JIMMA UNIVERSITY

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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDAULIC ENGINEERIG STREAM

CAUSE OF FAILURE OF MICRO EMBANKMENT DAM AND REMEDIAL MEASURES; A CASE OF GOMIT MICRO EMBANKMENT DAM, AMHARA REGION, ETHIOPIA

BY: GETASEW AYNALEM GEBEYEHU

A THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

November, 2016

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APPROVAL PAGE

This thesis entitled with "cause of failure of micro embankment dam and remedial measures a case of Gomit micro embankment dam, Amhara Region, Ethiopia" has been approved by the following examiners for partial fulfillment of the requirement for the degree of Master of Science in Hydraulics engineering.

Members of approval committee	Signature	Date
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DECLARATION

Getasew Aynalem, hereby declare that the thesis work "Cause of failure of micro embankment dam and remedial measures a case of Gomit micro embankment dam, Amhara Region, Ethiopia" is carried out by me for the award of the degree of masters of Science in hydraulic engineering by Jimma institute of technology. To the best of my knowledge the work has not been presented for the award of master's degree or any other degree either in Jimma institute of technology or any other institute of technology. Thorough acknowledgment has been given where reference has been made to the work of others.

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Candidate	Signature	Date
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Co-Advisor	Signature	Date
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Advisor	Signature	Date

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ABSTRACT

Safety of earth dams depends on the proper design, construction, and monitoring of actual behavior during the construction and operation of the structure. Many embankment dams are constructed in Ethiopia, However; their capacity reduces frequently before their design life time due to a number of reasons like improper design, lack of thorough investigation, inadequate care in construction and poor maintenance. In order to protect public safety, life and property, all embankment dams in service, regardless of their age, should be evaluated for their safe performance under all operational conditions.

Gomit micro embankment dam were constructed in 2002 GC to irrigate 90ha of irrigable land, But the dam has not providing a service as per design. The primary objective of this study was to identify the cause of failure of GMED and coming with the possible remedial measures. Through field investigation the dam has revealed that excess amount of water seeps from downstream toe of the dam and from right foot side of the spillway.

In order to realize such problem the analysis of seepage has been done with Darcy's law phereatic line and SEEP/W software model. The analysis was focused on checking the design quantity of seepage of the dam with different methods. The largest value of seepage estimated by this study at the normal pool level is $6.05*10^{-3}m^3/s$*, which is done by SEEP/W software model in the case of zoned dam with consideration of horizontal drainage filter and foundation; it is the actual type of the dam. In the same case but at the current water level quantity of seepage estimated by the software is* $9.25*10^{-3}m^3/s$ *which is larger than that of the quantity of seepage estimated at the normal pool level, this shows that the presence of failure of seepage on the study area. From the design document seepage has estimated in the case of homogenous dam with consideration of horizontal filter but the actual type of the dam is zoned therefore there was a problem in quantification of seepage. Based on the result of the study grouting, dawn stream berm, horizontal drainage filter, toe drain and upstream impervious blanket were recommended as the possible remedial measures to the existed seepage problems.*

***Key word**: Failure, Seepage, Remedial measures*

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBRIVIATIONS

C^0	Degree Celicious
CAD	Computer aided design
Cm	Centimeter
d/s	Dawn stream
EC	Ethiopian calendar
GC	Gregorian calendar
GIS	Geographic Information System
GPS	Global positioning system
ha	Hectare
K	Effective permeability
Km	Kilometer
masl	Meters above sea level
MED	Micro Embankment dam
mm	Millimeter
NHDES	New Hampshire department of Environmental Services
q	Seepage rate
U/s	Up stream
US	United States

1. INTRODUCTION

1.1. Background

A dam is a hydraulic structure constructed or created by either human built or results from natural phenomena such as land slide or glacial deposition across a stream, river or waterway for deferent purposes. Man made dams are constructed for the purposes like water storage for potable water supply, livestock water supply, irrigation, prevention of flooding, hydro – electricity, navigation, etc (Novak, 2001).

There are two types of modern dam which is constructed by humans namely embankment dam and concrete dam. Embankment dam is a water impounding structure constructed from fragmental natural materials excavated or obtained close to the dam site. The general philosophy in design of embankment dam has been to utilize locally available geologic materials; the natural fill materials are placed and compacted without the addition of any binding agent, using high capacity mechanical plant. Embankment dam is traditionally classified in to two main categories by type of soil mainly used as construction materials, and such as earth fill and rock fill dams, it consist of homogeneous earth-fill dam, zone type rock-fill dam, impervious core type rock-fill dam, facing type rock-fill dam and also blasted rock-fill dam (Kutzner, 1997). Homogeneous earth fill dams have a dam section consisting almost entirely of one type of material, and in the case of zoned earth dams both pervious and impervious materials can be obtained. Under these circumstances, the dam is made up of a relatively impervious central zone called the core and outer zones that provide the structure with the required stability (Terzaghi and Peck, 1967)

Earth fill embankments may be damaged by distortions at critical points. Differential settlement may be severe at steep abutments and at structural interfaces where effective compaction is difficult to obtain. At these locations, deformation of the fill may open dangerous paths of seepage. For this reason, there have been many failures along outlet conduits. Although properly constructed embankments are able to accommodate substantial movement, they have relatively poor resistance to overflow; so their freeboard and associated spillway capacity must be determined conservatively. Failure of dam can result in a major disaster with highly destructive losses of both human life and property.

Hydraulics, hydrology, sediment transport mechanism, and structural and geotechnical aspects are all involved in dam failures. Internal erosion and piping through a dam body or its foundation is one of the most important factors which define the safety structural condition and can represent a serious source of troubles (Foster, *et al*., 2000).

Embankment dam derive its strength from position, internal friction and mutual attraction of particles. Relative to concrete dams, embankment dams offer more flexibility; and hence can deform slightly to conform to deflection of the foundation without failure. All dams are designed and constructed to meet specific criteria such as a dam should be built from locally available materials wherever possible, The dam must remain stable under all conditions, during construction and ultimately in operation, both at the normal reservoir operating level and under all flood and drought conditions (Kutzner, 1997)

Gomit micro embankment dam was constructed sin 2001/2002 GC. Which is found from Amhara region South Gondar administrative zone of Istie woreda, Even though Gomit micro embankment dam ware built to irrigate 90ha of irrigable land, but structure has not giving the service as per design, this was due to the failure existed on the structure. In this study the current condition of the dam were assessed in order to identify the cause of failures and the analysis has been made by different methods in different conditions of the dam to make quantitative predictions and to compare alternatives.

Seepages on the downstream toe of the dam and on the right foot of the spillway and settlement of downstream slope (structural failure) has the main observable problems that were existed during field observation on Gomit micro embankment dam. From this study the analysis has been made on the seepage failure by the method of Darcy’s phereatic line and by SEEP/W software model with the help of the data obtained from the design document and supported with the other literature reviews. In addition to these the possible cause of failure of seepage and the possible remedial measures has been listed out in order to reduce the seepage problems.

1.2. Statement of the problem

Many embankment dams were constructed in Ethiopia most of which are used for irrigation purpose. However, their capacity reduces frequently before their design life time due to a number of reasons. The failures are mainly caused by improper design, lack of thorough investigation, in adequate care in construction and poor maintenance. The various causes of failure can be grouped in to Hydraulic, Seepage and Structural failure. For example many seepage problems and failures of earth dams have occurred because of inadequate seepage control measures or poor/incomplete cleanup and preparation of the foundations and abutments. Seepage can lead to piping and embankment sloughing or sliding, both of which can lead to dam failure. Once the dam has failed it is more expensive to repair. A minor problem can turn into a major reconstruction project. Out of 14 micro dams in Amhara only one of the 14 dams is functioning according to the plan of implementation, Seepage failure 58.3%, hydraulic problem 16.7%, structural failure 8.3% (Tefera, 2006). The structural stability of an earthen dam is to be assessed to ensure that the safety of people and property. And in order to take the corrective action, if a risk dos exist, frequent instrument reading and detailed field observation should be made to provide data and information which can be used to assess the performance of the dam. During filed observation the main problems existed from the study area was seepage from the downstream toe of the dam and from the right side foot of spillway and settlement of the downstream slop. Until some mitigation measures to be taken thesis condition may bring to damage or catastrophic failure on the structure and the downstream users. Therefore in order to minimize the possibility of failures, special care and consideration and the structural stability of the structure is to be made.

1.3. Objectives of the Study

1.3.1. General Objective

The general objective of this study was to identify the causes of failure of Gomit micro embankment dam and propose the possible remedial measures.

1.3.2. Specific Objective

1) To investigate the current conditions of Gomit micro embankment dam.
2) To investigate the causes of failures of Gomit micro embankment dam.
3) To prioritize analysis the severity of modes of failure existed in Gomit micro embankment dam
4) To suggest appropriate remedial measures to the prioritized failure.

1.4. Research questions

In order to achieve the above mentioned objectives and seek answers for the stated objectives the following major research questions were designed.

1) What look like the current condition of Gomit micro embankment dam?
2) What are the causes of failures of the dam?
3) Which failure mode is the major problem?
4) What are the possible remedial measures taken?

1.5. Significance of the study

The main significance of the study was to ensure the safe guarding of safety of the dam and thus protecting the downstream settlements of the dam. Furthermore, the final result of this research was expected to be used as a guide in redesign and maintenance of failed and existing projects, it will also helpful for research development as guide lines for other dams that have similar problems.

1.6. Scope of the study

The scope of the research has been limited in space and time. Spatially, the research has been conducted to investigate cause of failure of Gomit micro embankment dam and coming up the possible remedial measures.

2. LITRATURE REVIEW

2.1. General

A dam is a hydraulic structure constructed across a stream, river or waterway for deferent purposes; it may either be human-built or result from natural phenomena, such as landslides or glacial deposition. Human-built dams are the majority of dams which is constructed all over the world for the purpose like water storage for potable water supply, livestock water supply, irrigation, prevention of flooding, production of hydro-electricity, forming an artificial lake for navigation, leisure or recreation, activities, etc. Dams are individually unique structures. Irrespective of size and type they demonstrate great complexity in their load response and in their interactive relationship with site hydrology and geology. The design of dam is determined by the consideration of various factors like hydrological characteristics of the catchment area and climate, dam site geology and the mechanical properties of the foundation soil and the available construction materials, topography and regime of the river etc. (Novak, *et al*., 2001)

The two major categories of dam types are embankment dams, and concrete dams. The design and construction materials of the dam play a crucial role in how it counteracts the major hydraulic forces or resists erosion and seepage pressures. Concrete and Embankment dams are completely different in their structural design and susceptibility to certain deficiencies. To understand the causes and prevention methods of dam failures and incidents, it is important to first understand their design and material composition (Novak, *et al*., 2001)

Failures of earthen embankment dams or dikes can generally be grouped into three classifications: hydraulic, seepage and structural. Many embankment dams are constructed in Ethiopia most of which are used for irrigation purpose. However, their capacity reduces frequently before their design life time due to a number of reasons. The main causes of capacity reduction are Hydrological, Structural, Hydraulic and seepage failure. Seepage failures contribute 58% in Amhara region (Tefera, 2006).

This research has to be aimed to deal with cause of failure of micro embankment dam and remedial measure, issues related to cause of failure of embankment dam and its remedial measures, methods of analyzing and evaluating the failure will be reviewed in this chapter.

2.2. Types of dams

Dams may be classified according to material of construction, intended purpose, structure, and height. According to (Novak, *et al*., 2003) an initial broad classification of dams into two generic groups based on the principal construction material employed.

- Embankment dams: are constructed of earth fill and/or rock fill; upstream and downstream face slopes are similar and of moderate angels, giving wide section and high construction volume relative to height.
- Concrete dams: are constructed of mass concrete; face slopes are dissimilar, generally steep downstream and near vertical upstream, and dams have relatively slender profile. It includes gravity dam butters dam, multiple arc dams, thick arc dams, thin arc dams.

2.3. Embankment dam

Embankment dam is a water impounding structure constructed from fragmental natural materials excavated or obtained close to the dam site; it is the oldest and most wide spread type of dam. This is because of three main reasons such as: materials available within short distance are used, the embankment dam can accommodate a variety of foundation condition, and it is least cost when compared to other dam types. Embankment dams are numerically dominated for technical and economic reasons, and account for an estimated 85- 90 % of all dams built (Novak *et al*., 2003).

Traditionally embankment dams are classified in to two main categories by types of soil mainly used as construction material, such as earth fill and rock fill dams. When a dam section consisting almost entirely of one type of material is called homogenous earth dam whereas, at most sites both pervious and impervious materials can be obtained. Under These circumstances, the dam is made up of a relatively impervious central zone called the core and outer zones that provide the structure with the required stability such dams are called zoned earth dams.

The term rock fill dam refers to a dam in which the majority portion of the pressure exerted by the impounded water is transmitted on to the foundation through a rock fill (Terzaghi and peck, 1967).

Before initiating detail design analysis of earth and rock fill dam many considerations related to geological and environmental issues should be examined. Following subsurface and geological explorations, the earth and/ or rock-fill materials available for construction should be carefully studied. The study should include the determinations of the quantities of various types of material that will be available and the sequence in which they become available, and a thorough understanding of their physical properties is necessary. Theoretically earth dam embankments can be designed in such a way that soils of any type can be used. Practically large organic soils (peat) are not chosen because of low shear strength and high compressibility. Because of the construction difficulties inorganic clays of high plasticity (CH soils) are not desirable except when no other materials are available. Based on the configuration of dam section rock fill dam can be classified in to; rock fill dam with central core, rock fill dam with inclined core, and membrane faced rock fill dam (Narita, 2000).

In order to prevent loss of soil particles by erosion due to seepage flow through the embankment a filter zone should be provided in any type of rock fill dams. The central core checks seepage through the dam, it is constructed of clay, silt, silty clay or clayey silt. The pervious shell gives stability to the dam and it consists of sand, gravel, or a mixture of these materials. The upstream pervious zone provides free drainage during sudden drawdown. The downstream pervious zone acts as a drain to control the phereatic line. A vertical core located near the center of the dam is preferred over an inclined upstream core because the former provides higher contact pressure between the core and foundation to prevent leakage, greater stability under earthquake loading, and better access for remedial seepage control, In case where the dam foundation has a steep inclination along the river, where a blanket zone is provided in the previous foundation to be connected with the impervious core zone, and where different construction processes are available for the placement of core and rock fill materials The inclined core is adopted instead of the center core (Singh and Varshney, 1995).

2.4. Embankment dam failure

Dam failure can results in a major disaster with devastating losses of human life and property, it can release uncontrollable water flows which can result in severe consequences to downstream areas. When a dam breach occurs, the flooding can cause enormous economic losses, residential and agricultural damages, and even more importantly, loss of life**.** The phenomenon the dam failure is time dependent, multiphase water soil interaction and non homogenous or different materials, various degree of soil compaction etc. (Sharma and Ali Kumar, 2013).

Hydraulics, hydrology, sediment transport mechanism, and structural and geotechnical aspects are all involved in dam failures. The majority of embankment dam failures are generally the result of inadequate design, poor construction methods, deteriorated pipe, or significant environmental occurrence. According to (pisaniello, *et al*., 2006) construction flow, seepage/ piping, siltation and over toping and lack of maintenance are the major cause of earthen dams worldwide.

Small dams are very important for ensuring water availability and sustenance of livelihoods for rural communities especially so in semi arid and water scarce areas. Due to poor design and quality construction and due to lack of proper maintenance associated with small dams the frequency of failure of small dam is higher than that of large dams (FEMA, 1987 and Pisaniello *et al*., 2006).

Earth and rock fill dams must sustain very different loading conditions that arise during construction and subsequent operations. The acting loads include the self-weight, the varying reservoir water level, and the uplift pressures in the foundation, the seepage flow pressures and eventually earthquake-driven loads. Total failures of dams have been reported during each of the stages of the dam life (WIT, 2009).

2.5. Typical failure mode of embankment dams

The various causes leading to failure of earthen embankment dams can be grouped in to hydraulic, seepage, and structural failures.

2.5.1. Hydraulic failure

Hydraulic failures from the uncontrolled flow of water over and adjacent to the embankment are due to the erosive action of water on the embankment slopes. Earth embankments or dikes are not normally designed to be overtopped and therefore are particularly susceptible to erosion. Hydraulic failure is estimated to be 40% contributions on the failure of earthen dams. The failure under these categories may be related directly or indirectly due to the cause of over toping, erosion of upstream face, cracking due to frost action, erosion of dawn stream face by gully formation, and erosion of downstream toe (NHDES, 2011 and Garg, 1987).

1) Overtopping

When the design flood is under estimated, if the spillway capacity is not adequate or spillway gates are not properly operated, if the freeboard is not sufficient and if excessive settlement of the dam and the foundation occur the water may overtop over the dam crest.

To avoid overtopping, the design flood should be properly estimated and adequate spillway capacity should be provided. The freeboard should be adequate and it should take into account the likely settlements in the foundation and dam (NHDES, 2011)

2) Erosion of upstream face

when the wind is blowing on the upstream reservoir the wave may developed near the top water surface, it try to notch-out the soil from upstream face and may even sometimes cause the slip of the upstream slope. To avoid such failure riprap or stone pitching over the upstream slope of the dam should be provided.

3) Erosion of dawn stream face by gully erosion

During heavy rain falling directly over the dawn stream face of the dam, gully erosion may form these leads to removal of the top soil over the dawn stream face of the dam.

In addition to heavy rain the dawn stream slope may eroded due to the water coming from the reservoir due to over toping. (Ralston, 1987) discussed the mechanism of embankment erosion from overtopping. For non-cohesive embankments, materials are removed from the embankment in layers by tractive stresses. The erosion process from overtopping begins at a point where the tractive shear stress exceeds a critical resistance that keeps the material in place. For cohesive embankments, breaching takes place by head cutting. Usually, a head cut initiates near the downstream toe of the dam, and then advances upstream until the crest of the dam is breached. to avoid such failure proper maintenance, filling the cut from time to time especially during rainy season, by providing proper berm at suitable height and length to decrease the formation of erosive actions high velocity flow of water, and by grassing dawn stream slope (NHDES, 2011 and Garg, 1987).

4) Cracking due to frost action

A deposit of small ice formed on the upstream part of the dam during the period of cold weather or when degree of temperature is below freezing point, heaving and cracking of the soil with dangerous seepage may develop. For dams in area of low temperature additional free board allowance up to a maximum of 1.5m should provided (Garg, 1987).

5) Erosion of dawn stream toe

Due to tail water and cross currents that may come from the spill way buckets; the dawn stream toe of the earth dam may get eroded. Dawn stream slope pitching or a riprap up to a height slightly above the normal tail water depth and sufficient height and length of side wells of the spillway so as to prevent the possibility of the cross flow towards the embankment must be provided to avoid erosion of dawn stream toe (Garg, 1987).

2.5.2. Structural failure

Structural failures involve the separation of the embankment material and/or its foundation. About 25% of the dam failure has been attributed to structural failure (Garg, 1987). This type of failure is more prominent in large embankment dams. However, it is not exclusive to large dams and similar occurrences may be seen on earthen embankments or dikes.

Structural failure of an earthen embankment may take on the form of a slide or displacement of material in either the downstream or upstream face; it is generally caused by shear failures causing sliding. Sloughs, bulges, cracks or other irregularities in the embankment or dike generally are signs of serious instability and may indicate structural failure (NHDES, 2011 and Garg, 1987).

When the foundation of the earth dams are made of soft soils, such as fine silt, soft clay, or the seams of fissured rocks, shale's etc., may exist under the foundation, the entire dam may slide over the foundation and the top of embankment get cracked and subsides, the lower slope moves out ward forming large mud waves near the heel. Low shear strength of the soil leads the failure of the dam foundation; the reduction of shear strength of the soil may develop due to hydrostatic excess developed due to the consideration of clay seams embedded between sand or silt, excessive pore water pressure in confined seams of sand and silt, and due to artesian pressure in abutments. Sliding in embankments may occur when the embankment slopes are too steep, when the reservoir is full the dawn stream slope most likely slide and during the sudden draw dawn of the reservoir the upstream slope may be slide (Garg, 1987). Filling of the reservoir causes the shear stresses within the upstream slope to decrease because of the favorable effect of water pressure against the slope, while the average shear stresses under the downstream slope remain unchanged or increase slightly (Lambe and Whitman, 1969)

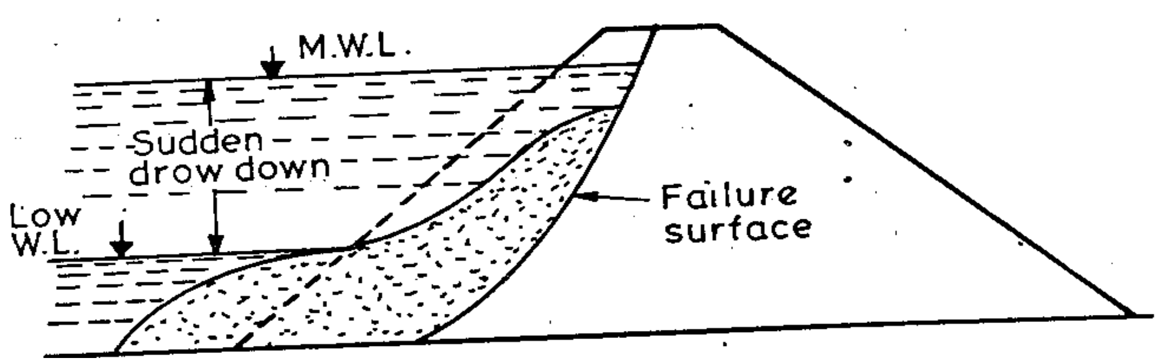

Figure 1 Upstream slope slides due to sudden drawdown (Garg, 1987).

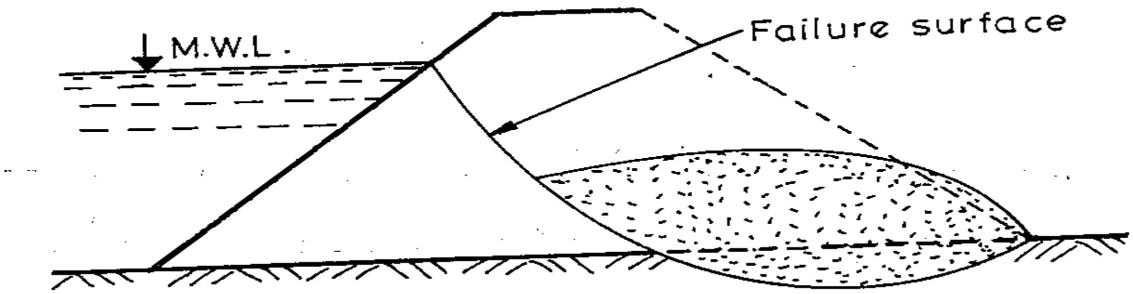

Figure 2 Dawn stream slope slides during full reservoir condition (Garg, 1987).

2.5.3. Seepage failure

Most embankments exhibit some seepage. However, this seepage must be controlled in velocity and quantity. Seepage occurs through the earthen embankment or dike and/or through its foundation. Seepage, if uncontrolled, can erode fine soil material from the downstream slope or foundation and continue moving towards the upstream slope to form a pipe or cavity to the pond or lake often leading to a complete failure of the embankment. This action is known as "piping." as defined by (ASTM, 2002) piping is the progressive removal of soil particles from a mass by percolating water, leading to the development of channels. Seepage failures account for approximately 40 percent of all embankments or dike failures (NHDES, 2011). Many seepage problems and failures of earth dams have occurred because of inadequate seepage control measures or poor/incomplete cleanup and preparation of the foundations and abutments. Seepage can lead to piping and embankment sloughing or sliding, both of which can lead to dam failure. If seepage occurs without dislodging and removing soil particles, no structural damage will result. However, if soil particles are washed away in seepage, severe problems may develop (www.waterpowermagazine.com). According to (McCook, 2004) seepage erosion occurs when the water flowing through cracks or defect erodes the soil from the walls of the crack or defect. After a large amount of embankment materials has been washed away by seeping flow, a free path is formed through the dam. Then, the erosion advances quite rapidly until the portion of the materials above the pipe becomes unstable and collapses. After the collapse, the subsequent erosion proceeds in the same fashion as in the case of overtopping (Xu and Zhang, 2009). Internal erosion and piping can be divided into four phases: initiation and continuation of erosion, progression to form a pipe and formation of a breach (Fell, *et al.*, 2003).

In general, the seepage erosion/piping failure initiates when the erosion/piping resistant forces are smaller than the erosion/piping driving forces, resulting in the removal of soil particles through large voids or existing discontinuities in soil.

Piping and internal erosion through the dam body and its foundation is one of the most serious causes of dam failure. As a progression of internal erosion caused by seepage Piping can occur in the embankment, through the foundation and from the embankment into the foundation. In the case of piping failure, the incidence of piping through the embankment is two times higher than piping through the foundation and twenty times higher than piping from the embankment into the foundation (Foster, *et al.,* 2000). Further, it was noticed that half of all piping failures through the embankment are associated with the presence of conduits. The different modes of piping associated with conduits are piping into the conduit, along and above the conduit or out of the conduit (Fell *et al.,* 2005). Other than conduit the internal erosion in the dam body can be caused by settlement cracks or even passages created by animals. Any leakage does not have to be underestimated and has to be carefully detected since quick erosion may increase initial minor defects and can become potentially dangerous. (Garg, 1987) said that, due to seepage problems more than 1/3rd of the earth dams have failed and the major cause of seepage failure are piping through the foundation, piping through the dam body, and sloughing of dawn stream toe.

- **Piping through the foundation**

Water may start seeping at a huge rate through the foundation if there are highly permeable cavities or fissures or strata of coarse sand or gravel in the foundation. The soil may erode due to these actions or it permits heavy seepage of water through it and causing erosion of soil which will result in the formation of piping. Resulting in a rush of water and soil thereby creating hollows below the foundation and the dam will settle or sink and leading to failure.

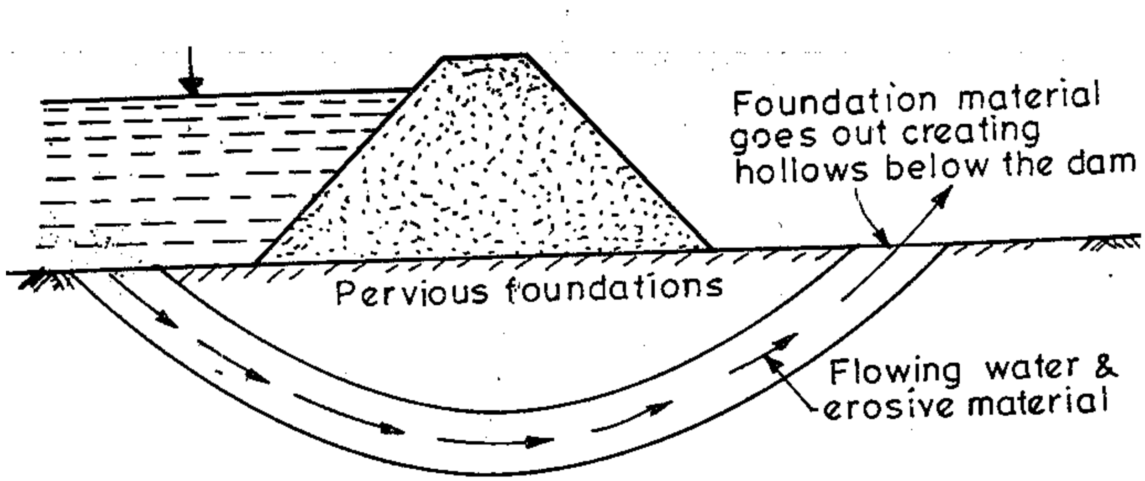

Figure 3 Piping through the dam foundation (Garg, 1987).

- **Piping through the dam body**

When concentrated flow channel may developed on the embankment due to one or more of faulty construction, insufficient compaction, cracks due to foundation settlement and if there is the possibility of leakage through conduits passing through the dam body, piping through the dam body will be developed and the soil may wash away towards the dawn stream face of the embankment, leading to the formation of hollows in the dam body and the subsequent failure of the dam. All these causes can be removed by better construction like properly compacting the soil and by preventing the possibility of leakage through the conduits with better maintenance of dam embankment. According to the comprehensive studies by (Foster *et al.,* 2000 and Fell *et al.,* 2003) internal erosion and piping have been the main causes of failure in embankment dams since they destabilize the downstream slope.

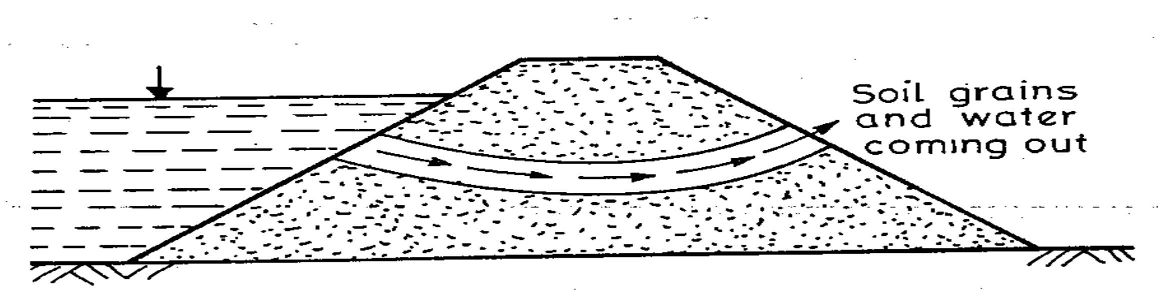

Figure 4 piping through the dam body (Garg, 1987).

❖ **Sloughing of dawn stream toe**

When the downstream toe of the dam becomes saturated internally and starts eroded, producing a small slump or a miniature slide. The process of failure due to sloughing is beginning, causing small slump or slide of the dam. The small slide leaves a relative steep face, which also becomes saturated due to seepage and also slumps again and form more unstable surface. The process of saturation and slumping continues, leading to failure of dam (Garg, 1987).

2.6. Seepage control in earth dam

Water stored behind a dam always seeks to escape or flow along the path of least resistance (Cedergren and Whitman, 1973) .when the water seeps through the dam foundation, embankment and abutment in excessive quantity, it results harmful to the overall stability of the dam causing piping through the body of the dam, softening and slowing of the slope due to development of pore pressure and finally resulting in the failure of the dam. To ensure safety of dam, it is very important to handle the seepage water in the dam so as to maintain the original practices of soils in their place. To prevent instability of the d/s slope, the excessive uplift pressure, piping through the embankment and foundation, migration of material through the void space of the dam measures to control seepage is Avery critical things in designing and construction of the dam (www.epa.gov).

It is difficult to control if seepage occurs after construction unless the draw dawn of the water level has occurred or the reservoir has been empty (Novak, 2001).

2.6.1. Seepage control through foundation

The amount of water entering the previous foundation can be controlled by adopting the following measures; the methods include Grouting and grout curtain, Cut-off trenches, Partial cut-off, Sheet pile cut-off, Cast-in-situ concrete diaphragm, upstream blanket, and Relief wells. The suitability of the method of treatment depends primarily on the nature of the foundation. It can control seepage flows and pressure within the foundation by cut offs and by drainage (Garg, 1987 and Novak, 2001).

(I) *Grouting and grout curtain:* grout is a mortar or paste for filling crevices, especially the gaps between walls or void spaces. When certain materials injected as grout in the previous foundation strata act as binder and fill the voids, thus reducing the permeability and increasing its stability of the foundation. The cut-off is formed by several parallel lines of staggered grout holes spaced at 2-3m centres. The general employed grouts are cement based grout but in difficult conditions more sophisticated and costly chemical grout are available particularly. In fractured rock and in cores grained soils grout cut off is the most effective method to permeability by one to three orders of magnitude.

(II) *Cut-off trenches:* cut-offs are impervious barriers which function as extension of the embankment core in to the foundation, in order to control the flow of water with in previous soils cut-off trenches with sides sloping or vertical are excavated below the dams and filled with well-compacted impervious material. Older cut-off was constructed as very narrow clay filled puddle trenches many providing vulnerable to hydraulic failure. Generally the cut-off may be: concrete diaphragm, cement bound curtain, sheet pile, etc. Cut-off is generally located under the core, but can also be located a short distance upstream and connected to the core by an impervious horizontal blanket under the shoulder. Due to developments in grouting technology like alluvial grouting technique the grouted zone type cut-off is now applicable to a wide range of foundation condition.

(III) *Partial cut-off trench*: the cut off may fully penetrate to impervious strata or if previous material occurs to considerable depth, may terminate where the head loss across the cut off is sufficient to effect the required degree of control the cot off may applied partially. Partial cut-off is effective in stratified foundations by intersecting more impervious layers in the foundation and by increasing the vertical path of seepage. A cut-off going to 80% of the total depth of pervious strata reduces the seepage discharge by only 50%. Thus, with a partial cut-off, the reliance is primarily on the length of the seepage.

(IV) *Sheet piling cut-off*: Steel sheet piling can be used in silty, sandy and fine gravel foundations. To form a cut-off under low head structure diaphragm walls of sheet pilling may be driven to depth of up to 20-25m. The cost of this type of cut off is moderate but unless supplemented by upstream grouting its efficiency is low.

(V) *Relief wells:* Their main purpose is to reduce artesian pressures which otherwise would cause formation of sand boils and piping. The wells should be spaced sufficiently close together (generally 15 m apart) to intercept seepage and reduce uplift pressures between wells. The possibility of the water to boil up near the toe of the dam may devolve when the seepage existed excessively through the previous foundation overlain by a thin less previous layer, such possibility can be controlled by constructing relief wells or drain trenches through the upper impervious layer so as to permit escape of seeping water. In addition to protect the dawn stream toe from possible sloughing due to seepage, provision of dawn stream berm beyond the toe of the dam is the other controlling method of sand boiling. The weight of the overlying material in such a case is sufficient to resist the upward pressure and thus preventing the possibility of sand boiling.

(VI) *Upstream blanket:* Impervious clay placed upstream of a dam and connected to the impervious section is a convenient way of effecting moderate reduction in the amount of seepage. The quantity of seepage is somewhat less than inversely proportional to the total length of impervious material. The blanket is carried upstream for a distance sufficient to lengthen the seepage path, and hence reduce flow to the required degree. The efficiency of an upstream blanket can be low relative to the considerable construction costs involved. For normal condition the thickness of the upstream blanket is kept between 1.5 and 3m and the length about 10 times the head of pended water. In case of fine sand or silty foundations, the length of blanket is kept 15 times the head. In general length and thickness of blanket can be computed as follows (Garg, 1987 and Novak, 2001).

Length of blanket: The length of the blanket is given by

$$L = \frac{khd - pqb}{pq} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$$

Where L = length of upstream blanket in meters

k = mean horizontal permeability coefficient of the pervious stratum

h = gross head in meters on impervious upstream blanket

d = depth of pervious stratum in meters

p = percentage (stated as a decimal) of flow under the dam without a blanket, to which it is desired to reduce the seepage by means of the blanket. For example, if the seepage is required to be reduced to 25% of its original value, then, p = 0.25.

b = length of impervious portion of base of dam in meters,

q = flow under dam, without blanket, per meter of dam = k (h/b) d.

Thickness of blanket: The thickness of blanket "t" a distance l from upstream toe of blanket may be determined from;

$$t = \left({}^{k_2}/_{k_1}\right) * l * {}^{b}/_{d} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.2$$

Where t = thickness of blanket at point under consideration

l = distance from point under consideration to upstream toe of blanket,

k_1 = average permeability of stratum,

k_2 = permeability of blanket,

b = length of blanket from upstream toe to impervious section,

d = depth of pervious stratum in meters

The following guidelines may be adopted in the selection of the most suitable and economical measures of seepage control (Garg, 1987 and Novak, 2001).

(I) Positive cut-off is generally the most suitable measure if the depth of pervious stratum is moderate

(II) When the pervious stratum is quite deep and extensive and its permeability is between 10^{-3} to 10^{-5} m/s, an upstream blanket combined with downstream relief wells and drainage trenches have been found to be quite effective.

(III) When the permeability of the pervious stratum is quite high, of the order of 10^{-3} m/s or higher, and the stratum is quite deep, grout curtains and diaphragms are generally economical

2.6.2. Seepage control through embankment

Drainage in earth dam is usually provided to bring the phreatic line well within the downstream face, reduces the pore pressure in the dawn stream portion of the dam and increases the stability of the dam. In order to safely discharge the flow of water and to prevent movement of fine materials towards the drain, the materials used to construct drains and filters shall be graded from relatively fine on the periphery of the drain to cores near the center. As the suggestion of Terzaghi a multi layer filter, generally called inverted filter or reveres filter is provided as a critical for the design of such filter (Garg, 1987 and Novak, 2001).

A widely employed empirical approach to defining appropriate filter material grading is given as suggested by the expression and determined from practical size analysis (Novak, *et al.*, 2001)

$$\frac{D_{15}\ of\ filter}{D_{85}\ of\ soil} \leq 5$$

$$\frac{D_{15}\ of\ filter}{D_{15}\ of\ soil} \geq 5$$

$$\frac{D_{50}\ of\ filter}{D_{50}\ of\ soil} \leq 2.5$$

Measures adopted for safe drainage of seepage water through the dam embankment include, horizontal drainage blanket, rock toe, chimney drain, toe drain and drainage trench. The application of drain in an embankment dam is a primary method to determine the location of phereatic line in an embankment dam with a drainage system (Numerov, 1942)

(I) *Horizontal drainage blanket*: application of horizontal drain in an embankment dam has been a prevalent method to lower the phereatic line and dissipate the excessive pore water pressure. It is commonly used for earth dams of moderate heights. The blanket extends from the downstream toe for a distance of about three times the height of the dam or about one-third of the base width of the dam. However, it should not be longer than two-thirds of the base width of the dam. In the case of a zoned section, it extends up to the core. The blanket must be very pervious to drain off the water effectively and it should be properly designed as per the filter criteria. As presented by (Chahar, 2004) to prevent the seepage flow from touching the dawn stream slope of the dam, he has determine and present the relationship of maximum and minimum effective drainage lengths, the mentioned equations have been derived considering the distance of phereatic line from the dawn stream sloping face . (USBR, 2003) also suggested practical methods to determine the suitable length of horizontal drain without the consideration of dawn stream slope cover.

(II) *Rock toe:* widely used in the homogenous dam and it provided at the d/s toe of an earth dam and it forms a part of the dam. It consists of stones of size varying from 15 to 20cm. The upstream face of the rock toe may be vertical or inclined, but d/s slope is always inclined and it is in the continuation of the d/s slope of the dam. A graded filter is provided between the rock toe and the soil mass in the dam to prevent piping. The graded filter is also provided between the rock toe and the foundation if it is pervious. The height of the rock toe is generally between H/3 and H/4, where H is the height of the dam. While fixing the height of the rock toe, it should be ensured that there is at least a minimum cover of 1m between the phreatic line and the downstream face.

(III) *Chimney drain:* is a vertical or nearly vertical drain, which is located inside the dam so that it intercepts as layers of the dam in the seepage zone. In addition to bringing the phereatic line dawn, horizontal filter provides drainage of the foundation and help in rapid consolidation. But when horizontal makes the soil more previous in the horizontal direction it may causes the formation of stratification, such that the filter be comes in sufficient to drain the seepage if the large scale stratification occurs. In such a case chimney drain is required so as to intercept the seeping water effectively. And to prevents the emergence of the seepage water on the d/s face of the dam. From the chimney drain, the water is carried to the d/s toe of the dam through a horizontal drainage blanket.

(IV) *Toe drain and drainage trenches*: it is used to collect and safely discharged the water towards spillway stilling basin or to the river channel below the dam that comes from the horizontal drainage blanket.

Generally, the above listed out drainage systems provided for the dam also serves the purpose of the drainage of the foundation (Garg, 1987 and Novak, 2001**).**

2.7. Evaluation of embankment dam

For the safe performance under all operational condition all embankment dam in service should be systematically evaluated. The principal requirement for dam safety evaluation is to protect public safety, life and property. To insure that the safety of people and property the potential for adverse incidents, such as excessive seepage, instability and major damage during floods and earthquakes, need to be assessed, and the corrective action need to be taken if the risk does exist.

Depending on the layout, the type of the project and the construction techniques that are used in the site, the type, quantity and location of the instrumentation tools used to evaluate the performance of the dam may vary. Available instruments that may be used during or after construction are piezometers: - used to evaluate the seepage condition and effectiveness of seepage cutoff and the performance of drainage system. In order to evaluate pore water pressure accurately in several cross section piezometers should be located in the foundation abutment and/or embankment in vertical planes perpendicular to the axis of the dam.

Casagrande piezometers are very simple piezometers from the various types of piezometers (U. S. Army corps of engineering, 1908). Surface monuments: - are used to measuring horizontal and vertical movements of the dam, which is located from the crest and upstream and dawn stream slope of the dam. In order to have data for a longer period of time and to be aware of any possible danger due to movements, surface monuments should be placed as early as possible after the completion of dam construction (U. S. Army corps of engineering, 1908). Inclinometers: - are devices that are used for measuring the horizontal deformation at certain depth. These devices are frequently used in landslide studies to detect the depth of the slide plane (U. S. Army corps of engineering, 1908). Pressure cells**:** - Pressure cells (or earth cells) which are used to measure the total earth pressure inside the dam are the least common equipments. Accelerographs (in areas of seismic activity), Settlement plates within the embankment, movement indicators, and strain indicators are the equipments installed in the dam used to evaluate the performance of the dam (The National Research Council Book, 1983).

In addition to the above mentioned equipments we can evaluate the performance of the dam by Geo-studio 2007 soft ware, which is a geo-technical software includes eight products: SLOPE/W for slope stability, SEEP/W for ground water seepage, SIGMA/W for stress-deformation, QUAKE/W for dynamic earth quake, TEMP/W for geothermal, CTRAN/W for contaminant transport, AIR/W for air flow, VADOSE/W for vadose zone & covers (Geo-Slope International Ltd, 2007).

The limit equilibrium and numerical methods used for evaluating the stability of slopes require an accurate and reliable estimate of the in situ shear strength of the slope materials. However, the shear strength parameters are strongly influenced by many complex conditions, including the in situ state of stress, drainage, loading rates and soil or rock composition (Abramson, 2001).

2.8. Estimation of seepage

There are many causes of failure of an earth dam. From many statistics, the failure of earth dams were mainly due to seepage or piping and it is widely recommended that the monitoring of seepage through an earth dam will control the safety of the dam (Singh and Vershney, 1995).

Seepage through the embankment, foundation and abutments must be collected and controlled to prevent excessive uplift pressures, piping, sloughing, and removal of material by solution, formation of cracks, joints and cavities. The design should consider seepage control measures such as foundation cutoffs, adequate and non brittle impervious zones, transition zones, drainage blankets, upstream impervious blankets and relief wells. Criteria for safe design have to be so specified that they cover all possible cause of failure (U.S Army Corps of Engineers, 1993).

The amount of seepage has to be controlled in all conservation dams and in order to avoid their failure the effect of seepage (i.e. position of phereatic line) has to be controlled. Seepage analysis is used to determine the quantity of water passing through the body of the dam and foundation and to obtain the distribution of pore water pressure. There are various methods available for determining the amount of seepage passing through the dam. Some are the analytical, numerical and graphical method

2.8.1. Analytical method /Darcy's Low – phereatic line Analysis

Phereatic line (seepage line) or saturation line is the line at the upper surface of the seepage flow at which the pressure is atmospheric. The location of the seepage line in earth dam is required for the following purposes: it give us dived line between the dry or moist and submerged soil, to take soil above the seepage line as dry and the soil below the seepage line as submerged for computation of shear strength of soil, To mark the top flow lines so that the flow net can be draw to determine the quantity of seepage and the pore water pressure, To ensure that the seepage line does not intersect the d/s face and cause it is softening or sloughing and consequent failure of the d/s slope (Arora, 1996 and Garg, 1987). The analysis of seepage and determination of phereatic line are varies with the type of dam and its drainage system and angle of inclination.

❖ Estimation of discharge and phereatic line determination for homogenous earth dam with horizontal drainage blanket

Except at the entrance or near the junction of the upstream face as we can see fig.5 the phereatic line in this case coincides with the base parabola, It has been found by experiments that the seepage line is pushed down by the filter. Let a base parabola with focus at F is drawn and produced so as to intersect the water surface at point A. Casagrande has shown that for dam with reasonably flat up stream slope, AB = 0.3HB. With the focus at F the base parabola AIJC can be drawn after knowing the point A, and from the upstream face of the dam GB becomes an equipotential line with fully covered with water, the seepage line shall be perpendicular to this face near its junction point B. Then it can be corrected for the curve BI such that BI is perpendicular to GB, finally BIJC can represent seepage line.

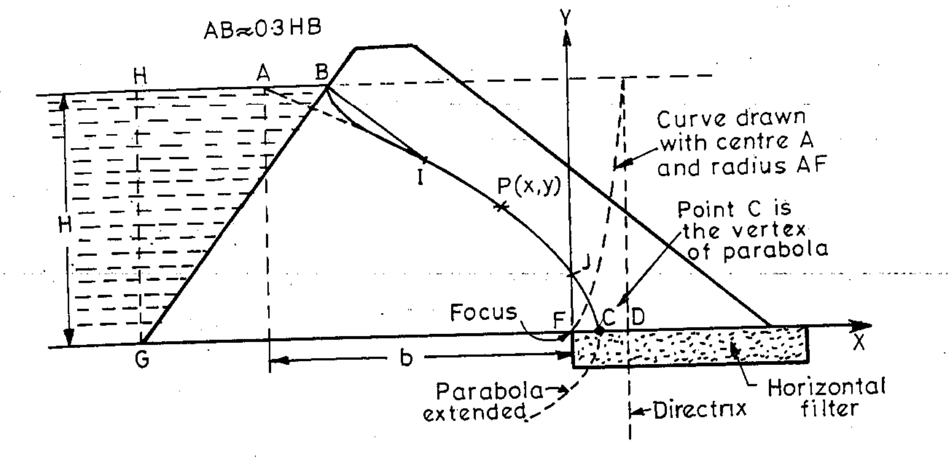

Figure 5 Phereatic line for a homogenous earth dam with horizontal drainage blanket (Garg, 1987).

The basic property of the parabola which is utilized for drawing the base parabola is that the distance of any point p from the focus is equal to the distance of the same point from the directrix. Taking the focus F as the origin the base parabola equation is written as (Garg, 1987).

$$\sqrt{x^2 + y^2} = x + FD \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.3$$

$$y = \sqrt{s^2 + 2xs} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..4$$

Where FD is the distance of focus from the directrix, it is represented by S or y_0, these is because of when x = 0, S = y_0 hence FJ will be equal to S = y_0 and it can be determined as

$$FD = s = \sqrt{b^2 + H^2} - b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.5$$

Where From point A (known), x = b and y = ht

Then by working out a few more coordinate points from the equation 4 the parabola can be easily drawn and corrected for the curve from the upstream face of the dam with known point A.

Discharge through the body of the earth dam can also be calculated as follows

According to Darcy's low, consider a unit length of the dam

$$v = ki$$

$$q = vA = kiA$$

$$i = \frac{dy}{dx}$$

$$q = k\frac{dy}{dx}y * 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..6$$

The discharge crossing any vertical plane across the dam section will be the same when steady conditions have reached.

Where q = seepage discharge per unit width of the dam

i = hydraulic gradient

A = cress sectional area.

From the parabola equation 4

$$y = \sqrt{s^2 + 2xs}$$

Then by substitute equation 4 from 6 and derivate it the discharge q can be computed as

$$q = k\frac{d\left(\sqrt{s^2 + 2xs}\right)}{dx}(\sqrt{s^2 + 2xs})$$

$$q = k\frac{s}{\sqrt{s^2 + 2xs}}(\sqrt{s^2 + 2xs})$$

$$q = ks \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where k = coefficient of permeability and s = focal distance, then the discharge q can be easily computed.

- **Estimation of discharge and phereatic line determination for homogenous earth dam without horizontal drainage blanket**

The focus in this case will be the lowest point F of the d/s slope. And the base parabola BIJC will evidently cut the d/s slope at J and extend beyond the limits of the dam, up to the point C (the vertex of the parabola) as shown by dotted line from figure 6. However, according to exit conditions, the phreatic line must emerge out at some point k, meeting the d/s face tangentially there.

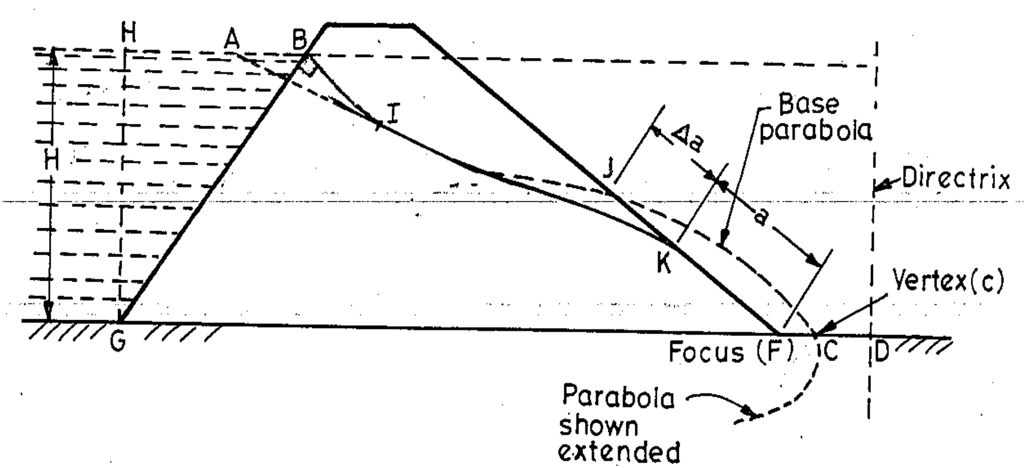

Figure 6 Homogenous dam section without filter (Garg, 1987)

The portion KF is then known as discharge face and always remains wet. The correction Δa, by which the parabola is to be shifted downwards, is found graphical solution by the value of $\frac{\Delta a}{a+\Delta a}$ given by Casagrande for various values of the slope α of the discharge face.

The slope angle α can even exceed the value of 90^0. $a + \Delta a$ Is the distance FJ and is known as shown from the table 1. Then Δa can be evaluated and $a\, and\, \Delta a$can be connected by the general equation.

$$\Delta a = (a + \Delta a)[\frac{180^0 - a}{400^0}]$$

Table 1 value of a with different angle of inclination defined by Casagrande

a in degree	$\frac{\Delta a}{a + \Delta a}$	Remark
30^0	0.36	Note, intermediate value can be interpolated, or read out from the graph between a and $\frac{\Delta a}{a+\Delta a}$ plotted with the value given here.
60^0	0.32	
90^0	0.26	
120^0	0.18	
135^0	0.14	
150^0	0.10	
180^0	0.0	

In order to fined the value of a analytically, Schaffernak and van Iterson assumed that the energy gradient $i = tan\alpha = \frac{dy}{dx}$ This means that the gradient is equal to the slope of the line of seepage, which is approximately true so long as the slope is gentle (i.e. $<30^0$). With the base of the this assumption the value of a can be easily driven (Garg, 1987)

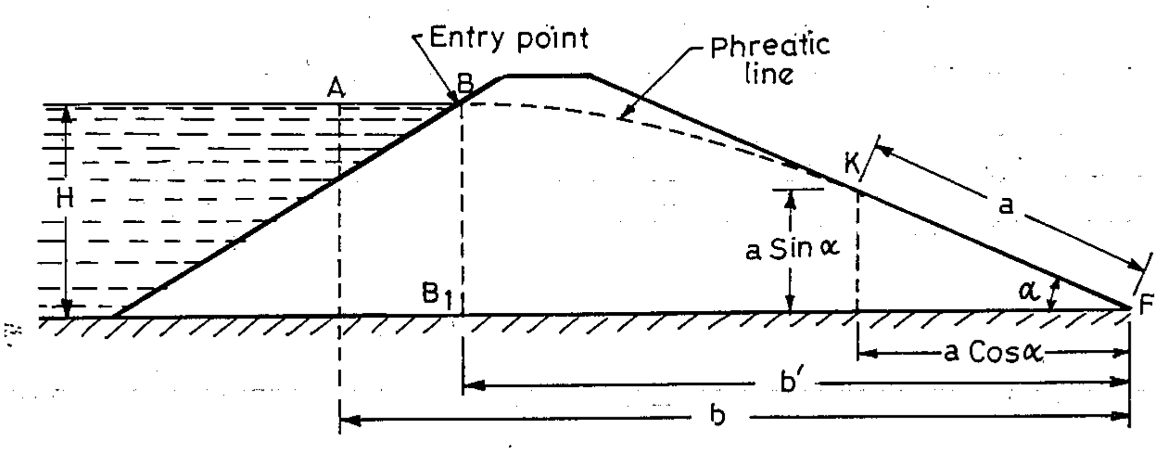

Figure 7 Homogenous dam section without filter **α** < 30^0 (Garg, 1987)

$$q = kiA$$

$$q = k\frac{dy}{dx}y * 1$$

$$q = k\frac{dy}{dx}y$$

$$i = \frac{dy}{dx} = tan\alpha \text{ And } y = asin\alpha$$

The expression of discharge computed as

$$q = k(asin\alpha)(tan\alpha) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.8$$

And to fined the value of a again

$$q = k\frac{dy}{dx}y = k(asin\alpha)(tan\alpha)$$

$$a(asin\alpha)(tan\alpha)dx = ydy$$

Integrating between the limits: $x = a(cos\alpha)\ to\ x = b'$

$$y = a(sin\alpha)\ to\ y = H$$

$$a = \frac{b'}{cos\alpha} - \sqrt{\frac{b'^2}{cos^2\alpha} + \frac{H}{sin^2\alpha}^{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

Another analytical solution of Casagrande for $30^0 < \alpha < 60^0$ will be observed that the previous solution gives satisfactory results for slope < 30^0. For steeper slopes, the deviation from correct values increases rapidly beyond tolerable limits. Casagrande suggested the use of sin α instead of tanα. In other words, it should be taken as (dy/ds) instead of (dy/dx), where s is the distance measured along the phreatic line, see figure 23 from the annex. The derived equation for determining the value of q and a in terms of H and b is

$$q = k(sin\alpha)(asin\alpha)$$

$$q = k(asin^2\alpha) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 10$$

$$a = \sqrt{b^2 + H^2} - \sqrt{b^2 - H^2cot^2\alpha} \dots\dots\dots\dots\dots\dots\dots 11$$

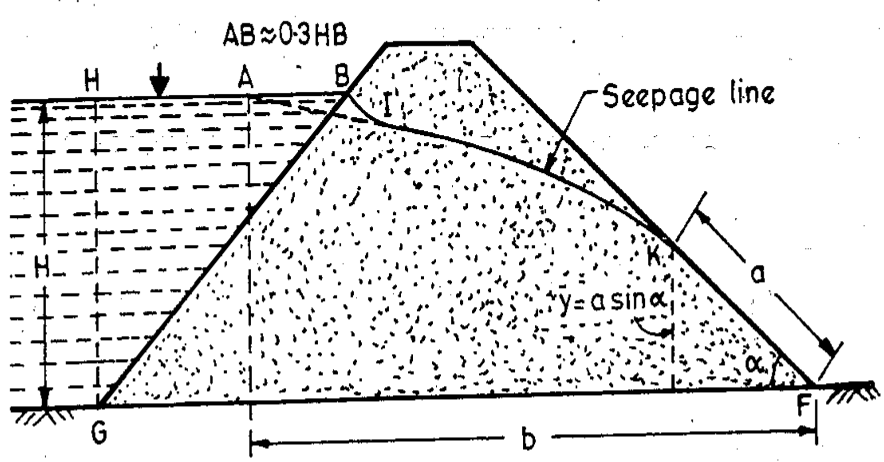

Figure 8 homogenous dam section without filter **α** lies between 30^0 and 60^0(Garg, 1987).

- **Phreatic line for zoned dam**

If the upstream and downstream shell materials are assumed to be infinitely permeable or a chimney drain is provided, the phreatic line can be computed by the method for a homogenous dam with its focus at F. In these case the focus of the base parabola will there for be located at the dawn stream toe of the core, and the effect of the outer zone can be neglected altogether. Then the phreatic line can be drawn as usual with free hand correction required at suitable place (Garg, 1987).

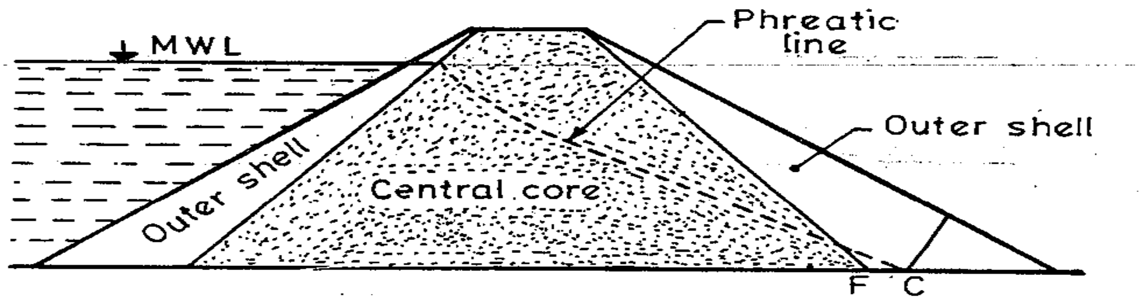

Figure 9 Zoned dam with the center impervious core (Garg, 1987).

2.8.2. Graphical/Flow Net Analysis

Flow net is a network of equipotential lines and flow lines which are mutually perpendicular to each others. The portion between any two successive flow lines is known as flow channel and the portion enclosed between two successive equipotential lines and successive flow lines is known as field. The analysis of seepage by flow nets contributes to the proper design and construction of many dams. The flow net is drawn by free hand sketching and making suitable adjustment and corrections until to draw the flow line and equipotent line intersect at right angle. The seepage rate (q) can be computed from the flow net, using Darcy's law. The analysis of seepage using flow net starting with drawing a flow net diagram with subjective division of equipotential line and flow line. If the number of division point increases the result become more accurate (Garg, 1987).

❖ **Computation of rate of seepage from flow net through the isotropic soil**

When the soil is isotropic horizontal permeability is equal to vertical permeability $K_H = K_v$, the amount of seepage can be easily computed from the flow net using Darcy's low as follows:

Assuming a unit width cross section of the dam as shown from fig. 10 the flow through the field of ABCD and applying the principle of continuity from Darcy's low

$$q = kiA$$

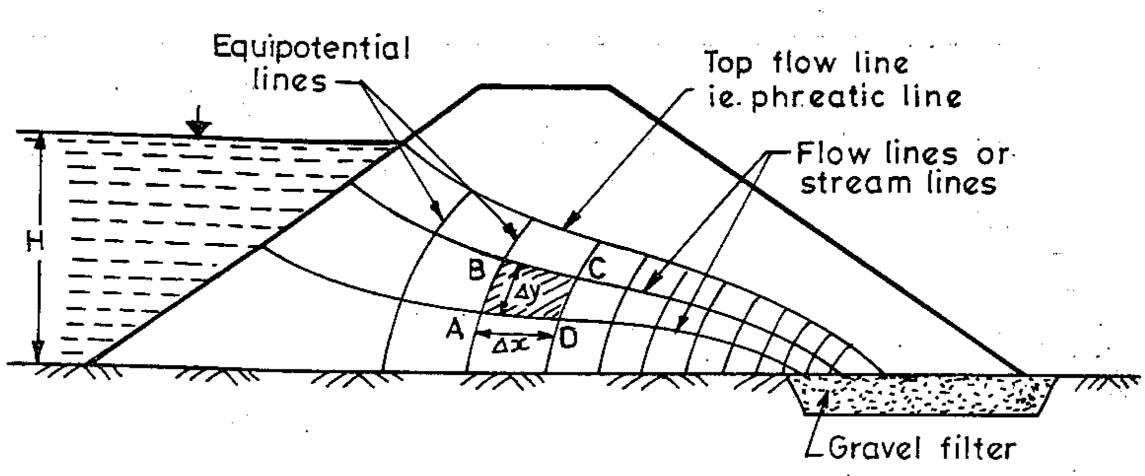

Figure 10 flow net in the earthen embankment dam (Garg, 1987).

$$\Delta q = k\frac{\Delta H}{\Delta x}\Delta y * 1$$

But $\Delta H = \frac{total\ head\ causing\ flow}{number\ of\ dropes\ in\ the\ complet\ floe\ net} = \frac{H}{N_d}$

After substituting and simplified the required expression, representing discharge passing through a flow new within the isotropic soil is

$$q = \sum\Delta q = \frac{kH}{N_d}N_f \ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots..12$$

Where

ΔH = head drop through the field.

Δq = discharge passing through the flow channel.

H = total head causing flow

N_f = number of flow channel

❖ **Computation of rate of seepage from flow net through the non-isotropic soil**

In the case of non-isotropic soil the permeability of the soil is different in the horizontal direction than that in the vertical direction, To plot of the flow for such a case, the cross-section through anisotropic soils is plotted to a natural scale in the y-direction, but to a transformed scale in the x-direction; all dimensions parallel to x- axis being reduced by multiplying by the factor $\sqrt{\frac{k_y}{k_x}}$. The flow net obtained for this transformed section will now be constructed in the normal manner as if the soil were isotropic. The actual flow net is then obtained by re- transforming the cross- section including the flow net, back to the natural scale by multiplying the x- coordinates by factor $\sqrt{\frac{k_x}{k_y}}$ The actual flow net thus will not have orthogonal set of curves. field of transformed section will be a square one, while the field of actual section (retransformed) will be a rectangular one having its length in x direction equal to $\sqrt{\frac{k_x}{k_y}}$ times the width in y direction. The discharge can then be computed the equation

$$q = \sqrt{k_H k_V}\,\frac{N_f}{N_d} H \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..13$$

2.8.3. SEEP/W Software Model

Many computer soft-wares have come in general use, and any hard computations and simulation can be carried out through them by giving them appropriate inputs and data. The numerical model SEEP/W can be employed to carry out simulation of seepage and phreatic surface. The SEEP/W program is capable enough to simulate quite effectively seepage rates and phreatic surfaces in homogenous and non-homogenous earthen dams (Mohammed, 2006). SEEP/W is a finite element software product which is a part of GEO-SLOPE international model that is leading of geotechnical modeling software products. This is capable enough to solve groundwater flow, seepage and excessive pore water pressure problems within the porous media such as soil and rock. The software is capable enough to resolve the problems ranging from simple saturated steady state issues to saturated/unsaturated time dependent problems. The software is also capable enough to employ in designing of geotechnical, civil, hydrological and mining engineering problems (Geo-Slope International Ltd, 2007).

Parameters required to analysis of the expected quantity of seepage through the embankment dam and its foundation by using seep/W software model are like model section of the dam, permeability coefficient of the dam materials, piezometers reading and boundary condition. (www.geo-slope.com).

After solving the problems by involving the procedures step by step SEEP/W offers many tools for viewing results and can be export results in to other applications such as Microsoft excel and word for further analysis and documentations. Procedures or steps followed to analyze and solve the problem are: setting (working area, scale and grid), sketch the problems, used to guide for drawing the finite element mesh and defining the boundary condition, specify the analysis type (steady state) and analysis control (two dimension), define hydraulic conductivity and material property, set finite elements, specify node boundary conditions, draw flux section, verify and solve the problem, finally can be view the results.

The SEEP/W CONTOUR function allows you to view the results of the problem analysis graphically by:

- ❖ Generating contour plots
- ❖ Displaying velocity vectors that represent the flow direction
- ❖ Displaying the computed flux across each specified section
- ❖ Clicking on individual nodes and elements to display numerical information
- ❖ Plotting graphs of the computed results

3. MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Location

The study area, Gomit micro earth dam, is found in Amhara region South Gondar Administration Zone, Istie woreda about 9km far away from the capital city of Istie woreda in South direction and 122km from Bahir-dar which is the capital city Amhara region and 682km from Addis Ababa. The study area is located on the coordinates of 11^{0}33’43” North latitude and 38^{0}46’20” East longitude in ziqura peasant association with an average altitude of 2348 amsl. The dam has to be constructed on the river Gomit to irrigate 90ha of agricultural land by impounding the flood for dry season irrigation. Gomit MED is situated between valley gorges having wider reservoir area and agricultural land and the catchment area of the site is 23.43km^{2}. The dam site is suitable for technical and social point of views (CO-SAERAE, 2011)

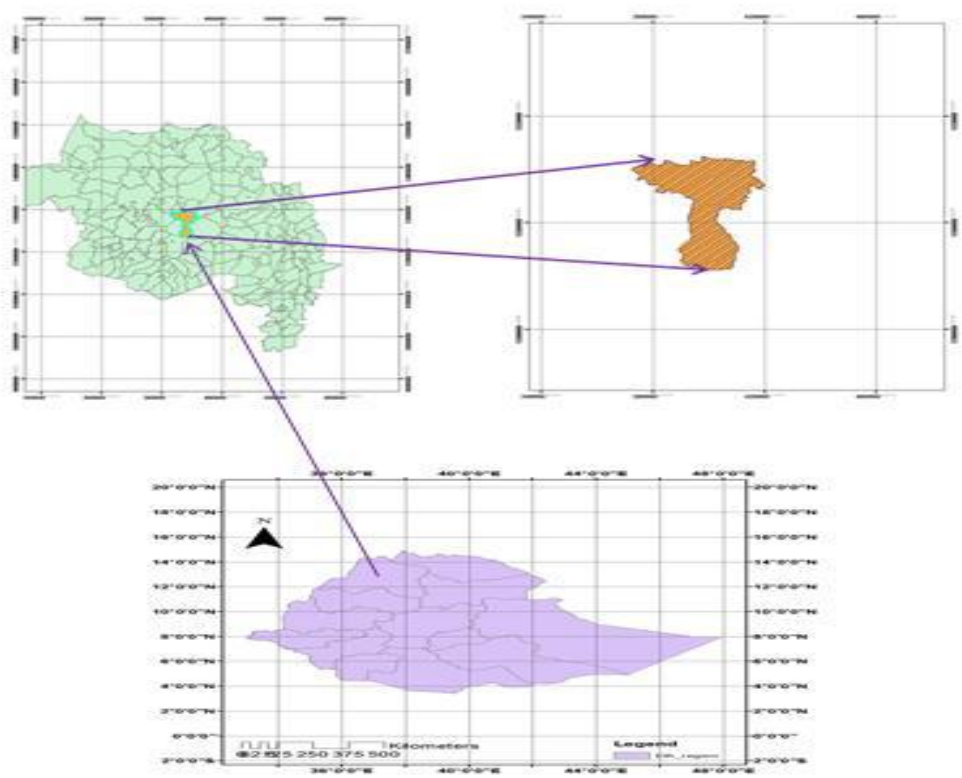

Figure 11 Location map of the study area

3.1.2. Topography and soil

The command area of the site found at the left side of the river Gomit. The potential irrigable area is about 100ha whose slope varies from below 1 to 6%. The whole potential area is cultivated plain land with three main gullies dissecting the command area. Most of the soil of the command area is deep heavy clay but as shallow as 10cm is found in some cases (CO-SAERAE, 2011)

3.1.3. Climate

The project area is classified as Dega agro climatically zone with an average altitude of 2343 m above mean sea level with two rainfall seasons of kiremit and non promising belg. Though it has two rainy seasons, the rainfall nature is uncertainly distributed and erratic as it is intercepted by Gunna Mountain

The project area including the catchment/ has the following climatic conditions.

- Mean annual rainfall = 1642.01 mm
- The mean annual air temperature is about 16.4^{0}c. The mean monthly maximum air temperature ranges from 20.1 to 27.2with a mean maximum of 27.2 occurring in March. The mean monthly minimum air temperature ranges between 7.4 and 11.1 with the mean minimum of 7.4 occurring in the month December. In general the hottest months are March and April.
- The relative humidity varies from 57% in April to 89% in July.
- The sun shine hour is in the order of 1.5hour in July, and August and 9.6hour in February (CO-SAERAE, 2011)

3.1.4. Geology

The general geology of Este woreda is dominantly covered by tertiary plateau volcanic, which are shield group of Miocene alkali-olivine basalt, tuff, agglomerates with basaltic flows and related spattered cones. Most part of Este woreda and vicinity of the area are covered by volcanic rocks of aphanites and trachyte basalt, tuff, and consolidated red ash rock formations. Geographically the woreda is found in the North western highlands of Ethiopia and it is bounded by Blue Nile (Abay) River in the South part and the area is free from any tectonic and seismic activity or risk (CO-SAERAE, 2011)

As the other parts of the woreda the areas around Gomit micro earth dam project and its catchment are dominantly covered by volcanic rocks of aphanitic and highly vesiculated trachy basalt, tuff and consolidated red ash. Especially all parts of the dam axis and most parts of the reservoir area (both right and left parts) are covered by highly vesiculated and weathered trachy basalt rock and this rock is continuous both sides (upstream and downstream) the project site and around the spill way site. While the ridge lands which are found on the left reservoir rim and upstream ends are covered by highly weathered basalt rock and there is local dyke, which surrounds the pick land (CO-SAERAR, 2001).

3.1.5. Accessibility

When we see the accessibility condition of the total 122km distance starting from Bahir Dar to the project Site: the 1st 38 Km is Asphalt road from Bahir Dar to Hamusit town; the next 76 Km is All weather Gravel road from Hamusit to Istie town, and for the remaining 8Km from Estie town to the project site, the first 4Km is all weather Gravel road along Estie town to Andabit road and the last 4Km which goes to the left direction to the dam site from Estie to Andabit road needs leveling and widening to mobilize construction materials and machineries to the dam site safely.

3.2. Study period and design

The study was conducted from March, 2016 to August, 2016 GC. To collect, generate and analyze relevant data on the existing problems at the study area, observation and dam surveillance design has been used, and the study was supported with design document of the study area, difference archive data’s and literatures.

3.3. Data type

Data were being collected and generated both at Primary and secondary level through personal observation, reviewing of archived data and design document.

3.4. Data collection

3.4.1. Primary data collection

Primary data was collected by Visual inspection,

- ❖ The current condition of the dam were assessed (dam surveillance)
- ❖ The information's were collected from the respondent persons of the regional and woreda offices and from beneficiaries within the command area by non structured interviews
- ❖ The location of seepage has been identified
- ❖ The pictures were collected that shows the locations of seepage failures at the side of the spill way footing and the dawn stream toe with digital camera.

The overall data's about the current condition of the study area were collected by primary data collection method are describes in chapter 4 results and discussions.

3.4.2. Secondary data collection

- ❖ Design document and geological report of the dam that have collected from the Water Resource Development Bureau of Amhara Region.
- ❖ Geometry of the structure, design data of the project and Construction material properties that have collected from the Water Resource Development Bureau of Amhara Region
- ❖ And the study was supported with Guideline, Manuals and Standard Design of small and Medium scale irrigation projects that have collected from the Water Resource Development Bureau of Amhara Region and from Istie woreda Water Resource Development office

The geometry of the structure have attached on the annex respectively and the other design document data's and construction material properties are described in chapter 4 result discussions respectively.

3.5. Data processing and analysis

Before analyzing the problem the current condition of the dam has been investigated through field observation, During field visit, Gomit micro embankment dam has suffered from seepage failure in order to identifying cause of failures of the dam. The analysis of seepage through dam has to be made because of it has an advantage to maintain the safety of the dam and minimizing loss of water. It will also help to take various seepage reduction measures. In the study area the analysis of seepage through embankment and dam foundation has to be made using Darcy's law Phereatic line and SEEP/W software model with help of the hydraulic design parameters of the dam adopted from the design report of Gomit micro embankment dam.

Analytically the analysis have been done in zoned type dam

$$q = k(a * \sin^2\alpha) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..10$$

$$a = \sqrt{b^2 + H^2} - \sqrt{b^2 - H^2\cot^2\alpha} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 11$$

3.6. Materials

The following materials has been used during the study

- ❖ SEEP/W soft ware model which is the product of geo technical software (Geo-studio 2007 software) to estimate the quantity of seepage passing through the dam body.
- ❖ AutoCAD 2007 software to draw the phereatic line of the dam
- ❖ Arc GIS map 9.3 to delineate the study area
- ❖ Digital camera to capture the pictures during field investigation

3.7. Ethical consideration

The data has been collected after approval was giving from Hydraulic Engineering Chair, Jimma institute of technology, Jimma University and Amhara water resource and development office. Before collecting the data through observation and interview the purpose of the study was clearly described to the organization and to the concerning persons. Then, after obtaining the full permission of the respondents, the available data was collected.

3.8. Data quality assurance

To assure the quality of the data the following mechanisms has been used:

- Preparing check list to check every day progress
- Conduct to Amhara water resource and development office to gate the permission and available data with the help of the concerned persons.
- After gating the permission of the regional office, conduct to Istie woreda water resource and development office. Then available data from the office was collected and observation of the study area was done with the help of respondent persons from woreda office.

3.9. Limitation of the study

The following was the major limitations encountered during this study

- Absence of full and complete design document
- There was no maintenance and construction history about the study area
- Absence of installed materials on the dam to evaluate the current condition of the dam
- Lack of transport during field observation, and lack of budget and time

4. RESULT AND DISCUTION

4.1. Assessment and evaluation of the current condition of the dam

The Gomit MED irrigation project was one of the irrigation projects in Istie woreda of south Gondar administrative zone. It was constructed on the river Gomit to irrigate 90ha of agricultural land by impounding the flood for dry season. The project has situated between valley gorges having wider reservoir area and agricultural land. It was designed and constructed by Commission for Sustainable Agricultural and Environmental Rehabilitation in Amhara Region (Co-SAERAR) from 2001/2002 G.C respectively.

The dam has zoned type embankment of 20m height, 4m top width and 324m crest length with upstream side slope of 2:1 and d/s side slope of 2:1; 2.5:1 above and below the dawn stream berm respectively. A riprap material of poorly graded was provided to protect the erosive action of waves on the u/s side of the dam. An ogee type spill way was existed on connected the right side of the dam to convey safely maximum design flood of 87.84m^3/s within the crest length of 25m and the height of 0.7m. 0.6m in diameter steel pipe outlet, stilling basin and valves were also existed.

The assessments was done so as to assess the current physical condition in order to get as much information as possible on the type of failure that are relevant to the dam in the area of study.

According to (Garge, 1976) the various causes leading to the failure of the earthen dam can be grouped in to three classes such us hydraulic, seepage, and structural failures. The failures under each category my occurred due to different reasons or factors.

Inspections and physical condition assessments were carried out on dam embankment; it was done by physically walking and inspecting the dam starting from the crest on one end walking to the other end. Inspecting was done on the downstream and the upstream slope, outlet and inlet works, abutments and micro-catchment. The spillway was then inspected after which the reservoir sides and throwback area were assessed by walking through and inspecting it. The physical assessments were more of qualitative (visual) and more to do with maintenance and inspection issues.

4.2. Problems or Possible failures encountered during field visit

Significant amount of water that seeps from the left dawn stream part of the dam and leakage at the right part of the spillway was clearly observed. In addition to these sloughing of downstream toe, wet spots or muddy areas, growth of greener grass on dawn stream toe and right side of the spill way and surrounding areas, was clearly observed on the study area, it may indicate the presence of concentrated seepage failure.

(a)

(b)

Figure 12 a and b, Location of seepage at right side of the spillway and downstream toe of the dam

The other problem observed during inspection was embankment sliding, the dawn stream slope settlement is clearly observed at the right part of the dam. Which is indicated the presence of structural failure on the dam.

Figure 13 GMED crest and upstream riprap

Figure 14 Downstream face of GMED

4.3. Major finding of the study

The study was mainly focused on identifying and analysis of the major problems existed from the case study area. Based on investigation held on the study area, seepage and structural failure were observed. Problem of seepage has been physically observed at the toe of downstream face of the dam. Moreover, leakages at the right side of the spillway were existed. When compared with seepage at the downstream toe, the amount of leakage at the side of spill way was significant and it has formed conduit which indicates that the structure really need attention. Unless some mitigation measures are taken these conditions may bring damage or catastrophic failure on the structure after some years. And the loss of water on the reservoir have an impact on the daily life of the beneficiary's whose life depend on the designed command area. In addition to physical observation the previous study indicates that seepage failure was significant than other failures. For example, According to a study in (Tefera, 2006), out of the 14 micro dams in Amhara only one of the 14 dams is functioning according to the plan of implementation, the study indicates that Hydraulic problems (16.7%),Hydrological problems (41.7%), sedimentation problems (33.3%), structural failures (8.3%) and seepage failures (58.3%).

As explained above the major task of this study was analyzing the main cause of failures on the structure. Due to the reference of the above literature and the result of field observation this study was decided that the first concentrated problem which is required making analysis was seepage failure and the second is structural failure. But on this study only seepage analysis has been done, structural or slope stability is remaining gap to be fulfilled by researchers. Therefore, the analysis of this study mainly focused on the design document which was supplemented by field investigation because the study area has no construction history, operation and maintenance manual. The analysis was mainly focused checking the designed quantity of seepage of the structure with different condition and methods, proposing appropriate remedial measures to protect the structure against from catastrophic failures; it was the overall finding of the study.

4.4. Analysis and presentation of finding

To achieve the research objectives of the study and to realize the seepage problem of the dam the analysis has been carried out with different methods. The methods used to quantify the expected amount of seepage through the embankment and foundation was analytically with Darcy's Law -phereatic line, and numerical model with SEEP/W software which is the product of Geo studio 2007, geotechnical software. The analysis was supported with the data gathered from archive data's and consulting the data from the design document.

4.4.1. Analysis of seepage with Darcy's Law-Phereatic line

Seepage occurs through the body of all embankment dam and through previous foundation of the dam. Even though Gomit MED has zoned type dam; the analysis of seepage at the design document was done only for homogeneous dam assuming that horizontal filter is provided. In this study the analysis has been carried out in the case of zoned dam. The data adopted from the design document that were used to the analysis of seepage in the study area are:-

Dam height = 20m

Normal Pool Level = 2367.00masl

Maximum Water Level = 2368.40masl

Min level of river = 2350.36masl

Bank top level = 2370.36masl

Top width = 4.00m

Crest length = 324.00m

Upstream slop = 2:1

Downstream slop above the berm = 2:1

Downstream slop below the berm = 2.5:1

Upstream and dawn stream slope of the core = 1:1

Upstream berm level = 2357masl

Dawn stream berm level = 2360.36masl

Depth of foundation = 9m

Permeability coefficient of materials:

Shell material, Ks = $1.53*10^{-4}$ m/sec

Core material, Kc= $2.3*10^{-6}$m/sec

Foundation material, K_f= $1.00*10^{-6}$m/sec

- **Zoned dam**

To estimate the quantity of seepage in the case of a zoned section having a central impervious core the effect of the outer zone can be neglected altogether. Furthermore the impact of permeability of shell material with the core material should be checked first. And if the ratio of permeability of shell material with Core material (Ks/Kc) is greater than 20; the effect of shell material on core is negligible (Tigist, 2008).

For this case the analysis is made as if the dam is homogeneous. The focus of the base parabola is located at the downstream toe of the core. The phereatic line can then be drawn as usual with free hand correction required at suitable place.

$$\frac{permeability\ of\ shell\ material}{permeability\ of\ corematerial} = \frac{1.53 * 10^{-4}}{2.3 * 10^{-6}} = 66.5 \gg 20$$

To determine the phereatic line for zoned dam section and the discharge passing through it the analytical method of Casagrande for the angle $30^0 < \alpha < 60^0$ is available.

The discharge passing through the dam (q) is determined by the formula

$q = k(a * sin^2\alpha)$ … … … … … … … … … . .10

Where the value of a is determined by the formula derived by Casagrande for the angle of α is between 30 and 60 degree.

$\tan^{-1} 1 = 45^0$ It is between 30^0 and 60^0

$$a = \sqrt{b^2 + H^2} - \sqrt{b^2 - H^2 cot^2\alpha} \dots\dots\dots\dots\dots\dots\dots 11$$

$$a = \sqrt{36.625^2 + 16.64^2} - \sqrt{36.625^2 - 16.64^2 cot^2\alpha}$$

$$a = 12.163m$$

Then calculate the seepage q per unit length

$$q = k(a * \sin^2\alpha)$$

$$q = 2.3 * 10^{-6}(12.163 * \sin^2\alpha)$$

$$q = 13.984 * 10^{-6} m^3 / s / m$$

The total seepage over the full length of 324m is estimated to be

$$q = 4.53 * 10^{-3} m^3 / s$$

To draw phereatic line first the value of y_0 or s should be determined

$$s = \sqrt{b^2 + h^2} - b$$

$$s = \sqrt{36.625^2 + 16.64^2} - 36.625$$

$$s = 3.6m$$

A few more coordinate of phereatic line are worked out in the table and described in the annex.

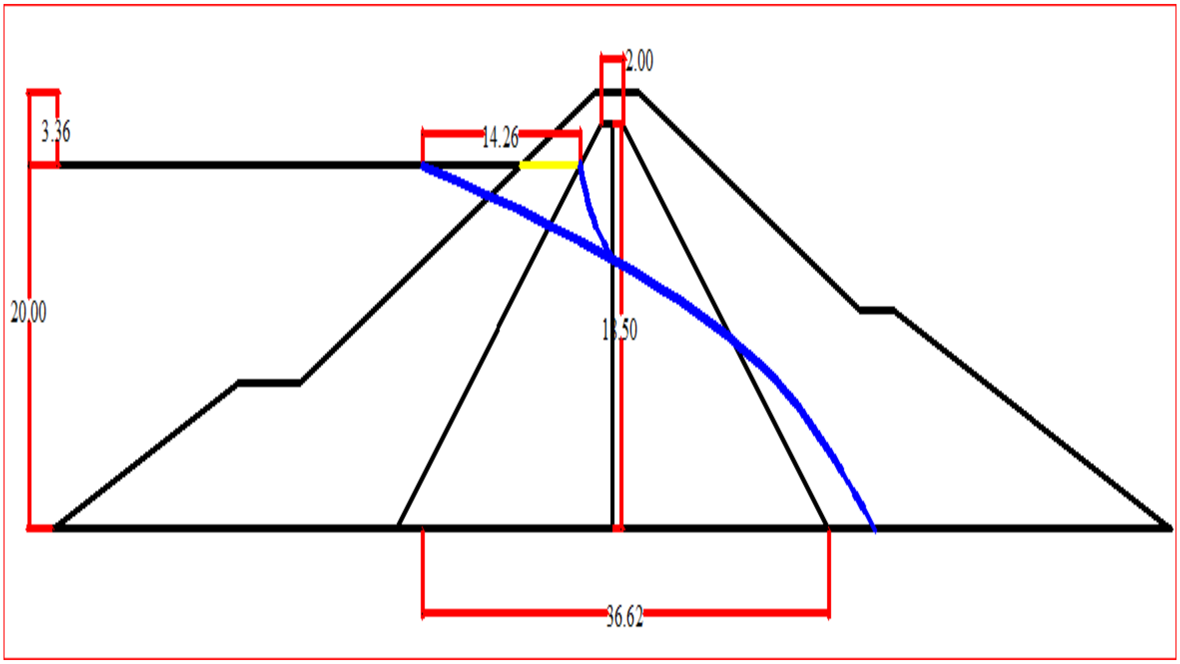

Figure 15 Phereatic line in zoned dam

4.4.2. Computation of seepage by SEEP/W Software Models

SEEP/W is a numerical model that can mathematically simulate the real physical process of water flowing through a particulate medium. It helps to analyzing groundwater seepage and excess pore-water pressure problems within porous materials such as soil and rock. It is a finite element software product which a part of GEO-SLOPE international model that is leading of geotechnical modeling software products. The model comprehensive formulation allows the analyses ranging from simple, saturated steady-state problems to sophisticated, saturated unsaturated time-dependent problems. SEEP/W can be used to analysis and design geotechnical and civil problems. In this study the analyses of seepage by SEEP/W software model have been done in the case of zoned, and zoned with foundation at the normal pool level and the current water level of the reservoir.

Procedures followed to analyze the seepage is

- ❖ When developing a numerical model, the first step is usually to set the working area, and to set the scale.
- ❖ Sketch the problem and defining the geometry
- ❖ Materials are first created and then assigned to geometry object;
- ❖ Boundary condition are created and assigned in the same way materials are created and assigned
- ❖ One of the objectives of this analysis was to compute the amount of flow through the earth dam. To do this, we can locate the fluxes section where the result will be labeled. Flux sections are used to identify elements where you want the software to compute and report the amount of flow crossing these elements during the solve process.
- ❖ Verify/optimize the data given If the data have no error, solve the problem
- ❖ We can view the results directly on clicking the contour and the flux section results can be viewed by labeled the flux section.

The data adopted from the design document that were used to the analysis of seepage in the numerical seep/W software model are:-

Table 2 construction material property of the dam

Materials	Type of material	Saturated water content (m^3/m^3)	K- saturation	Residual water content (m^3/m^3)
Shell	Sand and gravel	0.46	1.53E-04	0.046
Core	Silty clay	0.48	2.30E-06	0.048
Foundation	Silt	0.25	1.00E-06	0.025

The results of seepage computed by SEEP/W software model with different are presented below as follows. The cross section of the dam have attached to the annex respectively.

- **Zoned dam without horizontal drainage filter**

The estimated quantity of seepage by SEE/W software model for zoned dam without horizontal drainage filter is $1.3705 \times 10^{-5} m^3/s/m$ which is located at the center of the dam. See figure 16.

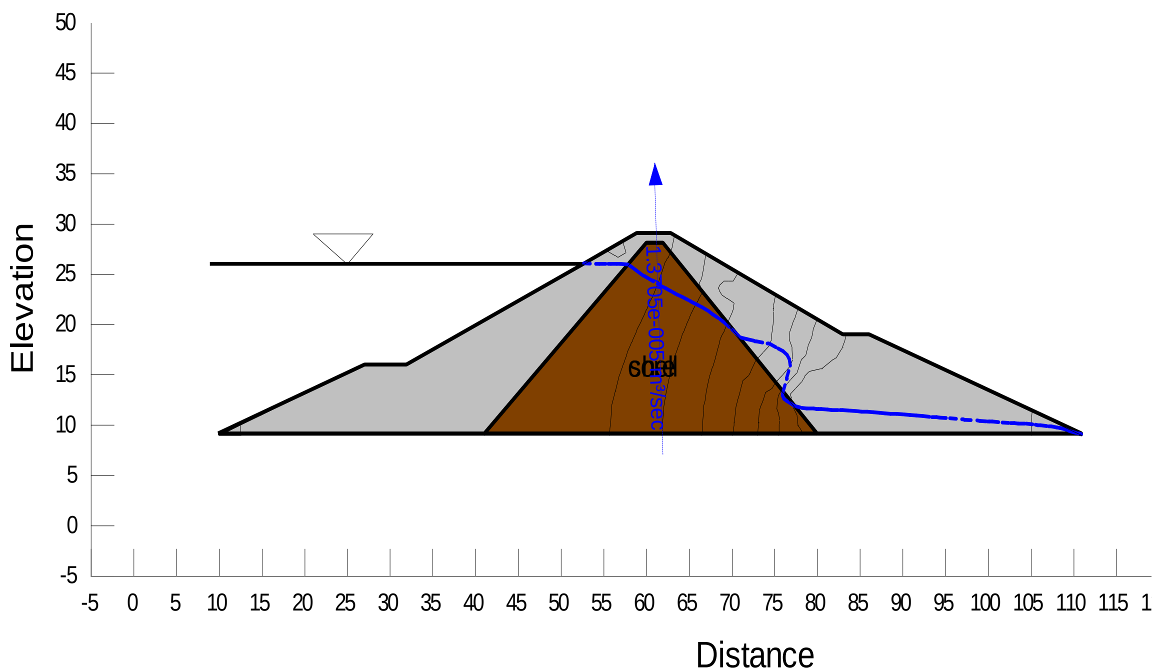

Figure 16 Seepage analyzed for zoned dam without horizontal filter

The estimated quantity of seepage for zoned dam with consideration of horizontal drainage filter is $1.5017*10^{-5} m^3/s/m$ which is located at the center of the dam. See figure 17.

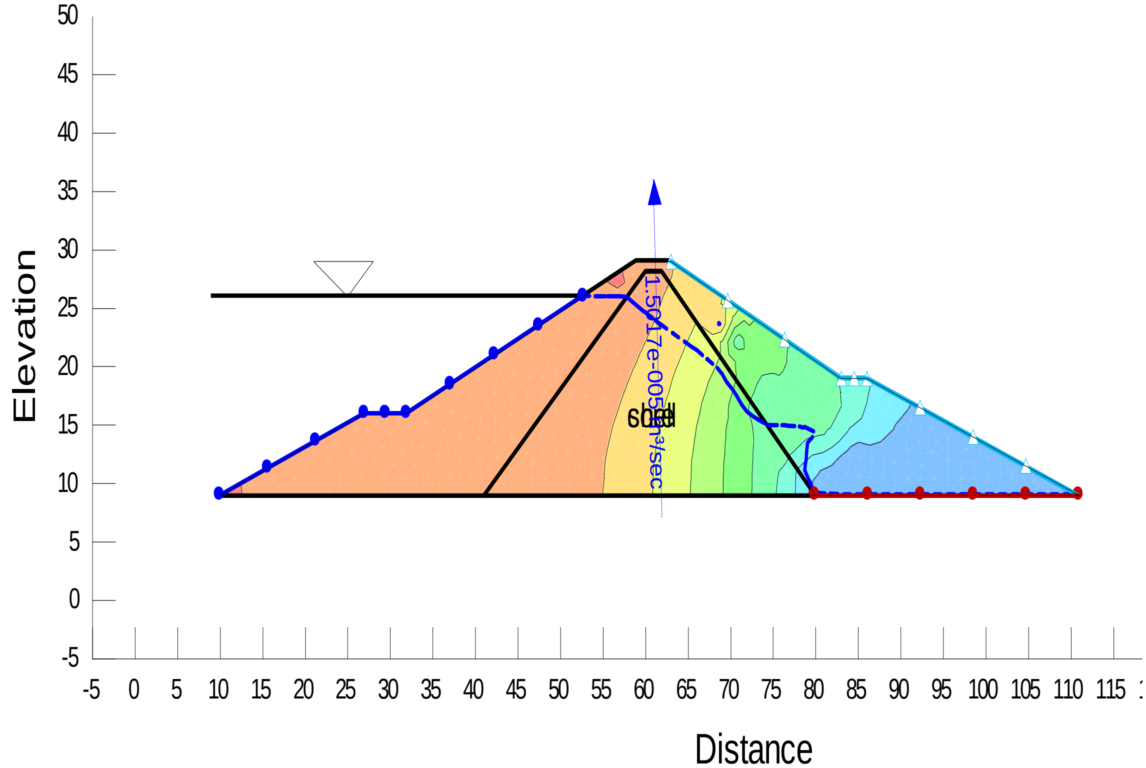

Figure 17 Seepage analyzed for zoned dam with filter

- **Zoned with foundation**

For these case the analysis of seepage was carried out for both the normal pool level of the reservoir that has similar to the above analysis and the current water level of the reservoir = 9m depth.

At the normal pool level the estimated quantity of seepage analyzed by the model is $1.87*10^{-5} m^3/s/m$ at the center of the dam without consideration of filter. See figure 18.

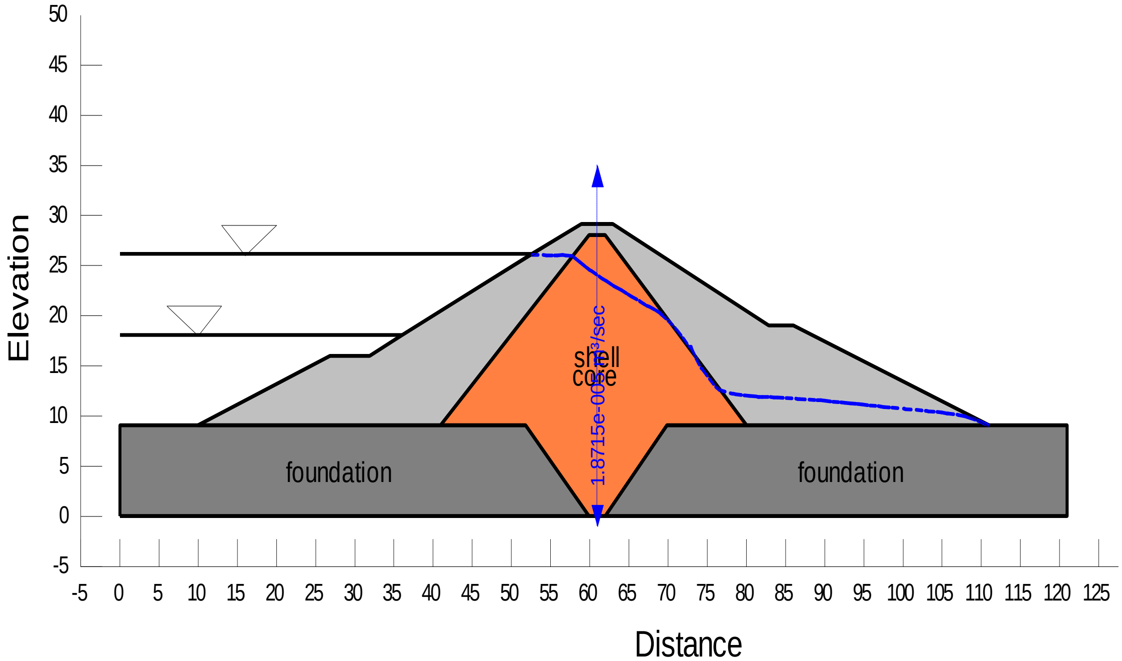

Figure 18 Seepage analyzed for zoned dam with foundation and without filter

Similarly as shown from figure 19 quantity of seepage estimated with filter is $1.869*10^{-5} m^3/s/m$ which is located at the center of the dam.

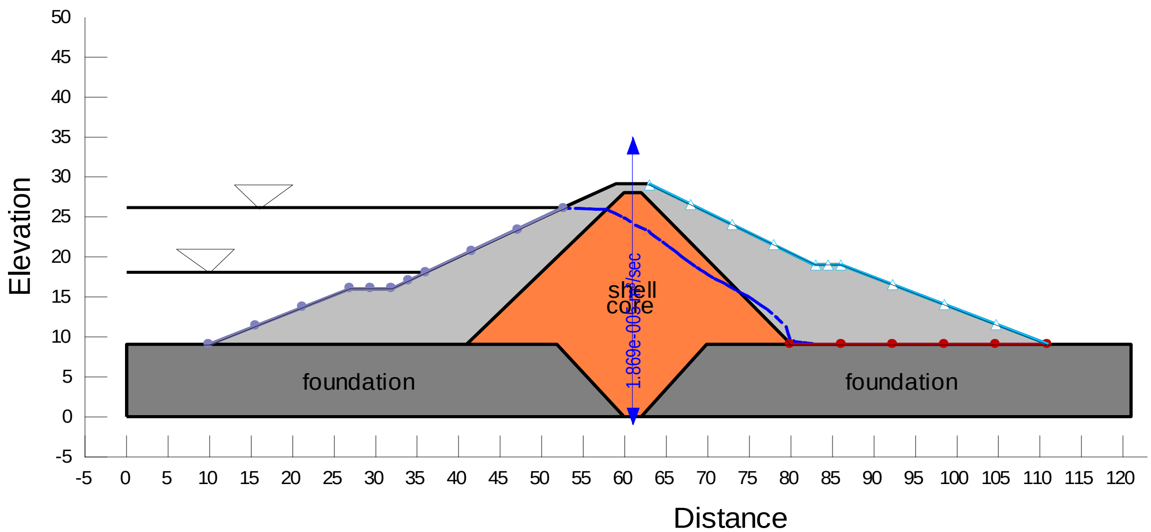

Figure 19 Seepage analyzed for zoned dam with foundation and filter

At the current water level = 9m which has gating from the report that has done by wereda super visor, the estimated quantity of seepage analyzed by the model is,$2.8551*10^{-5}m^3/s/m$ at the center of the dam with the consideration of d/s filter.

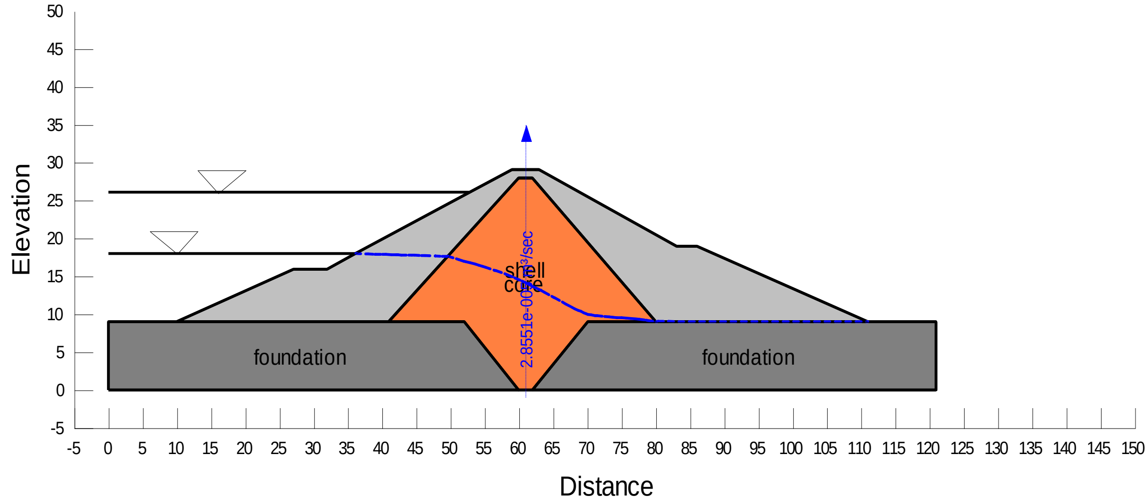

Figure 20 Seepage analyzed for zoned dam with foundation and filter at current water level

The main reason why seepage was computed for both the dam with and without horizontal drainage filter has to make quantitative predictions, and to compare alternatives. It is also very important to get more precise value.

The results of analysis for analytical and numerical methods, estimated of seepage from the design document and quantity of seepage estimated by zonal and regional experts is summarized in the table below.

Table 3 summarized result of the analysis

Water level	Method	Case	Seepage estimated(m^3/s)
At normal pool level	Darcy's low phereatic line	zoned	$4.53*10^{-3}$
	SEEP/W	zoned without filter	$4.44*10^{-3}$
		zoned with filter	$3.86*10^{-3}$
		zoned with foundation without filter	$6.05*10^{-3}$
		zoned with foundation with filter	$6.05*10^{-3}$
At current water level	SEEP/W	zoned with foundation with filter	$9.25*10^{-3}$
At normal pool level	Estimated seepage at design document	Homogenous with filter	$3.175*10^{-3}$
At current water level	Estimated by experts		$5.00*10^{-3}$

As we can see from table 3 quantity of seepage estimated from the design document is $3.175*10^{-3}m^3/s$. In order to show the gaps between quantities of seepage estimated from the design document and from this study, comparison between them is required. However from the design document the quantity of seepage was estimated in the case of homogenous dam with the consideration of horizontal drainage filter and the actual type of constructed dam is zoned dam.

Due to that it is impossible to compare the quantity of seepage between such different cases, because it is known that the estimated quantity of seepage is different with different cases in designing of embankment dam.

In this study the quantity of seepage has been analyzed in the actual type of dam at normal pool level and current water level in order to realize the failures of seepage that has physically observed during field observation.

At the normal pool level seepage estimated by the software in the case of zoned dam with foundation and d/s drainage filter was $6.05*10^{-3}m^3/s$. At the current water level estimated of seepage by the software in the case of zoned dam with foundation and filter was $9.25*10^{-3}m^3/s$ and estimated seepage by zonal and regional experts $5.00*10^{-3}$ m^3/s. This shows that the presence of observable seepage failure at the dawn stream part of the dam. In view of this fact, the intention of the study was to identify the main cause of failure and propose remedial measure for it. However it has difficult to judge the real cause of seepage failure in order to maintain the dam without complete understanding and detail investigation of the problem. These are due to the absence of installed and/or measured data from dam monitoring instruments and absence of all available data in the design document. Seepage failure my occurred due to one or more of the following causes.

- ❖ Piping through the foundation and the dam body: - piping is the progressive erosion and subsequent removal of the soil grain from within the foundation of the dam and the body of the dam. When there is an empty space within the solid object and having narrow cracks with in gravels and core sands in the foundation and the dam body, water may start seep at a huge rate through them. When the concentrated flow channels get developed in the dam body soil may be removed from the foundation and the dam body, leading to the formation of hollows and subsequent subsidence of the dam. These flow channel my developed due to insufficient compaction, shrinkage cracks, animal borrows, faulty construction, crack develop in the embankment due to foundation settlement, etc.
- ❖ Wrong placement and improper design of horizontal drainage filter: - Various alternatives have been suggested so far to prevent the seepage problem.

In this regard, the application of a horizontal drain has been a common method to control the seepage flow since it can alleviate the pore pressure and lower the phereatic line in the embankment. Poor design of filter create preferential flow path of crack through the dam body, foundation and at contact between the embankment and spillway and increase the seepage flow to downstream of the dam. Even so placement of the filter materials and drainage design and gradation curve are the critical part of embankment dam design, there is no clearly stated about them in the design document. The design document stated that the designer to use the available filter materials obtained from the dam site if the coefficient permeability ratio of shell material to core is greater than 25.

❖ Insufficient length and thickness of impervious blanket: - Impervious clay placed upstream of a dam and connected to the impervious section is a convenient way of effecting moderate reduction in the amount of seepage. From the design document the dam has an impervious up stream blanket that has connected to the core of the dam However, there may be a presence of cracks on the upstream blanket and resulting excess seepage through the dam foundation. Further investigation is required during the reservoir is empty in order to assure the presence of crack from the upstream blanket.

❖ If there is high variation between the horizontal (intra) permeability and vertical (inter) permeability or $K_h > K_v$ the water can seep towards the downstream part of the dam. The carful laboratory analysis is required by taking the sample of the construction material from the dam body in order to know the permeability of the present material.

As mentioned earlier the main objective of the study was to identify the cause of failure and proposes remedial measures. Seepage and leakage have been identified as a problem and the analysis has been made. However it has difficult to take action to maintain the problem of the structure once it suffers such failure. But to minimize the effect of the damage on the dam body and the downstream users' mitigation measure should be taken. The possible remedial measures proposed to the existed seepage problem of the dam are listed as follows: -

- A Certain materials such as cement and other materials with a suitable admixture injected as grout at the contact between the right side of the spillway foot and the embankment. It is act as binder and fills the voids, thus reducing the permeability and increasing its stability, Grouting is an effective and common method that is being applied for this type of problem.
- Impervious clay placed upstream of a dam and connected to the impervious section is a convenient way of effecting moderate reduction in the amount of seepage.
- Downstream slope stability of the embankment will normally increase because of the resistance to sliding provided by the berm. Seepage analysis must be made to determine the resisting load required of the berm. The weight of the berm plus top stratum is sufficient to resist uplift pressure and the water will not rise to the berm.
- Drainage in earth dam is usually provided to bring the phreatic line well within the downstream face. Measures adopted for safe drainage of seepage water through the dam and foundation include toe drain and horizontal drainage blanket, Rehabilitating or modifying the presence drainage filter and toe drains or adding both toe drains and drainage zones are one of the remedial measures.
- In order to adds weight and provides a working platform for installation of relief wells at points of excessive seepage, placement of impervious blanket with appropriate length and reasonable thickness over the soft seepage areas at the downstream face of the dam are one of the recommended remedial measures.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The general objective of this study was to identify the causes of failure of Gomit micro embankment dam and giving the possible remedial measures, therefore attempt has been made to analyze the problems encountered during field observation in order to insure or realize the physical observable problem that has existed in the dam during field visit. Quantity of seepage estimated from the design document was done in the case of homogenous dam with horizontal drainage filter; however the actual type of dam is zoned. To realize the existed problem the analysis of seepage has been done in the case of zoned dam with analytical and numerical SEEP/W methods at the normal and current water level.

In the case of zoned dam at the normal water level quantity of seepage estimated by Darcy's law are $4.53*10^{-3}m^3/s$ and the biggest value estimated by SEEP/W software model are $6.05*10^{-3}m^3/s$ which is done in the case of zoned dam with consideration of horizontal drainage filter and foundation at the normal pool level. In the same case but at the current water level quantity of seepage estimated by SEEP/W are $9.25*10^{-3}m^3/s$ it is a little bit larger than quantity of seepage estimated at the normal pool level, which shows that the presence of failure of seepage on the study area.

Even though it has difficult to know the real cause of seepage without the detail investigation and complete understanding, the possible cause of failure of seepage may one or more of the following: - Piping through the foundation and the dam body, Wrong placement and improper design of horizontal drainage filter, Insufficient length and thickness of impervious blanket, High variation between the horizontal (intra) permeability and vertical (inter) permeability or $K_h > K_{v.}$

The possible remedial measures proposed to the existed seepage problem of the dam has grouting, upstream impervious blanket, dawn stream berm; horizontal drainage filter and toe drain with adequate design.

5.2. Recommendations

Quantification of seepage from the design document was incorrect, because it was estimated in the case of homogenous with downstream filter but the actual type of the dam is zoned type. In this study quantification of seepage has been done in the actual type of the dam with the help of the hydraulic parameters of the dam that has getting from the design document. The designed quantity of seepage should be lies between $4.53*10^{-3}m^3/s$ and $6.05*10^{-3}m^3/s$.

As mentioned earlier, excess amount of water seeps from the downstream toe of the dam and from the right foot side of the spill way was clearly observed during field observation, and it has realized by making analysis with SEEP/W software model at the current water level. However from this study the analysis of the problem was done based on the inconsistency data from the design document and archive data's from regional and woreda offices. Before implement the possible remedial measure, this study recommended that detail investigations and studies should be done by the concerned organizations about the overall structural stability of the dam and impact of the remedial actions on the other part of the structure, degree of correction requirement and costs with multi-disciplinary teams.

The other problem encountered during field visit was sedimentation problems on the reservoir. On the right part of the embankment there was agricultural practice both to the toe side and very near to the right upstream of the dam which will contribute for the dam failure and sedimentation respectively. Therefore abandoned environmental and agricultural practice near to the reservoir and the upstream catchment area should be immediately taken to prevent siltation problem. Otherwise the structure hereafter is at risk and it may bring big loss of economical, social, and environmental aspects.

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7. APPENDIX

Appendix 1 Coordinate points of zoned dam

$$x^2 + y^2 = x^2 + s^2 + 2xs$$

$$y = \sqrt{s^2 + 2xs}$$

SN	X	S	$y = \sqrt{s^2 + 2xs}$
1	0	3.6	3.6
2	5	3.6	6.99
3	10	3.6	9.22
4	15	3.6	11.00
5	20	3.6	12.53
6	25	3.6	13.89
7	30	3.6	15.13
8	36.625	3.6	16.63

Appendix 2 Cross section area of the dam

ID	x	Y
1	0	9
2	10	9
3	26.6	15.64
4	32.1	15.64
5	58.82	29
6	62.82	29
7	82.82	19
8	85.82	19
9	110.82	9
10	41.32	9
11	59.82	27.5
12	61.82	27.5
13	80.32	9
14	51.82	9
15	59.82	0
16	61.82	0
17	69.82	9
18	0	0
19	120.82	9
20	120.82	0