquake of a given magnitude depends on amplitude, frequency and duration of the ground vibration and the site conditions (local soil effect). High amplitude (peak ground acceleration) corresponds to large magnitude earthquakes. However, it does not alone determine the damage potential, as these also depend on frequency characteristics of the ground motion and its duration. An earthquake of the given magnitude duration is responsible for the degree of destruction. According to Seed (2011), a very high acceleration developed for a very short period of time will cause little damage to many structures. An intermediate magnitude with long duration is more severe than high magnitude with low duration taking all the other factors uniform, particularly at resonance conditions.

Resonance is a condition in which the period of vibration of the earthquake induced ground shaking is equal to the natural period of vibration of the engineering structure. When resonance occurs, the shaking response of the structure is enhanced, and the amplitude of vibration of the structure rapidly increases. As a result, at resonance the structure will experience the maximum horizontal displacement. It is among the forces that the dam is designed to resist (Attewell and Farmer, 1976).

According to Attewell and Farmer (1976), resonance in low dams up to 100 ft (30.5 m) is not usually taken into account since the vibration period of the dam is normally much less than the range of 0.2 to 1 second, of the period associated with severe earthquake shocks.

The dam design in the earthquake prone area must include resistance capacity to the dynamic forces which can be applied during an earthquake. The seismic coefficient of the embankment varies with the height of the embankment, predominant frequency of the force cycles and the natural period of the embankment (Bhrahat Singh et al.,1995). See Table 2.3.

Table 2 - 2: *Dynamic seismic coefficient of embankment of different height (after USBR 1960)*

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

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

If the soils are unlikely to be vulnerable (either because of the nature of the soil or because the anticipated level of shaking is too small) then the pseudo-static method of analysis should provide a reasonably adequate design procedure. For soils that are likely to be vulnerable to major strength loss or to the development of excess pore pressure, the dynamic method of analysis offers a more realistic approach. This method can be used for all types of soil (Jansen, 1988). In the dynamic method of analysis, assessment of the dynamic behavior of the soil comprising the dam and the foundation such as shear modulus, damping characteristics, bulk modulus or Poisson ratio that influence the earthquake excitation should be made (Jansen, 1988).

2.6 Previous Works on the Study Area

Historic geological and geotechnical investigations at the dam site and its reservoir area is very limited, but at broad scale several geological investigations majorly scientific research oriented related to the Main Ethiopian Rifting and natural resource evaluation works are common. Some of historic geological works are discussed as follow:

As cited in the Geological and Geotechnical Investigation Works for Kalid Dijo Dam Feasibility Study report (2019); the regional geological studies include; Tsegaye et al. (1989), Jean Chorowicz et al. (1997) and Geological Map of Hosaena Sheet (GSE 2010).

Those regional geological studies generally inform that, the late Tertiary volcanics including Nazreth group, Bofa basalt & Chillalo volcanics covers major portions of central part of MER. A thick succession of stratoid silicics, ignimbrites, unwelded tuffs, ash flows, rhyolites and trachytes constitute the Nazreth group covering considerable parts of the rift floor and adjacent plateau margin. In the rift floor, the Nazreth group is overlain by Bofa basalt. Chilalo volcanic are shield volcanoes located on the eastern rift shoulder and represented by peralkaline ignimbrite, trachyte and alkaline basalt. Structurally, they defined two main fault systems: N30E-N40E trending fault system which characterizes mainly the rift margins, and a N-S to N20E trending fault system, the Wonji Fault Belt (WFB) which shows a number of sigmoidal, overlapping, right stepping en-echelon fault zones obliquely cutting the rift floor.

According to Fantu Zeleke, (2019), the main aquifer formations in the Dijo river catchment are lacustrine and volcanic sediments, pyroclastic deposits, weathered and fractured basalt, ignimbrite, rhyolites and welded tuff having a variable thickness, weathering and fracturing intensity. All groundwater and river water samples are below the limit of drinking water quality guidelines of the WHO (2011) ES (2013) of (50mg/l). But in the southern part of the Dijo river catchment which is found in downstream of the dam site, the concentration of fluoride is above the WHO limits (1.5mg/l).

Geotechnical Investigation Works for Kalid Dijo Dam Feasibility Study report (2019); shows a wide work on construction material assessment for the selected dam site for determination of the suitability and its available quantity. This work, which is the base for the present study, provides a basic setting on the type of the embankment material available at the site, its distribution, and the engineering properties of the selected materials.

The studies identified construction materials for the embankment dam namely; High plasticity Silt (MH) for core material within the reservoir area (it is discussed in detail in chapter 5). In general for filter and drainage, both the borrow area for sand to be used for fine filters and the quarry site for crushed aggregate (basaltic materials which is dark gray in colors, have aphanitic texture, it is fresh to slightly weathered forms hills and some of its top part indicate scoriaceous basalt as a cap, and vertically and randomly laterally jointed.) to be used for course filters and transition drainages, are identified at a distance ranging from 20 to 25 km from the dam site. Vesicular Scoriaceous gravel from relatively fresh to slightly weathered and light weighted scoria cones identified for shell within a distance less than 15km from the dam site. Quarry sites from rocks of Ignimbrite, forming flat to gently sloping topography and it formed relatively thick (up to one meter) sub-horizontally layered sheets, also it is fresh to slightly weathered hardened rock units identified for rock fill, masonry works and riprap also identified within economic distance of 3 to 5 km in the reservoir. The laboratory tests on the representative construction materials samples have also been carried out.

*****

CHAPTER 3 THE STUDY AREA

3.1 General Background of the Project

Food insecurity is the greatest problem of the people in general and worse in the lowland areas in particular. The predominant production system in the project area was integrated crop livestock farming but productivity was declining year after year on account of population pressure, land fragmentation, climatic variability associated with poor and erratic rainfall and continuous plowing. People are hardworking and very keen to adopt new technologies that would improve productivity, if available and approached the right way.

Irrigation is one means by which agricultural production can be increased to meet the growing demands. However, in order to meet reliable and sustainable food security development of irrigation schemes on various scales, through river diversion, constructing micro dams and water harvesting structures, those negative impacts on the sector should be taken into consideration. With this regard SNNPR, Irrigation Development and Scheme Administration Agency, has recently signed a contract agreement with Ethiopian Construction Design and Supervision Works Corporation, Water and Energy Design and Supervision Works Sector to undertake feasibility study and detailed design of Kalid-Dijo dam and irrigation project.

Once after completion of the principal components of the works: Undertaking detailed design level study for the selected dam type, Spillway (incorporating control section /Spill weir/, Approach Channel, Chute and Stilling Basin, Exit Channel) and Outlet works (incorporating Approach Channel, Intake structures, Transition, Tunnel and Outlet). The client of the project called FDRE, Irrigation Development Commission, has signed a contract agreement with South Water Works Construction Enterprise to accomplish the construction activities of the project within two years by taking the commencement date in June 2020.

The main objective of this project is to take advantage of the Dijo River flow and to irrigate the farmlands found downstream of the dam site. The dam is planned to impound 7.87million cubic meters of water to irrigate around 1,800-hectare farmland just downstream of the dam. The silent-feature of the proposed dam has a maximum dam height of 30.68m, crest length 1,731m, crest width 8m, the upstream and downstream slope of the dam is 1:2 and 1:1.90 respectively, and totally 4 berms having an average width of 5.5m are set downstream. The general layout of the project is annexed.

3.2 Location of the Project area

The project area is located in the central margin of the MER, about 175km south of Addis Ababa in the Southern Nations-Nationalities-Peoples Regional State (SNNPRS), Silte Zone; near Worabe Town. The proposed dam site is bounded by geographic coordinates of UTM (Adindan, Zone 37N) 412306 - 414377 E and 864305 -866892 N.

The project area can be accessed along the main asphalt road linking Addis Ababa and Southern Ethiopia through Butajira and Worabe towns and about 7km drive through gravel road joining Worabe and Dalocha town. The proposed dam site is located at about 4 km east of Worabe town and can be reached by 4WD vehicle through all-weather gravel road that branches off from the main highway at north of Worabe town. The location of the project area is shown in Figure. 3.1.

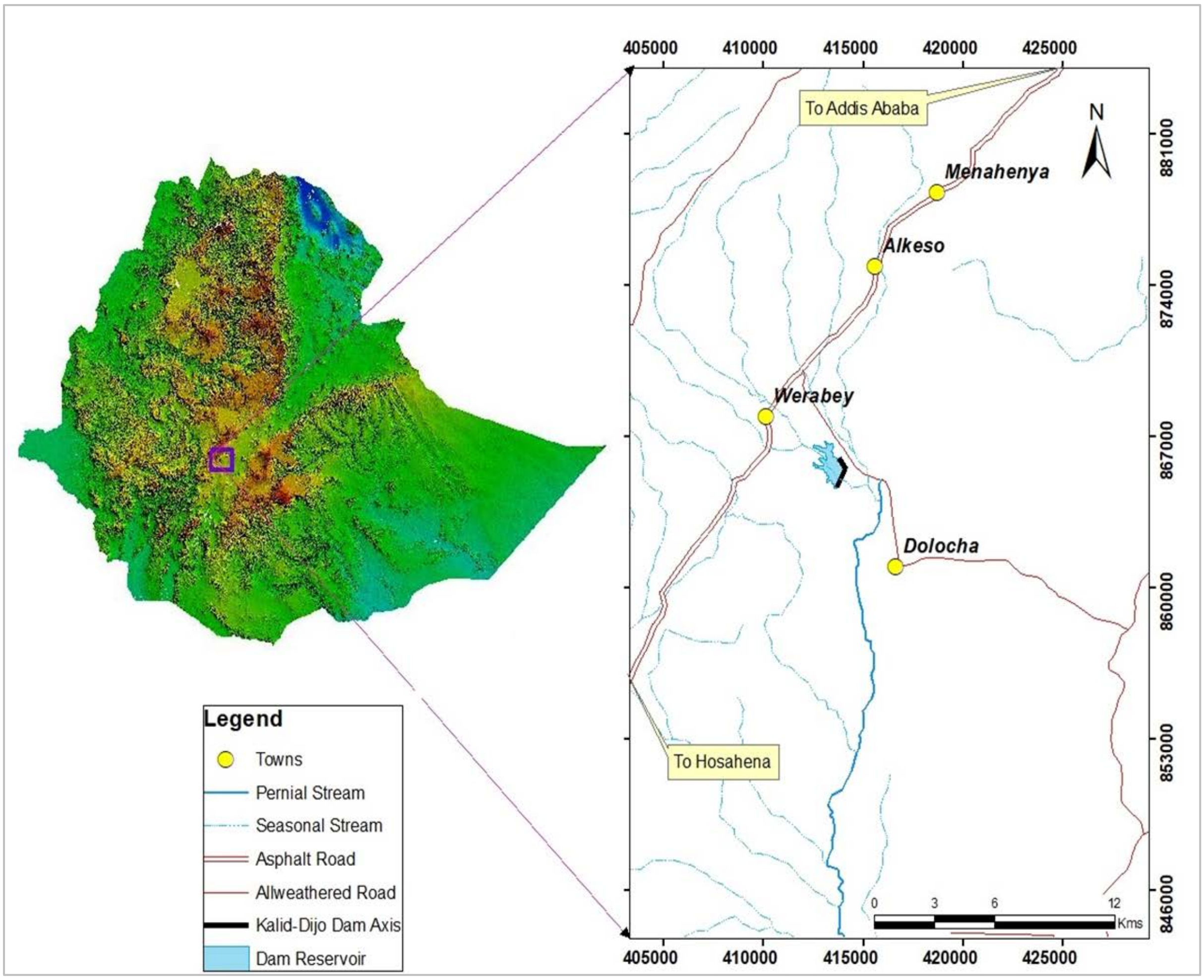


Figure 3 - 1: *Location map of the dam site and surrounding area.*

3.3 Topography

The topographic features of the MER are mainly the result of faulting and volcanism associated with rifting processes. The project area is situated at the western flank of Central Main Ethiopian Rift (CMER) that belongs to the central highlands, plateaus and associated lowlands and rift valleys of central Ethiopia represented by rugged topography as a result of uplift and subsequent development of the Main Ethiopian Rift (MER). As a result, the typical rift morphology is well developed and the three major physiographic regions, rift floor is the elevation < 1800m, escarpment the elevation is 1800 - 2500m and the highland rises to elevation of 2500 - 3158m a.s.l (Mugo Mountain) whereas the rift floor decrease regularly in to the rift center is 1551m a.s.l, (Fantu Zeleke, 2019).

The dam site and its surroundings are characterized by elevated landscape at southwest, north & northwest parts and relatively gently flat leveled dissected landscape at the dam site area and its reservoir extent. The dam site and the reservoir areas form gently sloping topography towards the southeast. Locally, the Kalid-Dijo dam and reservoir area is characterized by low-lying flats of volcanic pyroclastic deposits and soil, incised rivers/streams and dissected erosional galleys. The general 3-D map of the study area and its surrounding is shown through Figure 3.2.

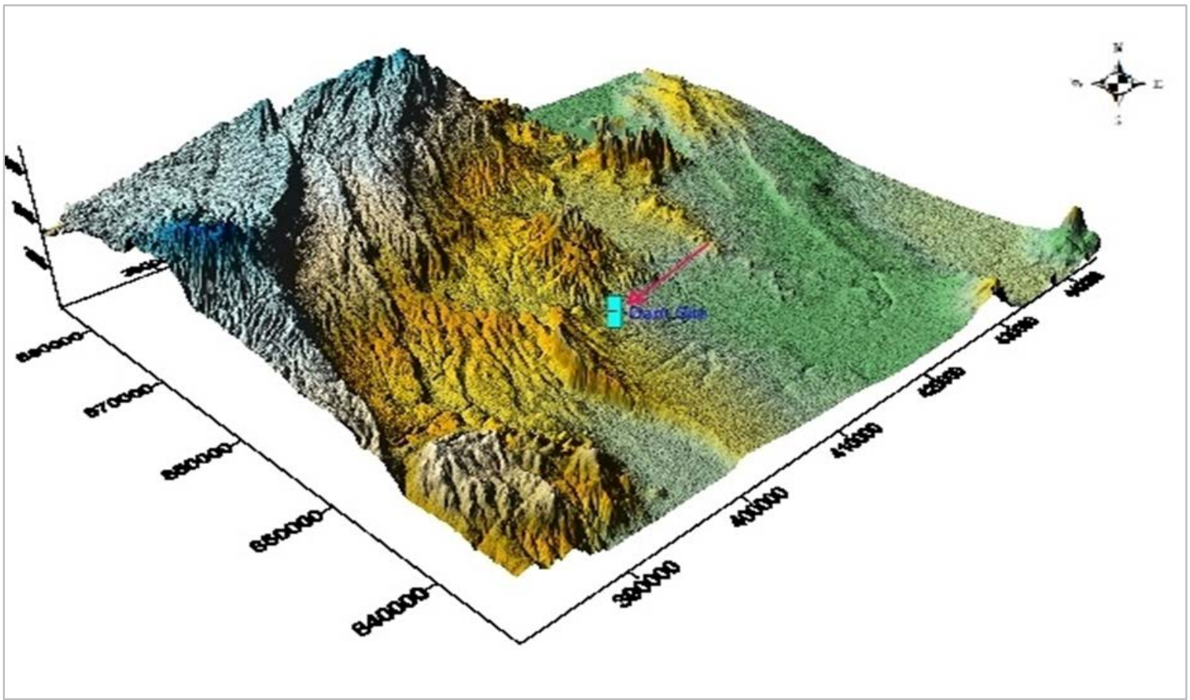


Figure 3 - 1: *The 3-D (topographic) map of the dam site and surrounding area.*

3.4 Drainage

All seasonal and intermittent streams arise from the upper threshold of the western Escarpment of the Ethiopian rift and nearby ridges then flow to the river Dijo. The streams in the area are intermittent and seasonal. The Dijo is a perennial river that finally drains to Lake Shala. The drainage patterns of the areas are dendritic patterns, all the tributaries that fed the Dijo river before draining to Lake shala. The drainage density is high in the plateau and escarpment area and very low in the rift floor. In many places, small streams disappear in the rift, by transmission in large faults and volcanic vents (Tenelem, 1998).

The dam site is located at the upper side of the Dijo river and it drains to the southeast. The dam site/reservoir at Dijo river is dissected by first and second order seasonal streams that drain to southeast & east to join Dijo river that finally drains in the southeast direction. Meanwhile, the local drainage system drains to the southeast towards the center of the Ethiopian Rift system. The general drainage pattern of the study area and its surrounding is shown in Figure. 3.3.

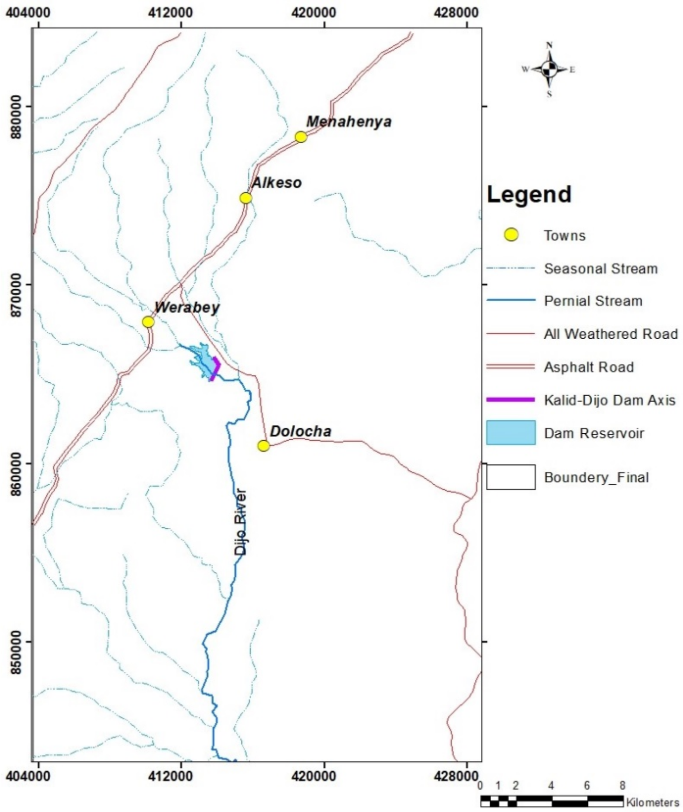


Figure 3 - 2: *Drainage map of the study area.*

3.5 Climate

The climate is humid to sub-humid in the highlands and semi-arid in the rift valley. The study area has a wet season from July to September, dry season from October to January, and a season of highly variable rainfall from February to June. The mean annual rainfall is no more than 650 mm/year in the vicinity of the rift floor, and rises to a maximum of 1200 mm/year at the high land above 2400m elevation. The general distribution of the mean monthly precipitation in the surrounding area is shown in Figure 3-4.

Mean monthly rainfall in the catchment are three seasons;

- October to February which is a dray season and locally known as "**bega**"
- March to May locally known as "**belg**" is a small rain season and
- June to September and locally known as "**kiremt**" is the high rain season.

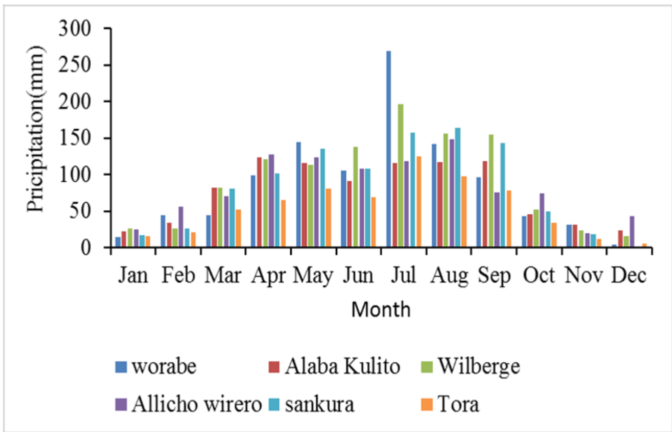


Figure 3 - 3: *Mean monthly precipitation of the surrounding area*

Within the study area where temperature decreases with increasing elevations, accordingly the mean annual temperature is less than 13.4ºC in the highlands and more than 22ºC in the lowlands. For winter months, mean monthly maximum temperatures are about 26.2ºC in the mountainous areas and about 34.5ºC in the low altitude (rift floor) areas near Mean monthly minimum temperature during winter ranges from 9.7ºC at the western highlands to 18.45ºC at the rift floor part of the study area. The mean monthly maximum and minimum temperature in the surrounding station is shown in Figure 3-5.

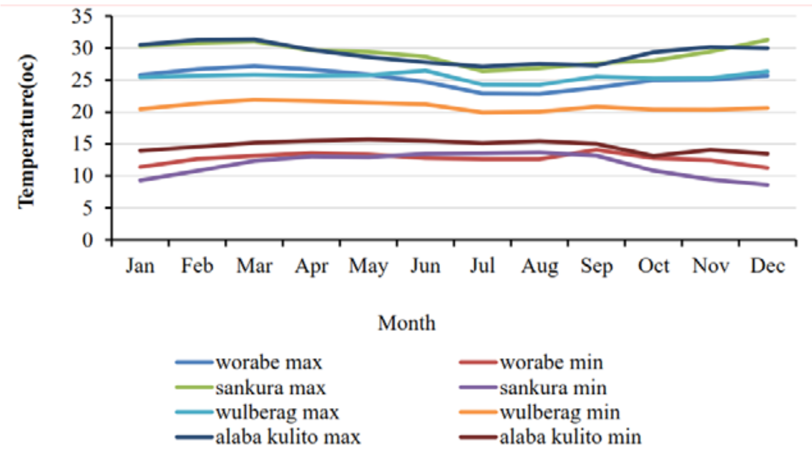


Figure 3 - 4: *Mean monthly max & min temperature of selected stations in surrounding area*

3.6 Soil

Soil map of the study area was used to initial estimate the availability and suitability of soil for intended embankment material. Soils are formed on the account of the climate, physiographic, geology and other factors responsible for formation and development. According to the Food and Agriculture Organization of the United Nations (2008) soil classification; there are three major soil units in the dam site and surrounding area.

- **Alluvial and Colluvial Soil (Eutric Cambisols)**; this type of soil derived from alluvial and colluvial deposit and also moderately developed soils characterized by slight or moderate weathering of the parent material. It is the dominant soil type in the northwest part of the surrounding area.
- **Clay and Sandy Loam Soil (Haplic Luvisols)**; this type of soil occurs typically in forest areas of humid to sub-humid areas. The soil is generally well drained, deep to very deep, fine to medium textured, clay loam and sandy loam soils. It is the dominant soil type in the highland western and northwestern part and eastern part of the dam site.
- **Residual Deposit Soil (Eutric Vertisols)**; are characterized by their high dominated clay content. They are often dark colored and texturally it is clay loam, hence common names such as 'black cotton soil' and they are very hard and crack when dry, sticky and plastic when wet. This soil type is found covering the Kalid-Dijo dam site and the proposed clay core borrow area at the Central part of the study area.

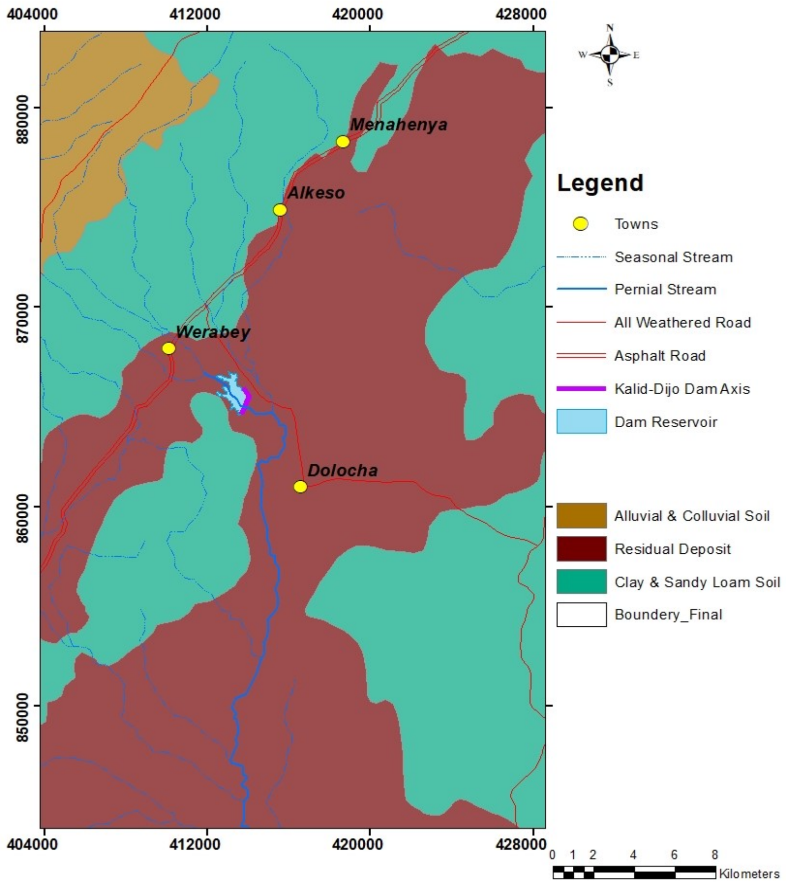


Figure 3 - 5: *Soil map of the study and its surrounding area source (FOA, 2008)*

3.7 Regional Geology

3.7.1 Structural set-up

The project area lies on western escarpment of Main Ethiopian Rift (MER), particularly in its central segment. Thus, discussing the regional geological set up of the MER and particularly the central Segment (CMER, Central Main Ethiopian Rift) is worthy in order to grab clues about the project site.

Uplift, doming and eventual rupture of the Afro-Arabian region resulted in the formation of the East African Rift system oriented in NE-SW and NNE–SSW directions. Initial sagging of the main Ethiopian Rift began around 15 to 14 million years (Ma) ago. The rift dissects the highlands of the country into the eastern and western plateaus and is bounded on two sides by a series of large normal faults. Continuous tectonic movement are confirmed by numerous young faults affecting Holocene rock units and by the intense seismicity of the whole region (Di Paola, 1972). The Ethiopian Rift at its northern segment bifurcates into Red Sea and Gulf of Aden.

An intense tectonic event occurred in the Pleistocene-Holocene in the main Ethiopian Rift related to the Wonji Fault (Mohr, 1967). With the formation of the Wonji Fault Belt, tectonic movements and volcanic activity produced step-like structures and associated volcanic activity, represented by ignimbrites, basalts and unwelded pyroclastics. The fault zone is straddled by central volcanoes disposed along the axial zone of the Wonji Fault Belt. The main products were rhyolite, trachyte lava flows, pumice, unwelded tuffs, obsidians and pitch stones. The products of the Wonji fault are referred as Wonji Group (Kazmin at al., 1978 and others). Another type of volcanic activity in Wonji Fault Belt was the eruption from fissures of Pleistocene to Recent basalt lava flows. The basalts are controlled by extensional fractures and commonly characterized by fresh surface. Chains of scorraceous cones follow the lines of fractures. These basalts are mostly found in the rift floor; recent flows in many cases follow pre-existing topographic low relief areas. Although the development of the rift was dominated by volcanic activity, sedimentation also occurred. Wonji Group rocks are intimately associated with lacustrine sediments related to the ancestral lake in the rift floor in the Pleistocene - Holocene times.

The Central MER (where Kalid-Dijo dam Site is located) is bounded by the Yerer-Tullu-Wellel volcano-tectonic lineament (YTVL) to the north and the Goba-Bonga lineament to the south. It is also bounded to the east and west by fault escarpments (some of them with offset more than 1500m) such as the Munesa and Guraghe rift margins. Tertiary to Quaternary volcanics are the major rocks exposed at the MER. Apart from minor fluvio-lacustrine sediments, mostly of Quaternary age, that were deposited on the rift floor. Outcrop of Precambrian crystalline basement rocks are also exposed at few places of the MER mainly eastern/western flanks and at places at center of rift floor also.

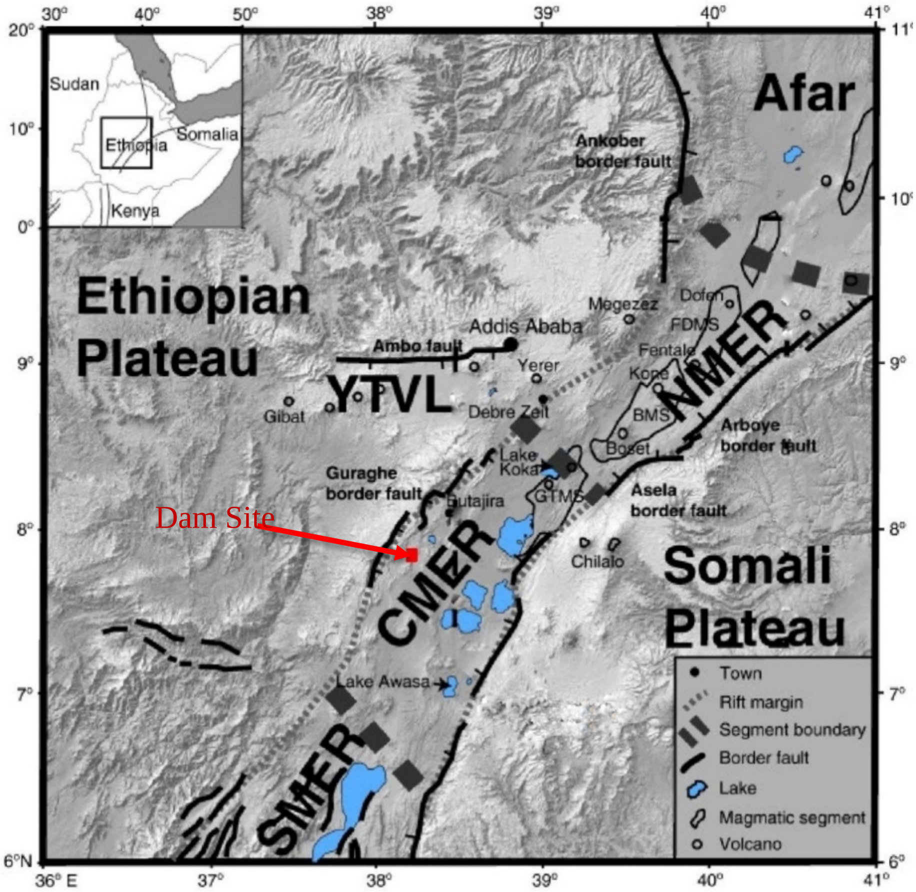


Figure 3 - 6: *Location of kalid-dijo dam site with respect to main Ethiopian rift. (after ECDSWC, 2019)*

3.7.2 Stratigraphy

Geology of the project area belongs to the geology of Central Main Ethiopian Rift (CMER) where a series of volcanisms, erosion, sedimentation and uplifting processes underwent for a long period of time. Such complex geological history with time span extending from late Proterozoic, through Paleozoic (Mesozoic rift basins) to Tertiary rifting that formed the Main Ethiopian Rift (MER) is illustrated by lithostratigraphic successions ranging from the oldest crystalline basement rocks to youngest quaternary superficial deposits accompanied by bimodal volcanic flows and clastic sediment depositions.

Parts of the central segment of main Ethiopian rift (including the project area) is covered by quaternary volcanic (younger than 1.6 Ma, Meyer et al. 1975) of the "Wonji Group" which is part of the latest volcanism in the Ethiopian Rift related to the axial extensional zone, referred as the Wonji Fault Belt (Mohr, 1967). This volcanism, however, is not confined to the Wonji Fault Belt only, but that it also occurred in other parts of the rift (Kazmin, 1978) depositing extensive volcanic formations including at Kalid-Dijo dam project area. The Wonji Group includes the entire rift volcanic formed after the last major event of rift faulting. Dino formation (stratoid silicic volcanoes of the rift floor and shoulders) comprising of volcanic ash, consolidated to unconsolidated tuff, welded ignimbrite and minor thin trachytic/obsidian flow layers covers the project area and their detail description is summarized in the local geology section.

In regional contexts, this formation cover a considerable portion of the rift floor and it comprises a number of flows of compacted fiamme ignimbrites in place intercalated with aphyric basalt and unwelded pyroclastics (Kazmin et al., 1980). In the main Ethiopian rift, the Bofa basalt and the Nazret Series are in most places, overlain by green ignimbrites with well-developed lithic fragments and associated unwelded pyroclastics and waterlian pyroclastics with associated lacustrine beds and aphyric basalts which have a maximum reported thickness of 50 meters were named as the Dino Formation (Kazmin & Berhe 1980). The pyroclastics of the Dina Formation may have sources from axial felsic volcanic eruptions complexes. The felsic lava of Dino formation is peralkaline in composition and have observed that the ignimbrite members are not confined only to the rift floor but are extensively developed on the escarpments (Kazmin et al. 1980).

3.8 Local Geology

Embankment construction material predictably occurs in geological formations that require knowledge of how these earth materials formed and the changes they have gone through. Understanding the distribution of geologic materials of varying genetic origin and its structural futures, used to evaluate the behavior characteristic and engineering significance of earth materials to be used in construction.

In the present study geological map was prepared using previous data from different studies, and field verification. The study area comprises a variety of volcanic and volcano-sedimentary rocks that exhibit different ages and composition of stratigraphic sequence. The Kalid-Dijo dam site and surrounding areas is mainly covered with Cenozoic volcanic and tertiary and quaternary sediments .The major formation which cover the area are; The Nazareth group(Ignimbrite, rhyolite, trachyte, tuff with basalts), Dino formation(Ignimbrite, tuff, rhyolite, pumice fall), Recent basalt and scoraiesas basaltic, and variety pyroclastic deposits of rhyolitic compositions. The highland and escarpments are mainly composed of ignimbrite, tuff, recent basalt with some scoria cones and lacustrine sediments. On the other hand, the rift floor is fully occupied by lacustrine sediments and acidic volcanic rocks comprising welded and unwelded tuff and pumice and obsidian.

Table 3 - 1: *Lithostratigraphy of the dam site and surrounding area.*

Period	**Category**	**Lithologic Symbols**	**Descriptions**
Pleistocene-Holocene	Quaternary Sediments	Ql	Lacustrine Sediment silt, clay diatomite
	Central Volcanic Complexes	Qwpu	Pumice and unwelded tuff
		Qws	Rhyolite and ignimbrite
	Basalts of the Rift floor	Qwbh	Basaltic flows and cones
	Dino formation	Qdi	Dino Ignimbrites
Upper Miocene-Pliocene	Nazret Group	NQS	Pumice, tuff, Ignimbrites, ash flows, rhyolites and trachyte

*(**source**: geological map of Hosaena map sheet)*

3.8.1 Ignimbrite, rhyolite, trachyte, tuff with basalt (Nazret Group and Dino Formation undifferentiated) (NQs)

In the rift escarpments, where in the Northwestern part of the dam site and surrounding area is thick succession of different silicic rocks is locally exposed, ignimbrite, rhyolite, trachyte, tuff with rare intercalations of basalt flows which occur in the highland of the study area .The oldest volcanic rocks (Plateau Trap Series) are exposed in the western escarpment and consist of basaltic lava flows, with inter-bedded ignimbrite beds, overlain by massive rhyolites, tuffs and basalts. Miocene to Pliocene basalt flows; rhyolites and tuffs unconformable cap the Early Tertiary volcanic units (Woldegabriel et al., 1990).

According Basalfew Zenebe et al. (2012) the silicic rocks of the Dino Formation are not only confined to the rift floor but are extensively developed in escarpments and on the adjacent plateau where they could not be separated from the silicic of the Nazret Group, they were mapped as Nazret Group and Dino Formation undifferentiated (NQs).

3.8.2 Ignimbrite, tuff, rhyolite, pumice fall (Quaternary Volcanics /Wonji Group of Dino Formation) (Qdi)

It is highly dominated in the dam site and surrounding area it is Dino formation such as welded ignimbrite, pumice fall, pre-alkaline rhyolite, ash with minor intercalated by basaltic lava flow. These units extend from the highland boundaries through much of the transitional escarpment, valley slopes into the rift floor.

According to Fantu Zeleke, (*2019*) the collected well log data shows that the thickness is varies from the highland to the escarpment and rift floor. The thickness above 200 m in the rift escarpment while on the highland it reaches only up to 80 m that associated with intercalated basalt in the highland and escarpment and also occasional lacustrine deposit or reworked water laid pyroclastic deposit in the rift floor. Rift floor ignimbrite (rhyolitic ignimbrites, welded ignimbrite, ash, tuff, pumice) and minor basaltic lava flows are out cropped in the western, (especially Alaba area and sankura) and North- East Halaba town (simibta Menzo fetena) area the thickness varies up to 480m and 250 m.

3.8.3 Rift floor basaltic lava flow and scoria cons (Basalts of the Rift floor) (Qwbp)

This unit consists of recent basalts which are located close to the Kalid-Dijo dam site, in the Dallocha area. Basalt flows vary in thickness from one or two meters up to tens of meters and located at northern part of the dam site. A more recent volcanic unit, it is clearly controlled by extensional fractures and crops out along the tectonically active Silte -Debrezeit Fault Zone (SDFZ) and the Wonji Fault Belt (WFB); it is made up of basaltic lava flows associated with pyroclastic and scoria cones. Chains of scoraceous cones follow the lines of fractures; it is clearly exposed around the Dallocha town, in the east, southeast and north of Kalid-Dijo dam site. The pyroclastic consists of the fine glass material, generally yellowish to brown in color containing small boulders of basaltic lava.

The basalts are alkaline or transitional, mostly mildly alkaline. Porphyritic types with mega-phenocrysts up to 3 cm are rather common. The alkali basalts consist of magnesian olivine, augitic clinopyroxene, labradorite and opaque phenocrysts, while in the groundmass these minerals are sometimes accompanied by alkali feldspar. The absolute age determinations available place most of the basalts in the Pleistocene (Morton et al., 1979).

3.8.4. Central Volcanic Complexes, Pumic and unwelded tuff (Qws & Qwpu)

Most of the central volcanoes of the Wonji group are disposed along the axial zone of the rift, the Wonji fault belt. They are either huge conical mountains formed in the place of older volcanoes. It is clearly observed near to the dam site in the southern direction with containing a number of volcanic centers.

The main rock types found in central volcanic complexes of surrounding the study area are Pleistocene to Holocene period of alkaline and per-alkaline products this are mainly represented by pumice and unwelded tuffs (Qwpu), often associated with obsidian and pitchstones. In several volcanoes in the eastern and surrounding the dam site and elsewhere, where ignimbrites, rhyolites and unwelded tuffs were mapped together, they are shown in the map as peralkaline silicic undifferentiated (Qws). Most of the products of central volcanoes are peralkaline rhyolites and trachyte's of pantelleritic or locally of comendetic affinity (Gibson, 1970; Di paola, 1976; Brotzu et al., 1980; Tsegaye et al., 2005). The composition of volcanics change from center to center. Radiometric (mainly K-Ar) and fission track ages conducted on obsidian, alkali feldspar separated minerals gave generally Quaternary age (Morbidelli et al., 1975; Kazmin et al., 1980; W/Gabriel et al., 1990 and others).

3.8.5 Lacustrine sediment (Quaternary Sediments), (Ql)

Lacustrine sediment deposits varying in composition from clay to gravel and depositional environment varying from lacustrine to fluvial, fan and talus deposits occur in the area. The dominant lacustrine and alluvial deposit occurs in eastern side of the dam site next to scoria cone chains in southeastern part. The sediment is composed of clay, sand and silt deposits alternating with reworked pyroclastic deposits such as pumice, ash, volcanic talus deposits and fan deposits and shells. Alluvial deposits composed of silt; sands and gravel occur along the lower reach of rivers such as Dijo Rivers around Agum and Sankura area. The lacustrine sediments are intercalated with redeposited volcanic ash and tuffs. The major components of the sediments (sand and silt) are volcanic origin, such as pumice and volcanic ash, obsidian, rhyolite and basaltic rock fragments (Tsegaye et al., 2005; Bevenuti et al., 2002).

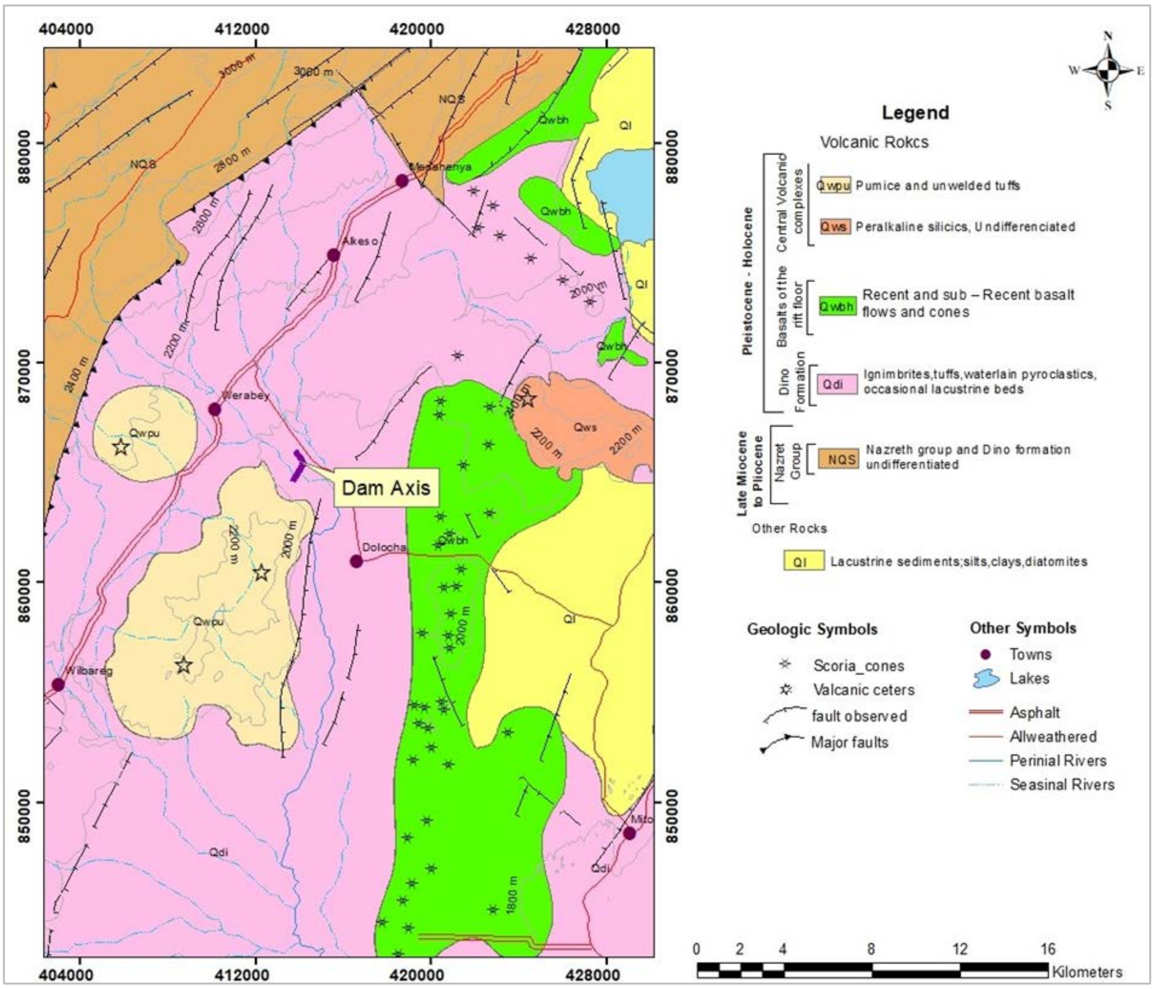


Figure 3 - 7: *Geological map of Kalid-Dijo dam site and its surroundings (after GSE, 2012)*

3.8.6 Geological Structures

The area of investigation belongs to the Central Main Ethiopian Rift which experienced different cycles and stages of tectonic deformations and rifting. This prolonged tectonic deformation resulted in different types of tectonic (Secondary) structures and also primary structures (formed at the time of rock formation) are common geologic features of lithologic units of the area.

According to ECDSWC, (2019); the prominent tectonic structure traced in the area is tensional jointing related to the Main Ethiopian rifting and the Red Sea rifting. These tensional joints are tight, penetrative, persistent, narrowly spaced, open and are traced transverse or parallel to the MER. Faulting as the major tectonic structures with significant displacement can be traced in the investigation area (majorly as part of the border faults at western flank of CMER).

Major part of the dam site and surrounding area is covered by thick residual soil & loose unconsolidated pyroclastic deposits and hence structural data capturing and measurements of their attitudes was difficult. The geological structures observed and measured during Geological and Structural Mapping, (2019); are presented below.

Primary Structures: - Primary structures (formed at the time of rock formation) including flow layering, grain/crystal fabrics and columnar/sheet cooling joints are common structural features of lithologic units of the area. Flow layering, cooling joints & vesicles in volcanic flow units; bedding on pyroclastic deposits; and lamination on water lain tuff deposits are the main primary structures noticed in the area.

Secondary Structures: - Secondary geologic structures that are developed after the formation/deposition of the strata by later coming tectonic processes are common in the detail investigation area. This includes all fabrics which are either developed by tectonic process or as a result of any secondary process. Lineaments, faults, joints/fractures, karsts/caves and folding are well recognized.

3.9 Hydrogeological Setting of the Study Area

The hydrogeological characteristics and ground water in Dijo river catchment are highly affected by the complexity of geology, physiography, climate and geological structures. As the study area is highly covered by volcanic rocks; the water bearing capacity of these rocks vary because of the difference in their texture, mineralogy and structure. The circulation and storage capacity of these rocks depend on the nature of porosity and permeability of the aquifer.

The geology of the study area mainly determines the groundwater reserve and quality. There are four main volcanic formations and sediments build up the study area. All rock structure possessing a primary porosity may not have necessarily permeability: i.e. without the original interconnection, the primary porosity may not give rise to the primary permeability, but later connection, by means of weathering or fracturing may results a secondary permeability (Alemayew.2006). The most important features governing the groundwater flow and storage in volcanic rocks are the following: Vertical permeability due to primary and secondary fractures, horizontal permeability due to horizons containing openings due to the lava flow and gas expansion during solidification.

3.9.1 Aquifer Units

According to Fantu Zeleke, (2019), the main aquifer formations in the study area are lacustrine and volcanic sediments, pyroclastic deposits, weathered and fractured basalt, ignimbrite, rhyolites and welded tuff having a variable thickness, weathering and fracturing intensity.

The most important features of the hydrogeological units in the study area are compiled from current information of surface geology and previous studies on water points inventory, borehole lithological log data, and pump test data by Fantu Zeleke, (2019). In general, the hydrogeological units in the study area are divided into three main groups

I. Aquifers are mainly characterized by permeability in rocks which include: lacustrine sediments, alluvial, gravel and scoria cones. These deposits usually represent important aquifers in the downstream southeastern part within the area; however lacustrine sediments composed of fine and poorly sorted are characterized by low aquifers.

II. Aquifers are mainly characterized by secondary permeability due to rock forming fracturing and weathering. This group consists of ignimbrite, tuff and basalts; the permeability of these rocks mainly depends on the intensity of faults and fractures. In place of intense faulting and fracturing they are good aquifers otherwise they are typical aquiclude.

III. Aquifers characterized by both primary and secondary rock permeability. In the area this group includes ignimbrite, basaltic lava flows rhyolite and pumice flow. Generally, these rocks form moderate to good aquifers, in places of intense faulting and fracturing they are a very good aquifer.

3.9.1 River water quality

Many natural factors can affect river water chemistry however, the primary factors include the chemical composition of the geological unite, and the amount of time the water has remained in contact with the geologic unit (residence time) are the main factors which can affect the type and quantities of dissolved constituents in groundwater and river water.

According to the thesis report of Fantu Zeleke, (2019), the most abundant dissolved constituents found in the Dijo river catchments are the major ions, which can be both cations and anions. The result of the river water chemistry is used to assess the chemical composition of the river water for the construction purposes and its potential to change the construction materials properties, which is used in different dam sections. In addition, this water used for mixing and curing should be free from injurious amounts of deleterious materials. The findings of this thesis report are summarized and presented below (Table 3-2).

According to the result the chemical composition of the river water in all tested samples are below the limit of drinking water quality guideline of the WHO (2011) ES (2013) of (50mg/l).

Table 3 - 2: *Major ions found in Dijo river water (After: Fantu Zeleke, 2019)*

Major ions found in dijo river	Average quantities (mg/l)	Major ions found in dijo river	Average quantities (mg/l)
Calcium (Ca^{2+})	25	Chloride (Cl^-)	17.04
Magnesium (Mg^{2+})	Very low	Sulphate (SO_4^{2-})	14.5
Sodium (Na^+)	18	Nitrate (NO_3^-)	3.1
Potassium (K^+)	11.12	Fluoride (F^-)	1.8
Bicarbonate (HCO_3^-)	102		

But in the southern part of the Dijo river catchment which is found downstream of the dam site, the concentration of fluoride is above the WHO limits (1.5mg/l). As a result, the river water has no potential to change the chemical composition of any of the dam sections, unnecessarily. Instead, it is possible to use it for mix and curing purposes.

3.10 Geomorphology

Dijo and Kalid valley areas belong to the Central Segment of Ethiopian Rift valley which is represented by NE elongated rugged ridges at both flanks and gently sloping dissected lowlands at rift floor areas. The Dam site/reservoir area is situated at western flank of the Central Main Ethiopian Rift and is bounded by elongated rugged mountains to north, northwest & west sides and gently southeast sloping low-lying lands to south and southeast parts (Figure. 3.2).

As the area is part of the Ethiopian Rift system; it experienced subsequent doming, uplifting, rifting, volcanism, erosion, sedimentation and other processes that resulted in present geomorphologic features of the project area and its surroundings. Locally, Kalid-Dijo dam and reservoir area is characterized by low-lying flats of volcanic pyroclastic deposits and soil, incised rivers/streams of tuffaceous pyroclastic deposits and dissected erosional gullies of ashes. The elongated rugged mountains to north, northwest & west sides are uplifted hills of trachy volcanic rocks and the gently southeast sloping low-lying lands to south and southeast parts are outcropped by the tuffaceous pyroclastic deposits of Dina formation comprising tuff, ash and minor ignimbrites as a result of volcanic flows/falls. The area is deeply dissected by Dijo and Kalid rivers and their tributaries and is controlled by both structural and lithologic set up. River/stream patterns majorly follow the local extensional fracture systems (NNW and NE trended) and at places diverted following soft formations.

As mentioned above; the land surface properties generally are related to tectonic-volcanic-fluvial geomorphic processes and this is well evidenced through field visits.

Drainage patterns of the area seem controlled by extensional fractures and lithologic units. First & second order tributaries of Dijo River are majorly related to the NE trending extensional fractures that parallels the rift system while the Dijo River itself is as a result of NW trended fractures which transverse the rift system. At places, parts of the rivers/streams meander following soft formation like ash and unwelded tuff to form dendritic drainage patterns.

According to the Geological and Structural Mapping of Kalid-Dijo dam (2019) reports, active and fossil geomorphological processes (such as surface erosions, slope and mass movement, volcano-tectonic) determined the current geomorphology of the dam site and surrounding area. Erosion and voluminous land mass movement could happen on areas covered by loose volcanic ashes and less compacted pyroclastic deposits (unwelded tuffs) on sloppy areas particularly at southwestern, western and northwestern parts of the dam site.

Up to 5m wide and 10m deep cracks are traced for several hundred meters forming widened erosional gullies downstream at southwestern hilly part of the mapped area which is outcropped by loose pyroclastic deposits consisting of unwelded tuff and ash. The cracking seems to follow the extensional fractures, but it is probably due to the dewatering of the soft pyroclastic deposits and ashes. It was noticed that these cracks are shallow and are limited to the soft formation only.

Moreover, according to the Geological and Structural Mapping of Kalid-Dijo dam (2019) reports, landmass movement like rock block toppling on river banks of major rivers/streams outcropped by unwelded tuff are noticed. Major evidence of this rock mass toppling is observed in the bank of Kalid river (Figure 3-8: Top Left) and this was frequently mapped on banks outcropped with soft formations.

Block failure (toppling)

Gully erosion following slopes of ash hills

Deeply incised gully erosion following NW trending cracks

Figure 3 - 8: *Landforms as a result of geomorphological process*

3.11 Seismicity

The project area is located at the western margin of the Gurage border fault where seismic activity is frequent due to Margin of the Central Main Ethiopian Rift System. As per the recent developments in earthquake engineering, large dams and safety relevant structures shall be designed to withstand safety evaluation earthquakes (SEE) without creating uncontrolled release of water and threat to life.

According to Figure 3-9, the dam site area is found within the peak ground acceleration of 0.1–0.115 and in seismic intensity of VIII (Mercalli Modified (MM) intensity scale) with 100 years return period and probably of 0.99 and the dam site falls under seismic zone IV with a corresponding major damage.

As the project is situated in a major settlement vicinity, the project component shall be addressed for safety issues against possible seismic induced instabilities. Thus, site specific seismic hazard assessment for different levels of return period is necessary for seismic design of dam and material selections.

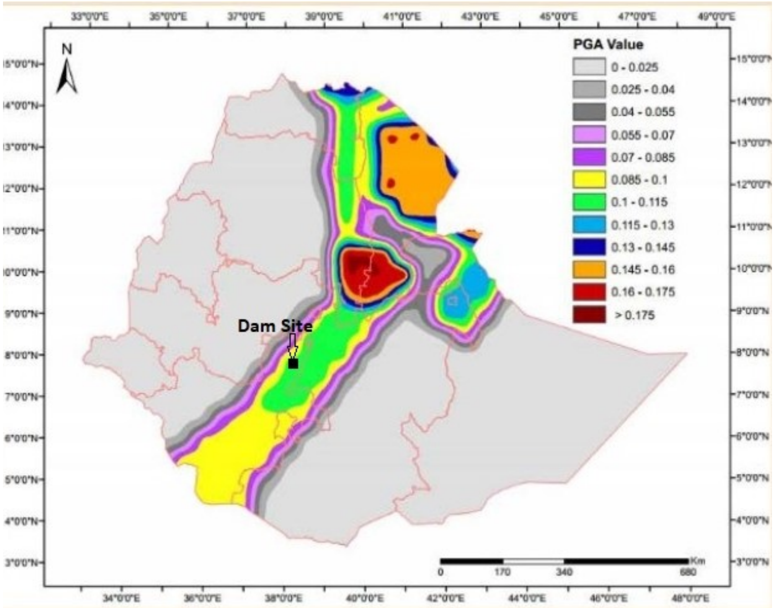
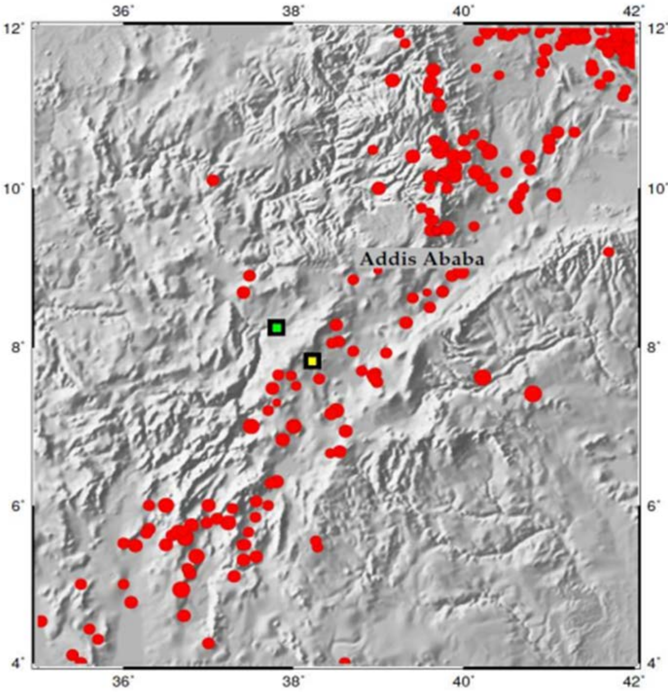


Figure 3 - 9: *Seismic hazard map of Ethiopia in peak ground acceleration* (After EBCS EN 1998)

Site specific Probabilistic Seismic Hazard Assessment (PSHA) study of the project site has been conducted as part of Kalid-Dijo dam and irrigation project. According to the site-specific seismic hazard assessment draft report (Atalay, 2019), the area found in Margin of the Central Main Ethiopian Rift System near to the Gurage border fault and it is famous for its frequent earthquake and it has high seismic hazard values.

The December 19, 2010 and March 19, 2011 earthquakes of magnitudes 5.1 and 5.0 in Hosanna and Yirga-Alem, respectively, posed concerns in the south and south-western part of the country and it is not far from Kalid-Dijo dam project which can induce site effect in future possible earthquake. The Hosanna earthquake was not that big in size but was felt from Mizan-Teferi in the south as far north as Addis Ababa and caused considerable damage in Hosanna town. The Yirga-Alem earthquake was felt by over 345,000 people and it induced panic among the locals as it occurred not long after the Japanese Tohoku earthquake and tsunami crisis of 2011 which was widely televised worldwide. In March and April 2015, a swarm of earthquakes occurred on the Gurage border fault which is quite close to Kalid-Dijo Dam project site (Figures 3-10) with maximum magnitude of 4.0 Ml.



Legend

earthquakes that occurred for the last 110 years in the region and size of the circles is proportional with magnitude.

*locations of the planned **KALD-DIJO** dam and irrigation project site*

location of Wabe Hydropower dam site.

***Source**: Kald-Dijo Site Specific Seismic Hazard Assessment Draft Report, 2019*

Figure 3 - 10: *Seismicity data for the Addis Ababa region and the Kald-Dijo project site;* **(**ECDSWC, 2019)

According to German standard Safety Evaluation Earthquake (SEE) where the earthquake ground motion of a dam site must be able to resist ground shake, without uncontrolled release of the reservoir where sliding stability safety factors of slopes of greater than 1.0 are required, a return period of 2,500 years is recommendable which is considered in this study. For 2,500 years return period, spectral ground acceleration of 0.512g for rock and 0.537g for soil sites, respectively, are estimated for Kalid-Dijo Dam site at 0.2 second spectral period. At the same spectral value and return period 0.56g is estimated using the latest software of EZ-FRISK 7.6 which both show that the hazard level at this site of interest is high (Atalay, 2019).

Table 3 - 3: *Ground Motion Amplitude in percentage of Gravity (%G).*

Return Period in Years	**Ground Motion Amplitude in % of g for Boore-Joyner-Fumal (1993, 1997)**					
	Period = 0.2 sec		**Period = 1.0 sec**		**Period = 2.0 sec**	
	Rock	**Soil**	**Rock**	**Soil**	**Rock**	**Soil**
100	15.04	15.99	4.92	5.60	3.23	3.58
500	31.54	33.48	9.13	10.53	5.57	6.31
1,000	41.12	42.76	11.91	13.82	7.05	8.06
2,500	51.16	53.72	16.93	19.81	9.61	11.13
10,000	71.20	75.87	27.64	32.11	15.36	18.14

(Source: Kald-Dijo Site Specific Seismic Hazard Assessment Draft Report, 2019)

*****

CHAPTER 4 MATERIALS AND METHODOLOGY

4.1 General

Natural impervious materials excavated from clay core borrow areas usually do not meet the specified requirements. The natural clay core materials in the Kalid-Dijo dam contains too much fine particles, identified as MH type of soils (USCS), that have poor engineering properties; high compressibility, low dry density, low shear strength, high swell potential and high volumetric shrinkage (ECDSWC, 2019). These the major drawback for MH type of soil so as an option to improve the quality of the core material certain contents of coarse gravel should be added. Therefore, the most frequently required techniques in preparing the gravel clay mix to get improved core materials through trial experiments are screening and/or blending and laboratory testing. This section discusses the experimental design and techniques which are followed during undertaking the laboratory experimental analysis.

4.2 Data Collection

All the preliminary documents including the feasibility design documents have been collected from Ethiopian Construction Design and Supervision Works Corporation (ECDSWC) Kalid-Dijo Dam Design Project. Besides that, a material sample of 300 KG has been collected. The core material sample is taken from the previously identified core borrow area at feasibility stage and the gravel material sample also taken from identified shell borrow area. At the feasibility stage, one clay core borrow site was identified. Four test pit samples were taken from this borrow site to the laboratory. The feasibility study report shows their similarity in character. Considering this and the security challenge, samples were taken from two pits of this borrow site. Representativeness of the sample was also assured after conducting tests on the new sample and comparing it with the previous feasibility stage study.

Figure 4-1 shows the location of the clay core and gravel borrow material sample area relative to the dam site. The borrow core material is 1.5km from the dam axis within the reservoir. The gravel is collected from the previously identified shell borrow site, which is 8.5km to the south of the dam axis and 10km to Clay borrow area.

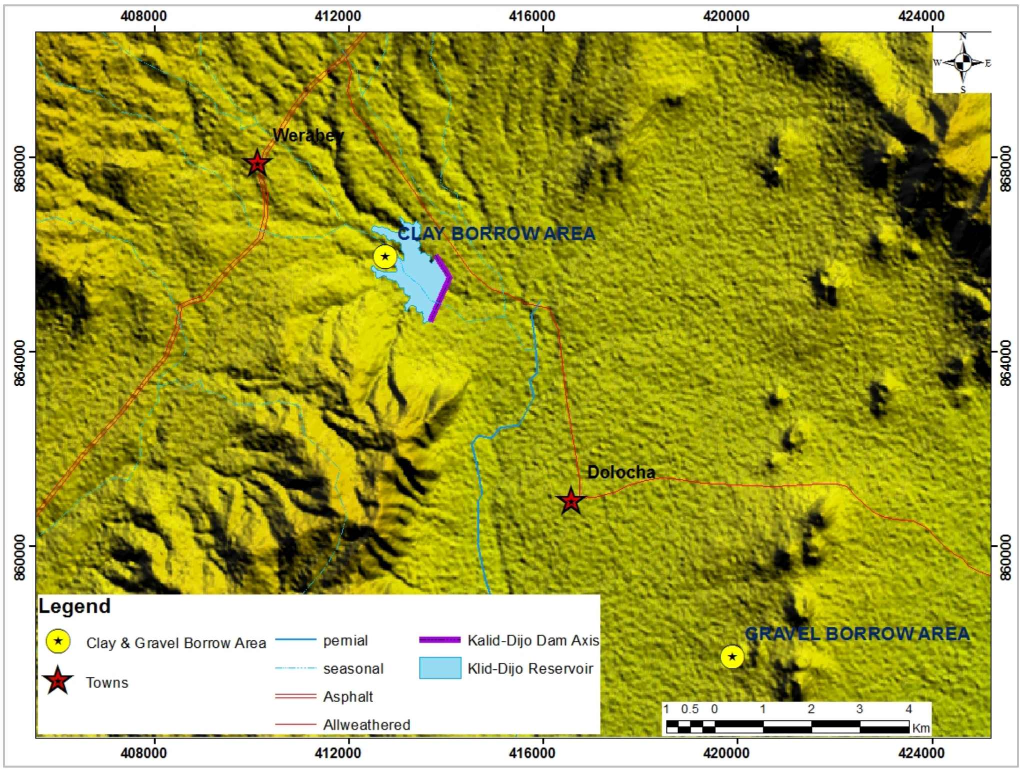


Figure 4- 1: *Dam axis and Borrow site location*

4.3 Analysis

4.3.1 Sample Preparation

At the feasibility study stage, the soil sample was carted away after the test. So, for blending purposes an estimated total weight of 300kg for conducting all tests in different proportions, have been collected from the proposed clay and shell borrow site.

4.3.2 Blending, Mix Ratio and Preparation

The mix ratio of the blending gravel and the borrow core material that needs improvement is done by volume in percentage. A volume parameter is chosen over the weight parameter because of its simplicity at the time of construction. Heavy construction materials of excavators and loaders with a known volume capacity of bucket can easily make the mixing in a clean place with a well steering process. The blending ratio is done in four different proportions. Reference projects like Kesem, Tendaho and Lower Awash Dam projects have been reviewed and the gravel to clay ratio in percentage of 50G/50C, 40G/60C, 30G/70C and 20G/80C selected as a laboratory trial ratio.

The blending ratio of the gravel is constrained between 20-50% in order to improve the clay core material index and engineering properties without deteriorating specification of permeability. After determining the total mass needed for the tests, which is 20 kg, a 22 kg mass of blended sample, with a contingency of 2kg for each proportion was done by volume proportion. Then the two types of the materials were homogeneously mixed with each other based on the desired percentage of combination. Materials above 19 mm diameter have been removed from the soil samples prior to the blending to meet the requirements of ASTM specifications for standard compaction, consolidation and direct shear test. After the blending laboratory tests for index and engineering properties have been done and results below are collected.

The gravel (previously identified as shell material) is used as a blending agent because of these reasons below.

- Local availability: The availability of gravel material locally in sufficient amounts.
- Economic efficiency: Using chemical stabilization and other mechanical stabilization methods are more costly as compared to the gravel mechanical stabilization method.
- Management easiness: The stabilization process and evaluation and supervision of the method can easily be done with this option. The mix is done by volume percentage, which the contractor can work on using the available ordinary construction machines. The supervisor team can also evaluate the process and identify problems easily by doing the ordinary index property tests.
- Other projects have practical results: This stabilizing agent and stabilizing method have succeeded to manage the same problem in other similar projects like Kesem and Tendaho Dam.
- Its technically efficient material which could lower expansiveness, swelling character and compressibility.

4.3.3 Laboratory Test

The laboratory test has been done in two phases. The first phase is testing the sample that is brought from the site before mixing it with the selected blending material of gravel. The reasons for this test are

- To compare the new sample material properties with the previous test results of the feasibility study selected borrow material.
- The borrow core material sample is brought from two pits (in the upstream within the reservoir) in a separate bag of 100kg. The blending gravel material is also brought from one site, which is a previously identified shell borrow site (8km to the south of the dam site and 9km to clay borrow area). Before starting the blending, it is necessary to evaluate if the materials property is similar. This minimizes the number of mix samples to be taken, by directing the research to consider the core material from the two pits as a one sample.

After referring to literature and design documents the following laboratory tests were carried out for borrow core material, gravelly shell and four mix ratios of gravel and borrow core materials.

a. Grain size analysis (sieve, hydrometer): - For the borrow core material, gravels as well as the blended mixes the procedure followed in the test is according to the ASTM D422 standard. Particles which have a greater diameter of 0.075µm have been tested using sieve, while less diameter particles were tested using Hydrometer.
b. Compaction (MDD, OMC): - Compaction test is done prior to its consecutive tests because permeability, shear strength and consolidation tests must be done at the maximum dry density condition with an optimum soil moisture content determined by a compaction test. A standard compaction test is usually done for the clay core of embankment dams. The standard compaction test could also show as if we have altered the 1.3g/cc less dry density of the borrow core material.
c. Atterberg limits: - The ASTM D4318-95 standard is followed to do this test, and the below results are obtained.
d. Swelling characteristic (free swell): - This test is done according to IS 2720 standard protocol. Determines the swelling potential of the soil. While doing the consolidation test, it is also suitable to check the swelling potential of the soil. Before proceeding to the load increment, a stress which counteracts, the swelling pressure of the soil to eliminate heaving effect was first applied during the consolidation test. The pressure which the expansive soil exerts, if the soil is not allowed to swell or the volume change of the soil is arrested.
e. Shrinkage: - This test is done according to ASTM D427 standard protocol.

f. Permeability: - The permeability of the samples taken was determined from the falling head permeability tests following ASTM D-2434 standard performed on each compacted sample.
g. 1D Consolidation: - The high compressibility of the clay borrow material indicated by the high liquid limit percentage can be checked if it is altered by mixing the gravel with it. The tests followed ASTM D-2435-90 standard.
h. Direct Shear: - This test is done under consolidated drained condition according to D3080 ASTM standard. The slope stability in addition to stress- strain behavior of the mix soils and the borrow core materials and pressure exerted on the adjacent shoulder is determined by this test. The laboratory machine could only perform an unconsolidated undrained triaxial test. The plotted graph will enable us to determine the internal friction angle of soil grains and the cohesion.
i. Dispersion: - Clays that disaggregate easily and rapidly in water of low salt concentration, and without significant mechanical assistance are said to be dispersive. This test is done using a double hydrometer test of ASTM D4221 standard.

All of the above tests were carried out by the standards of ASTM. The free swell test followed IS 2420 standard. The particle size distribution, atterberg limits and the compaction test were done prior to the other tests because of their directive uses.

*****

CHAPTER 5 CHARACTERIZATION OF EMBANKMENT MATERIAL

5.1 Introduction

The availability of the construction material within the economic distance is one of the decisive factors for the selection of embankment type. Based on the suitability of the available material/s the embankment dam type (homogeneous earth dam, zoned earth dam or rock fill dam) is selected. For this the material has to fulfill the required criteria of stability and water tightness within the embankment. To meet these criteria the embankment has to be broadly zoned into a central impervious core and the outer pervious material shell, or a rock fill or homogeneous type, where uniform material is used throughout the embankment. For stability against shear failure, the shear strength of the material has to be within the allowable limit particularly for outer parts of a zoned dam. The impervious zone and the reservoir area should be water tight to obtain the optimum quantity of water for desired purpose.

The selection of an appropriate construction material for various zones of an embankment is an important consideration for the safe functioning of a dam project. To meet this, it is necessary that the dam must be impervious enough to hold back the stored water and at the same time it must be stable enough to withstand all static and dynamic forces, to which it will be subjected, within its effective lifetime. The material identified for the construction of the embankment should be examined for existing and anticipated adverse conditions to which these would be subjected after placement in the embankment.

A systematic study of the engineering properties of the construction material for both, existing and anticipated adverse conditions is essential to assess its suitability of material for the desired purpose. For these appropriate in-situ and laboratory tests have to be performed on the representative samples. Further, mineralogy has a significant influence on the engineering properties of the construction material. Therefore, proper mineralogical analysis of the construction material is advantageous in understanding the engineering behavior of the material. Moreover, the site conditions also have a significant effect on the performance of the selected material. Therefore, it is important to discuss the anticipated conditions in relation with the engineering and mineralogical properties of the construction material. Further, the dynamic behavior/ property of the material also needs consideration in seismically active areas.

5.2 Construction Material for Kalid-Dijo Dam Irrigation Project

Based on the previous studies conducted by the Kalid-Dijo Dam project and Irrigation Project Offices, there are in total 10 major potential sites (Table 5-1) which were identified for various types of construction materials required for the embankment Dam. The construction material available from these sites includes; material for central core, fine filter, coarse filter, shell and rock fill/riprap. From these identified sites, one site provides material for clay core (Germama site) and three sites (Gete-Katiyo, Metea, and Jigalashow) provide sufficient quantity of material for shell. Besides, two sites (Agam &Sankura) may provide sufficient material for fine filters. Further, two sites (Senke and Sojat) identified quarry for the rock fill and riprap and one site (Kotobaloso) identified as quarry for concrete aggregate and coarse filter. Table 5-1 and Figure. 5-1 presents location details and other relevant information for identified potential material source sites.

Table 5 - 1: *Potential sites for Construction Material*

S. No	Potential Area	Approximate Volume (m^3)	Approximate Distance from main Dam	Material Type	ID
1	Germama	2 - 3 Million	2 - 2.5km within reservoir	Clay (impervious core)	DDCL
2	Kotobaloso		25km in the NE direction	Basalt (coarse filter)	DDRQ-01
3	Senke& Duna		2km in W direction	Ignimbrite (rock fill/riprap)	DDRQ-02
4	Sojat,		8km in NW direction	Ignimbrite (rock fill/riprap)	DDRQ-03
5	Gete	2 - 2.5 Million	8 to 10km in SE	Scoria-Cone (shell)	DDSH-01
6	Metea	1 - 1.5 Million	9 to 11km in SE	Scoria-Cone (shell)	DDSH-03
7	Jigalashow	2 - 1.5 Million	11 to 13km in SE	Scoria-Cone (shell)	DDSH-04
8	Agam		22 - 25Km in S	Sand (fine filter)	DDSA-01
9	Germama-Kalid		2 - 3km in E	Sand (fine filter)	DDSA-02
10	Sankura		23 - 25Km in S	Sand (fine filter)	DDSA-03

(Source: *Kalid-Dijo Dam Project GGI feasibility Report, 2019***)**

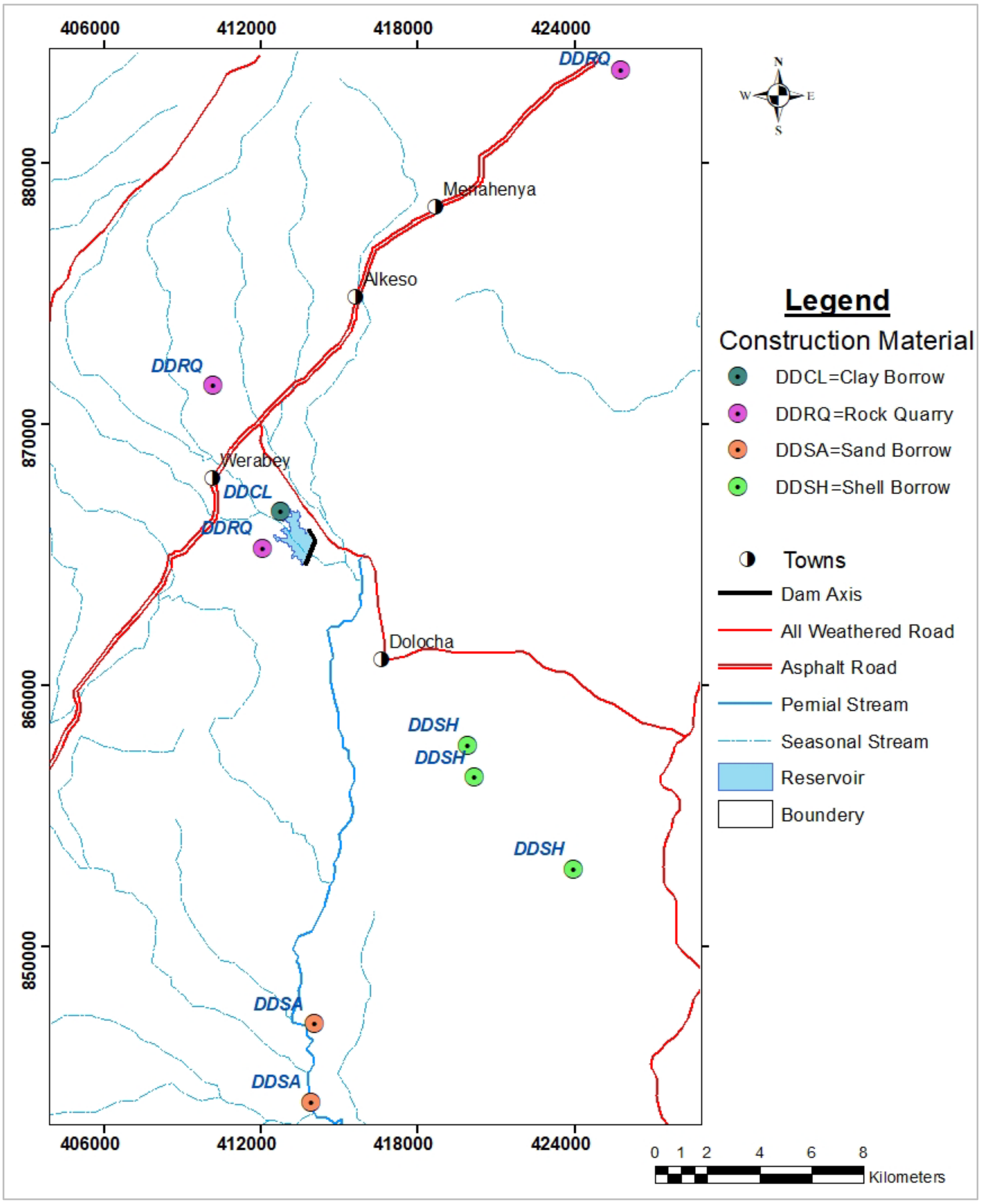


Figure 5 - 1: *Identified Sites of Construction Material for Kalid-Dijo Dam*

5.3 Construction Material for Clay Core

During the geological and geotechnical investigation by Ethiopian Construction Design and Supervision Works Corporation (ECDSWC) an investigation using test pits was made in selected borrow sites to determine suitability and its available quantity of the potential sources for construction material of earth fill material. A total of 4 test pits were excavated manually in the selected Germama borrow areas.

Germama clay borrow area is the only potential source of construction material, identified for impervious core. Availability at economic distance (1.5 to 2.5 km) from the dam axis within the reservoir site is one of the primary suitability of this site. Further, available quantities with relevant soil properties are the other suitability factors, this borrow site reserve estimated 2 to 3 million m^3, and this needs proper investigation. In order to establish the suitability of the construction material for an impervious core, the important soil properties that have to be considered during the study are permeability, compacted density, shear strength, compressibility, flexibility and erosion resistance. These properties are mainly affected by index properties of the soils. (Singh and Varshney, 1995).

Index properties of the soils are soil grain and soil aggregate properties (Murthy, 1989). The principle soil grain properties are specific gravity, size and shape of grains and the mineralogical character of the finer fractions (applies to clay soils). The most significant aggregate property of cohesive soils is the water content and the consistency whereas, that of cohesion less soils is the relative density.

As stated, before the construction material identified as suitable for the core has been obtained from Germama borrow area. Germama clay is characterized by reddish brown residual deposit of silty clay. The thickness of the soil varies in depth from 0.5 to 2 m and all samples for laboratory test were taken from this depth.

There are three layers based on color: the top layer 0 - 0.5m is dark gray; then followed by reddish brown (0.50 to 2.00m); and then yellowish brown, from 2.00m to the bottom (Plate 5-1). The first layer is dominated by black cotton clay of highly plastic, the second layers dominantly consist of silty clay and the third layer is highly weathered to decomposed Tuff. There is slight variation in gradation (increase in silt and fine sand content) with depth. For this clay borrow area the detailed laboratory tests have been conducted during the 2019 feasibility investigation stage. However, the study lacks detailed investigation in geotechnical characterization and analysis. Therefore, to fill this gap it needs additional summary field and laboratory works. Due to this all the parameters considered during the present study depend on the currently collected samples and the average value of the previous results. For this reason, the summary and detailed laboratory works for this borrow area are incorporated. In terms of quantity, the clay obtained from these borrow sites is sufficient to cover the entire volume required for the core. The summary of naturally available and identified clay core material, from Germama borrow area, are described as follows.

Plate 5 - 1: *Different layers of Germama clay in test pit KDCL-01 and KDCL-02*

5.4 Natural Clay Borrow Test Result and Discussion

As mentioned above, during the previous geological and geotechnical investigation by Ethiopian Construction Design and Supervision Works Corporation (ECDSWC) a total of 4 test pits were excavated manually in the selected Germama borrow areas and a number of laboratory tests were conducted, related ASTM standard were used during tests performed to determine the index and engineering properties of the materials, together with the current study of two soil sample laboratory test result, the index and engineering properties of the naturally available clay soil are described as follow.

5.4.1 Index properties of Germama Clay Borrow

Particle size analysis

For present study a wet sieve analysis and hydrometric test were performed on two samples collected from test pits (KDCL-01 to KDCL-02) and four samples previously from this borrow area (DDCL-01, DDCL-02, DDCL-03 & DDCL-04).

A perusal of Table 5-3 and Figure 5-2 indicates that, core material is fine grained material with particle size ranging from coarser sand to clay particles with negligible amount of gravel, in which more than 90% (in DDCL-01 to DDCL-04) and more than 70% (KDCL-01 & KDCL-02) of the particles are of fine fraction.

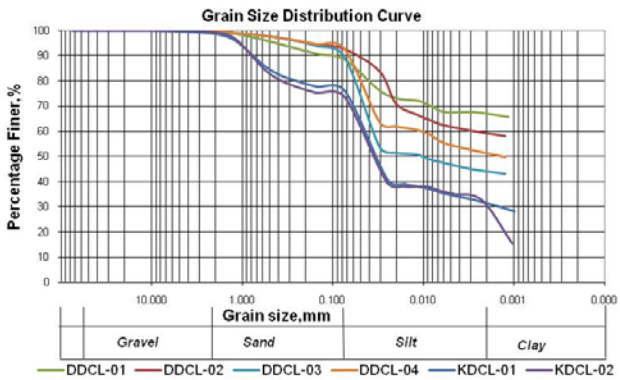


Figure 5 - 2: *Gradation curve for natural core material*

In general, the grain size distribution of core material from the borrow area, presented in Table 5-3, indicates that there are small coarse grain particles and almost no gravel fraction.

Therefore, when grain size distribution of Kalid-Dijo dam core material is concerned, addition of coarser material is necessary as it locks the propagation of crack of different size through the core of the dam depending on the size of the coarser material. Cracks that usually affect the core are measurable in millimeter to centimeter scales. However, it originates from microscopic scale (grain to grain detachment). In severe cases, it may lead to piping phenomena for embankment dams. Once the piping initiates it becomes progressively worse with increasing rate. It results in the loss of a huge volume of the embankment. Therefore, it must be prevented from the source through possible defensive measures during the planning or construction stage of the embankment. After the crack initiates it grows through propagation; micro cracks grow to small visible cracks and interconnection of small cracks leads to a larger crack. In a core of the dam constructed from uniform fine-grained soil, the micro crack glides easily to develop into a larger scale which may endanger the stability of the dam and permit high velocity flow of seepage water through the crack. However, if there is a significant proportion of coarser gravelly material, it limits the propagation and interconnection of the cracks. Further, it obstructs the flow and prevents development of high velocities within the crack and improves the shear strength of the core material (Singh and Varshney, 1995).

Consistency Limits

The test results on consistency of soil samples collected from the borrow area are presented in Table 5-3. Perusal of Table 5-3 and Figure 5-3 the test result indicates the liquid limits of all samples are greater than 50 and their plasticity index are greater than 30 except DDCL-03.

Therefore, as per unified soil classification system, the soils are grouped as MH or OH (inorganic/organic silts of high plasticity respectively) and CH or OH (inorganic/organic clay of high plasticity respectively).

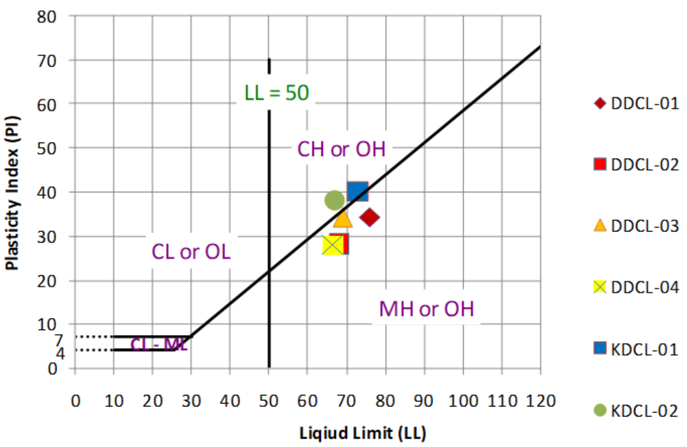


Figure 5 - 3: *Natural core material properties on casagrandes plasticity chart*

According to Sherard, 1967 and Indian Standard (IS: 88261978) as cited in Singh, B. and Varshney, R.S. (1995) CH (highly plastic tough clay) with PI greater than 20 is suggested as good material for core, however, the soils found in MH (silts of high plasticity with plasticity index greater than 12) are considered as poor material for construction of core.

Activity of the soil

For the core material of the borrow area, activity was determined using eq. 5.1 and is presented in Table 5-3. Perusal of Table 5-3 indicates that the soil samples DDCL-01 to DDCL-04 are inactive whereas KDCL-01 and KDCL-02 are normal.

$Activity\ (A) = Plasticity\ Index\ (I_P)/\%\ finer\ than\ 2\ micron\ (clay\ fraction)$------eq. 5.1

Specific gravity

Table 5-3 indicates that the specific gravity test results of the representative soil samples were collected from the borrow area. The determined specific gravities are greater than 2.5 except sample DDCL-02, which is 2.44. If the soil material has a specific gravity less than 2.5, it is an indication of a highly organic or peat soil.

Free swell

The free swell test results and calculated swelling potential values of the representative borrow area soil samples are presented in the Table 5-3 and as the calculated value indicate that the swelling potential of the core material is somewhat high. Therefore, the result indicates that all of the soil samples show swelling characteristics. This high free swell character is not favorable to use them as a core material.

Volume change characteristics

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

The change in the volume of clay soil during swelling or shrinkage depends on activity, according to Figure 5-4 activity chart of core material; all the samples collected from the borrow area found in high to very high range to be used as a core material.

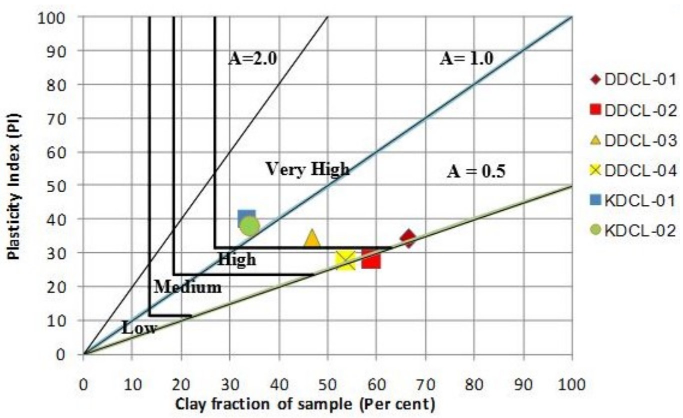


Figure 5 - 4: *Activity level of core material*

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

For Kalid-Dijo embankment dam to determine the swelling potential of the core material equations proposed by Seed et al. (1962(b)) and Chen (1988) are used. The equations are simple models using plasticity index parameters to assess the swelling potential of clay soils and are given as eq.5.2 and eq.5.3, respectively.

For natural soil; $SP = 60K[(PI)^{2.44}]$ ------------------------------eq. 5.2

$SP = B[e^{A}(PI)]$ ------------------------------eq. 5.3

Where, *SP is swelling potential, 'K' is a constant which is given as 3.6 x 10^{-5} for soils having clay content between 8 and 65%. A = 0.0838, B = 0.2558 are constants, and PI is plasticity index.*

Using equation 5.2, the swelling potential for the core material is ranging between 7.19 and 17.52 with an average value of 11.91%, and using equation 5.3, it ranges between7.73 and 11.13 with average value of 9.38%.

Table 5 - 2: *Swelling potential of core material*

Sample ID	Swelling Potential (SP) by eq. 5.2	Swelling Potential (SP) by eq. 5.3	Expansivity
DDCL-01	11.93	9.51	High
DDCL-02	7.39	7.81	High
DDCL-03	11.94	9.51	High
DDCL-04	7.19	7.73	High
KDCL-01	17.52	11.13	High
KDCL-02	15.46	10.57	High

Swelling potential of the soils classified as; (P. Purushothama, 2008)

Swelling Potential (Sp)	Expansivity
>25	Very High
5-25	High
1.5-5	Medium
<1.5	Low

It is observed that the values of the swelling potential computed by the two equations show slight variation. For both equations 5.2 and 5.3 expansivity of soil falls in high expansivity.

From the laboratory test result summary in Table 5-3, the similarity of fundamental index properties which are fine proportion, plasticity index and volume change character, allow us to consider the two pits sample as a one.

However, the identified borrow site for core material is one i.e. left and right bank of the Dijo river, there is a clear indication for the presence of a lateral variation in the soil exist in left and right side of the Dijo river that is MH and CH type soil respectively. Even though, the index and engineering properties of the material varies to some extent from test pit to test pit. Therefore, it is necessary to conduct detail study to determine its index and engineering property and to identify and delineated the lateral variation of clay within the proposed borrow area, which may have a chance to get more suitable soil types for the intended impervious core zone.

Table 5 - 3: *Laboratory test result summary for Index properties of the clay borrow material.*

PARAMETER		Previous Sample Test Result				Previous Sample Average	Remark for previous sample	New Sample Test Result		Average of the new sample	Remark for the new sample
		DDCL-01	DDCL-02	DDCL-03	DDCL-04			KDCL-01	KDCL-02		
Grain Size Analysis	Clay %	66.5	59.07	46.71	53.72	56.5		33.43	34.13	33.78	
	Silt %	21.8	33.47	44.16	36.46	33.9725		42.5	39.27	40.885	
	Sand %	11.44	7.24	9.13	9.82	9.4075		23.6	26.6	25.1	
	Gravel %	0.26	0.22	0	0	0.12		0.47	0	0.235	
Atterberg Limits	Liquid limit (%)	76	68.1	68.9	66.5	69.875		73	67	70	
	Plastic limit (%)	41.83	40.01	34.72	36.73	38.3225		33	29	31	
	Plastic Index (%)	34.17	28.09	34.18	27.77	31.0525	Highly Plastic	40	38	39	Highly Plastic
Unified soil classification		MH	MH	MH	MH	MH	Unsuitable	CH	CH	CH	Unsuitable
Activity Number (Ac)		0.51	0.48	0.73	0.52	0.56	Inactive	1.2	1.11	1.16	Normal
Free Swell (%)		96.5	102.5	100	80	94.75	Highly Expansive				
Specific Gravity		2.58	2.44	2.63	2.62	2.5675		2.57	2.54	2.555	

5.4.2 Engineering Properties of Germama Clay Borrow

From the laboratory test results performed on the two samples collected and four samples from previous study laboratory test results by ECDSWC (GGI of feasibility report, 2019) on the Germama borrow site, which is the only locally available and identified as potential source for clay core material, the index properties are discussed above and the engineering properties are summarized and discussed as follow.

The permeability laboratory test result shows in the order of 10^{-7} to 10^{-6}cm/sec (Table 5-4). However the materials (very fine sand and silts mixtures of both with clay) with a permeability of 10^{-4} cm/s to 10^{-7} and clayey soil can be used in cores of the earth dam (Tschebotarioff, 1955), but as per the engineering use chart for compacted soil after USBR, 1974 indicates that the workability of MH and CH group of soils is fair to poor for core of rolled earth dam.

However, the borrow material is non-dispersive soil and low permeable, due to lack of coarser grain, once a micro crack develops it glides easily to develop into a larger scale which may endanger the stability of the dam and permit high velocity flow of seepage water through the crack. Beside to this encompass only fine-grained soil may lead to demonstrate a shear strength parameter of lesser angle of shear resistance ‘Ø’ value and elevated cohesion ‘C’ value, the direct shear test results is presented in Table 5-4.

As per unified soil classification system, the soils are grouped as MH and CH (silts and clay of high plasticity); generally, it is considered as poor material for construction of impervious core. However, having high plasticity is good for its flexibility, but in contrast it is associated with high compressibility. In addition, having high plasticity may relate with its high swelling potential and high expansive characteristics of the core material; so that the volume changes (swelling and shrinkage) is expected during reservoir level fluctuation, the compressibility test result is presented in Table 5-4. Containing lower maximum dry density and greater optimum moisture value also may be associated with the soil having high water holding capacity, thus having high water contents may cause high pore water pressures to develop in the embankment under its own weight, the standard compaction test result is presented in Table 5-4.

Table 5 - 4: *Engineering laboratory test result summary of the borrow material.*

PARAMETER		Previous Sample Test Result				Previous Sample Average	New Sample Test Result
		DDCL-01	DDCL-02	DDCL-03	DDCL-04		KDCL-01
Permeability (cm/sec)		5.80E-06	3.56E-06	4.83E-07	9.05E-07	2.70E-06	---
Standard Compaction	MDD (gm/cc)	1.29	1.34	1.35	1.32	1.33	1.41
	OMC (%)	35.5	33.7	29.5	33.75	33.11	25.3
Direct Shear	C (kPa)	56	59.67	54.94	49.58	55.05	27.65
	Φ (Degree)	7.4	9.37	8.24	7.9	8.23	17.54
Consolidation Cc		0.171	0.216	0.261	0.306	0.24	0.373
Dispersion		ND	ND	ND	ND	ND	---

Due to the above unsuitable index and engineering property the proposed naturally available Germama clay borrow doesn't satisfy the criteria to be used as construction material for proposed core zone of the rock fill embankment dam, improving the unsuitable core material is still a gap which must be addressed.

Thus, this research is designed to forward alternative solutions that can be used as central core material for zoned embankment dams. Therefore, during the present study attempts were made to improve the quality of existing core material by blending with suitable and locally available coarser material.

5.5 Available Natural Gravel Material Test Result Analysis

During the time of field visite suitable gravelly material has been identified in economic distance, at shell material site, which is scoria cone deposits which is fresh to moderately weathered, layered and vesicular rock fragments of basaltic lava composition hill (8km to the south of the dam site and 9km to Clay borrow area).

Blending with gravelly material is one of the methods of improving the shear strength and compressibility property of the fine-grained soils. In clayey soils the shear strength does not show appreciable increase to gravel content of 30 to 35% but increases at higher gravel content (Bharat Singh, 1995). Besides, in the actual core of dams, the gravel content has to be limited to avoid the possibility of continuous leakage.

5.5.1 The Properties of Gravel Material

During the field visit, it was possible to find the existing gravelly scoria borrow used for the road construction, a total of four (4) gravelly scoria borrow areas were observed. The volume of those gravelly scoria materials is estimated at more than 4 million cubic meters.

During the previous geological and geotechnical investigation by Ethiopian Construction Design and Supervision Works Corporation (ECDSWC) a total of three samples were taken from the selected scoria shell borrow areas and a classification laboratory tests were conducted, together with one sample taken during the field visit (KDSH-01/B2) laboratory test result, the properties of the naturally available gravel material are described as follow.

Table 5 - 5: *Summary of laboratory test results of gravel materials (Source: ECDSWC, 2019)*

Sample ID	Grain size analysis (%)				Sp.gr
	Clay	Silt	Sand	Gravel	
DDSH-01	0.15	1	5.91	92.94	2.62
DDSH-02	0.18	4.59	2.47	92.77	2.75
KDSH-01	0.21	1	29.97	68.83	2.82
KDSH-01/B2	0.01	0.37	6.68	92.94	2.812

Considering the construction material selected for gravel, the material is widely distributed at economic distance from the Kalid-Dijo dam area. During a previous study by ECDSWC (GGI of feasibility report, 2019) materials which are identified to be used as shells are from the series of scoria cone deposits. The selected gravel material sources are located at distances 3 to 5 km, from Dalocha town, and 8 to 11 km from the proposed dam site. The area is characterized by isolated hills that are built from unconsolidated granular deposits ranging in size from silt to gravel (Table 5-5, Plate 5-2 and Figure 5-5). The material from this area is selected for additive gravel material.

Plate 5 - 2: *Plate showing grain size and shape of gravel material*

This material was previously used as a base-course material during the construction and maintenance of the road done surrounding the study area.

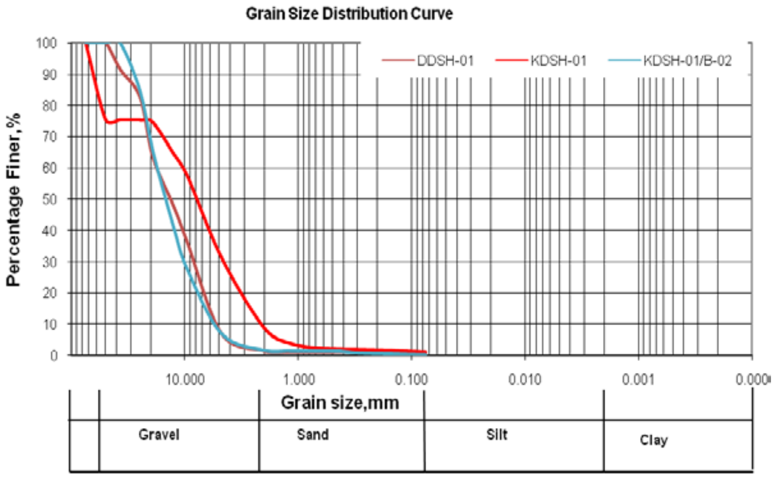


Figure 5 - 5: *Grading limits of the gravel borrow materials*

It ranges from poorly graded to well graded gravelly material with a range of gravel percentage from 68.83 to 92.94 % (Table 5-5 and Table 5-6). The degree of weathering is classified as fresh to slightly weathered scoria cone deposits.

Table 5 - 6: *Summary table of index properties of gravel material*

PARAMETER		Previous Study Sample				Currently Sampled
		DDSH-01	DDSH-02	KDSH-01	Average	KDSH-01/B2
Grain Size Analysis	Fines %	1.15	4.77	1.21	2.38	0.38
	Sand %	5.91	2.47	29.97	12.78	6.68
	Gravel %	92.94	92.77	68.83	84.85	92.94
Sand(S)/Gravel(G)		G>S≈G	G>S≈G	G>S≈G	G>S≈G	G>S≈G
Fines % (F)		F<5,	F<5,	F<5	F<5,	F<5
Cu		<4	>4	>4		<4
Cc		<1	>1 &<3	>1 &<3		>1 &<3
Sand (%)		S<15%	S<15%	S>15%	S<15%	S<15%
Group Symbol		GP	GW	GW	GP & GW	GP
Group Name		Poor-graded GRAVEL	Well-graded GRAVEL	Well-graded GRAVEL	GRAVEL	Poor-graded GRAVEL
Bulk Specific Gravity		2.62	2.75	2.82	2.73	2.812

The material is identified as sandy gravel and gravel with trace amounts of silt. The gradation of the scoria cone deposits consists of; 68-92% Gravel, 2.5-30% Sand and 2-5% Fines (Table 5-6). The locality area of Gete-katiyo, Geta, Metea, and Jigalashow Kebele, of Dalocha Woreda has been identified as a potential source of gravel material in scoria cone deposits.

The shape of grains is sub-rounded to angular; it was observed in the existing scoria borrow. The laboratory tests conducted on those samples (Table 5-15 and 6) indicate that the determined bulk specific gravity in average is 2.77. The gravel material has a better density than the proposed natural core material. Thus, blending may increases the density of the core material.

According to the above unified soil classifications, DDSH-01and KDSH-01/B-02 are composed of GP (poor-graded gravel) soils and DDSH-02 and KDSH-01 is composed of GW (well-graded gravel) soil (Table 5-6).

This GP and GW soils which are considered semi-pervious; and generally, a well-graded compacted sand/gravel has high shear strength and less compressibility than uniform soil; and good workability as a construction material.

Due to the nature of scoria having vesicles; the production mechanism, during transporting and compacting may cause considerable variation in grain size distribution of the material, this may give rise to change the results of blending, however due to having greater than 90% gravel, it doesn't become difficulties in using these materials as gravel material for the intended blending purpose. After-compaction test results were considered to better represent the actual condition during the construction period.

The previous material index property tested in feasibility study has been seen comparably with the new sample material (Table 5-6). Since our main focus is changing the character of the clay core, the new sample index properties are acceptable.

5.6 Blended Material Test Result

As mentioned earlier, blending of coarse gravelly (GP) material with high plasticity clay (CH) soil has been adopted to obtain more suitable construction material for impervious core. Accordingly, four different blending combinations were used with various proportions of gravelly material (GP type soil under USCS) and clay from the borrow area (Germama area). The volumetric percent fraction of gravel/clay material that was used during the blending was; 50:50, 40:60, 30:70 and 20:80.

The index and engineering laboratory tests such as classification tests, Atterberg Limits, Permeability, Proctor Compaction, Direct shear, Consolidation, Dispersion, Shrinkage (Volumetric) and Free Swell tests were carried out for each of the blended ratios.

5.6.1 Grain Size Analysis

Wet sieve analysis was made on blended material mixed from different combination of Germama clay of CH type soil consisting 33.43% clay, 42.5 % silt, 23.6% sand and 0.47% gravel and the gravel material of GP type soil consisting of 92.94% gravel, 6.68% sand and

0.38% fine. Besides, hydrometric analysis was also conducted on the clay fraction used for blending.

Figure 5-6 shows the grain size distribution graph of different blended ratios. Table 5-7 shows the percentage composition of clay, silt, sand and gravel for different blended combinations.

Table 5 - 7: *Grain size analysis of the blended core material*

Item No.	Mixed sample	Percentage				Soil Category (USCS)
		coarse		Fine		
		Gravel	sand	Silt	Clay	
1	20%GP & 80%CH	14.08	15.25	44.67	26	Fine grained soil
2	30%GP & 70%CH	27.92	8.25	36.55	27.29	Fine grained soil
3	40%GP & 60%CH	32.25	14.17	33.24	20.34	Fine grained soil
4	50%GP & 50%CH	42.59	14.25	31.93	11.24	Coarse grained soil

According to the unified soil classification system, the 50/50 blended ratio material is categorized under coarse grained soil, while the other three blended ratio materials are in the fine grained group. The particle size distribution Figure 5-6 of the soil clearly presents the difference in gravel content between mixes.

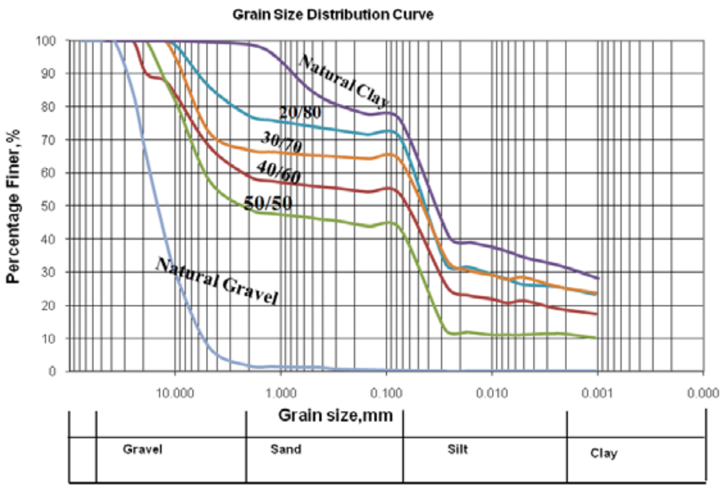


Figure 5 - 6: *Grain size distribution graph for blended material*

5.6.2 Atterberg limit

ASTM D4318-95 standard is followed to do this Atterberg limit tests, and the results obtained are presented below in Table 5-8.

Table 5 - 8: *Atterberg limit test result of blended material*

Parameter		Soil sample					
		Blending option				Borrow material (average)	
		20/80	30/70	40/60	50/50	100%CH	100%GP
Atterberg Limits	Liquid limit (%)	62	55	53	47	73	34
	Plastic limit (%)	30	28	25	23	33	NP
	Plasticity index (%)	32	27	28	24	40	-

The result of the limit test showed the significant improvement of the proposed core material. The previous 73% liquid limit was lowered to 47-62% liquid limit. This indirectly shows that the compressibility of the proposed soil is significantly decreased. Plasticity index is also lowered to 24-32% from 40%. This also shows the workability improvement and lower pore water retention capability. Figure 5-7 presents the plasticity chart as a result of the fine blended materials.

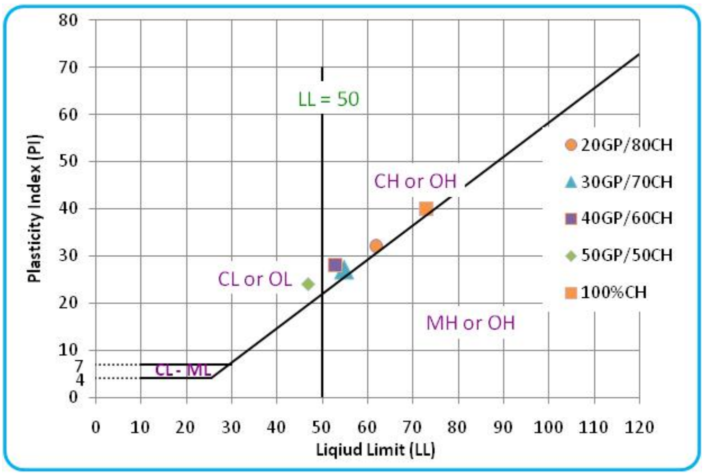


Figure 5 - 7: *Plasticity chart of blended materials*

Based on Table 5-7 and Figure 5-7, the only 50/50 blended ratio is coarse grained soil with greater than 12% fines of low plastic clay, according to USCS it is grouped in gravelly clay soil (GC). The other 40/60, 30/70 and 20/80 blended ratio are categorized in fine grained soil of high plasticity clay.

5.6.3 Compaction test

During the previous study by ECDSWC (GGI of feasibility report, 2019) the average maximum dry density of the proposed natural core material is 1.33g/cc at 33.11% optimum moisture content and currently sampled clay (KDCL-01) has 1.41g/cm^3 MDD and 25.30% OMC. Figure 5-8 and Table 5-9 shows the standard compaction result of all blended material.

As shown in Figure 5-8, after taking a minimum of three trials in a standard compaction test, computation of optimum moisture content which achieves maximum dry density is determined.

Table 5-9 summarizes and presents MDD and OMC determined for the borrowed core material originally proposed and for the mixes.

Table 5 - 9: *Laboratory test results of standard compaction test*

Item No	Description	Test Result	
		MDD (gm/cc)	OMC (%)
1	100% CH	1.41	25.30
2	20%GP & 80%CH	1.38	23
3	30%GP & 70%CH	1.45	27
4	40%GP & 60%CH	1.41	25
5	50%GP & 50%CH	1.57	24

Optimum moisture content is recommended to be 15-20% per Yilmaz and Karacan limits as well as 12-25 per DWA specifications. As the required water content becomes higher, problems with workability and pore-water pressure retention will be created. Regarding this, the high optimum moisture content of the borrowed material is lowered to a desired and acceptable level. (23-25).

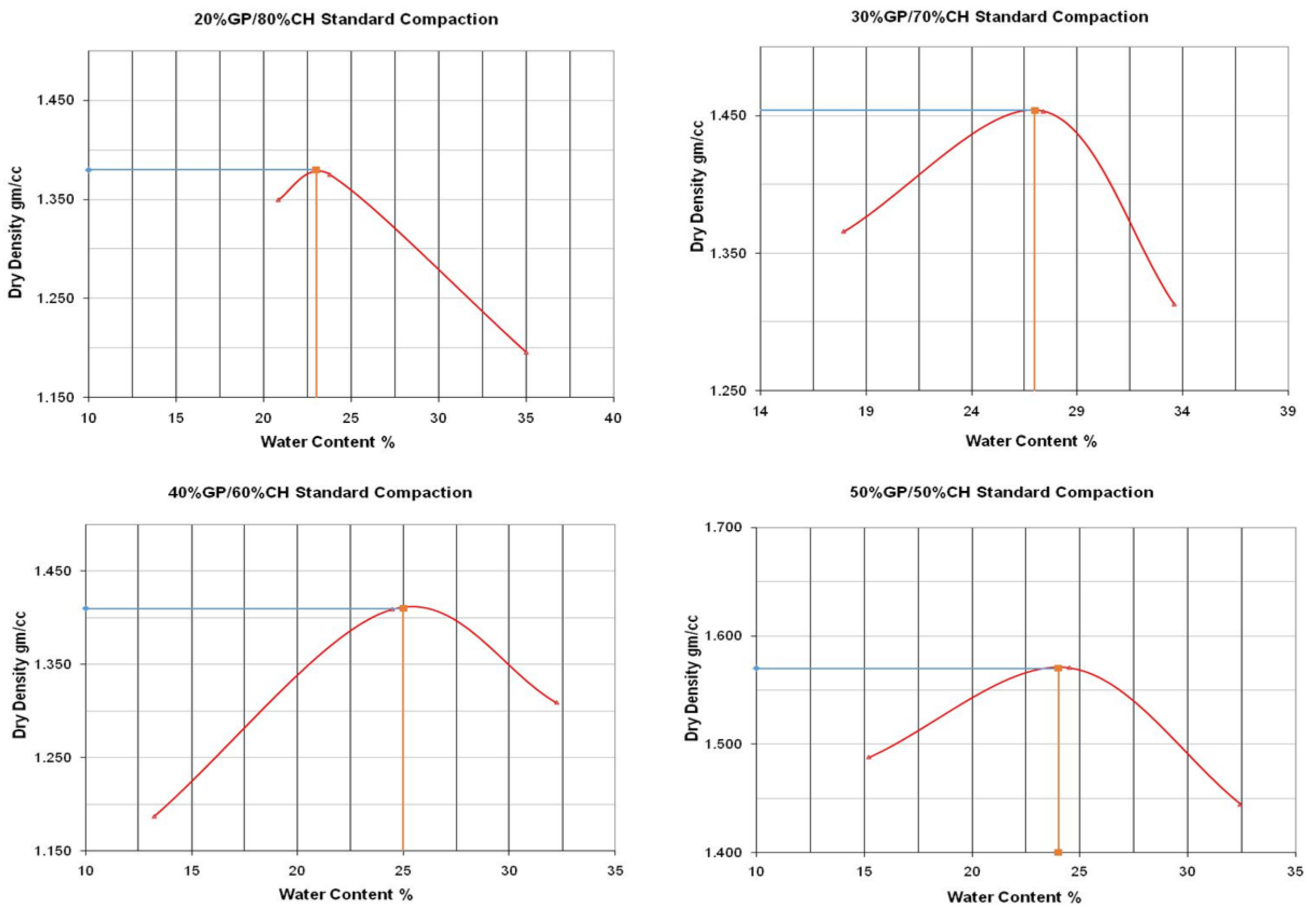
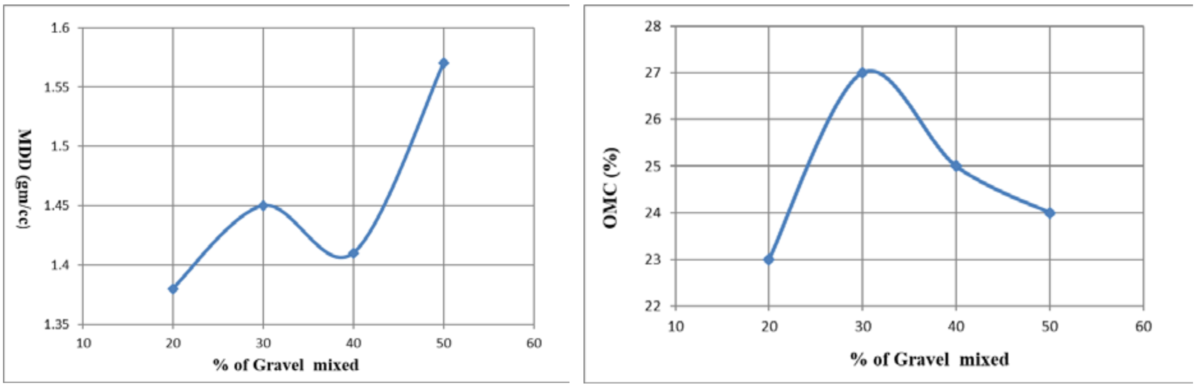


Figure 5 - 8: *Standard compaction test result for blended materials*

Common trends can be observed from Figure 5-9 (a): an increase in gravel from zero results in a steady increase in MDD. As it is observed in Figure 5-9 (b), the optimum water content decreases almost linearly when the gravel content increases. However, some laboratory data contradict with the trends that are obtained in literature, this may be due to the common errors occurring in laboratory works.



(a) (b)

Figure 5 - 9: *Compaction test results. (a) Maximum dry density and (b) optimum water content.*

5.6.4 Free swell and volumetric shrinkage test

The free swell test for the pure core material (unblended) was on average 94.75% from previous study laboratory results of MH soil samples from borrowed material. The result for the blended material tests is presented in Table 5-10. The high 94.75% average free swell property of the soil is found to be altered significantly, where all blended materials free swell is below 55%.

Table 5 - 10: *Free swell, volumetric shrinkage test and swelling pressure results*

Item No	Description	Test Result		Calculated Swelling Potential	
		Free swell (%)	Volumetric shrinkage (%)	using eq.=5.2	using eq.=5.3
1	Average 100% MH	94.75	17.45	17.52	11.13
2	20%GP & 80%CH	55	15.65	10.16	8.9
3	30%GP & 70%CH	50	15.20	6.71	7.51
4	40%GP & 60%CH	45	9.59	7.34	7.79
5	50%GP & 50%CH	40	8.87	5.04	6.68

Free swell is lowered to a desired level of less than 50% for 40/60 and 50/50 blended ratios. As free swell shows the expansiveness and the swelling potential of the soil, the high free swell character of the borrowed material (102.5%) is altered. This property modification is also seen in swelling potential calculated using eq. 5.2 and 5.3. In Table 5-10 we can see that the swelling potential of the borrowed material is reduced significantly for all blended proportions.

Currently on all the four blended ratios of fine-grained soil of blended proportions volumetric shrinkage tests are done. And the respective results of the fines are presented in Table 5-10. A high volumetric shrinkage indicates a large potential shrinkage of the soil mass on drying.

5.6.5 Consolidation test

The test is the one-dimensional consolidation test. Result could show the compressibility character of a material. Figure 5-10 presents the consolidation character of four blended proportions.

The major consolidation mechanism is expulsion of pore water. As the soil pore space is higher the higher it is compressible. In addition, the coefficient of compressibility, which is a ratio of change in void ratio and change in pressure. The coefficient of compressibility for proposed natural borrow material is 0.373, while the largest gravel proportion mix, 50/50 ratio is 0.306 as presented in Table 5-11.

Table 5 - 11: *The coefficient of compressibility result for natural and blended clay*

Item No	Description	Test Result
		Consolidation (Cc)
1	100% CH	0.373
2	20%GP & 80%CH	0.373
3	30%GP & 70%CH	0.398
4	40%GP & 60%CH	0.403
5	50%GP & 50%CH	0.306

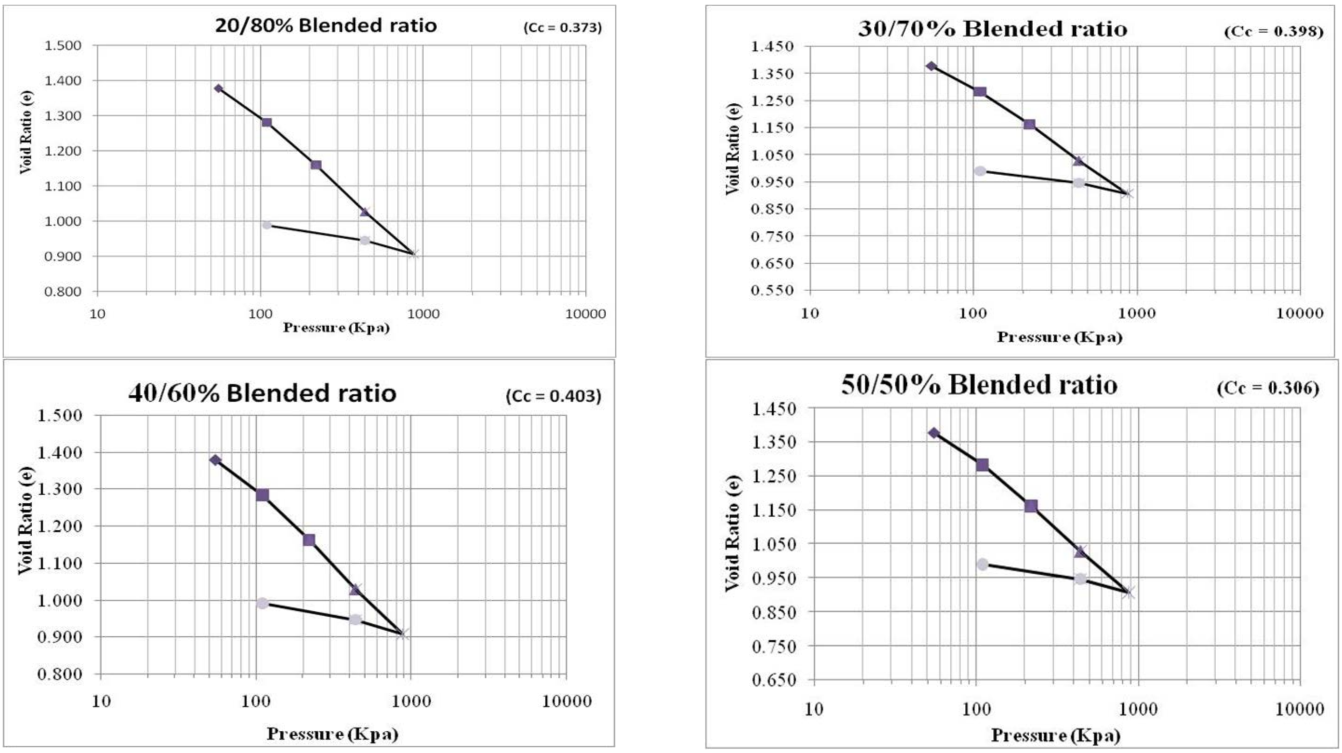


Figure 5 - 10: *Void ratio versus Log Pressure*

From odeometeric tests that have been conducted on blended ratio of 40/60 and 50/50 (gravel to clay ratio), the coefficient of volume change (Mv) decrease from 1.273 to 0.112 as the pressure rises from 55 kpa to 880 kpa for 40/60 and decrease from 1.295 to 0.118 as the pressure rises from 55 kpa to 880 kpa for 50/50 ratio. The coefficient of compressibility ‘Cc’ value for 40/60 is 0.403 and for 50/50 is 0.306 (Table 5-11).

5.6.6 Permeability test

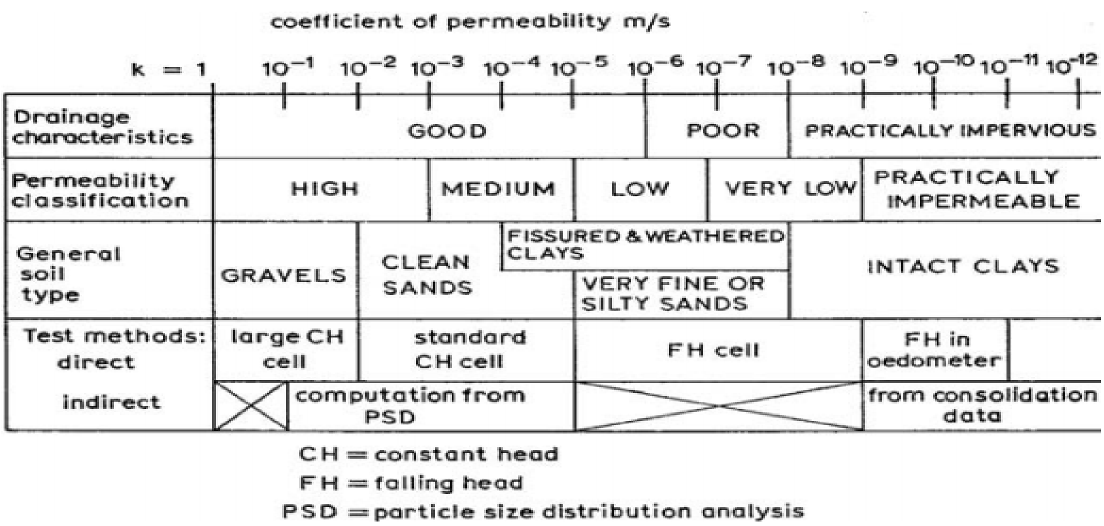
The laboratory permeability test was performed using Constant Head apparatus. The permeability coefficient obtained from the tests for naturally available high plastic silt (MH) is 2.69×10^{-6} cm/sec on average. Table 5-12 presents the permeability coefficient determined for blending clay.

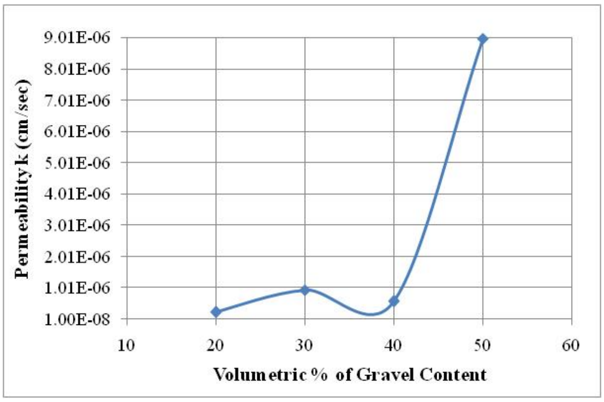
Table 5 - 12: *Permeability test result*

Item No	Description	Test Result
		Permeability (cm/sec)
1	20%GP & 80%CH	0.00000243
2	30%GP & 70%CH	0.00000095
3	40%GP & 60%CH	0.00000058
4	50%GP & 50%CH	0.000008987

According to the permeability classification all the samples are in poor drainage characteristics and in low to very low permeable regions. Refer Table 5-13 below.

Table 5 - 13: *Permeability and laboratory testing method for the main soil types (Head, 1985).*





A common feature of the approximating curves in Figure 5-11 is almost constant in permeability when the gravel content is increased from 20% to about 40%. Beyond this amount, the permeability coefficient increases rapidly with a further increase in gravel content.

Figure 5 - 11: *Permeability versus gravel proportion (%)*

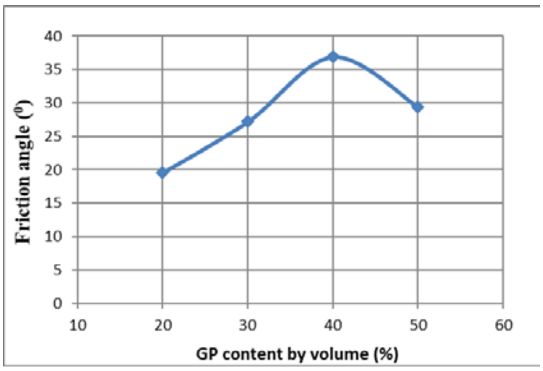
5.6.7 Direct Shear test

Table 5-14, present the tested result value of the shear parameters for different blended ratios. As we observe from Table 5-14 and Figure 5-12, as the gravel volume in the blended clay increases, angle of internal friction is found to increase up to 40/60 mix ratio then it decreases, while the cohesion constantly increases.

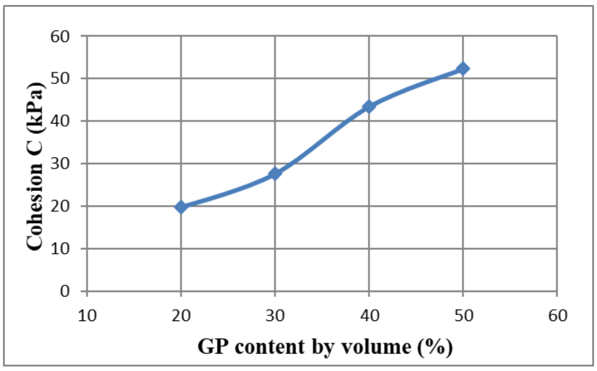
Core is not a structural component. The shear strength of core material is flexible. This is because the dam's main structural components are the upstream and downstream slopes. But a high shear strength core material is desirable than low, keeping the seepage and other index properties the same.

Table 5 - 14: *Shear parameters test*

Item No	Description	Test Result	
		Angle of internal friction Φ (Degree)	Cohesion C (kPa)
1	100% CH	17.54	27.65
2	20%GP & 80%CH	19.57	19.75
3	30%GP & 70%CH	27.18	27.65
4	40%GP & 60%CH	36.89	43.45
5	50%GP & 50%CH	29.38	52.33



(a)



(b)

Figure 5 - 12: *Influence of gravel content on the shear strength. (a) friction angle and (b) Cohesion.*

Direct shear test is done under consolidated drained condition to determine cohesion and friction angle parameters are mainly used in determining downstream long-term steady state condition. To obtain parameters for upstream sudden drawdown condition, Consolidated Undrained test, which drainage is permitted after application of confining pressure must be done. Therefore, for the detailed design, the shear strength determined in this research can be used for downstream steady state conditions.

Table 5 - 15: *Normal stress and shear stress value for the blended ratio*

Normal stress (KN/m2)	Shear stress (KN/m^2) blended material			
	50/50 %	40/60 %	30/70 %	20/80 %
0	52.33	43.45	27.65	19.75
100	109	119	79	55
200	165	194	130	91
300	221	269	182	126

From the direct shear test conducted the results indicates, as the normal stress increase from 0 to 300 (KN/m^2) the shear stress rises from 52.33 to 221 (KN/m^2) for 50/50 combination and 43.45 to 269 (KN/m^2) for 40/60 ratio (Table 5-15 and Figure 5-13), respectively.

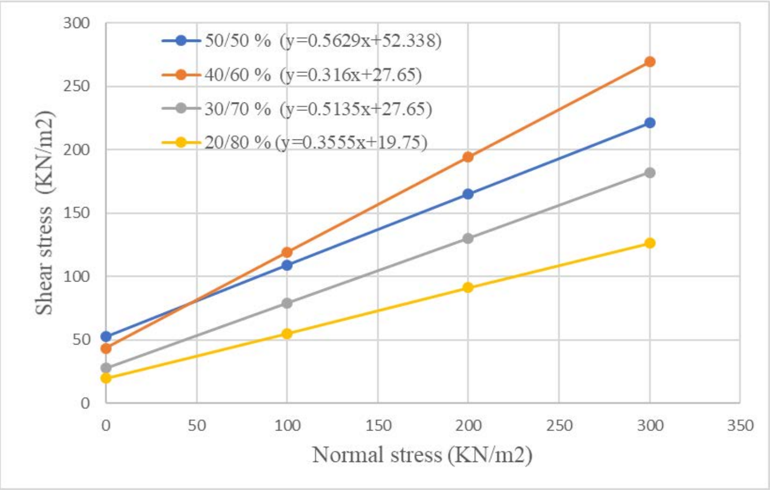


Figure 5 - 13: *Graph showing Shear stress vs Normal stress for all blended material*

5.6.8 Dispersion test result

Dispersive clays are those clays which possess unique property, under saturation or in contact with water that deflocculates and rapidly eroded and carried away by water. This property can result in disastrous consequences for embankment dams constructed from this material. The dispersivity of the soil is directly related with clay mineralogy and pore water chemistry (Jansen, 1988). It occurs when the interparticle forces of repulsion exceed those of attraction. Consequently, dispersive clay particles tend to react as single-grained particles and not as an aggregated mass of particles. The clay particles are detached and go into suspension which can cause the piping phenomena in earth dams.

The erodibility of the embankment material is checked through dispersion test. As per Sherard and J. L., Decker. (1977), the double hydrometer test is the most reliable test for identifying dispersive soils susceptible to piping failures of earth dams. Double hydrometer test conducted on all blended proportion sample indicates (Table 5-16) that all of the materials fall in less than 15%, according to Sherard and Decker, 1977, soils with dispersive characteristics, exhibited 30% or more dispersion when tested by this method, so all the blended core materials are drop in non-dispersive class. The dispersion test result is presented in Table 5-16.

Table 5 - 16: *Dispersion test result*

Item No	**Description**	**Test Result**	
		Double Hydrometer (%)	Dispersion class
1	100% CH		ND
2	20%GP & 80%CH	9.04	ND
3	30%GP & 70%CH	5.56	ND
4	40%GP & 60%CH	4.24	ND
5	50%GP & 50%CH	14.45	ND

ND is Non dispersive material.

5.7 Mineralogical Composition of Core Material

Clayey soils are usually selected for impervious core because of their low permeability. The engineering property of clayey soils mainly depends upon dominant clay minerals and the structure of the particles. Clayey soils are composed of an aggregate of clay mineral and non-clay minerals (Atwell, 1976). The behavior of clay minerals is governed by electrical and internal surface forces, which can be analyzed by the fundamental nature of the particles and clay water interaction. Therefore, identification of the type of clay mineral using X-ray diffraction is essential to understand the behavior of the soil. But due to the limitation of the XRD laboratory in the country, it is enforced to estimate clay minerals present in soil based on plasticity charts.

According to Day (2006), identification of clay minerals using X-ray diffraction patterns is a rather complicated, expensive, and involved special instrument that is not readily available to the geotechnical engineer. A more common approach is to use the location of clay particles as they plot on the plasticity chart to estimate the type of clay mineral present in the soil. Figure 5-14 shows the plasticity chart for natural and blended core material from the borrow area.

Perusal of Figure 5-15 indicates that the plot of samples from clay borrow area, four MH type soil samples collected during previous study (ECDSWC, 2019) falls within Kaolinite region.

On the other hand, two samples taken from clay borrow area during the present study (CH group) and all blended samples fall in Illites zone of plasticity chart. Besides, no samples fall within zone or close to Montmorillonite from Germama borrow area.

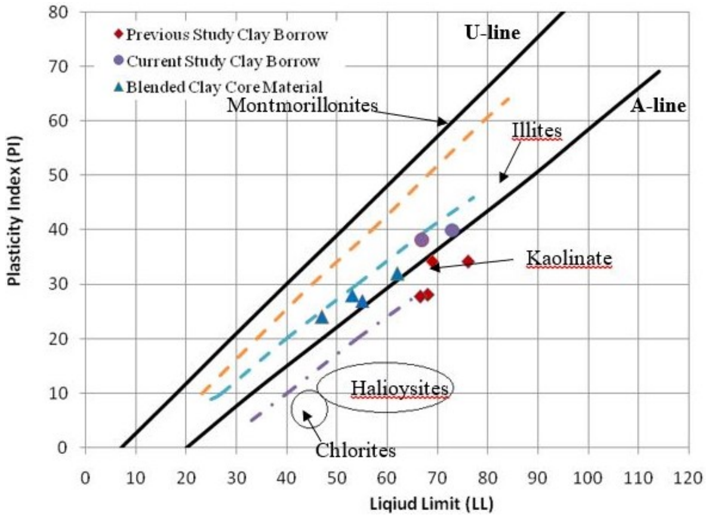


Figure 5 - 14: *Plasticity chart for core material (Source: Day, 2006)*

*****

CHAPTER 6 ANALYSIS AND DISCUSSION

6.1 Preamble

During the present study systematic analysis of the embankment material for core zones of Kalid-Dijo dam has been carried out. Besides the engineering property the suitability of the material has also been evaluated in terms of mineralogy (from plasticity chart), dynamic property and the site conditions. In the course of the work, particular attention was given to characterize the core material. Due to the limitations on time and resources it was not possible to cover other zones in a similar manner as it is done for the core material. Full emphasis was given to the core material as it is a crucial zone from the stability and performance point of view for an embankment dam.

6.2 Engineering property Blended core material vs Natural clay

Previously, various laboratory tests were conducted on clays, identified for core material (from Germama clay borrow area). The test results indicate that the core material, from these borrow areas, is dominantly CH and MH type of soil as per USCS classification (Table 5.3). According to the core material preference order for rolled dams, CH group soils are placed in 7th grade for their suitability as core material (Wagner, 1974). This material fails to satisfy the limits suggested by Yilmaz and Karacan (1996) for impervious material, to be used in the clay core of embankment dam (Table 6.1). In addition, the maximum dry density (MDD) and optimum moisture content (OMC), liquid limits and plasticity index; obtained from the tests conducted on normal MH and CH clay, do not fall within the permissible limits. Besides, low shear strength, low dry density, high compressibility and high swelling potential are the major drawbacks of CH and MH soils, to be used for high embankment dams, particularly within the earthquake prone areas.

Table 6 - 1: *Comparison of normal and blended core material*

Parameters		Limits as per Yilmaz and Karacan	Core material				
			Natural Clay CH	Blended Material (Ratio Gravel/Clay)			
			0/100	20/80	30/70	40/60	50/50
Standard Compaction	Max. dry density (g/cc)	≥1.6	1.4	1.4	1.5	1.4	1.6
	OMC (%)	15-20	25.3	23	27	25	24
Atterberg Limits	Liquid limit (%)	40-50	73	62	55	53	47
	Plasticity index (%)	14-20	40	32	27	28	24
Shear strength	C (kpa)	>20	27.65	19.75	27.65	43.45	52.33
	ø (Degree)	>20	17.54	19.57	27.18	36.89	29.38
OMC - Optimum moisture content, C - Cohesion, ø - Angle of shearing resistance							

Among the laboratory tests conducted on different blended proportions of clay and nearby fine shell material (gravelly material), general improvement in the desired properties of core material has been observed. The GC material is obtained at a mix proportion of 50/50 (gravel to clay ratio). From an engineering point of view the GC soil, at a blended ratio of 50/50 (gravel to clay ratio), may be considered as most appropriate to be used as core material. In terms of engineering properties, such as; shear strength, compaction and compressibility, the GC material at 50/50 (gravel to clay ratio) blending ratio is more preferred than the material achieved at 40/60, 30/70 and 20/80 (gravel to clay ratio) mix proportion.

The permeability of GC material, under proper blending in the laboratory, is also within the permissible limits. However, proper blending may be challenging in the field due to various reasons. In general, in actual core material the gravel content has to be limited to avoid the possibility of a continuous leakage path developed through segregation. Moreover, 40/60 (gravel to clay ratio) blended proportion is preferable in terms of economy, however the required engineering properties like compressibility and compaction is relatively lower.
Moreover, when permeability is concerned for the core material only slight variation is observed ($8.99x10^{-06}$ for 50/50 ratio $5.80x10^{-07}$ for 40/60 (gravel to clay ratio). Also, plasticity index and liquid limit of different blended ratios show slight variation. This is possibly resulted from the uniformity of plasticity of natural clay and fine fraction in the gravelly soil, sampled for Atterberg limit tests. The Optimum moisture content and plasticity index of core material, for all blended ratios, are slightly higher to the limit set by Yilmaz and Karacan (1996). Both plasticity index and optimum moisture content are equal to 24.00 for blending proportion 50/50 (clay to gravel ratio) is closest to the limit set (PI - 14 to 20 and OMC-15 to 20) for the core. Therefore, the 50/50 (gravel to clay ratio) blended proportion may be considered as satisfying both limits for liquid limit and plasticity index.

6.2.1 Volume change characteristics

A) <u>Volume Change Characteristic Based of Swell index and volumetric shrinkage</u>

Change in volume of soils may lead to change in strength and deformation characteristics that may affect the stability of the engineering structure founded or constructed from those soils. According to Bowels (1984) if the plasticity index of the material is greater or equal to twenty ($PI \geq 20$), there will be a volume change problem which require some kind of precautionary measures. In core of the embankment dam during reservoir level fluctuation volume change (swelling and shrinkage) is expected depending on the type of the material selected. Swell potential is one of the essential properties of the soil that has to be considered when clayey soils are desired to be used in the embankment. In case of core material for Kalid-Dijo dam, the swell potential of the soil identified for the core have high swell index with values ranging from 80 to 102.5% from previous study by ECDSWC (GGI of feasibility report, 2019). In order to determine the improvement in swell potential of the core material, shrinkage swell index tests was conducted on blended samples passing 4.75 mm sieve. The improvements in the swell potential of core material are shown in Figure 6-1.

Perusal of Figure 6-1(a) indicates that percent swell decreases as the gravel content increases. Usually, development of cracks in the core is directly related to shrinkage characteristics of the material used. Particularly, for dams located in arid and semi-arid regions, with high daily and seasonal temperature variation like; Kalid-Dijo dam site. The effect will be higher as compared to the humid region especially during a long period reservoir drawdown. However, from Figure 6-1(b) the interpolated volumetric shrinkage decreases, in the same mode as swell index, as gravel content increases for different blended ratios. Based on Figure 6-1 and the permeability results of different blended proportions, performed during the present study, addition of gravelly material up to 50% to the clayey soil can produce a low permeability and low shrinkage potential material. The test results clearly revealed that blending gravelly soils with fine grained CH soil may significantly improve the crack expected to develop in the core due to differential settlement and volumetric shrinkage.

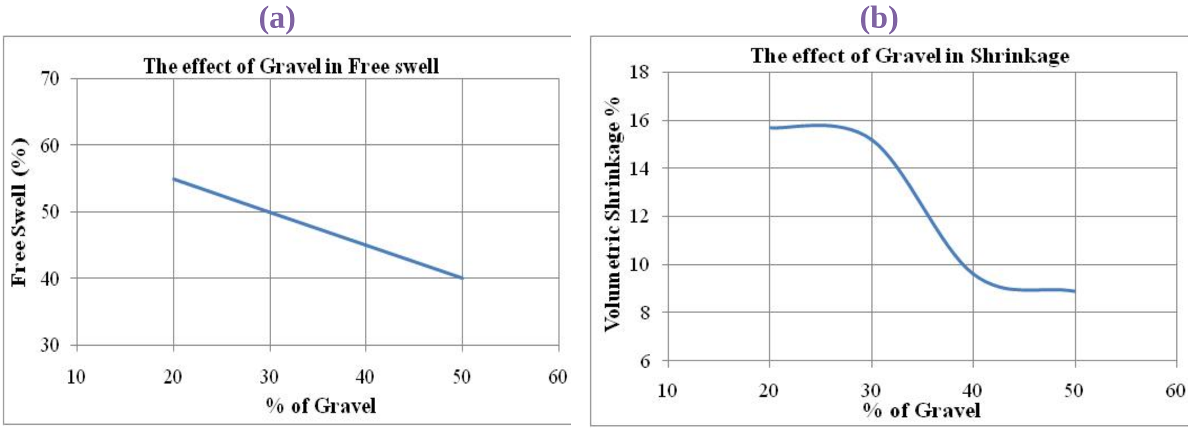


Figure 6 - 1: *(a) shows the decrease in swell potential of the core material as percentage of gravel increase (b) Shows decrease in volumetric shrinkage of the core material as percentage of gravel increase.*

Besides, addition of coarser material to uniformly fine material locks the propagation of crack of different size through the core of the dam depending on the size of the coarser material. Cracks that usually affect the core are measurable in millimeter to centimeter scales. However, it originates from microscopic scale (grain to grain detachment). In severe cases, it may lead to piping phenomena for embankment dams. Once the piping initiates it becomes progressively worse with increasing rate. It results in the loss of a huge volume of the embankment. Therefore, it must be prevented from the source through possible defensive measures during the planning or construction stage of the embankment. After the crack initiates it grows through propagation; micro cracks grow to small observable cracks and interconnection of small cracks leads to a larger crack. In a core of a dam constructed from uniform fine-grained soil (CH clay), the micro crack glides easily to develop into a larger scale which may endanger the stability of the dam and permit high velocity flow of seepage water through the crack. However, if there is a significant proportion of coarser gravelly material, it limits the propagation and interconnection of the cracks. Further, it obstructs the flow and prevents development of high velocities within the crack

B) Volume Change Characteristic Based on Activity chart

Another way of determining volume change characteristics of clayey soil is by using an activity chart proposed by Cartel and Bentley (1991) and plasticity index chart proposed by (Seed, et al., 1960). Significant change in volume of clay soil during shrinkage or swelling is a function of plasticity index and the quantity of clay colloid present in the soil. The plot of Plasticity Index (IP) and % clay for normal and blended material, identified for the core of the Kalid-Dijo dam, have been made on the plasticity index chart (Table 6-2 and Figure 6-2). Based on Figure 6-2, soil from the borrow area falls in zones of high to very high swelling potential (66.67% in very high and 33.33% in high zone of swelling potential). Whereas, the soil from the blended core material falls in zones of low to high swell potential.

Table 6 - 2: *Plasticity index, clay fraction, and activity of clay from borrow area and blended core material.*

Borrow material				Blended core material			
Sample ID	Clay (%)	PI	Activity	Sample ID	Clay (%)	PI	Activity
DDCL-01	66.5	34.17	0.51	20GP/80CH	26	32	1.23
DDCL-02	59.07	28.09	0.48	30GP/70CH	27.29	27	0.99
DDCL-03	46.71	34.18	0.73	40GP/60CH	20.34	28	1.38
DDCL-04	53.72	27.77	0.52	50GP/50CH	11.24	24	2.14
KDCL-01	33.43	40.00	1.20				
KDCL-02	34.13	38.00	1.11				

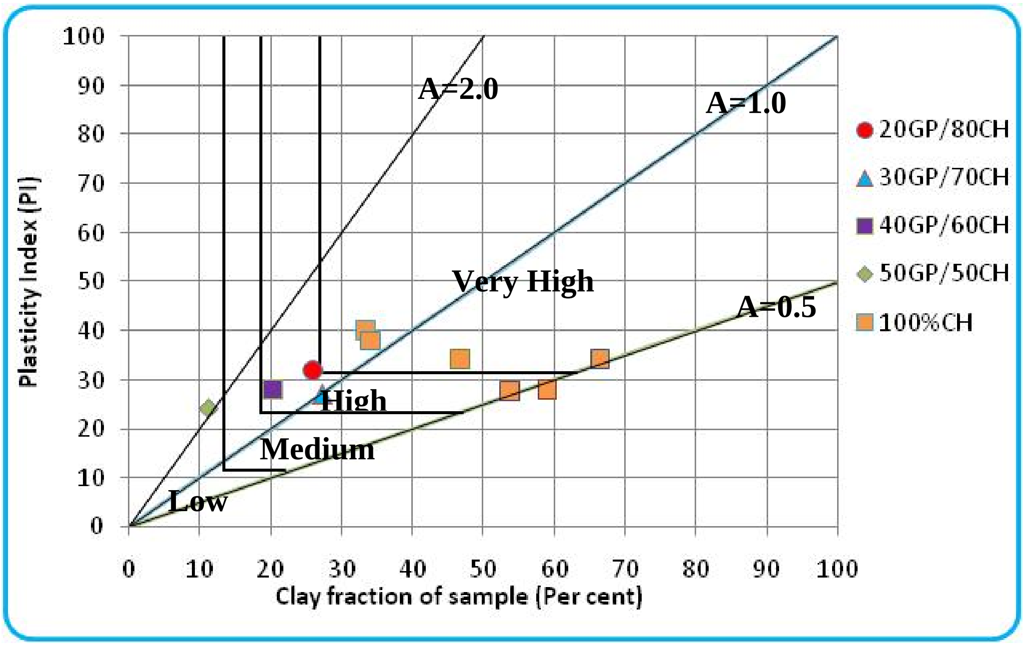


Figure 6 - 2: *Chart for evaluation of potential expansiveness (Seed, et al., 1960)*

6.2.2 Compressibility and shear strength characteristics

Consolidation and direct shear tests have been conducted on all blended ratios (gravel to clay ratio). The test results are compared with normal CH clay. From Figure 5-3 the initial void ratio of the normal clay (CH) is greater than the 50/50 ratio blended core material because of the percentage of fine. The compression index (Cc), for CH clay is 0.373 and that of blended clay at 50/50 ratio is 0.306, which implies that the compression response of CH clay core is more than the blended material. Higher compressibility of core material is associated with high settlement which may lead to differential settlement that ultimately results in development of cracks.

The results showed that the reduction in compressibility of the normal clay (CH group soil) may be achieved through blending. For 50/50 blended ratio compressibility is reduced by 18%. Therefore, safely it may be concluded that compressibility characteristics and expected settlement of the core material will be improved significantly through blending.

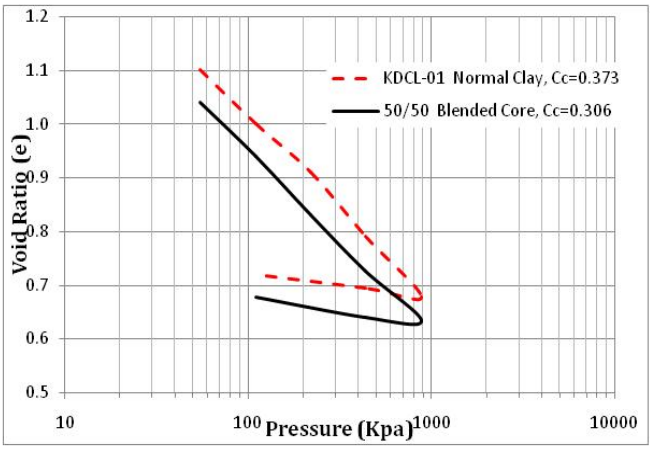


Figure 6 - 3: *Consolidation curve of void ratio verses vertical consolidation stress.*

Normal stress vs shear stress relations for core material at 50/50 blended ratio are drawn from CD direct shear test Conducted (Figure 6-4). In order to check the improvement in the shear stress behavior, the graph of normal stress vs shear stress for 50/50 blended ratio (gravel to clay ratio) is compared with the normal clay (CH soil). The graph of blended core material shows an improvement in the shear stress over normal clay soil. From the above test result carried on a blended sample shows the following advantages over CH normal soil. The blended GC material obtained from a 50/50 ratio showed 40% reduction in plasticity index (IP), 12% improvement in maximum dry density (MDD), 5% reduction in optimum water content, and 18% reduction in compression index. From the results it may be deduced that mixing of gravelly material to CH clay soils may reduce the swelling potential of the core during reservoir filling and it may also reduce the shrinkage crack potential during reservoir drawdown conditions.

The compressibility characteristic of 50/50 blended ratio GC material is highly improved in comparison with normal CH clay. Further, decrease in settlement may improve construction time as much time may be lost allowing immediate settlement in case of normal CH soils.

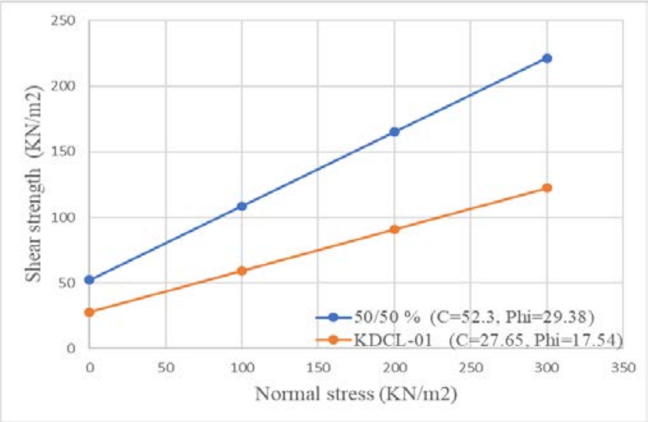


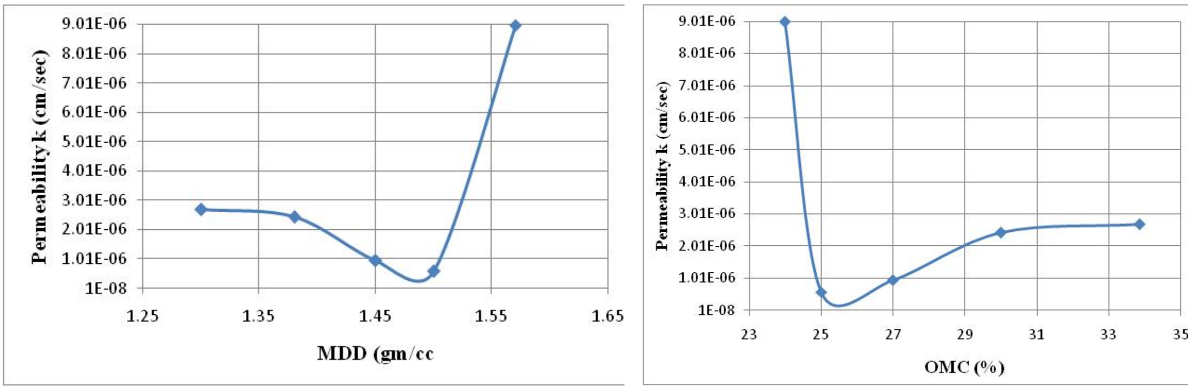
Figure 6 - 4: *Plot of normal stress vs shear strength during the shearing of the soil specimen*

The 50/50 blended ratio (GC soils) showed higher shear strength behavior than the normal clay. Further, the stress-strain characteristic of blended material shifts to the stiffer side, close to the stress-strain characteristics of the shell material which minimize the difference in stress strain characteristics of core and shell material.

6.2.3 Compaction and Permeability Characteristics

When the clay-gravel mixtures are embedding an increased amount of gravel particles leads to a decreased percent compaction of the fine fraction. This tends to increase the permeability of the mixture. On the other hand, the embedded particles serve as seepage barriers as the permeability of gravel particles is considerably lower than the fine fraction. These two competitive effects control the dependence of the permeability of the total material upon the gravel content.

The water content also has an influence on the permeability of compacted clay-gravel mixtures. Figure 6-5 shows typical results obtained from laboratory experiments. For blended ratio clay and gravel proportion and compaction test result, the coefficient of permeability (k) decreases when the dry density of the total material is increased. However, the rate of decrease in permeability also increases when the dry density is increased, indicating an increasing difficulty in reducing the permeability. For the given compaction effort applied, the maximum dry density of the total material was achieved when OMC = 24%. However, the permeability coefficient does not reach the minimum at this optimum water content: compacting the clay-gravel mixtures slightly wet of optimum results in a lower permeability although the resultant dry density is also lower than the maximum one (Figure 6-5(b)).



(a) (b)

Figure 6 - 5: *Influence of compaction on permeability. (a) Influence of dry density and (b) influence of water content.*

6.3 Mineralogical Property

In Chapter five the significance of mineralogy on the embankment material is discussed. From the test results, the minerals expected to have significance in the desired properties of the core material have been identified. Based on the minerals, identified in plasticity chart mineralogical analysis, there is no Na-montmorillonite that is commonly known for its dispersive potential in clay soils.

6.3.1 Dispersion and Activity Potential of Core Material

Clay mineralogy varies with location and not all clay soils exhibit shrink/swell potential. Soils with a clay mineral Montmorillonite which produces large volume changes in response to moisture and it is dispersive, while Kaolinite and related minerals (Hallosite) produces negligible volume change, they are non-dispersive and Illite tend to show moderately volume change and it is moderately dispersive (Fell et al, 1992).

Figure 5-14 shows the standard plasticity chart in use today with the principal clay groups superimposed. It can be seen that montmorillonite clay minerals are present if the Atterberg limit of the clay sample is close to the U-line. The A-line separates the illite from the kaolinite groups and other inactive clay minerals are below. Most soils contain more than one mineral, however the Atterberg limit may not coincide with a specific shaded area on the chart. The chart demonstrates that soils plotting below the A line are likely to contain stable clay minerals with no significant shrinkage potential. Soils plotting between the A-line and the U-line should be possible to further differentiate by reference to their Activity value.

For the present study only indirect mineralogical identification methods were used. Due to limitations of the laboratory for the direct method XRD analysis, the test was not conducted on the soil samples of the core material. Results of the analysis of the soil samples collected from four test pits during previous study by ECDSWC (GGI of feasibility report, 2019) shows that the clay minerals (Kaolinite) are observed, whereas from the soil sample collected during present field work from two test pits and four blended samples show the clay minerals (Illite) are observed. From the indirect test results (Casagrande plasticity chart), the minerals expected to have significance in the desired properties of the core material have been identified. Based on the minerals, identified in indirect mineralogical analysis, there is no Na-Montmorillonite that is commonly known for its expansive and dispersive potential in clay soils, while Kaolinite and related minerals (hallosite) are non-dispersive and Illite tend to be moderately dispersive (Fell et al, 1992).

6.3.2 Solubility Potential of Core Material

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

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

For the Kalid-Dijo dam core material case the dominant minerals are kaolinite and illite as observed in plasticity chart (Figure 5-14) and from the geological formation of the area as discussed in literature review the Dino formation of silicic rock is dominant and there is no calcite mineral that affect the suitability of the core material during operation through solubility. The solubility of silica which is one of the dominant minerals expected, increases with temperature, overburden pressure and ph**.** However, the site condition, temperature, overburden pressure and PH values of surface and groundwater do not favor solubility of silica in case of Kalid-Dijo dam core material.

6.4 Dynamic Behavior/ Property of the Core Material

One of the possible ways of earthquake induced embankment failure is piping through cracks induced by the ground motion and/or differential settlement. A material used for the construction of the dam should have self-healing property and be able to adjust readily to differential settlements.

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

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

Conducting cyclic tests on the representative samples of the embankment material is important to measure the combined effect of the initial static stresses and superimposed dynamic stresses. It also helps in determination of the generation of pore water pressures and the development of strain (deformation) in the soil for evaluation of the cyclic resistance of the soil. For the present study because of the limitation of resources and financial constraints it was beyond the reach of the present study to conduct a cyclic direct shear test to determine dynamic behavior/ property of the core material. However, an attempt has been made to evaluate dynamic behavior/ property of the core material based on the classification tests and literature reviews.

If there is a possibility to select a material to construct an impervious core, the soil which is most resistant to piping should be selected. Under severe agitation semi- consolidated soil of any type with high proportion of fine, settles more than a gravelly material. In case of core material for Kalid-Dijo dam (CH and MH soil), there will be considerable loss in shear strength because of the density (average 1.325g/cc) and increase in differential settlement under dynamic loading. Therefore, CH and MH type clay is not recommendable as clay material. Increment of differential settlement under dynamic shaking and increase in total settlement can be minimized by using material which is less subject to settlement effect. Based on the above discussion for soils with moderately high to high density, the possibility of the strength loss under dynamic loading is very low (Singh, 1995). Therefore, from the blended core material proposed during the present study, considerable improvement in shear strength loss and differential settlement will be achieved. As a result, the stability of the core of the dam may significantly increase under dynamic loading.

Besides, the density of the core material is related to the natural period of vibration of the embankment. Other factors aside, the degree of damage of seismic waves the same distance from an earthquake would be higher on low density, low velocity soil than on high density, high velocity rock. The properties which affect most the level of ground motion are impedance and damping/absorption (Reiter, 1994). Damping is the decrease in amplitude of free vibration energy due to frictions, thermal effects, etc. Impedance is the resistance to particles of rock or soil motion. It is higher in hard rock than in soft materials. At higher frequencies the impact of damping can be very severe while at low frequencies it is less. As per Reiter these effects of impedance and absorption are balanced at a frequency of about 5Hz. Based on this idea the effect of impedance dominates at frequency less than 5Hz. As per Fell et al., (2005) for embankment dams, lower frequency (0.2 to 5Hz) motion corresponding to their natural frequency is most important.

Therefore, improving the density of the core material minimizes the impedance contrast between the embankment material and foundation rock that is responsible for amplification of shear wave within the embankment. On the other hand, increase in density decreases the damping that is responsible for de-amplification. However, its effect is minimal within the specified frequency (0-5Hz) for the embankment dam. Thus, density improvement of the core material minimizes seismic wave amplification resulting from impedance contrast (sharp change in density and shear wave velocity from foundation rock to the embankment fill) during ground vibration. The density increment has also an advantage of increasing in shear wave velocity. As the density of the blended material increases the shear wave velocity increases and the fundamental period of vibration of the dam decreases. Besides, using material of good quality minimizes the thickness of the core zone required for a seismically active area. As per Sherard (1963), larger thickness of core has to be used in seismic areas where there is a greater chance of cracking.

6.5 Suitability for Transition Filter and Drains

All earth and rock-fill dams are subjected to seepage through the embankment, foundation, and abutments. Seepage control is necessary to prevent excessive uplift pressure, instability of the downstream slope, piping through the embankment and/or foundation and erosion of material by migration into open joints in the foundation and abutments (Earth Manual, 1968). Placement of more pervious material in the outer zones in the embankment is one of the methods to control seepage. For this filter is essential to control seepage and for the safe functioning of any embankment dam. Moreover, the filter drains ensure core material not to be washed away with the seeping water and transition filters check the development of destructive internal water pressures. Therefore, the zone immediately downstream of the core is designed to serve as a filter which prevents the migration of particles from the core into the downstream shell. The design of drainage system is primarily governed by height of the dam, cost and availability of the pervious material, nature of base and pervious material and foundation conditions (Jansen, 1988).

For the proposed Kalid-Dijo dam the suitable construction material for the fine filter is obtained from Agum and Sankura borrow areas which are approximately 20 to 25 km away in the south direction from the dam site.

The particle sizes which are commonly used for filter selection criteria are D_{15}, D_{50} and D_{85} of the filters and the protected layers. These particle sizes of the base and filter material, which are deduced from the gradation curve, are presented in Table 6-3. Different criteria give varied emphasis to a certain particle size.

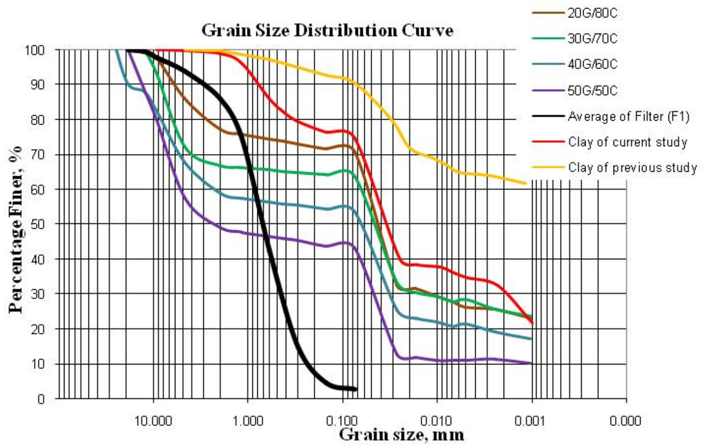


Figure 6 - 6: *Grain size distribution curve for filter and core materials*

Table 6 - 3: *Key particle sizes of the filter and core material*

Diameter of Particles	Filter Material	Blended Core Material				Natural Core Material			
						Currently Sampled		Previous Study	
	Average	50G/50C	40G/60C	30G/70C	20G/80C	KDCL-01	KDCL-02	DDCL-01	DDCL-02
D_{85}	1.93	12.00	11.00	7.50	4.50	0.60	0.70	0.06	0.04
D_{50}	0.70	2.20	0.07	0.05	0.04	0.04	0.04	0.00	0.00
D_{15}	0.30	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Based on grain size distribution of the base material required, filter material between the core and the shell is relatively finer when MH and CH groups of soils are used as a base whereas when the core material is blended the required filter becomes slightly coarser.

According to Terzaghi (1930), the soil particles from the protected zone should not pass through the pores of the filter material. This places an upper limit on the size of the filter material. Perusal of Figure 6-6 the available material for filter ‘F1’ satisfies these criteria when blended core material is used as the base in place of using MH and CH material as the base.

As can be seen from Table 6-4 the identified Agum and Sankura sand satisfies all the requirements set as filter criteria when blended (50/50) is used as base material. However, as observed in Table 6-4 the other fails to satisfy the second criteria set by Indian standards and Terzagi. Particularly the DDCL (MH group soil) does not satisfy almost all the criteria to be used as a base material.

Table 6 - 4: *Results of filter criteria*

Criteria	Requirement	Blended Core Material			Natural Core Material		
		Ratio	Result	Criteria	ID	Result	Criteria
Indian	$\frac{D_{15}\ of\ filter}{D_{85}\ of\ base} < 5$	50/50	0.03	Satisfied	KDCL-01	0.49	Satisfied
		40/60	0.03	Satisfied	KDCL-02	0.42	Satisfied
		30/70	0.04	Satisfied	DDCL-01	4.94	Satisfied
		20/20	0.07	Satisfied	DDCL-02	8.48	Not Satisfied
	$\frac{D_{15}\ of\ filter}{D_{15}\ of\ base} > 4\ \&\ < 20$	50/50	9.89	Satisfied	KDCL-01	UN	Not Satisfied
		40/60	UN	Not Satisfied	KDCL-02	296.67	Not Satisfied
		30/70	UN	Not Satisfied	DDCL-01	UN	Not Satisfied
		20/20	UN	Not Satisfied	DDCL-02	UN	Not Satisfied
	$\frac{D_{50}\ of\ filter}{D_{50}\ of\ base} < 25$	50/50	0.32	Satisfied	KDCL-01	20	Satisfied
		40/60	10.77	Satisfied	KDCL-02	20	Satisfied
		30/70	15.56	Satisfied	DDCL-01	UN	Not Satisfied
		20/20	16.67	Satisfied	DDCL-02	UN	Not Satisfied
USArmy Corpsof Engineers (1995)	$\frac{D_{15}\ of\ filter}{D_{85}\ of\ base} \leq 5$	50/50	0.03	Satisfied	KDCL-01	0.49	Satisfied
		40/60	0.03	Satisfied	KDCL-02	0.42	Satisfied
		30/70	0.04	Satisfied	DDCL-01	4.94	Satisfied
		20/20	0.07	Satisfied	DDCL-02	8.48	Not Satisfied
	$\frac{D_{50}\ of\ filter}{D_{50}\ of\ base} \leq 25$	50/50	0.32	Satisfied	KDCL-01	20	Satisfied
		40/60	10.77	Satisfied	KDCL-02	20	Satisfied
		30/70	15.56	Satisfied	DDCL-01	UN	Not Satisfied
		20/20	16.67	Satisfied	DDCL-02	UN	Not Satisfied
.Terzagi	$\frac{D_{15}\ of\ filter}{D_{85}\ of\ base} < 4$	50/50	0.03	Satisfied	KDCL-01	0.49	Satisfied
		40/60	0.03	Satisfied	KDCL-02	0.42	Satisfied
		30/70	0.04	Satisfied	DDCL-01	4.94	Not Satisfied
		20/20	0.07	Satisfied	DDCL-02	8.48	Not Satisfied
	$\frac{D_{15}\ of\ filter}{D_{15}\ of\ base} > 4$	50/50	9.89	Satisfied	KDCL-01	UN	Not Satisfied
		40/60	UN	Not Satisfied	KDCL-02	296.67	Satisfied
		30/70	UN	Not Satisfied	DDCL-01	UN	Not Satisfied
		20/20	UN	Not Satisfied	DDCL-02	UN	Not Satisfied
Sherad's	$\frac{D_{15}\ of\ filter}{D_{85}\ of\ base} < 9$	50/50	0.03	Satisfied	KDCL-01	0.49	Satisfied
		40/60	0.03	Satisfied	KDCL-02	0.42	Satisfied
		30/70	0.04	Satisfied	DDCL-01	4.94	Satisfied
		20/20	0.07	Satisfied	DDCL-02	8.48	Satisfied

*****

CHAPTER 7 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

In the present study the embankment material identified for Kalid-Dijo dam has been characterized in terms of; engineering properties, from the results of the engineering properties further mineralogical composition, dynamic behavior/ properties and its relative response to the site conditions. The general suitability has been analyzed for core zones only. In order to characterize the core material, systematic methodology has been adopted, which includes; detailed literature review, scrutinizing previous works and various field and laboratory tests. Further, based on test results the suitability of construction material for core zone has been worked out and appropriate recommendations are being made.

During the previous studies the core materials was identified as MH type soils and through the present study from the same borrow area it was identified as CH type (USCS). Proximity to the dam site and availability in sufficient quantities were the main advantages of using this clay for the core of the dam. However, in terms of engineering properties; High compressibility, low dry density, low shear strength, high swell potential and high volumetric shrinkage were the major drawbacks for CH and MH type of soil for the core material. Besides, the material failed to satisfy the general design specification criteria and limits suggested by Yilmaz and Karacan (1996) for impervious material to be used in the clay core of embankment dams.

During the present study a number of field and laboratory tests were made to identify the means by which the engineering properties of these soils could be improved. Further, attempts were made during the present study to perform blending of naturally available clay and gravelly material, which are available at reasonable and an economic distance, as an option to improve the quality of the core material. For this various tests were conducted on normal clay and on different blending proportions of the normal clay (from Germama clay borrow area) and the gravelly material (from shell borrow area). These tests include; classification, Proctor compaction, consolidation, free swell, volumetric shrinkage, direct shear, dispersion and permeability tests.

The test result shows a significant improvement in the desired engineering properties of the core material when blending was done. Through different blending proportions, GC material (USCS) has been obtained at a mix proportion of 50G/50C. Based on results, from engineering point of view the GC material with blending ratio 50G/50C (having MDD = 1.6, OMC = 24, WL = 47.00, PI = 24.00, C = 52.33 and Ø = 29.38) may be considered as appropriate core material. However, it has better shear strength and compressibility characteristics than other mix proportions, maybe it needs proper care for its potential of segregation, likely to be resulted from improper mixing in the field that may lead to continuous leakage path within the core during performance stage. Based on permeability results, all the blended ratios were classed as low to very low permeability with values less than or equal to 10^{-6}. Blended ratio of 40G/80C and 30G/70C is preferable in terms of economy, however the required engineering properties like compressibility and compaction is relatively lower. Therefore, the 50G/50C blended proportion can satisfy the standard limits set for design for impervious core material without significant violation.

In general, blended core material (50G/50C) has the following advantages over CH and MH natural clay. It shows 40% reduction in plasticity index (IP), 12% improvement in maximum dry density (MDD), 5% reduction in optimum water content (OMC), and 18% reduction in compression index or compressibility. It reduces the swelling potential and shrinkage crack or crack due to differential embankment or foundation settlement, stronger and stiffer than the normal clay and the Stress-Strain graph shifts in the direction of the expected stress-strain graph of the shell material to minimize undesired stiffness contrast between the two zones. Due to the presence of coarse material it locks or stops propagation and interconnection of cracks of different size through the core of the dam. It obstructs the flow of water and prevents development of high velocities within the crack.

The main disadvantage of blending is it slightly increases the cost and the material is more susceptible to segregation. However, this is insignificant as compared to its advantages when an efficient mechanism of blending is adopted and proper field control has been made during material development and placement stage.

Another important test conducted related to CH and MH type of core material is its dispersion nature. The test conducted for the analysis of dispersion is a double hydrometer. From the tests conducted that all the blended material shows non-dispersive results have been observed. However, there is no threat regarding dispersion character in both the natural borrow core material and blend core material. Since this test method may not identify all dispersive clays, design decisions based solely on this test method may not be conservative. It is often run in conjunction with the crumb test, the pinhole test, or the analysis of pore water extract, or combination thereof, to identify possible dispersive clay behavior.

Further, the mineralogical composition of the core material has been indirectly analyzed using a plasticity chart. The dispersive nature of clayey soils is known to be directly related with clay mineralogy. The possible source for dispersive nature in clayey soils is the presence of Na-montmorillonite. Though, in the present case no Na-montmorillonite minerals were identified during indirect mineralogical analysis, potentially non-dispersive core material. Based on the analysis, kaolinite and illite are the common clay minerals identified in all samples. Further, from the geology of the area, silica which is among the dominant minerals, the analysis has been made to check whether it affects the stability of the core zone for its potential solubility. Based on the actual site conditions, it has been observed that the solubility potential of the core material does not favor the solubility of silica.

Referring to the dynamic behavior/ property, the shear strength loss under dynamic condition is expected when CH and MH type soils are used as core material. However, the density improvement of the core material through blending significantly improves the shear strength characteristics under dynamic loading. Besides, improving the density of the material blending also minimizes the impedance contrast between the embankment material and the foundation rock that is responsible for amplification of shear wave amplitude within the embankment. Further, it generates higher shear wave velocity within the core zone.

Because of material properties no core material is perfectly impervious and most of the core material possesses a potential for development of cracks. In this regard, safe interception and passage of seepage are necessary to ensure vital performance of an embankment. For an economically safe design, different options of selecting the core and filter material should be considered in parallel. The technical limitations present in one material can be improved economically through improving the properties of the other material. Accordingly, the blended and natural CH and MH type soil with respect to the available fine filter material were evaluated with different filter criteria. Only 50G/50C mix proportion of gravelly clay material satisfies all the filter criteria set.

7.2 Recommendations

From the results of the present study on proposed core, blending is strongly recommended for the followings reasons;

- As per the design requirement, in the blended material, a general improvement has been observed in plasticity index (IP), maximum dry density, optimum water content, strength and stiffness.
- General reduction in; compressibility, swelling potential, crack potential due to shrinkage crack or differential settlement, undesired stiffness contrast with shell material.
- Blended material may limit the propagation and interconnection of cracks and obstruction for the flow of water and high velocity development through the crack.
- Through blending there may be reduction in hazardous impedance contrast between the embankment and foundation rock and creation of higher velocity of the shear wave within the embankment.
- Increase the suitability with respect to the available fine filter material in erosion resistance resulted from filter criteria of core material and without losing its non-dispersive nature and flexibility.
- Improvement in the workability of the material.

Even though there is uniformity in gradation for gravelly material (used for blending) throughout the borrow area, the effect is clearly observed in the result of blended material. There is lateral variation in gradation of clay (between MH and CH type soil), the identified borrow site for core material is one i.e. left and right bank of the Dijo river. However, the index and engineering properties of the material varies to some extent from test pit to test pit. Therefore, it is necessary to conduct a detailed study to determine its index and engineering property. For the present study CH soil with average grain size distribution of 33.43% clay, 42.5% silt, 23.6% fine and medium sand and 0.47% gravel have been used for blending. The blending was also restricted to one site only (right side of Dijo river). The recommended ratio can possibly work for CH soils, reported in the area, without significant variations. However, for MH soils, similar test procedures shall be adopted to select an appropriate blending ratio.

In addition, to check the consistency of the present results, a certain number of tests shall also be repeated on CH soils from the borrow area. For other clay borrow areas, the same test procedures should also be adopted as per additional requirement for the core material.

However, the density improvement of the core material through blending significantly improves the shear strength characteristics under dynamic loading; it is also greatly recommended to conduct cyclic dynamic shear tests to simulate the seismic effect of the site conditions on the proposed core material.

For each layer lateral uniformity of the material shall be strictly followed, to avoid the longitudinal variation that is responsible for the development of transverse crack in the core zone. Besides, low construction water content and inadequate compaction particularly, at abutment and concrete structure contacts that favor high post-construction settlement, resulting in cracking, should be avoided through strict supervision during placement and compaction. For proper utilization of the material during construction, the lateral variation of clay within the borrow area shall be delineated first within the borrow area. Further, efficient developing mechanisms should be selected for blending in an economic way. Because of its simplicity and efficient mechanism of blending, the ‘’horizontal spreading and vertical extraction’’ is widely used. This common blending practice recommended in Kalid-Dijo dam may be simply described as transporting, stockpiling and horizontally spreading gravelly material on a layer of natural clay and developing a layer thickness simultaneously as per recommended ratio. A number of such inter-layers are possible to place, forming artificial horizontal soil strata. Power shovels with a specified bucket volume were subsequently used to excavate the soil strata vertically from the bottom in the borrow pit or in blending ground. Sufficient mixing is achieved by running the open bucket through the clay-gravel mixture several times before loading. Before further hauling/transporting of one material to the placing site, laboratory tests are obliged to conduct to ensure the desirable material obtained as per the design requirements.

The identified minerals using plasticity charts and site geology have no effect on stability of the core material as well as the site condition does not favor dissolution of those minerals, particularly silica. Beside to the observed mineralogy there may be additional major and trace elements found in the core material it is highly recommended to conduct the XRD tests, based on the observed result, further the effect of the site condition (temperature, groundwater and reservoir water chemistry) on dispersion should be analyzed before utilizing the proposed core material. It is recommended to conduct more than two different types of dispersion tests to simulate the actual site conditions by using the reservoir water and ground waters.

However, as observed from the present analysis the 50G/50C blended ratio used as a base material with the available fine filter satisfies most of the criteria set by different authors. So, as the engineering, mineralogical and chemical properties of the filter material affect the performance and safe functioning of the embankment dam, it is highly recommended that to conduct engineering, mineralogical and chemical tests on identified filter material before construction. Moreover, as the Kalid-Dijo dam site is found in a seismic prone area, analysis for dynamic property is also essential.

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

*****

References

Ali Aman, (2008). *Multi-Dimentional Characterization and Suitability Analysis of Embankment Material*. Graduate thesis at Addis Ababa University, School of graduate.

Arora, K.R, (1997). *Soil mechanics and Foundation Engineering*, A.K. Jain, standard Publishers.

Ashok Kumar Gupta. (2008). Relashinship between the mean particle size, the optimum moisture content and permeability of sandy soils. *The 12th International conference of international association for computer methods and advances in geomechanics*, Goa, New Delih, India.

American Society for Testing Materials (ASTM) (2006). *Standard practice for classification of soils for engineering purposes (Unified soil classification system)*. D2487-06, West Conshohocken, United States.

Attwell, P.B. and Farmer, I.W. (1976). *Principles of Engineering Geology*. John Wiley & Sons Inc., New Work.

Bell, F. G. (1992). *Engineering in Rock Masses*, Butterworth-Heinemann, London.

Bureau of Indian Standards (1987). *Classification and identification of soils for general engineering purposes*, First Revision, UDC624.131.2, New Delhi, India, 1987.

Chen F.H. (1975). *Foundation on Expansive Soils*, Elsevier Scientific Publishing Company.

Day, R.W. (2002). *Geotechnical Earthquake Engineering Hand Book*, McGraw–Hill, New York.

Day, R.W., (2006). *Foundation Engineering Hand Book*, McGraw–Hill, New York.

Ethiopian Construction Design and Supervision Corporation (ECDSWC) (2019), *Kalid-Dijo Dam and Irrigation Project, Geological and Geotechnical Investigation Study and Design Feasibility Report*, Volume – II part–IV, Unpublished Report, Addis Ababa, Ethiopia.

Fell, R., MacGregor, P. and Stapledom, D. (1992). *Geotechnical Engineering of Embankment Dams*, A.A. Balekma, Netherlands.

Fell, R., MacGregor, P. & Stapledom, D. (2005). *Geotechnical Engineering of Dams*, A.A. Balekma, London.

Geological Survey of Ethiopia, 2006. *Geology Geochemistry and Gravity Survey of the Hosaena Area.*

Goodman, R. E. (1993). *Rock in Engineering Construction-Engineering Geology*, John Wiley & Sons Inc., Canada.

ICOLD (1990), *Dispersive soils in embankment dams*. International comission on large dams, bulletin77, Paris, France.

Janson, R.B. (1998). *Advanced Dam Engineering for Design, Construction, and Rehabilitation*, Van Nostrand Reinhold, New York.

Kazmin, (1978). *Explanation of the geology map of Ethiopia*

Kramer Steven L. (1996). *Geotechnical Earthquake Engineering*. New Jersy: Prentice-Hall, Upper Saddle River.

Li Yong-Hong. (2012). *Modification study and practice of Impervious soil of Ultra-High Core rockfill dam*, Power Chengdu Engineering Corporation.

LM Zhang et at. (2007). *Analysis of earth dam failures-a database approach*, Shanghai Tongji University, China.

Ouhadi, V.R. and Goodarzi, A.R. (2005). *Assessment of the Stability of the Dispersive Soil Treated by Alum*, Bu- Ali Sina University, Hamedan, Iran, *Engineering Geology, Elsevier***89**: 94-98.

Krauskopf, K.B. and Bird, D. K. (1995) Introduction to Geochemistry, McGraw-Hill 3rd Edition, p87- 90.

Mitchell, J. K. (1976). Fundamental of Soil Behavior, John Wiley & Sons Inc., Canada.

Murthy, V.N.S. (1989). Soil Mechanics and foundation Engineering, Volume I 3rd Edition, Bangalore, India.

Peccerillo, A. and Gezahegn Yirgu (1996). *Introduction to Geochemistry*, Addis Ababa Unversity, Addis Ababa, Ethiopia.

Reiter, L. (1994). *Earth Hazard Analysis*, Columbia University press, New York.

S.R.TaftiandA.Shafie and M.M.Rajabi. (2008). *The influence of clay core composition on the permanent displacement of embankment dams*. The 14th World Conference on Earthquake Engineering, Beijing, China.

Sherard, J. L., Decker, R. S., and Ryker, N. L., (1972). "*Piping in Earth Dams of Dispersive Clay*," Proceedings of the Speciality Conference on Performance of Earth Supported Structures, American Society of Civil Engineers.

Sherard, J. L., Woodward, R. J., Gizienski, S. F. and Clevenger W. A., (1963). *Earth-Rock Dams Engineering Problems Design and Consideration.* John Wiley & Sons Inc., New Work.

Sherard, J.L. (1973). *Embankment Dam Cracking Engineering.* John Wiley and Sons Inc., New York.

Singh, B. and Varshney, R.S.(1995). *Engineering for Embankment dams*, A.A. Balkema, USA.

Tschebotariof G.P. (1951). *Soil Mechanics, Foundation and Earth Structures,* McGraw-Hill Book Company, Inc., USA.

U.S. Bureau of Reclamation (USBR) (2012). *Embankment Dams, Design Standards No. 13,* U.S. Department of Commerce National Technical Information Service spring Field, Virginia.

U.S. Army Corps of Engineers (1994). *Earthand Rock-Fill Dams General Design and Construction Considerations,* Washington DC, July 1994

United States Society on Dams (USSD) (2011). *Materials for embankment dams*, USA.

William P. Creager, The late Joel D. Justin & Julian Hinds (1945). *Engineering for Dams*. John Wiley and Sons Inc., New York. Vol. I

William P. Creager, The late Joel D. Justin & Julian Hinds (1945). *Engineering for Dams*. John Wiley and Sons Inc., New York. Vol. III

Wuletaw Adane, (2007). *Appropriate solution for impervious core of embankment dams*. Graduate thesis at Addis Ababa University, School of graduate.

Yilmaz, I. and Karacan, E. (1996). *Geotechnical Characteristics and Mineralogy of Compacted Clays Used as an Impervious Core of the dam*

Zhongzhi F. Shengshui Ch. Enyue J. Guoying L. and Yang L. (2020). *Using Clay-Gravel Mixtures as the Impervious Core Materials in Rockfill Dams.* Unpublished Report.

*****

Appendix

Appendix 1: *Summery of the Laboratory Result*

	Company Name: በኢትዮጵያ የኮንስትራክሽን ዲዛይንና ሱፐርቪዥን ሥራዎች ኮርፖሬሽን ETHIOPIAN CONSTRUCTION DESIGN & SUPERVISION WORKS CORPORATION

Title:	Geotechnical Laboratory Report	Document No.:- OF/ECDSWC/ 0996	Issue No; 1	Page No. 1 of 36

Client Ref	
Date Received	7/5/2021
Reported on	3/6/2021

Lab No. :- **3602/13-3608/13**
Submitted by :- **South Water Work Enterprise**
Project :- **Kalid -Dijo Dam and Irrigation Infrastructure Construction Project**
Station :- **Clay Material**
Test Requested :- **Volumetric Shrinkage, Specific Gravity, Free Swell, Atterberg Limit, Particle Size Analysis, Double Hydometer, Direct Shear, Compaction and Consolidation.**
Reported to :- **South Water Work Enterprise**

No	Test type	Standard Test Methods	Soil Sample Test Result						
			Lab No : 3602/13 ID: KDCL-01/B-02 Depth (m) ----	3603/13 ID: KDCL-02/B-02 Depth (m) ----	Lab No : 3604/13 ID: KDSH-01/B-02 Depth (m) ----	Lab No : 3605/13 KDCL-01/B-02:KDSH-01/B-02 80:20 ----	Lab No : 3606/13 70:30 ----	Lab No : 3607/13 60:40 ----	Lab No : 3608/13 50:50 ----
1	Volumetric Shrinkage (%)	ASTM D427	-	-	-	15.65	15.20	9.59	8.87
2	Free Swell (%)	IS 2720	-	-	-	55	50	45	40
3	Atterberg Limits								
	Liquid Limit (%) Plastic Limit (%) Plastic Index (%)	ASTM D4318	73.00 33.00 40.00	67.00 29.00 38.00	34.00 NP -	62.00 30.00 32.00	55.00 28.00 27.00	53.00 25.00 28.00	47.00 23.00 24.00
4	Particle Size Analysis								
	Gravel (%) Course Sand (%) Medium Sand (%) Fine Sand (%) Silt (%) Clay (%) Colloids (%)	ASTM D422	0.47 0.84 15.58 7.18 42.50 5.31 28.12	0.00 0.78 17.99 7.82 39.27 18.77 15.36	92.94 5.42 0.35 0.91 0.37 0.00 0.01	14.08 8.75 3.42 3.08 44.67 2.71 23.29	27.92 5.17 1.67 1.42 36.55 3.59 23.70	32.25 8.75 3.08 2.33 33.24 2.97 17.37	42.58 8.25 3.08 2.92 31.93 1.12 10.12
5	Double Hydrometer (%)	ASTM D4221				9.04	5.56	4.24	14.45
6	Direct Shear								
	C (kpa) φ (Degree)	ASTM D3080	27.65 17.54	- -	- -	19.75 19.57	27.65 27.18	43.45 36.89	52.33 29.38
7	Consolidation(Cc)	ASTM D2435	0.373			0.373	0.398	0.403	0.306
8	Standard Compaction								
	MDD (g/cc) OMC (%)	ASTM D698	1.41 25.30	- -	- -	1.38 23.00	1.45 27.00	1.41 25.00	1.57 24.00
9	Constant Head Permeability K_s(cm/sec)	ASTM D2434	'-	'-	'-	2.43E-07	9.50E-07	5.80E-07	8.99E-07

REMARK: The samples were collected & submitted to the laboratory by Client.
- Indicates test was not given by Client.

Processed by :- Solomon K.
Geotechnical Engineer

Checked By :- Biruk A.
Senior Geotechnical Engineer

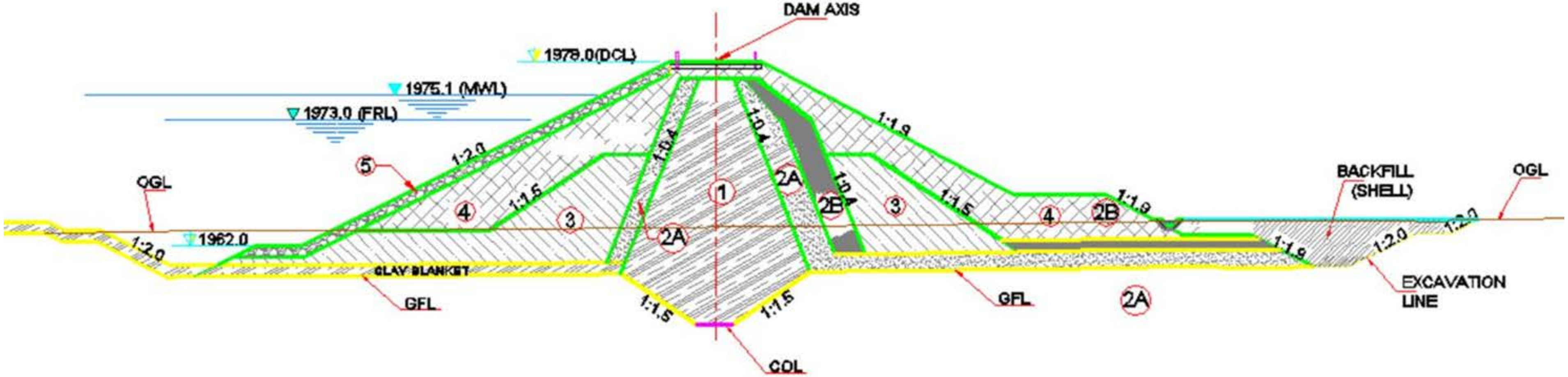
Approved By :- Getu D.
Geotechnical Lab S/P Manager

Among The major service Rendered by the Geotechnical and Material Laboratory Testing S/Processes of Ethiopian Construction Design & Supervision Works Corporation.

- **In Geotechnical Laboratory**:-Testing the engineering properties of Soil Mechanics and Rock Mechanics.
- **In Material Testing Laboratory**- Testing the engineering properties of various Construction materials, such as Aggregates, Asphalts/Bitumen/, Cements, Rocks, Water, Reinforcement steel bars, Hollow blocks, Bricks, Ceramics, Tiles, Asplalt and Concrete Core Tests, Concrete Mix Design, Asphalt Mix Designs, Sampling of the soil and construction materials, and so on.

Please make sure that this document is the correct version before use

Appendix 2: *Cross Section of Kalid-Dijo Dam*



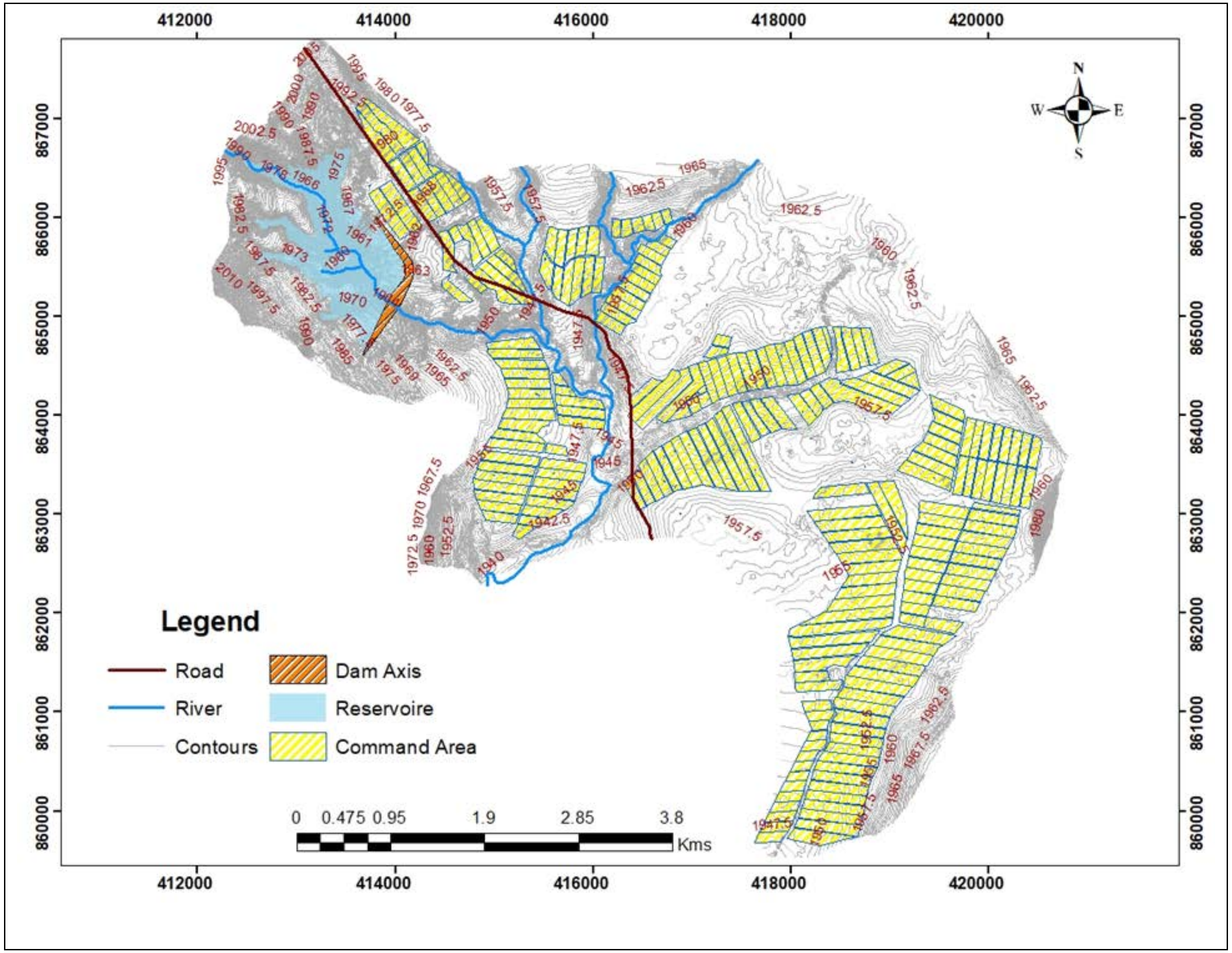
ZONING:

ZONE 1 - CLAY CORE
ZONE 2A - FINE FILTER WHICH IS LOCATED BOTH U/S AND D/S
ZONE 2B - COARSE FILTER
ZONE 3 - SHELL AT BOTH U/S AND D/S
ZONE 4 - ROCK FILL (IGNIMBRITE ROCK)
ZONE 5 - RIPRAP
ZONE 6 - ROCK TOE DRAIN

LEGENDS:

MWL - MAXIMUM WATER LEVEL
FRL - FULL RESERVOIR LEVEL
MOL - MINIMUM OPERATION LEVEL
DCL - DAM CREST LEVEL
CCCL - CLAY CORE CREST LEVEL
OGL - ORIGINAL GROUND LEVEL
GFL - GENERAL FOUNDATION LEVEL
COL - CUTOFF LEVEL

Appendix 3: *General layout of the project area*



*****