Addis Ababa University

School of civil and environmental engineering

Hydraulics engineering stream

Geotextile Reinforcement Possibility
The case of Ajima Dam

By Hiwot Yeshitila Kidane

Advisor Dr- Ing. ASSIE KEMAL

March, 2019

Geotextile Reinforcement possibility the case of

Ajima Dam

Hiwot Yeshitila

A thesis submitted to the school of Civil and Environmental Engineering

Presented in partial fulfillment of the Requirement for the degree of Masters of Science (Major Hydraulic Engineering)

Addis Ababa University
Addis Ababa, Ethiopia
March, 2019

Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

Geotextile Reinforcement possibility the case of Ajima Dam

This is to certify that the thesis prepared by Hiwot Yeshitila, entitled: Geotextile Reinforcement possibility the case of Ajima Dam submitted in partial fulfillment of the degree of Masters of Science (Civil and Environmental Engineering (Major Hydraulic Engineering)) complies with the regulation of the university and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

ASSIE KEMAL (Dr. –Ing) ------------------

Advisor

Signature

Mebruk Mohammed (Dr._Ing) ----------------

-

External Examiner

Signature

Yilma Seleshi (Dr) ----------

-

Internal Examiner

Signature

Henok Fikrie (Dr.) ------------------

Chairman (Department ofGraduate Committee) Signature

DECLARATION AND COPY RIGHT

I, Hiwot Yeshitila, declare that this is my own original work and that it has not been presented and will not be presented to any other University for similar or any degree award.

Signature_____________________________

Date______________________________

This dissertation is a copyright material protected under the Berne Convention, the Copy Right Act, 1999 and other international and national enactments in the behalf, on the intellectual property. It may not be produced by any means in full or in part, except for short extracts in fair dealing, for research or private study, Critical scholarly review or disclosure with an acknowledgement, without written permission of the School of Graduate Studies, on the behalf of both the author and the Addis Ababa University.

Hiwot Yeshitila Kidane

hiw.saved@gmail.com

+251 921093021

March, 2019

ACKNOWLEDGMENTS

I praise the almighty GOD for providing me the power and courage to carry out this thesis. I would also like to thank the Ministry of Education for providing female scholarship opportunities.

I would like to express my most sincere gratitude to DR. Ing Assie Kemal for his guidance and suggestions throughout the course of this research and all my manager and colleagues at world vision whose help was instrumental throughout my classes.

I am grateful to my friends and classmates Selam and Abrehet for their cooperation and harmony. I am also thankful for Yared Mulatu for his extra support. I would also like to thank my mother, brothers and Mulunesh for their support and encouragement.

Finally, I want to thank to all of my friends for their support and encouragement throughout this work.

Addis Ababa, March, 2019

Hiwot Yeshitila

LIST OF ABBREVIATIONS AND SYMBOLS

(E/ADSWE); Amhara Design & Supervision Works Enterprise Eastern Amhara Branch Office

MCE: Maximum Credible Earthquake

OBE: Operating Basis Earthquake

ICOLD: International Commission on Large dam

MER: Main Ethiopian Rift

SW: South West

SEE: Safety Evaluation Earthquake

TABLE OF CONTENTS

Contents Page

LIST OF TABLES

List Of Figures

ABSTRACT

The Ajima Dam is located mainly at Kita alegn Kebele, Angolelana tera Woreda of North Shewa Zone in the Amhara Region. At an altitude of about 2806m a.m.s.l, with 45.5 m height and dam crest length of 377m. Although dams are so much important, their overall construction cost is high. In order to reduce this challenge, this study is intended to incorporate reinforced geotextile in part of the dam region. This technique is used to decrease the construction cost with decreasing the required construction period. Geo-synthetics Materials are presently used widely in international dam construction practice as impermeable elements, filters, drains, reinforcing and separating members, and for protecting and reverting slopes of earth dams. The stability analysis has been done by using limit equilibrium method. The analysis is conducted for three different slope options using geo slope 2007. After generating the result the more stabilized and economical one slope is taken. Reinforced geotextile has been laid with horizontal layers with different length and spacing depending on the slope. The safety factor were increased from the previous in the same in situ material for the reinforced geotextile. Beside to this the construction cost is decreased by 29.83% with the planned construction period.

Key word; - *Ajima dam*, *geotextile*, *Geo-slope, safety factor,* Geosynthetics

1. INTRODUCTION

1.1. Background of the Study

Various dams have been built of concrete or earth-filled structures in the world. Since the early history, the embankment dams have used as a structure to block a flowing water for water supply, flood control, irrigation...etc. Generally, there are various reasons to prefer the embankment dams rather than concrete ones, particularly the costs of the materials and unique construction site requirements. Concrete is more expensive than earth materials; thus, it might be costly to construct the concrete dams by massive and wide formworks to pour concrete compared with the construction of the embankment dams, as the earth materials required might be supplied from the project site itself or the nearby mines. Further, construction sites with high bearing capacity have been yet utilized for building concrete dams in the country; however, there are poor beds and sites, which could be favorably used to construct embankment dams.
Ethiopia is constructing many embankment dams in order to satisfy demands for irrigation and water supply. And there are several embankment dams under construction. Ajima dam is one of the embankment dams which are under construction in Ethiopia Amhara region Angolela tera woreda at a cost of 2.7 billion birr.

The dam failure has a negative impact on the country's economy because the initial and the operation cost is high with the long construction period. For the embankment dams the construction materials have their own contribution in order to accelerate the problem. Geo-synthetics have become well established construction materials. As these products are manufactured relatively in easy way compared to solutions they are providing, the use of these materials becomes very popular to the construction industry. The principal functions of geo-synthetics are filtration, drainage, separation, reinforcement protection, and erosion control. The most common uses of geo-synthetics in earth dams are:

• As a separator/filter between embankment material and a layer of riprap placed on the upstream slope or in a downstream discharge area.

• As a filter zone between riprap used to line watercourses and the underlying foundation soils.

• As a filter in a downstream trench drain where the coarse drainage layer does not meet filter requirements for the foundations soils.

Geo-synthetics are a variety of man-made materials including geotextiles, geo-membranes, geo nets, geo-grids, etc. Which are use depend on the requirement into earth dam applications. Geo-synthetics are economically and it reduces costs up to 30% or above in earth dam projects, the number of dams constructed in various countries with the use of geo-synthetics and is continuously increasing (Radchenko and Semenkov, 1992). The active use of geo-synthetics in the construction of hydraulic and earth dams began at the end of the 1950s in various countries. The first large earth dam using geo synthetic material was built in 1970 in France (Valcros dam) in which geotextiles were used for filtration purpose. In case of embankment dams, geo-membrane was first used as waterproofing element in 1959 at 32.5 m high Contrada Sabetta rock-fill dam in Italy (Cazzuffi, 1987). A number of earth dams have been provided with geo-membrane as waterproofing (ICOLD 1991).

For new construction, the first dam in which geo-synthetics have been used with reinforcement function was 8 m high Maraval dam in France, constructed in 1976. The dam has a sloping upstream face lined with a bituminous geo-membrane and a vertical downstream face obtained by constructing a multi-layered geotextile-soil mass (Kern 1977). Among others, soil reinforcement is one of the most accepted methods of geosynthetics technology and this has been used in almost all types of dams and others, like, railways and road projects, both for new construction and rehabilitation purposes (Duncan,2005).

Embankment dam slopes are reinforced to have strong and economical structure as reinforced slopes gets steep slope and use less material than which have been designed in conventional design procedures. Stability of dam means maintaining a balance and preventing movement of components of a dam against the static forces. It is observed that the stability of the dam is a relative problem and by changing the ratio of the unbalanced forces to the resistance forces, different degrees of stability can exist.

And in dam designing, the stability of slope is measured by safety factor criterion (Ghaffari, 2010).

Therefore, this requests for discovery and familiarizing the economical, safe and easy method for embankment dam in terms of avoiding long period of construction, significant dam failure problem and being economical in our country. Hence, this paper is intended to conduct a research on an effect of introduction of geotextile reinforcement for Ajima dam. The adoption of soil reinforcement technology is found to highly efficient in terms of ensuring stability and also very cost effective with requiring less construction period.

1.2. Statement of the problem

Embankment dam is usually constructed using near site materials. Consequently, it is mostly common in many dam projects more than concrete ones. These near site construction materials can resist pressure and shear forces very well. However, they cannot tolerate tensile forces. Embankment dam materials attain structural safety at flatter slopes because of their filling material characters. This makes the filling material to be plentiful in amount and increase the fill cost. So, if one can reduce the slope by making it steeper in engineering techniques, much optimization in economic aspect can be realized while still achieving safety requirements. Most embankment dams which are constructed in our country have taken large construction period and consumed high amount of initial construction cost.

The work on the Ajima dam has been already started and the employees' camp is already completed. However, the construction of the dam has not been started at all. The total budget needed for this purpose is 2.7 billion birr and obviously the country's economy doesn't allow that amount of budget easily. This is also a major issue because there are additional compensation fees needed to be paid to the relocates.

Therefore, all of these factors have combined to deter the commencement of the dam. As a result, to resolve the above mentioned problems, geotextile reinforcement techniques can be introduced as the simplest method to ease the economic challenges. It used in stabilizing embankment (slope) dams to moderate the shear resistance of soil layer in different earth structures. By introducing geotextile reinforcement, it is possible to decrease both the initial and maintenance construction cost and construction period. In addition, using geotextile reinforcement in both upstream and downstream faces of dam can increase the dam stability in a proper provision. Therefore, this study will introduce the geotextile reinforced earth fill dam and come up with percentage improvement in terms of safety compared with unreinforced dam and a much reduced cost and construction period.

1.2.1. Objective of the Study

1.2.2. General Objective

The general objective of this research is

- To confirm the potential improvements on the safety or stability of Ajima embankment dam if geotextile is use as reinforcement.

1.2.3. Specific Objectives

- To verify the possibility of realizing a minimized construction cost by reducing the dam fill material.
- To analyze the increment of static safety of the dam.

1.3. Scope of the study

This thesis has been intended to introduce the benefit of geosynthetics as reinforcement and increase the appropriate use of geotextile in our country for embankment dam in order to minimize the construction cost as well as the construction period. Without losing its stability. The scope of the study has been limited to introducing the geosynthetics as reinforcement for shell part of the dam.

1.4. The significance of the study

In conservative way of design procedures, the dam constructed with a large volume. And it covers a huge area for construction and volume of materials that resulted in uneconomical and take long construction period. Though, if an embankment dam is reinforced, it will have a steep slope than unreinforced dam. Thus, reinforcement will have advantage of saving construction cost, decreases construction period so that the project can be utilized early and will be a suitable solution for shortage of construction materials

1.5. Organization of the thesis

Chapter one:-Introduction and background of this thesis has been discussed

Chapter Two; -A review of previous works regarding soil reinforcement technique is presented, Limit equilibrium, finite element method of slope stability analysis concepts which have been approached by different researchers and advantage and disadvantage of geotextile are presented.

Chapter three: -The Ajima earth fill dam site and project area has been described, the method how to done the paper and Seismicity of the area and considerations discussed in well

Chapter four: -Both limit equilibrium and finite element based Geo Studio software used for the analysis have been discussed. In this section, a brief description of different methods, techniques and constitutive models is presented.

Chapter 5: - presents the results of analysis of Ajima earth fill dam by introducing geotextile material as reinforcement.

Chapter 6: -Conclusions of the findings of the study are presented. Recommendations for practical works and for further researches are also provided in this chapter.

Chapter 7: - different result are discussed as an Appendixes

2. LITERATURE REVIEW

2.1. Theoretical Review

2.1.1. Geotextile Definition and Function

Reinforcement are the geotextile interacts with soil through frictional or adhesion forces to resist tensile or shear forces. To provide reinforcement, geotextile must have enough strength and embedment length to resist the tensile force generated and the strength must be developed at sufficiently small strains to prevent excessive movement of reinforced structure. Both woven and nonwoven geotextiles can be used in the reinforcement functional application, although geo grids another type. This application is particularly suited for rehabilitation of embankment dams, especially in the raising of dams or in increasing the slope on an existing dam. In this case the geotextile used as reinforcement for new dam. In addition, Soil reinforcement can be defined as a technique to improve the engineering characteristics of soil. The method improves the soil response by interaction between soil and inclusive reinforcing materials. The improving method depends on the life of inclusive reinforcing materials. State of soil is not changed in this method and it is widely used method for many types of soils. Soil reinforcement can consist of stone columns, root piles or micro-piles, soil nailing and reinforced earth. Mainly, reinforced earth is a composite material consisting of alternating layers of compacted backfill and man-made reinforcing material. So, the primary purpose of reinforcing soil mass is to improve its stability, to increase its bearing capacity and to reduce settlements and lateral deformations. (Kumar, 2018,) Systematically reinforced soil is a soil reinforced with geo-synthetics (woven geotextile/ geo-grid/ geo composite sheets or strips of galvanized steel in desired directions and is currently widely used in civil engineering practice. The reinforcement can easily be handled, stored and installed. The soil that constitutes most of its bulk may be locally available and can be placed in position in limited time in an economical way by modern hauling and compaction equipment. The flexible nature of reinforced soil mass enables it to withstand vibrations caused by earthquake and large differential settlements without significant distress. Systematically reinforced soil thus permits construction of geotechnical structures over poor and difficult sub-soil conditions. (PODIW, 2012)

Geotextiles are a permeable geo-synthetics comprised exclusively of textiles (ASTM, 2005). Geotextiles perform a variety of geotechnical engineering functions and are used for a variety of both critical and noncritical applications in all aspects of Civil Engineering design on a large number of dams worldwide (Zornberg, 2008).

Geotextiles are a direct link to technical textiles or typical products of the textile industry. In fact the first geotextiles were textiles manufactured for purposes other than geotechnical applications. Geotextile are textiles are but they consist of synthetic fiber rather than natural ones such as cotton, wool, or silk. Thus biodegradation and subsequent short time is not a problem in geotextile, not susceptible to corrosion have relative low stiffness and flexible enough to tolerate large deformation. Woven and non-woven Geotextiles are the most common type. Geotextiles are polymer fabrics used in the construction of roads, drains and breakwaters, and for land reclamation and many other civil engineering purposes.

Geotextiles are a kind of geo-synthetics material that has become more and more popular over the past years. The material be obligated its success in more than 80 applications to a significant extent to its resistance to biodegradation (Zornberg, 2008). Geotextiles are certainly textiles, however not in the traditional sense of the word. Geotextiles are synthetic fibers that can be made into a flexible, porous, nonwoven needle felt fabric. Geotextile polymers are predominantly polypropylene (PP) (95% at present), polyester (PET) and polyethylene (PE) with some geotextiles (nonwovens) using combinations of polymers. Nylon (polyamide) is used to a lesser extent.

Geotextile structures are classified in different group depend on their material content:

2.1.2. Nonwoven Geotextiles

Geotextiles formed with continuous or short fibers arranged in random directions and then bonded together into a planar structure which can include the following:

- Nonwoven Mechanically Needle punched
    - Continuous Filament Fiber
    - Staple Fiber (short fibers)
    - Nonwoven Heat Set

- Continuous Filament Fiber

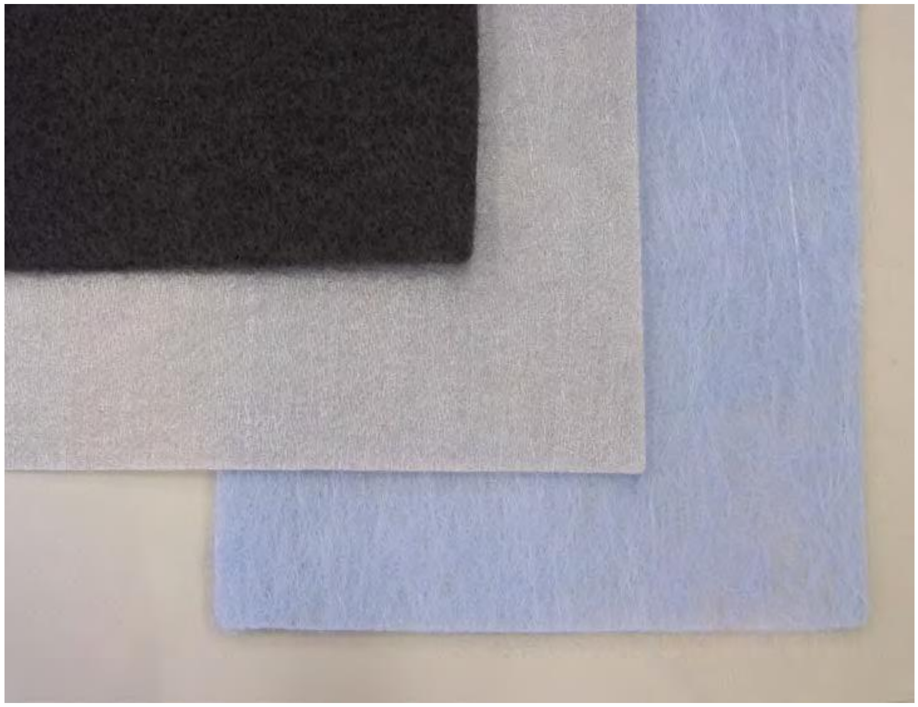


Figure 1. showing examples of nonwoven geotextiles

2.2. Woven Geotextiles

Geotextiles composed of two sets of parallel yarns or tapes systematically interlocked to form a planar structure which can include the following:

- Multifilament woven
- Monofilament woven
- Slit Film woven

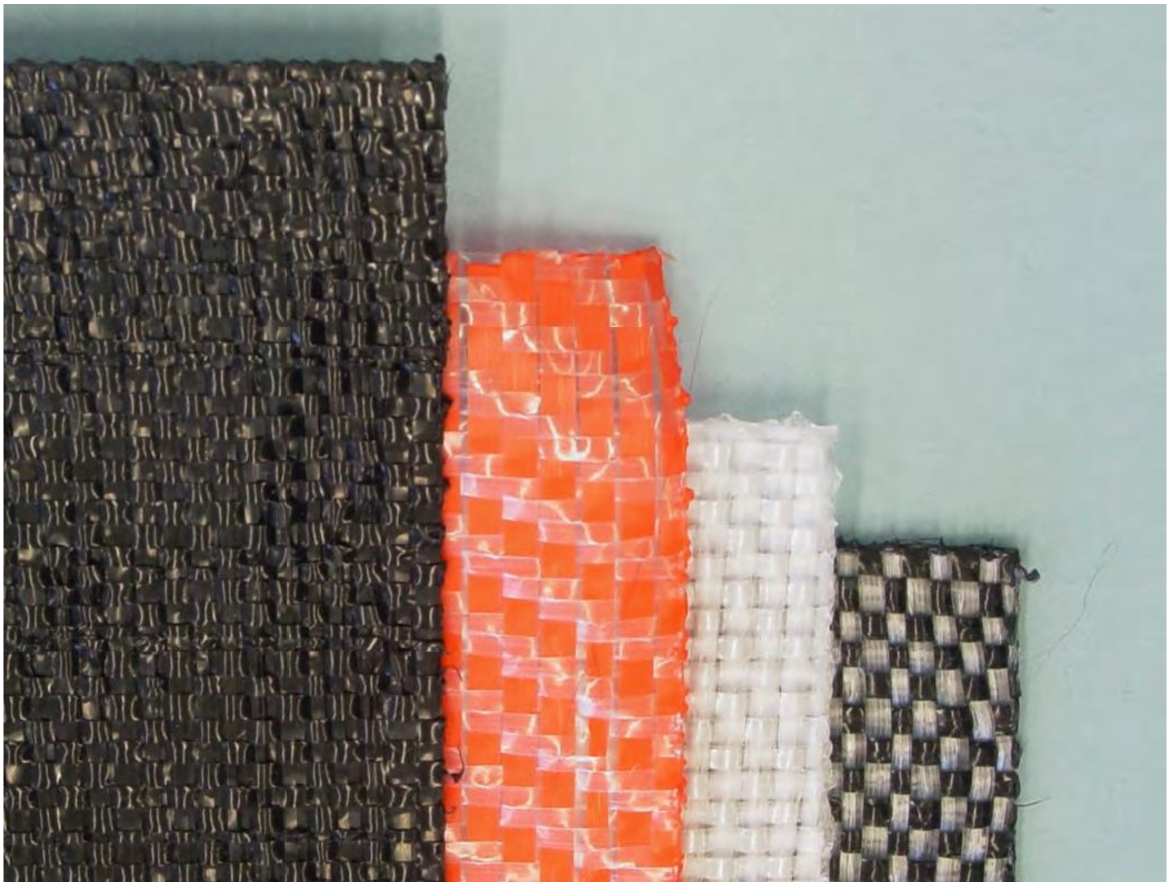


Figure 2: showing examples of woven geotextiles.

2.3. Knitted Geotextiles

- Geotextiles formed by interlocking a series of loops of one or more yarns to form a planar structure. Knitted geotextiles are a subset to woven geotextiles and are found mostly as filters on pipes as in two stage filter applications.
- Multilayer Geotextiles are formed by bonding together several layers of fabrics which can be layers of nonwovens or layers of woven and nonwovens to form a geotextile that could be a high strength filter geotextile or a high thick protection geotextile.

2.4. Function of geotextiles

The functions of all geo-synthetics in Dam Construction were briefly discussed. It should be noted that with the exception of the liquid barrier function, geotextiles are shown as a possible choice to fulfill all other functions. It is important from a designer's point of view to know what the functional application is and where it can be used relative to embankment dams in order to consider a geotextile for use in a particular function. Geotextile performs one or more functions such as filtration, drainage, separation, erosion control, sediment control and reinforcement. In any one application geotextile may be performing several of these functions.

Filtration: - geotextile placed in contact with and down gradient of soil to be drained. The plane of the geotextile is normal to the expected direction of water flow. Long term blockage is a concern when geotextiles are used for filtration. Geotextiles are an ideal interface for reverse filtration in the soil adjacent to the geotextile. In all soils water allows fine particles to be moved. Part of these particles will be stopped at the filter interface; some will be stopped within the filter itself while the rest will pass into the drain. The complex needle-punched structure of the geotextile allows the retention of fine particles without reducing the permeability of the drain.

Drainage: at this case geotextile acts as conduit for the movement of liquids in the plane of the geotextile. Geotextiles will efficiently collect excessive water from structures, such as rainwater or extra water, from the soil and discharge it.

Figure 3: Geotextile use for drainage

Erosion control: the geotextile protects soil surface from the tractive forces of moving water or wind and rainfall erosion.

Sediment control: Geotextile serves to control sediment when it stopes particles suspended in surface fluid flow while allowing the fluid to pass through.

Separation: Geotextiles will prevent two soil layers of different particle sizes from mixing with each other, as is illustrated the image below.

Figure 4: geotextile use as separation

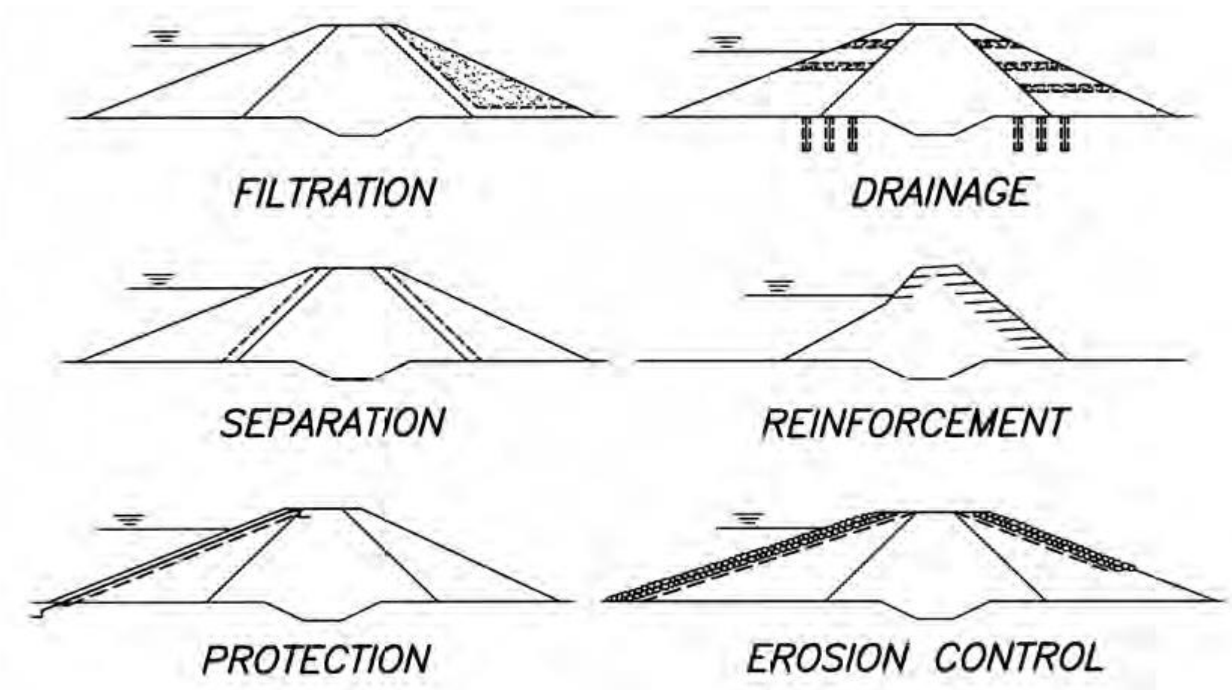


Figure 5: Examples of some of the functions of geotextiles in dams.

2.5. Theories of Reinforced Soil

A reinforced soil mass is somewhat similar to reinforced concrete in that the mechanical properties of the mass are improved by reinforcement placed parallel to the principal strain direction to compensate for soil's lack of tensile resistance. The improved tensile properties are a result of the interaction between the reinforcement and the soil. The composite material has the following characteristics:

Stress transfer between the soil and reinforcement takes place continuously along the reinforcement. Reinforcements are distributed through the soil zone with a degree of consistency and limited to a small area.

2.6. Advantage of Reinforced Soil

Reinforced soil is very cost effective technique compared to other construction techniques. The major benefit of reinforced soil is:

- The inclusion of reinforcement in soil improves the shear resistance of the soil thereby improving its structural capability.

- The inclusion of reinforcement enables the use of poorer quality soils to be used as structural components.
- Land acquisition can be kept a minimum because reinforced structures can be made steeper than unreinforced soil.
- Construction time can be reduced when reinforced soil techniques are used.
- Decrease the construction cost

2.7. Disadvantages of Reinforced Soil

The below general disadvantages may be associated with all reinforced soil structures, and are dependent upon local and project conditions:

- Require the use of select granular fill.
- The design of soil-reinforced systems often requires a shared design responsibility between material suppliers and owners.

2.7.1. IMPORTANT CHARACTERISTICS OF GEOTEXTILES

2.7.2. The characteristics of geotextiles are broadly classified as:

1. **Physical properties:**

a) Specific gravity
b) Weight
c) Thickness
d) Stiffness
e) Density.

2. **Mechanical properties**:

a) Tenacity (Persistence)
b) Tensile strength
c) Bursting strength
d) Compatibility
e) Flexibility
f) Tearing strength
g) Frictional resistance

3. **Hydraulic properties:**

a) Porosity

b) Permeability

c) Permittivity

d) Transitivity

e) Turbidity /soil retention

f) Filtration length etc.

4. **Degradation properties:**

a) Biodegradation

b) Hydrolytic degradation

c) Photo degradation

d) Chemical degradation

e) Mechanical degradation

f) Other degradation occurring due to attack of rodent, termite etc.

5. **Endurance properties:**

a) Elongation

b) Abrasion resistance

c) Clogging length and flow etc.

2.7.3. Selection of fiber for geotextile

Different fibers from both natural as well as synthetic category can be used as geotextiles for various applications (B.V.M. Engineering College, V.V.Nagar, Gujarat,India)

Natural fibers: Natural fibers in the form of paper strips, jute nets, wood shavings or wool covering are being used as geotextiles. In certain soil reinforcement applications, geotextiles have to serve for more than 100 years. But bio-degradable natural geotextiles are deliberately manufactured to have relatively short period of life. They are generally used for prevention of soil erosion until vegetation can become properly established on the ground surface. The commonly used natural fires are –

- **Ramie:** These are subtropical cover fibers, which are obtained from their plants 5 to 6 times a year. The fibers have silky luster and have white appearance even in the unbleached condition. They constitute of pure fiber and possess highest resolve among all plant fibers.

- **Jute:** This is a versatile vegetable fiber which is biodegradable and has the ability to mix with the soil and serve as a nutrient for vegetation. Their quick biodegradability becomes weakness for their use as a geotextile. However, their life span can be extended even up to 20 years through different treatments and blending. Thus, it is possible to manufacture designed biodegradable jute geotextile, having specific tenacity, porosity, permeability, transmissibility according to need and location specificity. Soil, soil composition, water, water quality, water flow, landscape etc. physical situation determines the application and choice of what kind of jute geotextiles should be used. In contrast to synthetic geotextiles, though jute geotextiles are less durable but they also have some advantages in certain area to be used particularly in agro-mulching and similar area to where quick consolidation are to take place. For erosion control and rural road considerations, soil protection from natural and seasonal degradation caused by rain, water, monsoon, wind and cold weather are very important parameters. Jute geotextiles, as separator, reinforcing and drainage activities, along with topsoil erosion in shoulder and cracking are used quite satisfactorily. Furthermore, after degradation of jute geotextiles
- **Synthetic Fibers:** The four main synthetic polymers most widely used as the raw material for geotextiles are – polyester, polyamide, polyethylene and polypropylene. The oldest of these is polyethylene which was discovered in 1931 by ICI. Another group of polymers with a long production history is the polyamide family, the first of which was discovered in 1935. The next oldest of the four main polymer families relevant to geotextile manufacture is polyester, which was announced in 1941. The most recent polymer family relevant to geotextiles to be developed was polypropylene, which was discovered in 1954.
- **Polyamides (PA):** There are two most important types of polyamides, namely Nylon 6 and Nylon 6, 6 but they are used very little in geotextiles. These are manufactured in the form of threads which are cut into granules. They have more strength but less

moduli than polypropylene and polyester they are also readily disposed to to hydrolysis.

- **Polyesters (PET):** Polyester is synthesized by polymerizing ethylene glycol with dimethyl terephthalate or with terephthalic acid. The fiber has high strength modulus, creep resistance and general chemical inertness due to which it is more suitable for geotextiles. It is attacked by polar solvent like benzyl alcohol, phenol, and meta-cresol. At pH range of 7 to 10, its life span is about 50 years. It holds high resistance to ultraviolet radiations. However, the installation should be undertaken with care to avoid unnecessary exposure to light.
- **Polyethylene (PE):** Polyethylene can be produced in a highly crystalline form, which is an extremely important characteristic in fiber forming polymer. Three main groups of polyethylene are – Low density polyethylene (LDPE, density 9.2-9.3 g/cc), Linear low density polyethylene (LLDPE, density 9.20-9.45 g/cc) and High density polyethylene (HDPE, density 9.40- 9.6 g/cc).
- **Polypropylene (PP):** Polypropylene is a crystalline thermoplastic produced by polymerizing propylene monomers in the presence of stereo-specific Zeigler-Natta catalytic system. Homo-polymers and copolymers are two types of polypropylene. Homo polymers are used for fiber and yarn applications whereas co-polymers are used for varied industrial applications. Propylene is mainly available in granular form. Both polyethylene and polypropylene fibers are creep prone due to their low glass transition temperature. These polymers are purely hydrocarbons and are chemically inert. They swell by organic solvent and have excellent resistance to diesel and lubricating oils. Soil burial studies have shown that except for low molecular weight component present, neither HDPE nor polyethylene is attacked by micro-organisms.
- **Polyvinyl chloride (PVC):** Polyvinyl chloride is mainly used in geo membranes and as a thermos plastic coating materials. The basic raw materials utilized for production of PVC is vinyl chloride. PVC is available in free- flowing powder form.
- **Ethylene copolymer Bitumen (ECB):** Ethylene copolymer bitumen membrane has been used in civil engineering works as sealing materials. Production, the raw materials used are ethylene and butyl acrylate (together forming 50-60%) and special bitumen (40-50%).

- **Chlorinated Polyethylene (CPE):** Sealing membranes based on chlorinated poly ethylene are generally manufactured from CPE mixed with PVC or sometimes PE. The properties of CPE depend on Quality of PE and degree of chlorination.

2.8. Usage of Reinforced Soil Slopes

Reinforced soil slopes are a form of mechanically stabilized earth that incorporate planar reinforcing elements (typically geosynthetics) in constructed earth sloped structures. Multiple layers of reinforcement are placed in the slope during construction or reconstruction to reinforce the soil and provide increased slope stability. Reinforced soil structures are cost-effective alternatives for new construction and reconstruction where the cost of fill, right-of-way, and other considerations may make a steeper slope desirable. Reinforcement is used to construct an embankment at an angle steeper than could otherwise be safely constructed with the same soil. The increase in stability allows for construction of steepened slopes on firm foundations for new highways and as an alternative to flatter unreinforced slopes and to retaining walls. The second purpose for using reinforcement is at the edges of a compacted fill slope to provide lateral resistance during compaction. The increased lateral resistance allows for an increase in compacted soil density over that normally achieved and provides increased lateral confinement for the soil at the face. Even modest amounts of reinforcement in compacted slopes have been found to prevent sloughing and reduce slope erosion. Edge reinforcement also allows compaction equipment to more safely operate near the edge of the slope. Further compaction improvements have been found in cohesive soils through the use of geosynthetics with in-plane drainage capabilities (e.g., nonwoven geotextiles) that allow for rapid pore pressure dissipation in the compacted soil. Compaction aids placed as intermediate layers between reinforcement in steepened slopes may also be used to provide improved face stability and to reduce layers of more expensive primary reinforcement.

Another applications of reinforced slopes are:

- Decreased Bridge spans.
- Temporary road widening for detours
- Prevention of surface sloughing during periods of saturation.
- Embankment building with wet, fine-grained soils.

- Permanent barriers.
- Temporary flood control structures.

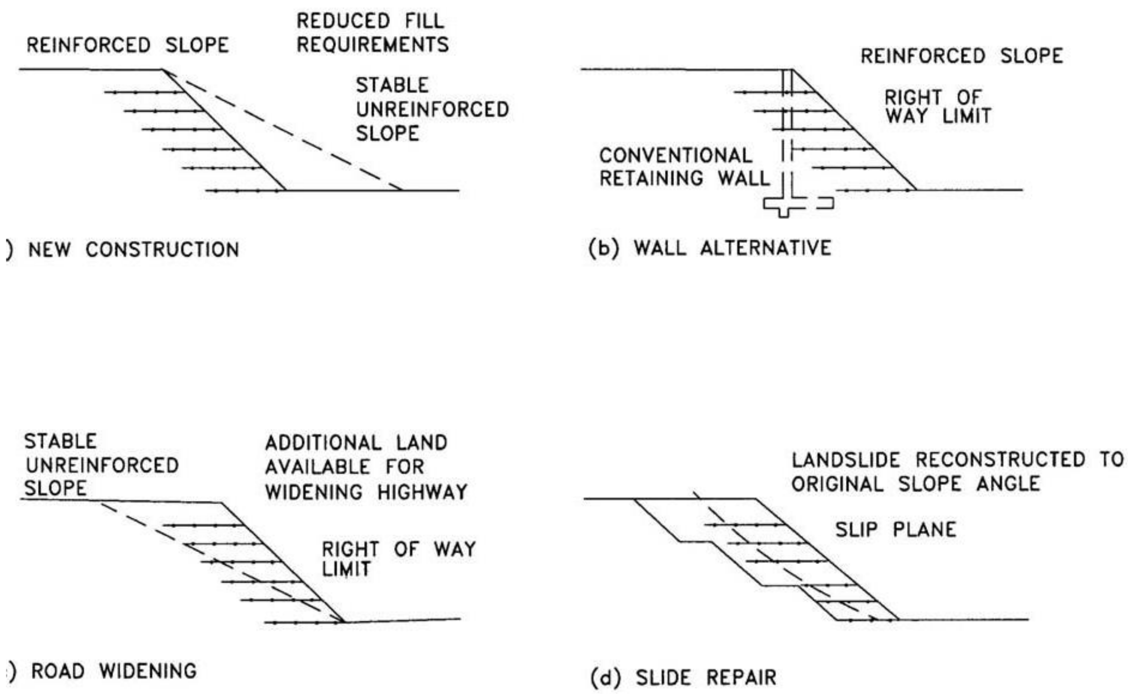


Figure 6. Use of reinforced soil slopes.

2.9. Reinforced geotextile and Embankments

Geosynthetics have played a major role in solving various complex civil engineering problems. Being a polymer product, it is durable and provides good strength. Geosynthetics are generally designed for a particular application. Geotextiles are widely used in various engineering projects to perform one or more of their recognized functions (Zornberg, 2008). The principal functions of geosynthetics are filtration, drainage, separation, reinforcement protection, and erosion control. The most common uses of geosynthetics in earth dams are:

- As a separator/filter between embankment material and a layer of riprap placed on the upstream slope or in a downstream discharge area.
- As a filter zone between riprap used to line watercourses and the underlying foundation soils.

Soil can resist pressure and shear forces very well, but it is not able to tolerate tensile forces. Reinforced soil is composite material that contains components that can easily stand tensile forces. Nowadays, reinforcing materials are widely used to overcome technical problems. Reinforced soil is used in stabilizing embankment (slope), fill dams, retaining walls, foundation and in-situ slope for increasing the shear resistance of soil layer in different earth structures.

Soil Reinforcement is a technique where tensile elements are placed in soil to improve stability and control deformation. To be effective, the reinforcement must intersect the potential failure surface in the soil mass. Strains in the soil mass generate strains in the reinforcement, which in turn, generate tensile loads in the reinforcement. These tensile loads act to resist soil movements and thus impart additional shear strength. This results in composite soil reinforcement system having significantly greater shear strength than soil mass alone. Reinforced soil is very cost effective technique compared to other construction techniques. Literature clearly established that the reinforced soil technique provides cost effective solution with lesser construction period and higher stability of the completed structure.A great number of reinforced soil structures, particularly for retaining walls, for railways and highways has been constructed in recent parts and showed successful performance even in the seismic loading condition. It is also recognized that the technology is useful to reinforce and rehabilitate soil structures to have higher stability, rainfall and water flow as well.

The adoption of soil reinforcement technology is found to be highly efficient in terms of ensuring stability and it is also very cost effective. The conventional method of embankment dams to a stable slope for a given height may involve considerable expenses in construction material, construction equipment, construction time and extension to the base area of embankment dam. However, these issues can be minimized using appropriate solutions. One of the solutions to this issue is to make the dam slopes much steeper than obtained by conventional design procedure. The slopes of embankment dam can be made steeper by reinforcing them with suitable reinforcing material. Reinforcement has been used in four different types of applications (Duncan, 2005):

- *Reinforced soils.* Multiple layers of reinforcement at various elevations within fill slopes have been used to increase the factor of safety for slip surfaces that cut through the Reinforcement, making it possible to construct slopes steeper than would be possible without reinforcement.
- *Reinforced embankments on weak foundations.* Reinforcement at the bottom of an embankment on a weak foundation can increase the factor of safety for slip surfaces passing through the embankment, making it possible to construct the embankment higher than would be possible without reinforcement.
- *Reinforced soil walls or mechanically stabilized earth walls.* Several different branded systems have been developed for reinforced soil walls, which are used as alternatives to conventional retaining walls.
- *Anchored walls.* Vertical soldier pile walls or slurry trench concrete walls can be tied back or anchored at one or more levels to provide vertical support for excavations or fills. Anchored walls have been used in both temporary and permanent applications.

2.10. Structure Selection Factor

The major factors that influence the selection of reinforced soil structure another for any project include: Geologic and topographic conditions, Environmental conditions, Size and nature of the structure, Aesthetics, Durability considerations, Performance criteria, Availability of materials, Experience with a particular system or application, Cost . Some manufacturers of geotextile reinforcement are provide services including design assistance, preparation of plans and specifications for the structure, supply of the manufactured wall components, and construction assistance.

The various reinforced systems have different performance histories, and this sometimes creates difficulty in adequate technical evaluation. The selection of the most appropriate system will thus depend on the specific project requirements.

Reinforced embankments have been constructed with a variety of geosynthetics reinforcements and treatments of the slope face. These factors again may create an initial difficulty in adequate technical evaluation, but with the use of this manual easily addressed by department personnel to prepare generic designs.

Specific technical issues focused on selection factors are discussed in the following sections.

2.10.1. Evaluation of Pullout Performance

The design of the soil reinforcement system requires an evaluation of the long-term pullout performance with respect:

- Pullout capacity: - the pullout resistance of each reinforcement should be adequate to resist the factored tensile force in the reinforcement with a specified resistance factor (or factor of safety in the case of reinforced soil).
- Allowable displacement: - the relative soil-to-reinforcement displacement required to mobilize the design tensile force should be smaller than the allowable displacement.
- Long-term displacement: - the pullout load should be smaller than the critical creep load.

The pullout resistance of the reinforcement is mobilized through one or a combination of the two basic soil-reinforcement interaction mechanisms, interface friction and reflexive soil resistance against transverse elements of reinforcements such as bar mats, wire meshes, or geo-grids. The load transfer mechanisms mobilized by a specific reinforcement depends primarily upon its structural geometry (i.e., composite reinforcement such as grids, versus linear or planar elements, thickness of transverse elements, and aperture dimension). The soil-to-reinforcement relative movement required to mobilize the design tensile force depends mainly upon the load transfer mechanism, the extensibility of the reinforcement material, the soil type, and the confining pressure.

The long-term pullout performance (displacement under constant design load) is predominantly controlled by the creep characteristics of the soil and the reinforcement material. Soil reinforcement systems will generally not be used with cohesive soils susceptible to creep. Therefore, creep is primarily controlled by the type of reinforcement. Pullout performance in terms of the main load transfer mechanism, relative soil-to reinforcement displacement required to fully mobilize the pullout resistance.

2.10.2. Durability of geotextiles in embankment dams

The design engineers of embankment dams are traditionally very conservative in their design and the materials used in construction of the dam. To this end, geosynthetics and geotextiles in particular have not played a prominent role in most embankment dam design and rehabilitation. There are two primary reasons for this: Education and Longevity (Durability). Education is ongoing and the design of structures with geosynthetics is becoming routine and accepted with many educational institutions and texts available that are devoted to design practice (Koerner, 2005a). But what about the durability of geotextiles in structures such as embankment dams that should last well over 100 years?

Polymeric materials undergo a gradual deterioration in properties over time due to a variety of known ageing mechanisms resulting in molecular level bond breaking, cross-linking or simple extraction of components. The below mechanisms are fully described in detail in Van Zanten (1986) and Koerner (2005a):

- Ultraviolet degradation due to sunlight
- High temperature degradation
- Oxidation degradation
- Hydrolysis degradation
- Chemical degradation
- Radioactive degradation
- Biological degradation

It must be emphasized that geotextiles buried in embankment dams are protected from exposure to the elements, and from to many environmental degradation mechanisms including damaging effects of UV, high temperatures or even temperature fluctuation and accelerated oxidation due to exposure (thermo-oxidation and photo-oxidation). Hydrolysis degradation (chemical decomposition by addition of water) is associated with extremes of pH which are usually not a problem unless immediate contact with concrete is anticipated (alkaline environment) or the dam is a investigations dam or water containment dam that may be exposed to acidic impoundment solutions, and then this only affects geotextiles. Chemical and radioactive degradation are usually associated with waste containment applications and is not a consideration in buried soil environments such as internal to a dam. Biological degradation is also not generally associated with geotextiles other than by biological clogging which will occur in some soil environments but which does not degrade the polymer. The long-term performance of geosynthetics in dams has been demonstrated by over 45 years of historical use (Koerner, 2005).One key point to remember is that geosynthetics, and geotextiles in particular, must be treated as any other construction material used in civil engineering in that their strengths and weaknesses must be recognized and be properly addressed in design and construction. Geotextiles have been used as the sole method of providing filtration and drainage for some dam embankments constructed in France, Germany, and other foreign countries.

2.10.3. Environmental Conditions

The primary environmental condition affecting reinforcement type selection and potential performance of geotextile reinforcement structures is the aggressiveness of the in-situ ground regime that can cause deterioration to the reinforcement. Post construction changes must be considered where melting salts or fertilizers are subsequently used.

A secondary environmental issue is site accessibility. Sites with poor accessibility or remote locations may lend themselves to lightweight facings such as geotextile or geogrid wrapped facings and vegetative covers; welded wire mesh, gabions, modular blocks which could be erected without heavy lifting equipment.

2.10.4. Reinforced Fill Soil

The selection criteria of reinforced fill should consider long-term performance of the completed structure, construction phase stability and the degradation environment created for the reinforcements. Much of engineering communities' knowledge and experience to date has been with select, cohesion less backfill. Hence, knowledge about internal stress distribution, pullout resistance, and failure surface shape is constrained and influenced by the unique engineering properties of these soil types. Granular soils are ideally suited. Many agencies have adopted conservative reinforced fill requirements for both walls and slopes. These conservative properties are suitable for inclusion in standard specifications or special provisions when project specific testing is not feasible and when the quality of construction control and inspection may be in question.

In general, these select reinforced fill materials will be more expensive than lower quality materials. The specification criteria for each application (walls and slopes) differ somewhat primarily based on performance requirements of the completed structure (allowable deformations) and the design approach.

2.10.5. Mode of Reinforcement Action

The primary function of reinforcements is to contain soil deformations. In so doing, stresses are transferred from the soil to the reinforcement. These stresses are resisted by the reinforcement tension and/or shear and bending.

Tension is the most common mode of action of tensile reinforcements. A “longitudinal" reinforcing elements (i.e., reinforcing elements aligned in the direction of soil extension) are generally subjected to high tensile stresses. Tensile stresses are also developed in flexible reinforcements that cross shear planes.

Shear and Bending. "Sloping" reinforcing elements that have some rigidity, can
With stand shear stress and bending moments.

2.10.6. Formal Characteristics

Two types of formal characteristics can be considered:

Strips, bars, and steel grids. A layer of steel strips, bars, or grids is characterized by the cross-sectional area, the thickness and perimeter of the reinforcement element, and the center-to-center horizontal distance between elements (for steel grids, an element is considered to be a longitudinal member of the grid that extends into the wall).

Geotextiles and geogrids. A layer of geosynthetics strips is characterized by the width of the strips and the center-to-center horizontal distance between them. The cross-sectional area is not needed, since the strength of a geo-synthetics strip is expressed by a tensile force per unit width, rather than by stress. Difficulties in measuring the thickness of these thin and relatively compressible materials check reliable estimates of stress.

2.11. Strength Properties of Geo-Synthetics Reinforcement

Selection of long-term nominal tensile strength, for geo-synthetics reinforcement is determined by thorough consideration of all possible strength time dependent strength losses over the design life period. The tensile properties of geo-synthetics are affected by factors such as creep, installation damage, aging, temperature, and confining stress. Furthermore, characteristics of geo-synthetics products manufactured with the same base polymer can vary widely requiring determination for each individual product with consideration of all these factors.

Polymeric reinforcement, although not susceptible to corrosion, may degrade due to physicochemical activity in the soil such as hydrolysis, oxidation, and environmental stress cracking depending on polymer type. In addition, these materials are susceptible to installation damage and the effects of high temperature at the facing and connections. Temperature acts to accelerate creep and aging processes and temperature effects are accounted for through their determination. While the normal range of in-ground temperature vary from 55o F (12o C) in cold and temperate climates to 85o F (30o C) in dry desert climates, temperatures at the facing and reinforcement connections can be as high as 120o F (50o C). Confining stress is not directly taken into account other than indirectly when installation damage is evaluated. For creep and durability, confining stress generally will tend to improve the long-term strength of the reinforcement.

The determination of reduction factors for each geo-synthetics product and product line requires extensive field and/or laboratory testing which can take a year or more to complete. Polymeric reinforcement, although not susceptible to corrosion, may degrade due to physicochemical activity in the soil such as hydrolysis, oxidation, and environmental stress cracking depending on polymer type. In addition, these materials are susceptible to installation damage

- Tult = Ultimate Tensile Strength (strength per unit width). The tensile strength of the reinforcement is determined from wide strip tests per ASTM D4595 (geotextiles) or D6637 (geo-grids) based on the minimum average roll value (MARV) for the product.
- RF = Reduction Factor. The product of all applicable reduction factors.

- RFID = Installation Damage Reduction Factor. A reduction factor that accounts for the damaging effects of placement and compaction of soil or aggregate over the geo-synthetics during installation. A minimum reduction factor of 1.1 should be used to account for testing uncertainties.
- RFCR = Creep Reduction Factor. A reduction factor that accounts for the effect of creep resulting from long-term sustained tensile load applied to the geo-synthetics.
- RFD = Durability Reduction Factor. A reduction factor that accounts for the strength loss caused by chemical degradation (aging) of the polymer used in the geo-synthetics. Much of the long-term strength loss does not begin to occur until near the end of the reinforcement design life. Because of varying polymer types, quality, additives and product geometry, each geo-synthetics is different in its resistance to aging and attack by different chemical agents.

Therefore, each product must be investigated individually, or in the context of product line where the same polymer source and additives are used, and the manufacturing process is the same for all products in the product line. This product line approach makes it possible to interpolate reduction factors for products in the product line not specifically tested using the reduction factors determined for the products in the product line that are specifically tested for each degradation mechanism.

2.11.1. Geo-synthetics Reinforcement Resistance Factor

The resistance factor for geo-synthetics reinforcement accounts for potential of local overstress due to load non uniformity and uncertainties in long-term reinforcement strength. For strength limit state conditions, a resistance factor equal to 0.90 is used for geosynthetics reinforcements (Koerner, 2005).

2.11.2. Ultimate Tensile Strength, Tult

The value selected for Tult, for design purposes, is the minimum average roll value (MARV) for the product. This minimum average roll value, accounts for statistical variance in the material strength. Other sources of uncertainty and variability in the long-term strength result from installation damage, creep extrapolation, and the chemical degradation process.

It is assumed that the observed variability in the creep rupture envelope is 100% correlated with the short-term tensile strength, as the creep strength is typically directly proportional to the short-term tensile strength within a product line. Therefore, the MARV of Tult adequately takes into account variability in the creep strength. Note that the MARV of Tult is the minimum certifiable wide width tensile strength provided by the product manufacturer.

2.11.3. Installation Damage Reduction

Damage during handling and construction, such as from abrasion and wear, punching and tear or scratching, notching, and cracking may occur in geo-synthetics. These types of damage can only be avoided by using care during handling and construction. Construction equipment should not travel directly on geo-synthetics materials.

Damage during reinforced fill placement and compaction operations is a function of the severity of loading imposed on the geo-synthetics during construction operations and the size and angularity of the reinforced fill. (Elias et al., 2009) and in ASTM D-5818.

2.11.4. Creep Reduction Factor

The creep reduction factor is required to limit the load in the reinforcement to a level known as the creep limit, which will prevent excessive elongation and creep breach over the life of the structure. The creep limit strength is thus equivalent to yield strength in steel. Creep is essentially a long-term deformation process. As load is applied, molecular chains move relative to each other through straightening out of folded or curved chains or through breaking of inter-molecular bonds, resulting in no strength loss.

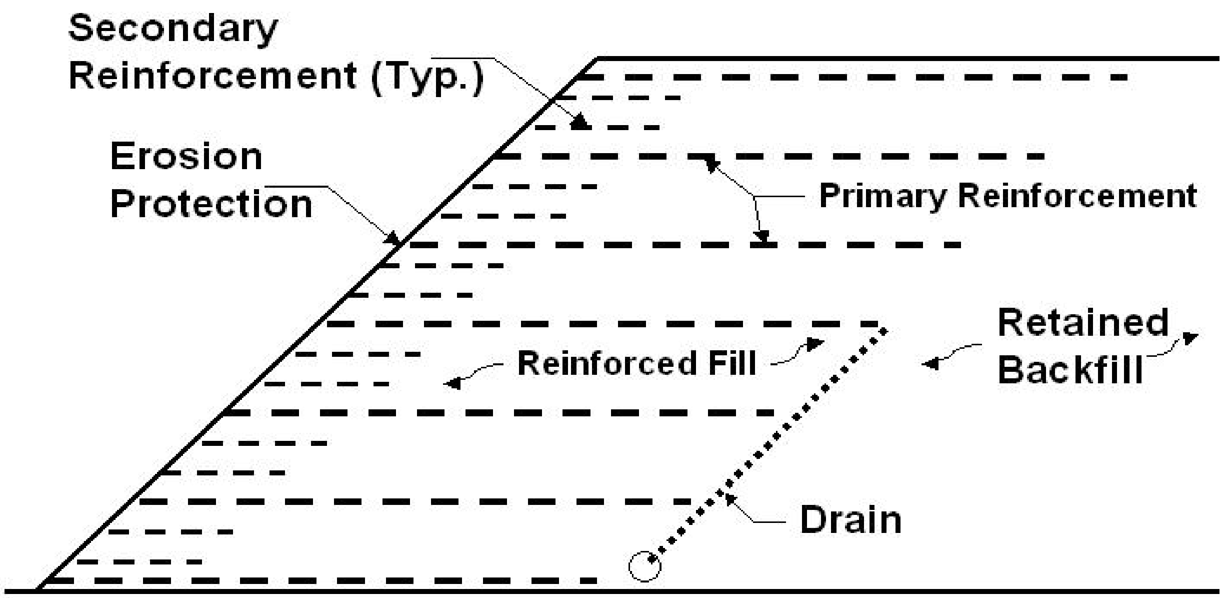


Figure 7: Generic cross sections of reinforced slope structures,

2.11.5. Select Types of Soil Reinforcement

Soil reinforcements are either inextensible it is mostly metallic or extensible it is mostly polymeric materials.

The current method of limit equilibrium analysis uses a coherent gravity structure approach to determine external stability of the reinforced mass, similar to the analysis for any conventional or traditional gravity structure. For internal stability evaluations, it considers a bi-linear failure surface that divides the reinforced zone in active and resistant zones and requires that an equilibrium state be achieved for successful design. The lateral earth pressure distribution for external stability, is assumed to be based on Coulomb's method with a wall friction angle assumed to be zero. For external stability calculations, the current method assumes an earth pressure distribution, consistent with the method used for inextensible reinforcements. For internal stability computations using the *simplified method*, the internal coefficient of earth pressure is again a function of the type of reinforcement, where the minimum coefficient is used for walls constructed with continuous sheets of geotextiles and geogrids(FHWA RD 89-043). For internal stability, a Rankine failure surface is considered, because the extensible reinforcements can elongate more than the soil, before failure, and do not significantly modify the shape of the soil failure surface.

2.12. Fundamentals of Limit Equilibrium Analysis with Concentrated Lateral Loads

An important concept that needs to be fully comprehended is that all reinforcement fundamentally is a concentrated point load in a limit equilibrium formulation. The concentrated point loads act on the free body, which is the potential sliding mass, and must therefore be included in the moment and force equilibrium equations.

Reinforced slopes can be analyzed using limit equilibrium procedures by including the reinforcement forces in the analyses as known forces. (Zoernberg) The effect of reinforcement can conceptually act immediately or develop with some strain. A pre-stressed anchor, for example, acts immediately. The force is induced by the pre-stressing. The force in a geofabric (geotextile), on the other hand, may develop over time during construction and during stress re-distribution upon completion of the construction (Hoek, 1974). In other words, the reinforcement forces are mobilized in response to damaging in the same way that the soil strength is mobilized as the soil strains. Two methods have been used for limit equilibrium analyses of reinforced slopes (Duncan, et al., 2005).

- *Method A.* The reinforcement forces used in the analysis are *allowable* forces and *are not divided* by the factor of safety calculated during the slope stability analysis. Only the soil strength is divided by the factor of safety calculated in the slope stability analysis.
- *Method B.* The reinforcement forces used in the analysis are ultimate forces, and are divided by the factor of safety calculated in the slope stability analysis. Both the reinforcing force and the soil strength are divided by the factor of safety calculated in the slope stability analysis. When a computer program is used to analyze reinforced slopes, it is essential to understand which of these methods is being used within the program, so that the appropriate measure of reinforcing force (allowable force or ultimate force) can be specified in the input for the analysis.

2.13. Function of Geo-grid as of reinforcement

Geo-grid is one of the type of geo-synthetics product and also use in the same application area of geotextile reinforcement.

To ensure that the amount of fill material was minimized, a reinforced earth solution was proposed to achieve a steep slope and assist in reducing the overall footprint of the structure.as well as the geo-grid ensure the sustainability of the dam during earth quakes. In addition, in some literature it used for earth dam heightening. (**M.De La Torre -** *Management, Geo-service, Lima, Per.***V.Garga —** *Professor, Department of Civil Engineering, Ottawa University, Canad.)*By using the geo-grid in the slopes under embankment dam, the safety factor is improved then the slope angles of the earth dam are increased and the dam embankment volume is decreased.

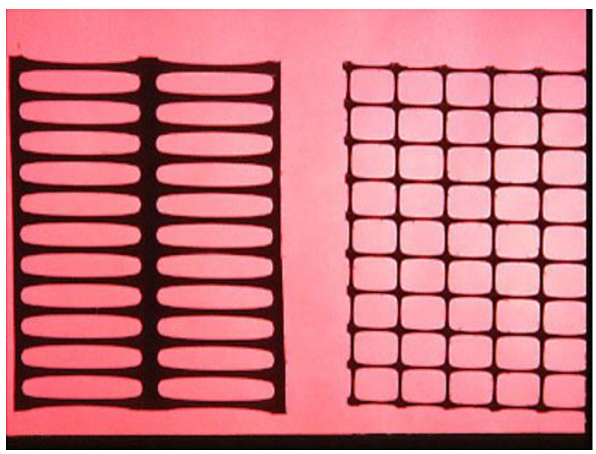


Figure 8a: Used for soil reinforcement **Figure 8b:**geo-grid picture

Figure 9: Embankment works, revised fill, impact on geogrid reinforcement

2.14. Functions of Geotextiles in Embankment Dams

Geotextiles are widely used in various engineering projects to perform one or more of their recognized functions. The principal functions of geotextiles are filtration, drainage, separation, reinforcement protection, and erosion control. The use of geotextiles in embankment dams has been in limited applications, largely in secondary roles where failure of the geotextile would not expose the safety of the dam nor present a situation that would be difficult or costly to repair.

Geotextiles have been used in many applications as components in the design and construction of embankment dams. These products have been used more frequently in repair of existing dams where dam safety concerns mandate rapid construction. In the construction of new dams, particularly in the United States, geotextiles are usually a secondary or composite component in combination with natural materials. Geotextiles have been substituted for natural materials in dams by some practitioners when the availability or expense of natural aggregates makes them impractical.

Geotextiles have been considered for the following functions in various design applications associated with dams:

• Filtration, Drainage Conveyance, Separation, Protection, Reinforcement, Surface Erosion Control.

Geotextiles have been used more frequently as a separator function for drainage aggregates or riprap and far less frequently as traditional filter/drainage applications in dams. Another common application is in soil reinforcement or to improve the slope stability of an embankment. Geotextiles in general are gaining wider acceptance in many applications in dams and some dam designers (Hollingworth and Druyts, 1982), (Biche, 1987), (Cazzuffi, 2000), (Legge, 2004), (Fell et al., 2005) contend that geotextiles may be used for non-critical or redundant filter applications. Others relegate the use of geotextile filters in locations in dams where they can be easily reached with construction equipment without affecting the safety of the dam such as the toe of the dam. Some recommend their use only outside the footprint of the dam collecting nuisance seepage from abutments and side channel springs or seeps. In some filtration applications, the use of a geotextile has advantages over graded granular filter material because of:

• Installation expediency and ease of construction.

Reduced excavation and less wasted materials.

Lower risk of the contamination and segregation of drainage aggregate during construction installation.

The use of less or lower quality drainage aggregate.

Processing costs

Transportation costs

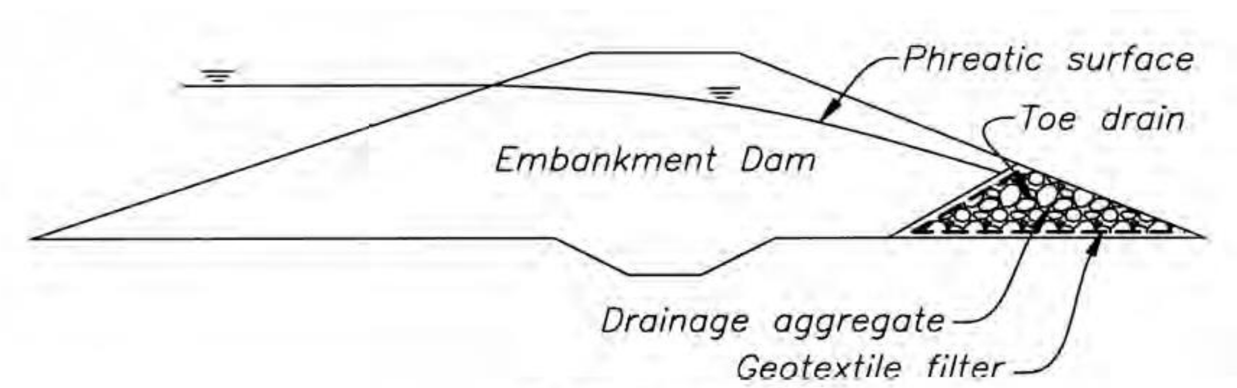
Although they may in some cases require more surface preparation, geotextiles can be easier to place or install than natural material, particularly for those applications that require multiple layers of aggregates. For example, Section 3.1.3 Foundation Trench Drain shows a trench drain system for an embankment located at the toe of a dam consisting of a trench lined with geotextile and filled with gravel. The alternative to this design is a two-stage granular filter with a gravel core inside a trench filled with filter sand. Placing two zones of granular filter requires more construction effort than the single zone of gravel which is possible with the geotextile-lined trench.

Additionally geotextiles have been used in a number of applications as the filtering element or in conjunction with conventional graded granular filters in drainage applications near the toe of dams. Filtering capacity is necessary to prevent soil from migrating into high capacity drainage aggregate such as gravel, rock, or other geosynthetics materials.

Drains that incorporate geotextiles can also be placed in the toe of the embankment for improved slope stability or simply located to control trouble seepage that can sustain a wet toe or abutment of a dam and/or downstream wet area. Use of a geotextile as the single filter in this manner rather than using a natural filter is not consistent with accepted engineering practice in the United States. The geotextile in this design is both inaccessible for replacement and critical to safety. Also, it would not be possible to provide a redundant natural filter if the geotextile were to experience excessive clogging. Seepage would not reach the drain. The seepage would likely exit above the drain on the downstream slope thus subjecting the dam to potential failure due to piping and downstream slope instability. Determine which product should be used in a particular design, because both have advantages and disadvantages. An example of this comparison is as follows: **ran verse embankment cracking protection zone**

Geotextiles have been used in dams as a crack stopper or for the purpose of controlling internal erosion through relatively small sloping cracks that can develop in embankment dams from dryness or from differential foundation movements (fig. 3.7). This design application is not a drainage function, because the geotextile is intended as a cutoff screen more than as a drainage element. This application has been used primarily on single purpose flood control dams

.



TOE DRAIN

Figure 10: Illustration of a geotextile filter used in construction of a rock toe drain. The geotextile filter in this configuration is considered a critical element and is not constant with accepted practice by most dam engineers.

Table 1: Corps of Engineers Policy Documents Related to Use of Geotextiles in Dams

Year	Reference	Title	Notes
1984	ETL 1110-2-286	Use of Geotextiles Under Riprap	Lessons learned from Tennessee-Tombigbee Waterway.
1986	EM 1110-2-1901	Seepage Analysis & Control for Dams, Appendix D - Filter Design Fabrics should not be used as filters on upstream face or within embankment.	Use in inaccessible areas must be considered carefully.
1992	ETL 1110-2-334	Grouted Riprap	Geotextiles are included as needed. Filters can consist of uniformly graded granular material with underlying geotextile.

1995	TM 5-818 (UFC 3-220-08FA)	Engineering Use of Geotextiles	Where duration is critical to life safety and where the geotextile is inaccessible, (e.g. earth dams), current practice is to use only geologic materials.
1996	EP 1110-2-13	Dam Safety Preparedness	Definitions include geotextile filters, but never mentioned elsewhere.
2003	EM 1110-2-1902	Slope Stability	Casual mention of geotextile reinforcement.
2004	EM 1110-2-2300	General Considerations for Dams	Geotextiles should not be used in conjunction with relief wells.
	EM 1110-2-2300	General Considerations for Dams	Geotextiles should not be used in conjunction with relief wells.

Table 2: Geosynthetics Functions in Dams

Function of Geosynthetics	Typical Geosynthetics Used
Filtration of Soils Particles	Geotextile Nonwoven

	Geotextile Woven
	Geotextile Knitted (2 stage only)
Separation of Dissimilar Materials	Geotextile Nonwoven
	Geotextile Woven
	Geocomposite
Planar Drainage	Geotextile Nonwoven Geonet Geocomposite Geomat Structured Geomembrane (drain)
Reinforcement	Geotextile Nonwoven Geotextile Woven Geogrid
Fluid Barrier	Geotextile Nonwoven Geotextile Woven Geogrid Geocomposite
Protection	Geomembrane GCL (limited) Geocomposite (with geomembrane)
Surface Erosion Control	Geotextile Nonwoven Geocomposite
	Erosion Control Geocomposites Geocells

A geo-synthetic that allows stress transfer from a soil or adjacent material to the geo-synthetics provides structural reinforcement. Thus soil layers on slopes or within walls can be reinforced with geo-synthetics specifically designed for taking stress. This will improve the stability of slopes or walls. Geo-grids are products specifically designed for this function although woven and nonwoven geotextiles have been used where lower stress transfer is required.

2.15. Geotextile materials, properties, and applications

The second largest volume use of geo-synthetics used in dams is geotextiles which is the subject of this status report. Geotextiles are second only to geo-membranes in dam construction considering all types of dams. Again, by definition, geotextiles are a "permeable geo-synthetic comprised solely of textiles", ASTM (2005). Geotextiles perform a variety of geotechnical engineering functions including separation, filtration, drainage, reinforcement and protection (of geo-membranes), all of which have been used in dam construction and rehabilitation. The first use of a geotextile in dam construction was in the Valcros Dam, France in 1970 where it was used functionally as a filter according to Giroud (1992, 2003)**.** This geotextile has been performing its intended function and has shown little degradation since its installation over 25 years ago (Giroud, 1992)**.** Since then, geotextiles have been used for a variety of functions and applications on a large number of dams worldwide with great success. The following will give a brief but necessary introduction to geotextiles – what are they, what are their properties and where are they used in dam construction and rehabilitation?

2.15.1. Separation and protection functions

Geotextiles have been used most commonly in dams as a separator of natural materials to prevent the contamination of adjacent zones in an embankment. A related function is protection. Just as a separation layer prevents one soil layer from intruding and mixing with another layer, in protection the geotextile prevents a soil or gravel layer from intruding and damaging the material to be protected such as a geo-membrane.

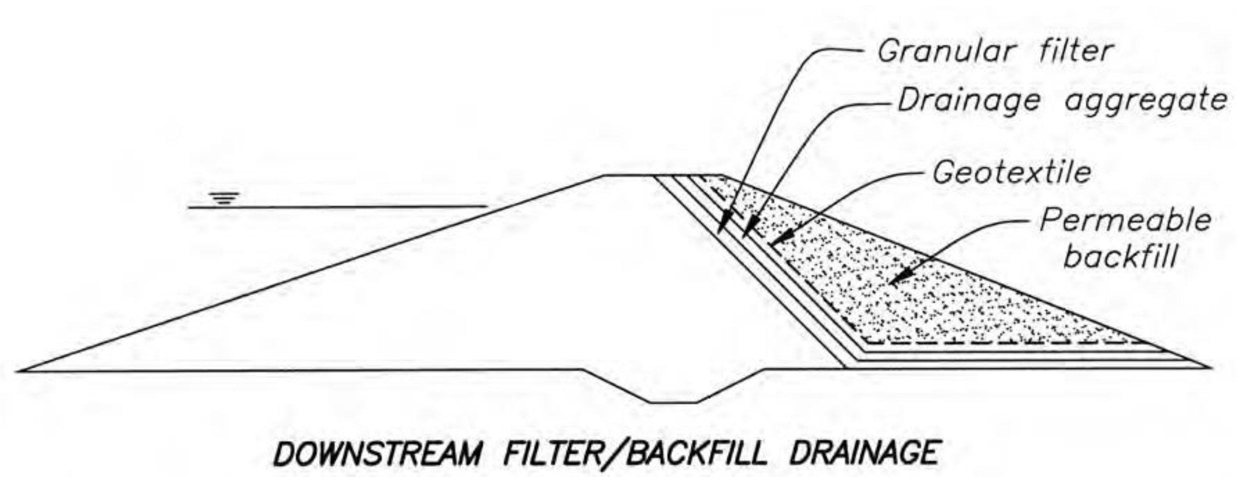


Figure 11: Geotextiles use as a separator of natural materials

2.15.2. Soil reinforcement

High modulus geotextiles have been utilized to provide a tensile strength component to a soil mass when placed under or within an embankment or foundation. This tensile reinforcement can reduce stress and strains within the soil mass or embankment enabling the embankment to resist large differential settlements and lateral spreading or slope movements. The use of reinforcement in embankment construction may allow for:

- An increase in the design factor of safety.
- An increase in the height of the embankment dam.
- A reduction in embankment earth fill quantities during construction

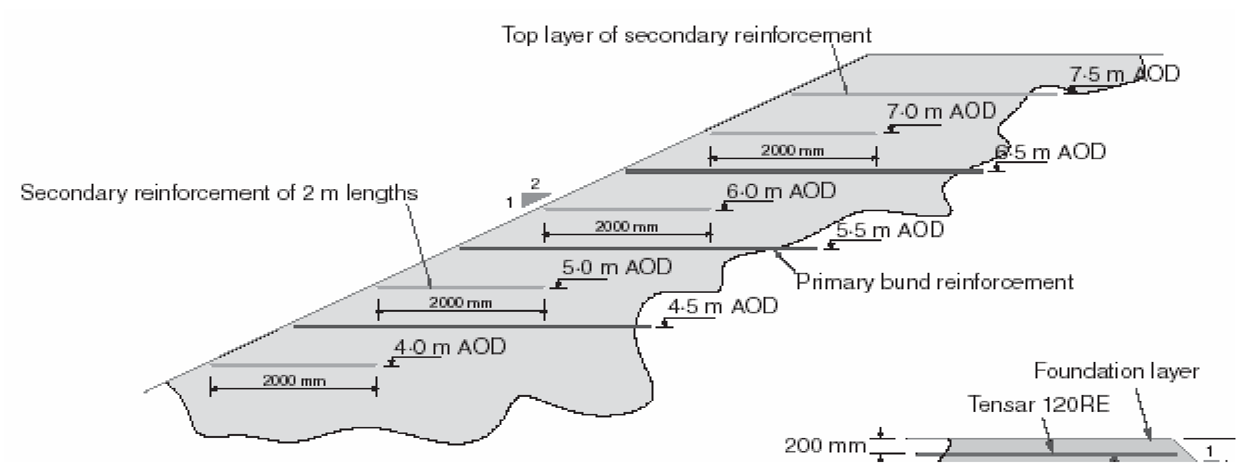


Figure 12: Reinforced embankment

2.15.3. Reinforced slopes

Geotextiles can be used to improve the stability of the embankment slopes by adding tensile reinforcement. This allows the slopes to be constructed at a steeper angle and can be important where expanding the dam footprint is not an option (Engemoen, 1993).

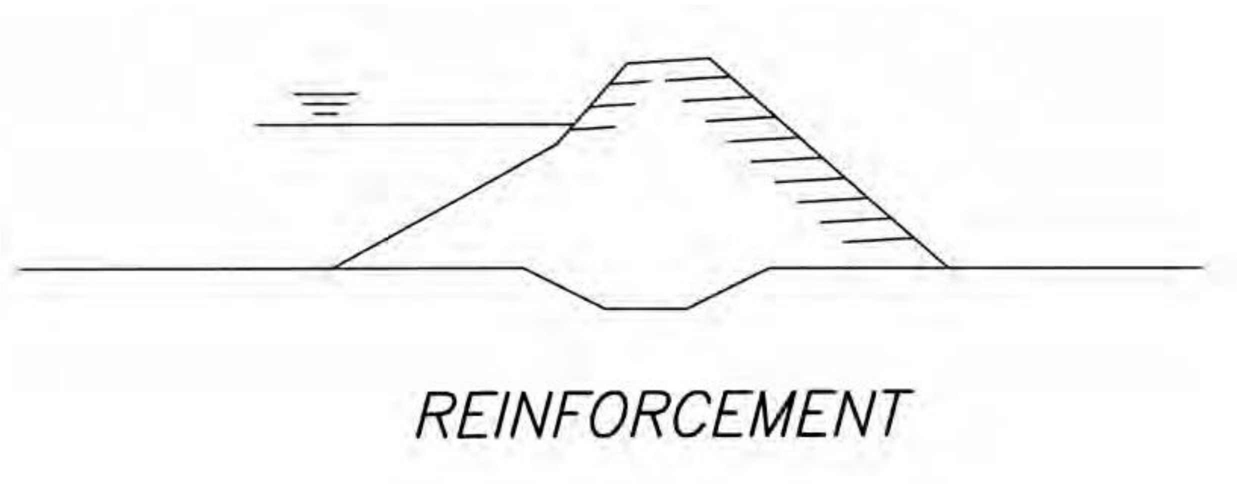


Figure 13: Illustration of an embankment whose slopes have been steepened by incorporating geotextile layers into the soil as slope reinforcement

2.16. Slope instability

The combination of one or more geo-synthetics materials into a soil mass creates a potential failure plane.in order to stable the zone dam combination of different geotextile products are the simplest way. Using a geotextile placed against a geo-membrane is often found to form the weakest interface surface in a layered geo synthetic and soil slope configuration. Surfaced geo-membranes help increase the interface friction and resulting factor of safety against sliding failures.

Another area of concern is the buildup of pore water pressures on top of a geo-membrane or behind a geotextile. In the first case, consider a geo-membrane placed near the upstream slope of a dam to act as an impermeable barrier to contain the reservoir and prevent excessive seepage through the embankment. The geo-membrane is typically covered by soil and riprap to protect it from the elements. As the reservoir is drawn down by operation of its outlet works pore pressures can build up at the geo-membrane surface and potentially cause a slope failure. To guard against this type of problem a drainage layer is usually placed immediately above the geo-membrane. The drainage layer is typically a geotextile or a geo net, geo composite.

Another problem with pore pressure can occur where a geotextile is used underneath riprap. The soil under the geotextile must be able to dewater through the geotextile to dissipate pore pressure as the reservoir is drawn down or under significant wave action. If the geotextile has too small an opening size or becomes excessively clogged, it may not adequately transmit the water and a slope failure can occur. Some designers prefer using a woven monofilament geotextile for placement under riprap because of the ability of woven material to rapidly drain when impacted by large waves (Christopher and Valero, 1998).

Movement along the interface between a soil and a geo synthetic material or between two geo synthetic materials must be properly evaluated during design. Failures have resulted where the interface frictional strength has not been properly determined or where the buildup of soil pore water pressure has occurred. This problem has occurred in numerous instances in the solid waste industry (Koerner, 2005a).

While use of published values can often be used to approximate soil slope stability, it is a dangerous approach for final geo synthetic design. The actual soil to geo synthetic frictional strength can vary considerably from published values and must be determined in the laboratory.

It is recommended that large scale shear testing (ASTM D5321) be performed with the site specific soils and samples of the actual geo synthetic materials that are proposed for use. Where the construction soils are not available ahead of time, the required testing program can be included as part of the construction performance specifications so that the design assumptions can be confirmed early on and prior to building the entire project.

Large scale shear testing must include all of the layers to be placed under and over a geo synthetic and must model the loading and soils compaction characteristics.

Figure 14: Photograph showing proper depositing of geotextile product rolls.

2.16.1. Material transition zone

Geotextiles have been placed within embankment dams to separate earth fill material zones (fig 3.10). An example would be placing a geotextile between a filter/drainage zone and a downstream earth fill zone. Geotextiles used for this application can potentially save material and placement costs by ensuring a definite and consistent boundary of clean uncontaminated material in the drainage aggregate layer.

2.17. Application of geotextile in Ethiopia

Geo-synthetics product has been used in different application area of our country but it is not widely used. Setema LTD is one the supplier of geo-synthetics products from Fibertex Nonwovens Company which is in South Africa. As a recorded data different type of geotextiles has been used for different purpose.

In road category work it uses for parking areas, road widening, permanent road, temporary road, air ports, railways, paths and walking areas.

In construction category reinforced geotextile uses for building concrete floors, retaining walls for Jemo River.

In ground system category geotextile reinforcement uses for slopes (erosion control), storage areas water reservoir and for waste disposal uses for protection layer. Afrotsion general contractor also used geotextile products for road construction in different site.

3. METHODOLOGY

3.1. General Description of the Study Area

The Ajima Dam project is located mainly at Kita alegn Kebele, Angolelana tera Woreda of North Shewa Zone in the Amhara Region. The reservoir will be on Kita alegn and Asa Bahir kebeles around Chacha town, at about 120 km from Addis Ababa. The proposed Dam project is to be undertaken on Ajima River at an altitude of about 2806m a.s.l and geographical coordinates of 558102E (UTM) & 1048539N (UTM) as shown on Figure 1.2 below. The irrigation and drainage system networks are specifically located at nine kebeles of Angolelana Tera woreda and one kebele of Basona woreda.

The project requires about 45.5 m high dam on the Ajima River. The dams crest length is 377m. The catchment area for reservoir is 83 km2.

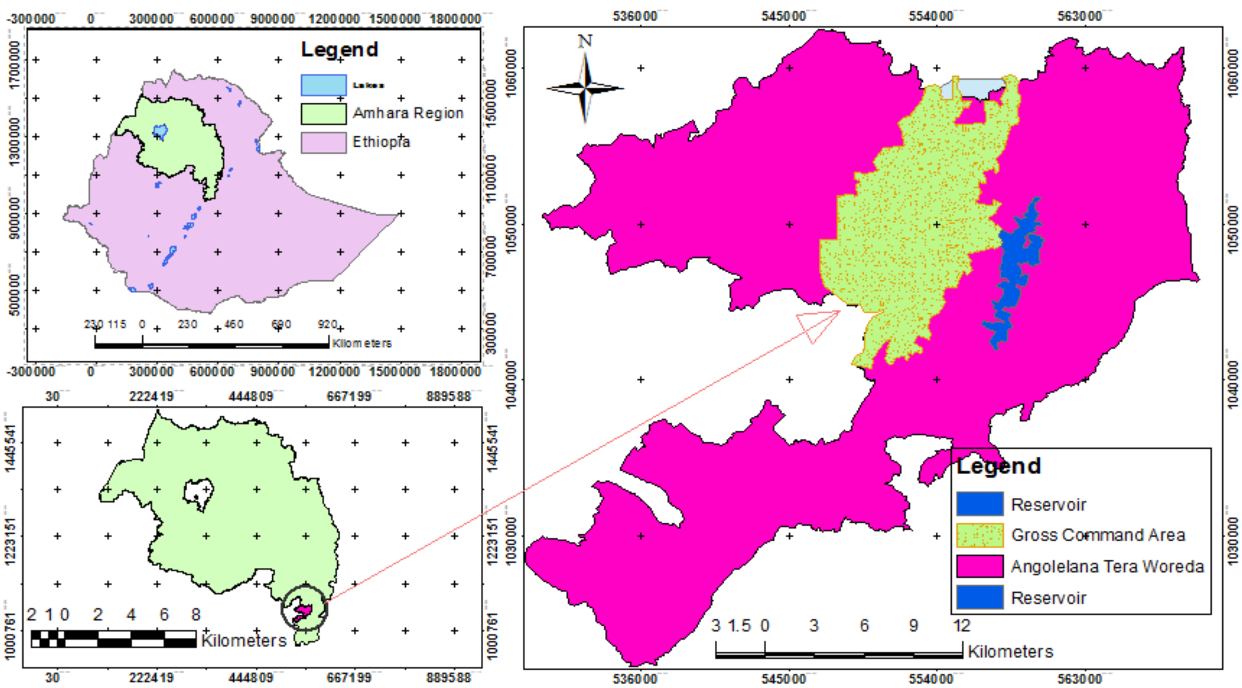


Figure 15: Location map of Ajima dam and irrigation project

The maximum possible command area for scenario one is 7000ha for wet season and 4570ha for dry season whereas for scenario two it is possible to irrigate 6200ha for dry season only. The mentioned irrigable area is achieved when the reservoir elevation is at 2846m;

3.1.1. Embankment Geometry Zoning

The proposed dam is an earth fill dam with impervious central core composed of clayey material from borrow areas; in the reservoir and downstream nearby areas. The minimum top width of the core as specified by Indian standards is 3m and usually from construction point of view the minimum width recommended is 3m. Therefore the top width of the core is maintained to be 3m. Fell et al (2005) stated that according to common practice, a core width at the base, or cutoff, should be at least 25 to 50% of the difference between the maximum water level in the reservoir and the minimum tail water elevation. According to Indian standard the thickness of a core at any section is specified to be above 30% (preferably not lesser than 50 percent) of the maximum water head acting at that section.

Ajima Zoned Earth Fill dam with central clay core

Zone 1: Impervious clay core

Zone 2a: Fine Filter also refereed as F1

Zone 2b: Coarse Filter also refereed as F2

Zone 3: Quarry run shell

Zone 4: Riprap

Table 3: Summary of embankment fill and foundation material characteristics used in seepage and stability analysis (Zoned Earth Fill dam with central clay core) adopted from final design report

Zone	Function	Unit Weight (KN/m^3)	Permeability(m/s)	C'(Kpa)	ϕ'(o)
1	Core	15.0	$1.04x10^{-8}$	28.22	19
2A	Fine filter	18.0	$1x10^{-4}$	3.0	29
2B	Coarse filter	18.0	$5x10^{-4}$	0.0	32
3	Quarry run shell	18.0	$1.34x10^{-4}$	8.0	29
4	Riprap	22.0	0.01	0.0	40
	Foundation bed rock	Bed rock	$1x10^{-7}$	Bed rock	Bed rock

3.2. Data Collection

The primary data has been collected from project office **(E/ADSWE** kombolecha office. Geometrical, material property and earthquake data inputs were collected from project office & reviewed literature. The dam zone and foundation material data were collected from the. Literature review is conducted about reinforcement technique and stability analysis of embankment dam.

3.3. Methods of Analysis

1) The static analysis has been conducted using Geo slope families. Static stability analysis has been carried out for different exposure conditions using Seep/W and Slope/W before reinforcement. Horizontal layers of geotextile material are introduced in both face of the dam and modeling and analysis has been carried out. Also dynamic analysis has been conducted using Quick/W.

3.3.1. Steady State Seepage Analysis

The Steady Seepage Condition For zoned and homogeneous types of embankment dams and when the reservoir is full of water and some steady seepage into the embankment is established, the conditions to be considered for the steady state seepage analysis should be:

• Steady state seepage pore pressures which are fully developed as a result of the reservoir have being storing water over a long period of time. In this case there is a Phreatic Surface Line under steady seepage state.

3.3.2. Slope Stability Analysis

This section of the analysis is used to compare the instability occurred on the slope due to the earthquake after shaking. To do this the SLOPE/W component of the GEO-STUDIO software has been used. The SLOPE/W component of the software uses the limit equilibrium analysis technique in the numeric. Limit equilibrium technique of numerical analysis tries to satisfy the equilibrium of statics. For both the upstream and downstream face of the dam at steady state seepage, the slope stability factor of safety is determined before the earthquake with and without reinforcement. It can easily be guessed that the factor of safety for the upstream is more than for the downstream, because of the additional hydrostatic normal force of the impounded water in the upstream face. The analysis used in this slope stability determination is the Spencer type. The Spencer type slope stability analysis tries to satisfy both the horizontal and moment equilibrium of statistics. The pore water pressure found in the Seep/W component is a parent for this analysis, to know the saturated part of the dam and foundation. The constitutive model for the materials is Mohr-Coulumb.

3.3.3. Seepage Analysis Using SEEP/W

The flow of water through soil is one of the fundamental issues in geotechnical and geo environmental engineering. In fact, if water were not present in the soil, there would not be a need for geotechnical engineering. A numerical model is a mathematical simulation of a real physical process. SEEP/W is a numerical model that can mathematically simulate the real physical process of water flowing through a particulate medium. Numerical modeling is purely mathematical and in this sense is very different than scaled physical modeling in the laboratory or full-scaled field modeling.

3.3.4. Material Models and Properties

Here are four different material models to choose from when using SEEP/W. A summary of these models and the required soil properties are given below and a discussion of the individual parameters and functions are provided in the next section (Seep/W, 2007).

Material models in SEEP/W:-

1) None (used to removed part of a model in an analysis)

2) Saturated / Unsaturated model
   - Hydraulic conductivity function, ratio and direction
   - Water content function

3) Saturated only model
   - Hydraulic saturated conductivity (Ksat), ratio and direction
   - Saturated water content

4) Interface model
   - Hydraulic normal and tangent conductivity

The Saturated only soil model is very useful for quickly defining a soil region that will always remain below the phreatic surface, but it should not be used for soils that will at some point during the analysis become partially saturated. If this happens, the model will continue to solve but you will be saying, in effect, that the unsaturated zone can transmit the water at the same rate as for the saturated soil. This will result in an over estimate of flow quantity and can result in an unrealistic water table.

Based on the above stated clues, material models which have been attached to different zones of embankment material have been shown in Table below.

Table 4: Material models and properties used in seepage analysis using Seep/W Material zone Model Material properties

Zone	Materials	Model	Material Properties
1	Core	Saturated /Unsaturated	Hydraulic conductivity function and water content function
2A	Fine filter	Saturated /Unsaturated	Hydraulic conductivity function and water content function
2B	Coarse filter	Saturated /Unsaturated	Hydraulic conductivity function and water content function
3	Quarry run shell	Saturated /Unsaturated	Hydraulic conductivity function and water content function
4	Riprap	Unsaturated	Hydraulic conductivity function and water content function
	Foundation bed rock	Saturated only	Hydraulic conductivity function and water content function

3.3.5. Boundary Condition

Fundamentals

SEEP/W uses finite element approach in seepage analysis. For a seepage analysis, the finite element equation is (Seep/W, 2007):

$$[K]\{H\} = \{Q\}$$

Where: {H} = a vector of the total heads at the nodes, and {Q} = a vector of the flow quantities at the node

In a finite element analysis, the prime objective is to solve for the primary unknowns, which in a seepage analysis is the total hydraulic head at each node. The unknowns will be computed relative to the H values specified at some nodes and/or the specified Q values at some other nodes. Without specifying either H or Q at some nodes, a solution cannot be obtained for the finite element equation. In a steady-state analysis, at least one node in the entire mesh must have a specified H condition. The specified H or Q values are the boundary conditions. A very important point to note is that boundary conditions can only be one of two options. We can only specify either the H or the Q at a node (Seep/W, 2007).

When specifying seepage boundary conditions, you only have one of two fundamental options you can specify H or Q. These are the only options available, but they can be applied in various ways.

Head boundary conditions

In SEEP/W the primary unknown or field variable is the total hydraulic head, which is made up of pressure head and elevation. The elevation represents the gravitational component. In equation form the total head is defined as:

$$H = u/\gamma + y$$

Where:

H = the total head (meters) u = the pore- pressure (kpa) γ = the unit weight of water (KN/m3) y = the elevation (meters) The term u/ is referred to as the pressure head – represented in units of length

3.3.6. Boundary functions

SEEP/W is formulated to accommodate a very wide range of boundary conditions. In a steady state analysis, all of the boundary conditions are either fixed heads (or pressure) or fixed flux values. In a transient analysis however, the boundary conditions can also be functions of time or in response to flow amounts exiting or entering the flow regime. Among different boundary functions integrated in SEEP/W, head versus time boundary function is a very useful boundary condition used in the present analysis. Head versus time A very useful boundary function is user-specified Head versus Time. The advantage of using a Head versus Time function on the reservoir side of the dam is that it avoids a “shock” unloading of the water pressure on the dam if the water level in the reservoir were instantly drawn down to some elevation.

3.4. Seismic Hazard and Ground Acceleration Time-Histories

The Main Ethiopian Rift (MER), which trends SSW from the Afar Depression is one of the well-developed continental rift segments in East Africa that marks the boundary between Nubia and Somalia plates. The proposed Ajima dam is not far from the rift margins which needs more investigation as damaging earthquakes are possible along the plateau margin. The Ajima Dam site is located at the active rift margin of the Ankober region where earthquake occurrence is common. Landslide is also a big problem in the Tarma Ber and other rift margin areas. Ajima dam is located within the influence range of the Main Ethiopian Rift and the Afar Depression which are both part of the East African Quaternary rift (23 million years to present) which is a seismically active region that need to be assessed for the potential earthquake hazard which can damage property and human life.

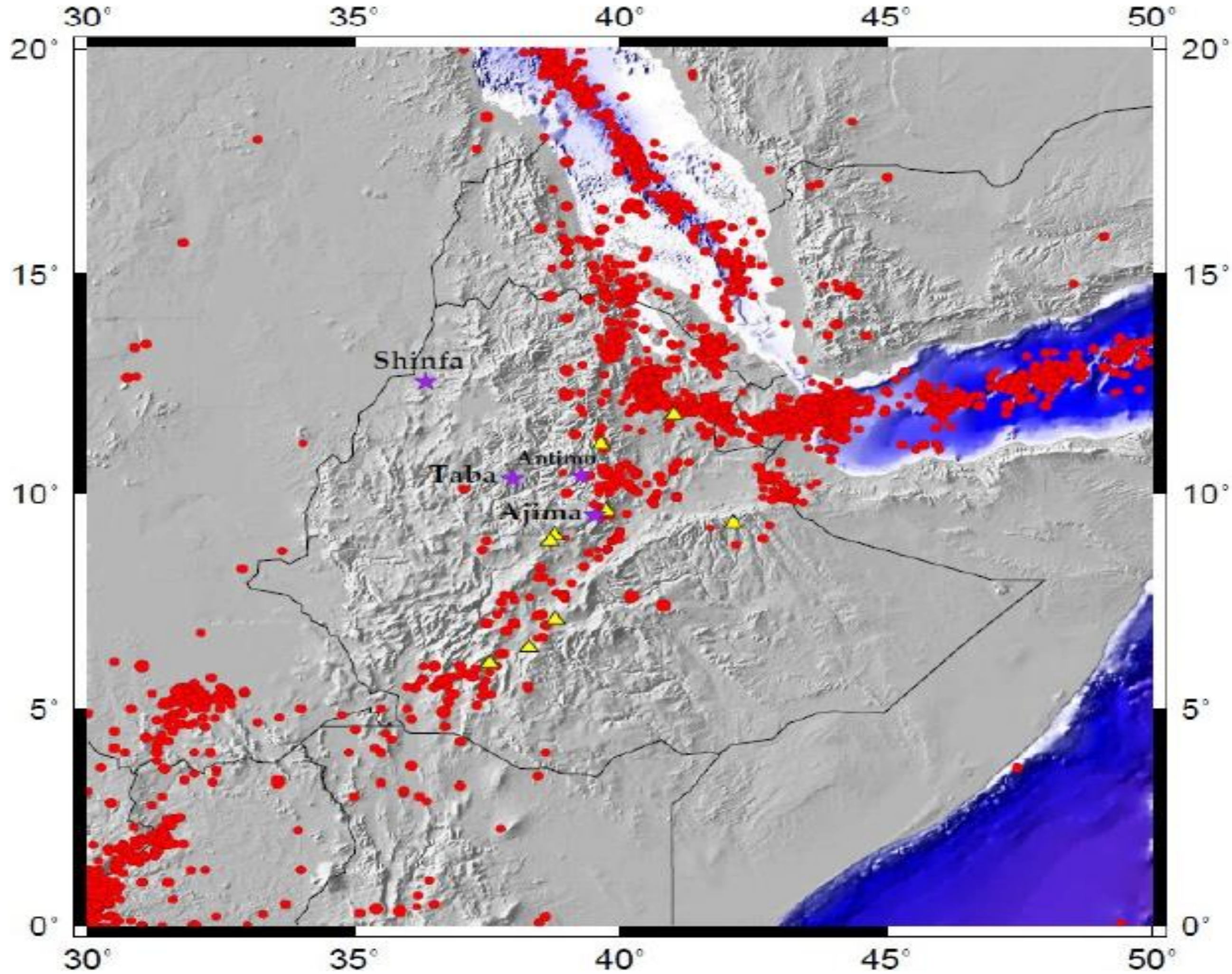


Figure 16: Seismicity data for the Horn of Africa; purple circles represent earthquakes that occurred for the last 110 years in the region and size of the circles is proportional with magnitude. The yellow star shows the location of the Ajima dam project site.

3.4.1. Results of Specific Seismic Hazard Assessment

The site Specific Seismic Hazard Assessment for Ajima Dam following the probabilistic approach has been carried out following accepted standard procedures.The PGA values are very high, because Ajima dam is located within the influence range of the Main Ethiopian rift and the Afar Depression which are both part of the East African Quaternary rift (23 million years to present) which is a seismically active region. Dams are normally allocated a hazard category using the method of ICOLD bulletin 72 which takes into account reservoir capacity, dam height, number of persons at risk and potential downstream damage.

3.4.2. Selection of earthquake

Return Periods

Earthquakes must be defined for analytical purposes so that appropriate seismic evaluation parameters can be selected. According to ICOLD Bulletin 72, seismic hazard of a specific project at interest can be studied either through the deterministic or probabilistic approach. The first demands understanding the structural setting and analysis of faulting systems of the project area which is complicated task also difficult to get reliable information. Therefore, alternatively the probabilistic approach is commonly exercised to evaluate the seismic hazard of given study area.

ICOLD Bulletin 72, has defined the Safety Evaluation Earthquake (SEE) which is a replacement of Design Basis Earthquake (DBE), Operating Basis Earthquake (OBE) and Maximum Credible Earthquake (MCE).

SEE: It is that level of shaking for which damage can be accepted but for which there should no uncontrolled release of water from the reservoir. The SEE is normally characterized by a level of motion equal to that expected at the dam site from the occurrence of a deterministically evaluated maximum credible earth quake or of the probabilistically evaluated earthquake ground motion with a very long return period for example 10,000 years.

OBE: The operating Basis Earth Quake represents the level of ground motion at the dam site for which only minor damage is acceptable. As stated in ICOLD Bulletin 72, it is appropriate to choose a minimum return period of 145 years. Since the consequences of exceeding the OBE are normally economic, it may be justified to use a more severe or less event for OBE.

The site specific seismic hazard report produced for the project suggested adapting 1:2500 years return period considering Germany’s experiences. However, the ICOLD Bulletin recommends using 1:10000 for SEE loading. In conclusion the Ajima Dam is not far from the rift margin which needs more investigation as damaging earthquakes are possible along the plateau margin and any potential failure might affect the settlement in Chacha town and important infrastructure downstream of the dam. Therefore, this calls for adapting very conservative values and therefore 1:10000 years return period is considered for SEE and 1:200 years return period for OBE considering the recommendation of ICOLD Bulletin 72 and site specific facts.

Ground acceleration period

As shown in Table 5.1, the PGA is indicated with respect to three periods. The site specific seismic hazard didn't indicate which duration will be appropriate for this project. For concrete dams and dam appurtenant structures in most cases the peak amplitude is determined by considering shorter periods. But considering the flexibility nature of embankment dam relatively higher period is considered in design exercises. Because adapting shorter duration for the embankment designs will make the design uneconomical as a result of being more conservative. Material behavior and dam height are very sensitive and determining factors in period selection. Researches in Tendaho dam which is located at the very high tectonic area the amplitude period is about 0.45 seconds. There are empirical equations that can be used to estimate the amplitude period which consider the dam height and wave propagation velocity. Accordingly, the estimated amplitude period is about 0.40seconds and the corresponding PGA value for SEE loading (10,000 years return period) read from Figure 5.2 is 0.6g. Similarly, for OBE loading corresponding to 200 years return period obtained by interpolating the values indicated in Table 5.1 is considered to be 0.23g.

Direction of the peak ground acceleration was assumed to be horizontal since nothing has been mentioned in the site specific hazard assessment report concerning the direction of peak ground acceleration. Moreover, because the report did not specify the magnitude of the peak ground acceleration in vertical direction, the magnitude of the peak vertical ground acceleration was estimated to be 50% of the peak horizontal ground acceleration.

The PGA values indicated above will be an input for evaluating the stability analysis of the embankment dam for either Pseudo static or dynamic analysis. The results of Pseudo static analysis are critically dependent on the value of the seismic coefficient, kh. Selection of an appropriate Pseudo static coefficient is the most important, most difficult aspect of a Pseudo static satiability analysis. Pseudo static method is conservative and also it assumes that the earthquake force is constant and acts only in a direction that promotes slope instability. For this reason, Pseudo static coefficients generally are selected to be some fraction of the peak acceleration to account for the fact that the peak acceleration acts only briefly and does not represent a longer, more sustained acceleration of the landslide mass. Jibson, R.W (2011) has compiled the following table based on some published researches.

Table 5: Pseudo static coefficients from various studies

Investigator	Recommended Pseudo static Coefficient (K)	Recommended Factor of Safety (FS)	Calibration Conditions
Terzhagi (1950)	0.1 (R-F=IX)	>1	Unspecified
	0.2 (R-F=X)		
	0.5(R-F>X)		
Seed (1979)	0.10(M=6.50)	>1.15	< 1m displacement in earth dams
	0.15(M=8.25)		
Marcuson (1981)	(0.33-0.50)xPGA/g	>1.0	Unspecified
Hynes-Griffin and Franklin (1984)	0.50xPGA/g	>1.0	< 1m displacement in earth dams
California Division of Mines and Geology (1997)	0.15	>1.1	Unspecified, probably based on <1m displacement in dams

Note: R-F is Rossi-Forel earthquake intensity scale, M is earthquake magnitude, PGA is peak ground acceleration, g is acceleration of gravity

(U.S Army Corps of Engineer manual EM-1110-2-6053) recommends the Pseudo Static Coefficient shall be two third of the horizontal peak ground acceleration. For the dynamic analysis of the dam by a Finite Element Method Horizontal and vertical acceleration time histories are key input parameters. Therefore, site specific horizontal and vertical ATH for the Ajima dam should be produced using the peak accelerations and records of actual earthquakes. However, since there are no ATH records near the dam site or project area it is a common practice to adapt actual accelerographs recorded elsewhere and scaled into the PGA (0.6g for SEE) magnitudes of the considered embankment dam model (Hadush et al (2010).

Accordingly, the ATH data scaled to the horizontal SEE PGA values 0.60g and horizontal OBE PGA values 0.23 for the Electro record is presented in Figures 5.2 and 5.3 respectively.

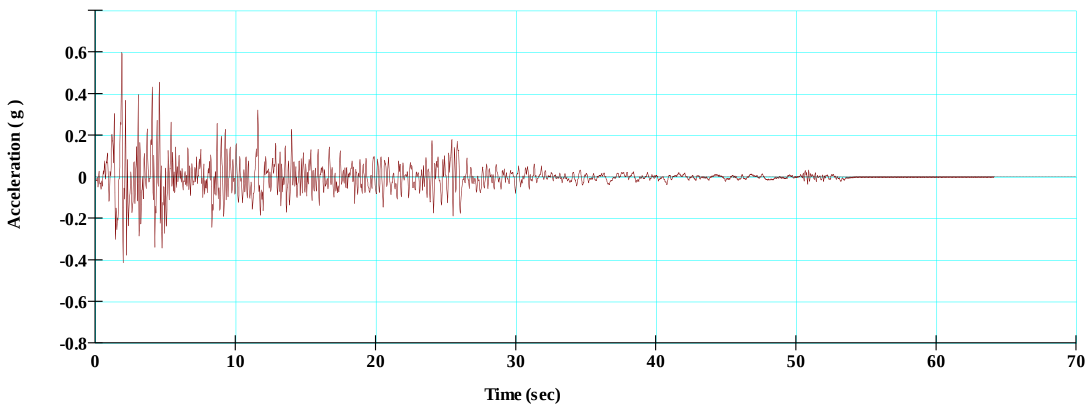


Figure 17: Horizontal Safety Evaluation Earthquake time history based on 1940 Elecentro record.

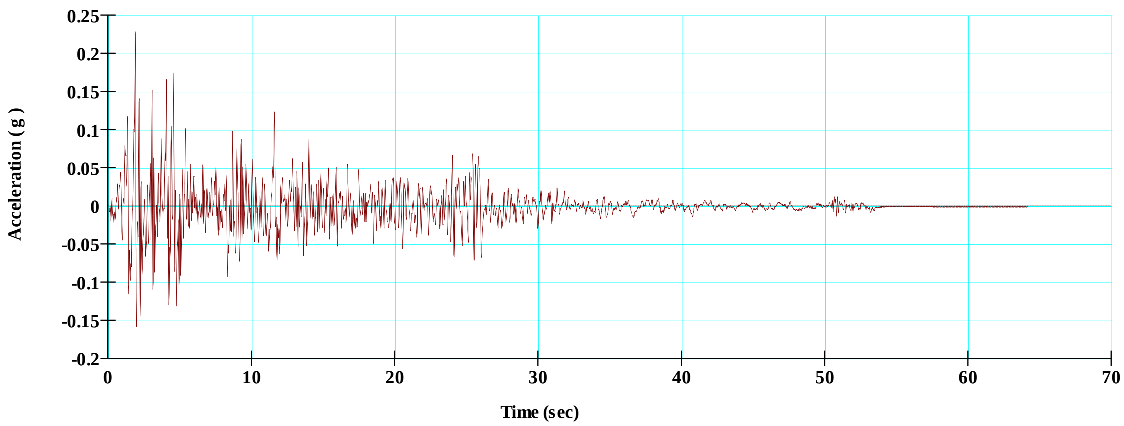


Figure 18: Horizontal Operating Basis Earthquake time history based on 1940 Elecentro record.

3.5. Analysis Types

There are two fundamental types of finite element seepage analyses, steady-state and transient. Numerous additional constraints and conditions can be applied within each fundamental type. In steady state analysis; the pore pressure condition is estimated for long term steady state situation. Hence, the condition of the analysis is constant.

Transient seepage analysis, on the other hand, is carried out in a changing condition of pore water pressure. It is changing because it considers how long the soil takes to respond to the user specified boundary conditions. And it is critical condition for earth fill embankment dam in the upstream dam body.

3.5.1. Seepage Analysis Result from SEEP/W

The dam modeled by Seep /W, which could be used to analyze any seepage problem. According to Geo-Slope International (Geo-Slope) 2007, "SEEP/W is a finite element software product for analyzing groundwater seepage and excess pore-water pressure dissipation problems within porous materials such as soil and rock. Its comprehensive formulation allows for one to consider analyses ranging from simple, saturated steady-state problems to sophisticated, saturated/unsaturated time-depended program. SEEP/W can be applied to the analyses and design of geotechnical, civil, hydrogeological, and mining engineering products in other words, SEEP/W is a useful tool that uses numerical modeling to solve complex groundwater seepage problems.

There are two fundamental types of seepage analysis: steady state and transient. A steady-state seepage analysis is an analysis type where water pressures and water flow rates do not change with time. Since steady-state analyses ignore the time domain, it greatly simplifies the equations being solved. A transient analysis, on the other hand, has pressure conditions that change with time. In general, a transient analysis can provide more accurate results when soil conditions are modeled, however, they are significantly more complicated than steady-state analyses. Both the initial conditions as well as future boundary conditions must be provided. If the initial or future conditions are not accurately represented, the analysis will provide inaccurate results. When developing a numerical steady-state model using SEEP/W, one must determine geometry, assign materials, assign boundary conditions, then review and generate the finite element mesh. Soil Geometry The first step to determine soil geometry is to create a scale model of the cross-section of the system being evaluated. The second step is to define soil regions to the cross-section. Creating Cross-section There are two features that will allow the user to create a cross-section in SEEP/W. The first feature utilizes the DRAW function to create lines that make up the geometry. This can be an easy tool for creating cross-sections where the user wants to simplify geometry. The second feature uses the KEYIN function to manually enter points along a cross-section. This feature can be more time consuming, but is useful if the user wants to define actual contours derived from topographic mapping.

3.5.2. Slope Stability Analysis Using SLOPE/W

Soil slope stability problems in engineering works are often analyzed using limiting equilibrium methods. A number of methods are based on the method of vertical slices in which assumptions about the geometry of the failure surface are made. For homogeneous soils the assumed failure surface is often of a regular shape, but for a layered profile the shape of the failure surface is more complex, making it difficult to find the critical failure surface Janbu's simplified method and Spencer's method are used. Slope stability analysis is the other basic analysis to announce geotextile reinforcement in embankment dam. Using Slope/W has been conducted. SLOPE/W is a limit equilibrium method software package and has different methods available for slope stability analysis. The effect on factor of safety is studied and compared by considering the slopes of the dam to be reinforced and not.

3.5.3. Define Critical Slip Surface

The critical slip surface in a simple reinforced soil wall is assumed to coincide with the maximum tensile force, in each reinforcement layer. The shape and location of the critical failure surface is based upon instrumented structures and theoretical studies.

This critical failure surface has been assumed to be approximately bilinear in the case of inextensible reinforcements, approximately linear in the case of extensible reinforcements, and passes through the toe of the wall in both cases.

When failure develops, the reinforcement may elongate and be deformed at its intersection with the failure surface. As a result, the tensile force in the reinforcement would increase and rotate. Consequently, the component in the direction of the failure surface would increase and the normal component may increase or decrease. Elongation and rotation of the reinforcements may be negligible for stiff inextensible reinforcements such as steel strips but may be significant with geosynthetics. Any reinforcement rotation is ignored for internal wall stability calculations with the simplified method. However, reinforcement rotation may be considered in compound slope stability analysis

3.5.4. Create Vertical Layout of Soil Reinforcements

Use of a constant reinforcement section and spacing for the full height of the wall usually gives more reinforcement in the upper portion of the wall than is required for stability.

Therefore, a more economical design may be possible by varying the reinforcement density with depth. However, to provide a clear reinforced soil zone, vertical spacing of reinforcement should not exceed 32 in. (800 mm).

3.5.5. Material Properties in Design

Reinforcement of soil adds tensile strength to the previously unreinforced soil. Geotextiles and geo-grids have been considered the same for reinforcing purposes and indeed they both provide a reinforced soil mass with tensile strength in the critical. In reinforcement applications, the primary material property of the geo synthetic needed is the tensile strength of the geo synthetic. Tensile strengths of geo-synthetics may differ depending on direction. Other properties to consider in analysis might be included:

a) Friction behavior
b) Seam strength
c) Creep
d) geo synthetic degradation

For the entire analyses during this study, dam, foundation and shells behavior was simulated with the Mohr-Coulomb model. Mohr-Coulomb model is a common model for the shear failure of the soil and well integration with slope/w is one of important reasons for choosing this model. All the above mentioned analysis steps has been described in the below analysis diagram from Geo-slope 2007 software.

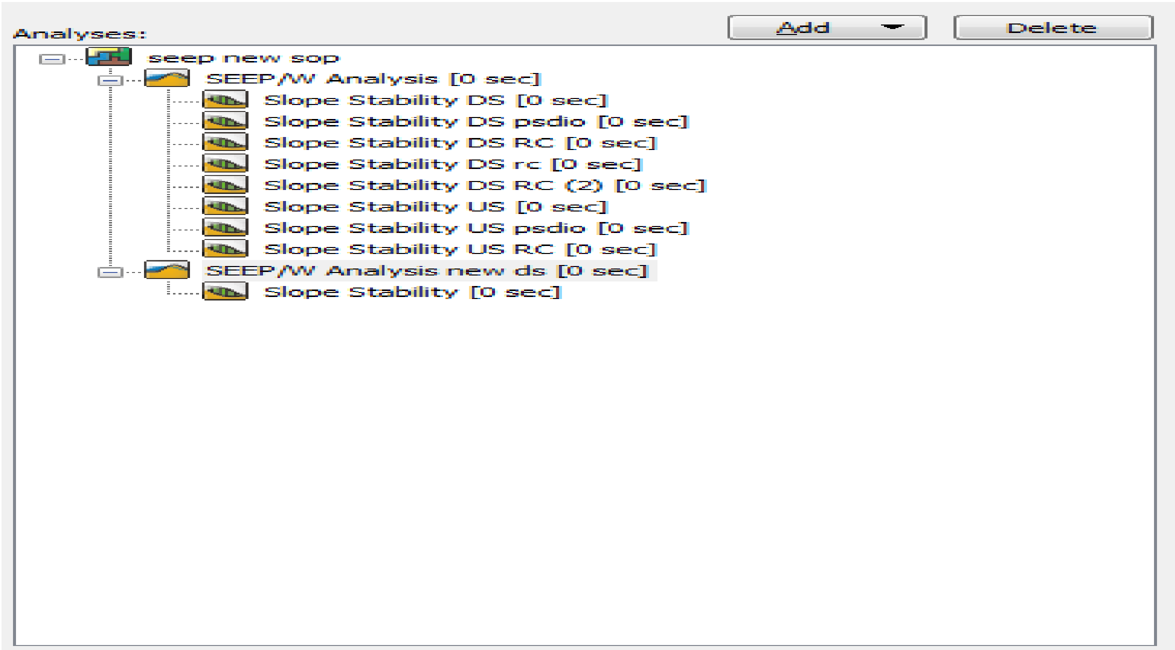


Figure 19: Diagram showing the sequence of analysis followed in this research

3.5.6. Geotextile Reinforcement Parameters

When a geotextile is used as a reinforcement material the critical properties required are the tensile strength and pullout resistance due to friction or adhesion**.**

Table 6: geotextile tensile strength as reinforcement

Name of fabric	Mass per unit area ASTM D5261 (g/m2)	Reinforcement Applications					
		Wide Width Tensile/Elongation ASTM D 4595 (kN/m)/ (%)				Creep Limited Strength-MD ASTM D5262 kN/m	LTDS MD kN/m
		Strength @5% strain		Ultimate Strength % (T_{ult})			
		Machine Direction	Cross Machine Direction	Machine Direction	Cross Machine Direction		
Comtrac175(W/PET)	410	90	NA	200(10)		122	95
Comtrac400 (W/PET)	700	180	NA	400(10)	50	245	203

Geo-fabric reinforcement

The specified parameters for fabrics are shown in Table below.

Table 7 Fabric (geotextile) parameters used in the analysis

Fabric property	**Value**
Bond skin friction	150 KPa
Fabric capacity	360KN
thickness	4mm

3.5.7. Reinforcement Forces

The effect of reinforcement can conceptually act immediately or develop with some strain. The force is induced by the pre stressing the reinforcement forces are mobilized in response to straining in the same way that the soil strength is mobilized as the soil strain. Also the reinforcement increases the safety of factor and shearing resistance. Mobilized reinforcement forces are reinforcement forces and soil force divided by the factor of safety. The specified parameters for Geo-fabric reinforcement is bond skin friction per unit area, Bond safety factor, Fabric ultimate capacity, Fabric safety factor and load orientation.

3.6. Recommended analysis for reinforced geotextile in embankment dam

The limit equilibrium analysis is recommended for design of geotextile reinforced embankments. These design procedures are quite similar to conventional bearing capacity or slope stability analysis. Even though the rotational stability analysis assumes that the ultimate tensile strength will occur instantly to resist the active moment ,some geotextile strain and consequently embankment displacement will be necessary to develop tensile stress in the geotextile .the capacity of movement within embankment may limited by the use of high tensile modules geotextile reinforcement that expose good soil reinforcement frictional properties .conventional slope stability analysis assumes that the geotextile reinforcement acts as a horizontal force to increase the resisting moment.

The following analytical procedures should be conducted for the design of geotextile reinforcement in embankment:

1) Over all bearing capacity

2) Slope stability

3) Sliding wedge analysis for embankment spreading (splitting)

4) Analysis to limit geotextile deformation

5) Determine geotextile strength in the direction sloping to the longitudinal axis of the embankment or longitudinal direction of geotextile.

Additionally embankment settlements and creep also be considered in the analysis

1) Overall bearing capacity:-the overall bearing capacity of an embankment must be determined whether or not geotextile reinforcement is used .if the overall stability of the embankment is not satisfied, then there is no point in reinforcing the embankment .If the overall bearing capacity analysis indicates an unsafe condition, stability can be improved by adding berms or by extending the base of the embankment to reduce the risk of lateral spreading. Wick drains may be used in case of low bearing capacity to consolidate the soil rapidly and achieve the desired strength. The construction time may be accelerated by using geotextile reinforcement.
2) Slope stability analysis: - after getting satisfactory result of overall bearing capacity then the rotational failure potential should be evaluated with conventional limit equilibrium slop stability analysis. This analysis consists of determining the most critical failure surfaces, then adding one or more geotextile layers at the base of the embankment with sufficient strength at acceptable strain levels to provide the necessary resistance to prevent failure at an acceptable factor of safety.
3) Sliding slice analysis: - these force consist of an actuating force composed of lateral earth pressure and a resisting force created by frictional resistance.

3.7. The construction steps for soil reinforcement:-

- **Site preparation.**

Proof roll the foundation prior to placement of each layer of reinforcement geotextile and backfill.

- **Place geotextile reinforcement layer.**

  Verify the geotextile's primary strength direction for proper installation orientation.

  Correct orientation of the geotextile

  Check tensile strength on the geotextile's data sheet
- The geotextile is laid directly on the horizontal surface of compacted fill
- Place the geotextile in one continuous piece with the primary strength direction extending the full length of the reinforced area.
- Tension the geotextile by hand until free of wrinkles and lying flat
- Minimize unnecessary uv exposure to the geotextile by place the amount required pending fill placement.

Overlapping

- Follow project guidelines for overlaps
- Typically 100% coverage is required
- Pins or staples may be required to hold the geotextile in place:-sand bags or piles of backfill are additional option.
- Place and compact backfill on reinforcement.
- Place back fill as indicated in the construction documents
- Compact backfill per project specifications
- Perform soil compaction tests on every soil lift
- Maintain consistent lift thicknesses between placements of adjacent layers of geotextile.
- After installation of the first reinforced fill layer has been completed, the next layer of geotextile can be placed.
- Place additional reinforcement and reinforced fill.

Installation

Construction installation requirements depend on the site conditions and specific geosynthetics application. The prepared subgrade surfaces that will receive the geotextile are usually inspected for approval immediately prior to geotextile placement. Requiring subgrade approval just before geotextile placement is necessary to ensure the prepared surfaces have not become degraded by equipment traffic or adverse weather.

Damage during deployment often results from improper handling. While rolled products can be safely deployed by hand labor, it must be done to minimize stresses from dragging over the ground surface. Dragging can abrade or tear the geotextile, and disrupt angular rock fragments from the subgrade leading to punctures. Typically, loaders or fork lifts are fitted with spreader bars that allow the geotextile rolls to be unrolled like a roll of paper towels onto the subgrade.

The geotextile should be placed in intimate contact with the soil. Care must be taken not to announce lines in the geotextile during placement. In near surface applications, such as below riprap, lines can lead to formation of erosion channels below the geotextile. The geotextile is then forced to carry the load of the overlying soil in tension which is likely to result in destroying the material.

In general, the geotextile should be unrolled with the length of the roll in the direction of estimated water flow or movement. Successive geotextile rolls are overlapped such that the upstream panel is placed over the downstream panel and/or upslope over downslope. Some geo composite materials, such as a tri-planar geo net geo composite, have a flow direction which must be aligned for the material to function properly. In reinforcement applications, geotextiles should be laid in strips transverse (perpendicular) to the centerline of the embankment.

Anchor trenches are typically used at the top of slopes to anchor the geotextile. The geotextile should extend down the side and across the bottom of the anchor trench. In certain application.

Covering

Once installed in the field, geotextile materials should be covered with the specified materials as soon as practicable. On many projects, the contractor wants to delay cover placement until all of the geotextile is placed. UV exposed geotextiles should be covered within 3-5 days of exposure and within 21-30 days for UV treated and low UV exposed polymer geotextiles. The covering operation must be carefully controlled to avoid damage to the geotextile. Immediately prior to covering, the installed geotextile should be inspected to ensure it is still in proper position and that the subgrade has not been compromised. The cover soil must meet the specification requirements. On slopes, cover soil placement should begin at the toe of a slope and proceed up the slope.

Nonwoven geotextiles include both needle punched and heat bonded fabrics. Needle punched nonwoven geotextiles have a significant thickness and are able to transmit flow in the plane of the geotextile. These versatile fabrics serve as filters, drains, separators, and reinforcement in many applications. Heat bonded fabrics are thin and are typically used to filter fine-grained soils such as clays.

3.8. Performance problems

The factor affects the performance of the geotextile in the overall application is Oxidation, ultraviolet light, and other environmental can degrade geotextiles; however; burial of the material significantly reduces the rate of degradation. Excessive clogging remains as a concern for geotextile applications. Knowledge of the effects of geotextile compression upon filtration properties, better filtration and permeability design criteria, and development of construction practices (use of fine gravel) to provide for intimate contact of the geotextile with the base soil, have provided more reasonable designs than past practices. In addition, the issue of installation damage from construction activities and post installation service remains as the most significant objection to the use of geotextiles in embankment dams. The issue includes:

- Installation damage that can occur during construction and may not be detected
- Plant intrusion after construction that clogs void space and reduces its permeability;
- Burrowing animal damage (holes or cuts) which compromises filter performance; and

- Destroying of the fabric due to settlement and cracking of the embankment.
- To avoid internal erosion, the geotextile filter must be constructed without holes, tears, or defects. This is difficult to achieve in typical construction operations.

4. ANALYSIS OF RESULTS AND DISCUSSIONS OF AJIMA EARTH FILL DAM

4.1. Loading Condition and Minimum Factor of Safety

The stability of the proposed Ajima Dam has been analyzed using state of the art software- Slope/W from Geo-Slope International Ltd of Canada. The stability analysis has been conducted in order to determine the factor of safety for various slip surfaces of; downstream slopes and upstream slope under steady state seepage condition without reinforcement and reinforced.

Table 9: Minimum factors of safety (adapted from USBR design standards: embankment dams, static stability analysis)

Loading condition	Slope	FOS min
During construction	Downstream/upstream	1.3
End of construction	Downstream/upstream	1.3
Sudden drawdown	Upstream for un drained earthen fill dam	1.25
Steady state seepage	Downstream	1.5
Steady state seepage with earth quake	Downstream	1

In order to analyze a reinforced slope, the requirements include:

a) The desired slope geometry
b) The forces the structure must resist to ensure stability including external and seismic loading;
c) The pore water pressure
d) The soil parameters and properties;
e) The reinforcement parameters and properties;

f) The interaction of the soil and the geo-synthetics.

The design of a reinforced soil slope usually involves determining:

a) The final geometry;

b) The required number of reinforcement layers of a particular type;

c) The vertical spacing of reinforcement layers;

d) The embedment lengths of the reinforcement layers in order to prevent pullout and sliding;

e) How to prevent the slope face from sloughing or eroding;

f) Installation considerations.

Geo-synthetics reinforcement of slopes is a relatively new option available to the civil engineer. Slope angles can be increased arid "poor" soil can be, utilized to construct economical soil-geo-synthetics facilities. Uncertainties exist in the complex interaction between the soil and the geo-synthetics but there are numerous procedures which ignore this in the design. The design procedures available may be

Conservative yet still may be an economical alternative when compared to more conventional options.

The soil properties needed in the design of reinforced slopes are the same as those needed for a conventional slope design and can be obtained from the usual geotechnical procedures. In fact, a conventional slope design, without reinforcement, should be evaluated first in order to determine the need for a reinforced slope.

In addition to the soil and geo-synthetics properties, the interaction between the two is required to design a reinforced slope. The actual mechanics of the interaction appear to be very complicated. The increment of the shear resistance (strength) of the reinforced soil is due to:

a) bond stresses between the reinforcement material and the soil;

b) Reinforcement material properties;

c) Serviceability limits on allowable tensile

4.2. Downstream Slope Stability Analysis of Dam for Steady State Seepage Condition

The steady state slope stability analysis has been checked for the downstream slope which is expected to be the worst case compared to the upstream face. The hydraulic conductivity and the volumetric water content values are used as input for SEEP/W of Geo studio 2007 to generate the water table and pore water pressure required for the slope stability analysis. The shear strength parameters are used for slope stability analysis using Slope/W of Geo studio 2007 package. The analysis is made when the water level is at Normal Pool level (2846m).

4.3. Seepage Analysis Results from SEEP/W

The dam in this study is modeled by SEEP/W, which could be used to analyze any seepage problems. Seep/w uses the finite element method for two dimensional Darcy's flow in both saturated and unsaturated soils.

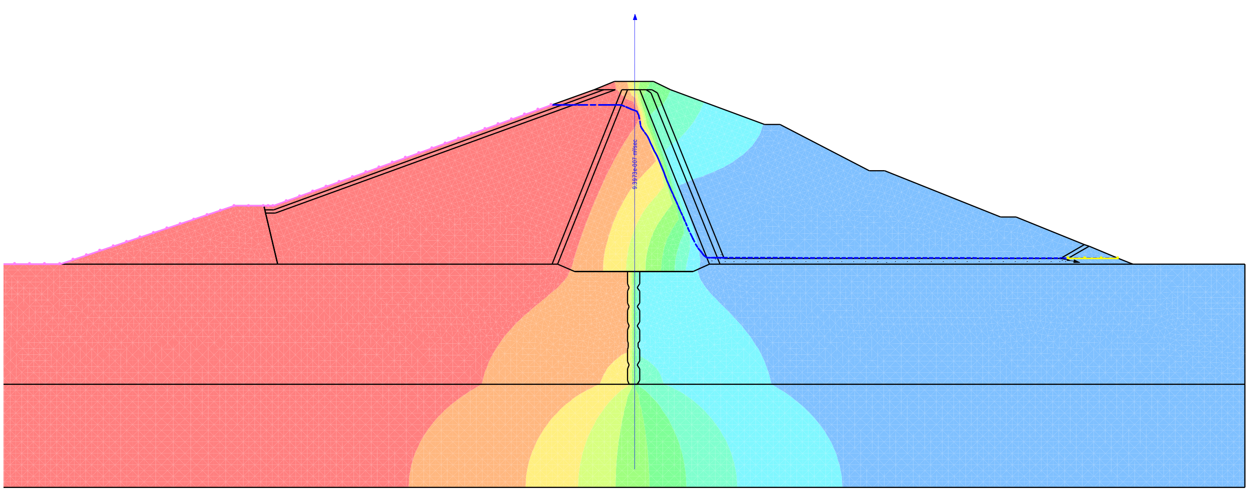


Figure 20: Model of 2.75 H: 1V U/S and D/S 2.25 H: 1V below two berm Slope case

The stability analysis of downstream slope under steady state condition has been checked by considering Normal water level (NWL) for normal condition. The phreatic surface computed with the help of Seep/W.

4.4. Stability Analysis of Reinforced Downstream Slope for Steady State Seepage Condition (Using SEEP/W Generated Pore Pressure)

The downstream slope of Ajima earth fill dam is then considered to be reinforced with horizontal layers of geotextile. As provision of reinforcing layers of geotextile would result in increase in factor of safety, steeper slopes may be provided to the downstream side of the dam. The downstream slope of the dam is therefore decreased by 0.5H: 1V. The spacing between reinforcing layers was varied from 0.4 to 2.5m for each case. Analysis is then carried out for each case separately. Analysis results for each case is presented as in the following section. Analysis has been made for each slope before reinforcement and horizontal layers of geotextile have been introduced to the slope and analysis is made by varying spacing of reinforcement.

Stability analysis of a downstream slope for long term steady state seepage condition before reinforcement is carried out. Then, horizontal layers of reinforcement have been introduced to the slope and analysis is done.

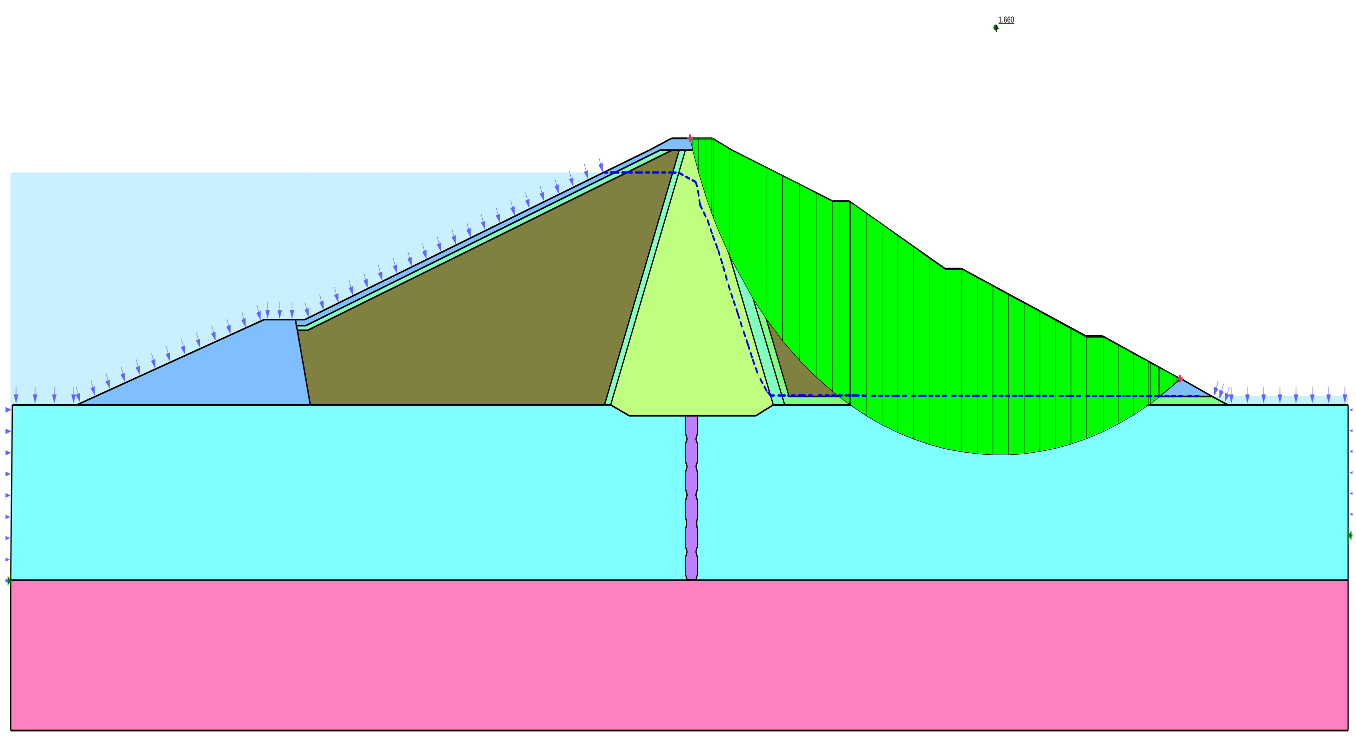


Figure 21 : Stability analysis of downstream slope under steady state condition (unreinforced: 2.25 H: 1V below two berm 2.5 H: 1V case)

The stability analysis of downstream slope under steady state condition has been checked by considering Maximum water level (MWL) for normal condition.

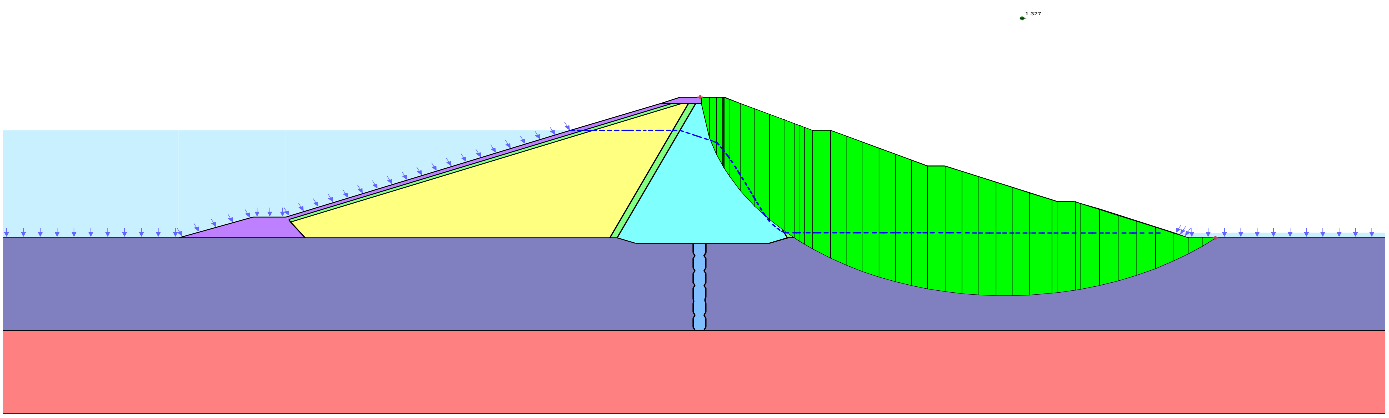


Figure 22: Stability analysis downstream slope under steady state condition (unreinforced 1.75H: 1V & 1:1.85 below berm Slope case)

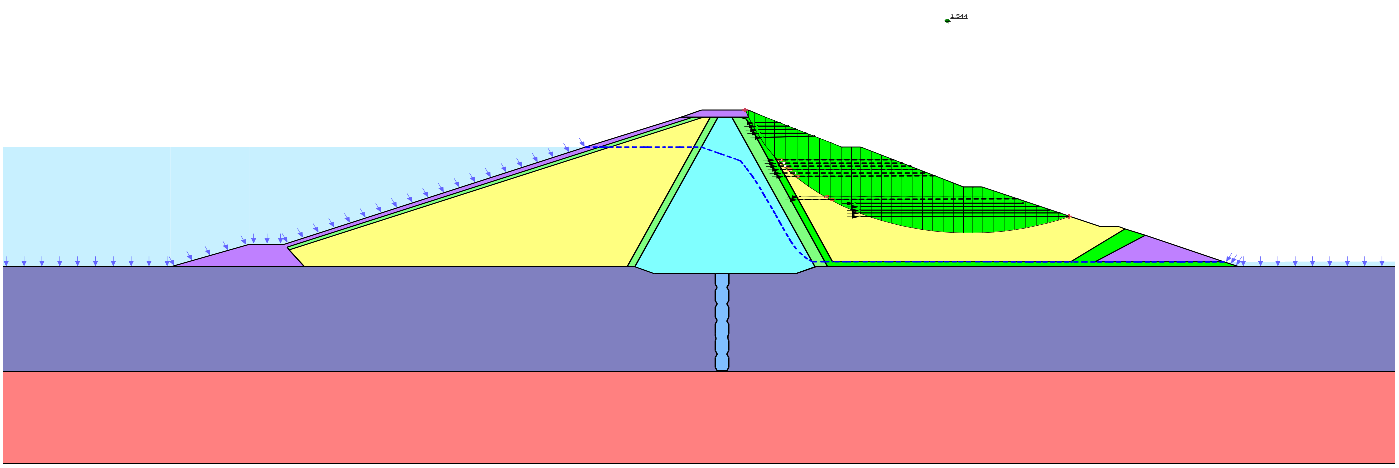


Figure 23: Stability analysis downstream slope under steady state condition (reinforced 1.75H: 1V & 1:1.85 below berm Slope case)

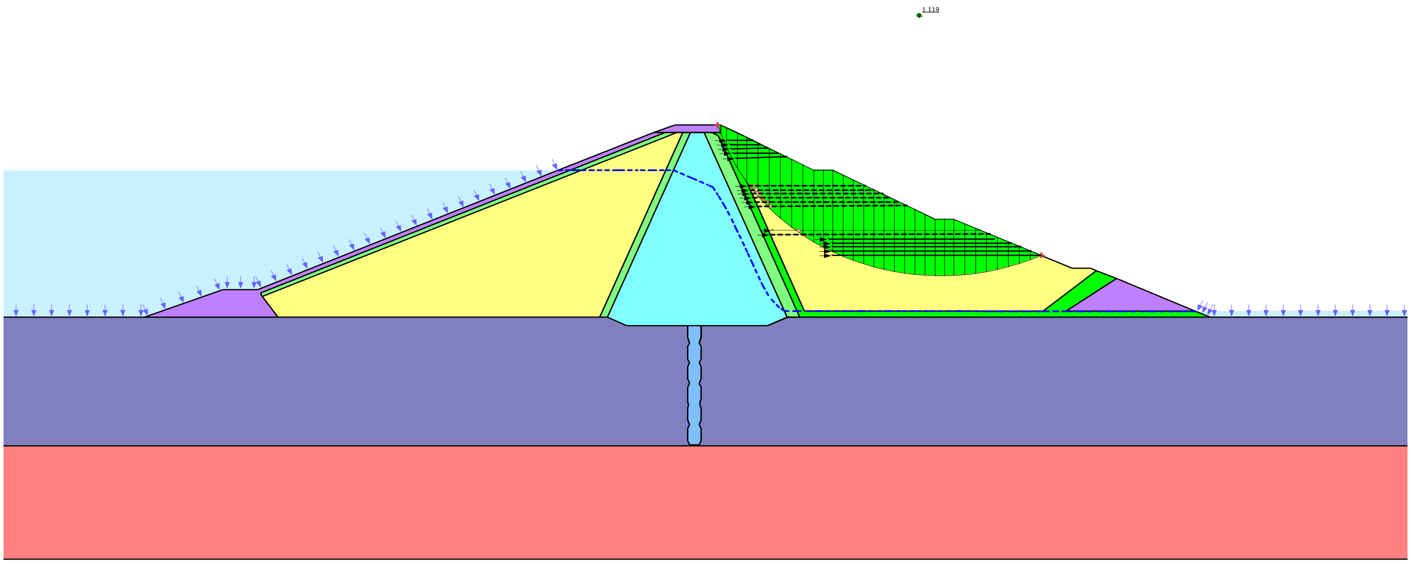


Figure 24: Stability analysis downstream slope under steady state condition with earthquake (reinforced 1.75H: 1V & 1:1.85 below berm Slope case)

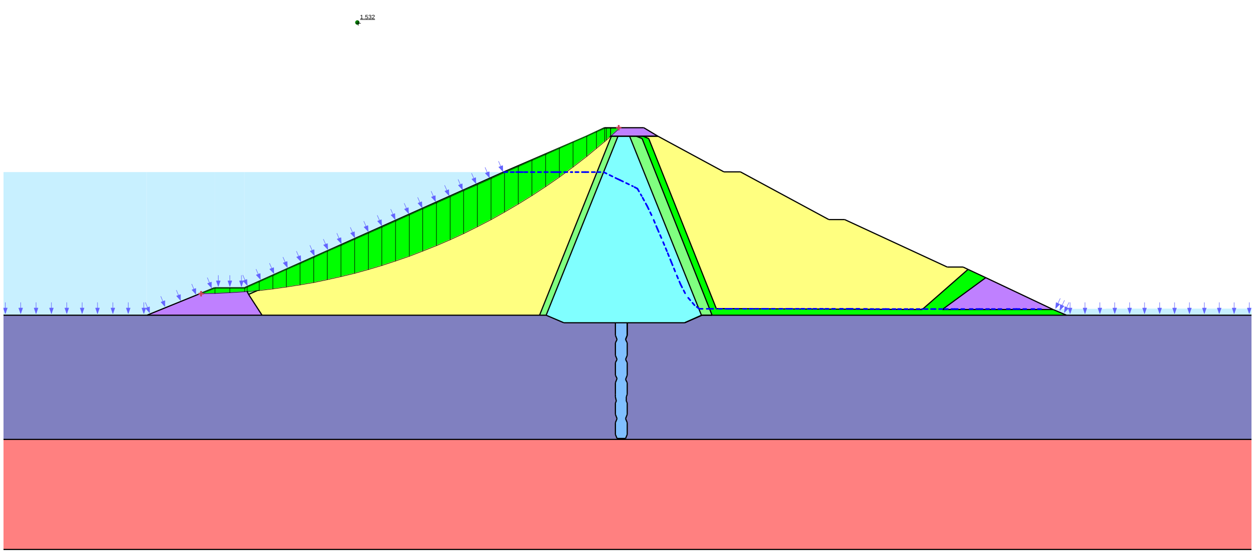


Figure 25: Stability analysis upstream slope under steady state condition (unreinforced 2H:1V Slope case)

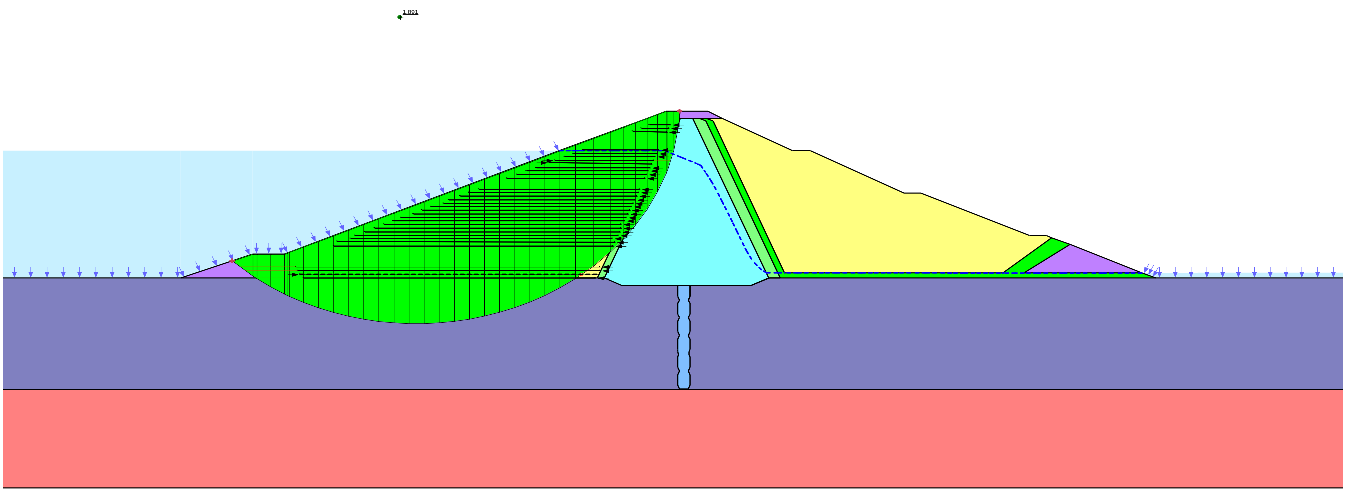


Figure 26: Stability analysis upstream slope under steady state condition (reinforced 2H:1V Slope case)

4.5. Summary of Results and Discussions for Downstream and Upstream Unreinforced and Reinforced Slope Analysis

The results of the downstream and upstream **unreinforced** and reinforced analysis under steady state seepage condition have been summarized and tabulated as depicted below.

Table 5: Summary of analysis result

Downstream	**slope**	**FS WITH OUT REINFORCEMNT**	**FS WITH REINFORCEMNT**	**Remark**
Trial 1	1V:2.75H	1.65	1.75	
Trail 2	1V:2.0H	1.48	1.59	
Trial 3	1V:1.75H	1.32	1.54	
Upstream	**slope**	**FS WITH OUT REINFORCEMNT**	**FS WITH REINFORCEMNT**	**Remark**
	1V:2.75H	2.16	3.63	
	1V:2.25H	1.53	1.89	
	1V:2H	1.79	1.98	

From this different trail selected the steeper slope for upstream 1V:2H and 1V:1.75H found safe factor of safety 1.98 and 1.54 respectively for reinforced embankment. In unreinforced in the same slope found 1.79 for upstream and 1.32 for downstream. Which means the reinforced soil slope is stable than unreinforced soil slope.

4.6. Cost Analysis for Ajima Dam to Compare the Construction Cost with and Without Reinforcement

Table 6: Cost analysis

	Upstream			**downstream**		
description	Quantity (m3)	cost/m3	total cost	Quantity (m3)	cost/ m3	total cost
Excavation	210000	100	21000000	24000	100	2400000
compacted fill	190440	250	47610000	173000	250	43250000
total cost			68610000			45650000
total cost for both upstream and downstream work without reinforcement						**114260000**
	Quantity (m^2)	cost/m^2	total cost	quantity (m^2)	cost/ m^2	total cost
Geotextile reinforcement with transportation	403001	100	40300100	266126.9	100	26612690
Total for two						**66912790**
difference amount						47347210
Total cost of geotextile reinforcement in USD						1338256
Amount saved (%)						**41.4381**

The analysis has been done for selected the steeper slope for upstream 1V:2H and 1V:1.75H. Depend on the above analysis, there is a significant difference in terms of the construction cost profitability of the unreinforced and the geotextile reinforced total cost for both upstream and downstream work. In the case of dam construction without reinforcement, the work requires a total of **114260000*ETB***. However, when it is constructed with geotextile reinforcement a total of **41.4381**% of this total investment can be saved because it will only require **66,912,790 *ETB.***

4.7. Earthquake

Applying the corrected acceleration time histories are more common in dynamic analysis. This method is used to investigate the behavior of the structure under the influence of a given earthquake. One of the most important features of accelerometers is the frequency and the range of earth motion at various frequencies. New materials in construction of hydraulic structures such as earth dams can be very effective. In recent years, geo-synthetics have played a major role in earth dam and reservoir rehabilitation projects and provided promising solutions to the safety issues for earth dams which these properties have attracted engineers' attentions. Geo-synthetics materials are presently used widely in international dam construction practice as watertight elements, filters, drains, reinforcing and separating members, and for protecting and reverting slopes of earth dams. In previous studies, the effect of these materials on the performance of the earth dams' shell during earthquake has been less emphasized using, Slope/W software from Geo-Studio series has been utilized to investigate the seismic behavior of earth dam slopes in the presence and absence of geo-synthetics and get the safety factor in both analyses and comparing them with nailing system. The results of the analysis clearly showed that geo-synthetics depending on the type of soils enhance the stability of the earth dam shells approximately 10 % under earthquake loading conditions while nailing increased safety factor about 2 times in comparison with static conditions. In this paper, conventional pseudo-static design methods for unreinforced and reinforced geo structures adopted in seismic norms. In difference, numerical simulations provide accurate and reliable results within the range of those obtained by similar experiments. Along these lines, it was shown in the presented investigation that, similar to experimental behavior, a separate failure surface is not developed in finite element analyses, as a more extensive failure is observed. In other words, compared to an unreinforced slope a wider region of a reinforced earth structure is affected but to a significantly minor extent due to the presence of the reinforcement, however, this depends on the type of the soil material and other parameters. Therefore, numerical analyses contribute not only to the more accurate evaluation of the dynamic response of reinforced geo structures, but also to the identification of the developed failure modes. Hence, they can be efficiently utilized within a framework of a displacement-based approach, in the viewpoint of contemporary performance-based design, is more reliable and realistic than conventional approaches for the evaluation of seismically-induced deformations of reinforced soil slopes and wall.

4.7.1. Pseudo Static Analysis for Reinforced Slope

This analysis considers a seismic coefficient of acceleration for both horizontal and Vertical force computation and add more two external forces due to earthquake other than the static force. At the ground motion the seismic coefficients will be taken which creates an inertial movement, then changed to a force multiplying by the mass of the material of slices. This approach is a limit equilibrium approach. Past practice and most current practice in the analysis of embankment stability against earthquake forces involves the computation of the minimum factor of safety against sliding when a static, horizontal force of some magnitude is included in the analysis. The analysis is treated as a static problem and the horizontal force is expressed as the product of a seismic coefficient K, and the weight W, of the potential sliding mass. If the factor of safety approaches unity, the section is generally considered unsafe, although there is no generally recognized limit for the minimum acceptable factor of safety.

Sometimes is assumed that the embankment dam behaves as a rigid body and so the accelerations will be uniform throughout the section and equal at all times to the ground accelerations. The main limitations of this approach are:

1) It is evidence from field tests that all earth dams do not behave as rigid bodies;

2) The maximum acceleration will be developed in an embankment dam for only a short period of time, so that the deformation resulting from it may be small (Seed, 1979).

4.7.2. Results of Specific Seismic Hazard Assessment

The site Specific Seismic Hazard Assessment for Ajima Dam following the probabilistic approach has been carried out following accepted standard procedures. Results of the hazard assessment for the Ajima extracted from the study document are presented in Table below.

Table 7: Ground motion amplitude in percentage of gravity (%g) for rock and soil sites at different periods of motion and for different return periods at the Ajima Irrigation Project Site

Return Period in years	Ground Motion Amplitude in % of g for Boore-Joyner-Fumal (1993,1997)					
	Period =0.2sec		Period =1.0sec		Period =2.0sec	
	Rock	Soil	Rock	Soil	Rock	Soil
100	20.85	22.12	6.18	7.11	3.63	4.10
500	40.44	42.22	11.75	13.64	6.45	7.41
1000	48.52	50.99	15.50	18.06	8.26	9.56
2500	61.74	65.44	22.17	25.75	11.46	13.38
10000	88.90	95.46	36.61	41.81	18.79	22.02

The PGA values in Table 5.1 are very high, because Ajima dam is located within the influence range of the Main Ethiopian rift and the Afar Depression which are both part of the East African Quaternary rift (23 million years to present) which is a seismically active region. Dams are normally allocated a hazard category using the method of ICOLD bulletin 72 which takes into account reservoir capacity, dam height, number of persons at risk and potential downstream damage.

4.7.3. Selection of Earthquakes for Analysis

Earthquakes must be defined for analytical purposes so that appropriate seismic evaluation parameters can be selected. According to ICOLD Bulletin 72, seismic hazard of a specific project at interest can be studied either through the deterministic or probabilistic approach. The first demands understanding the structural setting and analysis of faulting systems of the project area which is complicated task also difficult to get reliable information.

The PGA values indicated above will be an input for evaluating the stability analysis of the embankment dam for either Pseudo static or dynamic analysis. The results of Pseudo static analysis are critically dependent on the value of the seismic coefficient, kh. Selection of an appropriate Pseudo static coefficient is the most important, most difficult aspect of a Pseudo static satiability analysis. Pseudo static method is conservative and also it assumes that the earthquake force is constant and acts only in a direction that promotes slope instability. For this reason, Pseudo static coefficients generally are selected to be some fraction of the peak acceleration to account for the fact that the peak acceleration acts only briefly and does not represent a longer, more sustained acceleration of the landslide mass.

Table 8: Pseudo static coefficients from various studies

Investigator	Recommended Pseudo static Coefficient (K)	Recommended Factor of Safety (FS)	Calibration Conditions
Terzhagi (1950)	0.1 (R-F=IX)	>1	Unspecified
	0.2 (R-F=X)		
	0.5(R-F>X)		
Seed (1979)	0.10(M=6.50)	>1.15	< 1m displacement in earth dams
	0.15(M=8.25)		
Marcuson (1981)	(0.33-0.50)xPGA/g	>1.0	Unspecified
Hynes-Griffin and Franklin (1984)	0.50xPGA/g	>1.0	< 1m displacement in earth dams
California Division of Mines and Geology (1997)	0.15	>1.1	Unspecified, probably based on <1m displacement in dams

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The principal driver for expanding the use of geotextiles in dams is the potential cost savings over conventional construction practices with granular materials. Through applying geotextile reinforcement, the stability analysis was conducted for both upstream and downstream dam body for different trail by steeping the slope. Through this analysis was done to find out the steeper slope with safe factor. After conducting the analysis for upstream 1V:2H and for downstream 1V:1.75H slope has been selected. This trail safety factor is for upstream and for downstream 1.98 and 1.54 respectively. This safety factor is improved by 0.75 for upstream and 0.5 for downstream when compared to the unreinforced proposed design. In the analysis the geotextile is used in the shell region. The construction cost is saved by 41.4381% which is compared from unreinforced gentled design. If the dam is constructed without reinforcement, the construction cost for excavation and compacted fill in shell region will be **114260000*ETB*.** However, if the dam is constructed with geotextile reinforcement, the total budget required for excavation and compacted fill in the shell region will be **66,912,790 *ETB.*** That means a total of **47347210 ETB** will be saved in line with a considerable time saved in the process of construction. Therefore, this research has helped to conclude that using geotextile reinforcement will be not only beneficial but also time and cost saving.

5.2. Recommendation

Geotextile reinforcement technique is recommended to embankment dam to be economical, to complete the construction with the reasonable time and safe in static and dynamic loading condition. This method also has positive impact in order to stabilize the embankment during dynamic loading but it is not intended in this study. The Ajima embankment dam requires high amount of initial construction cost. Therefore, implementing this technology would help minimize construction time, cost and energy. If further research is undertaken on this issue, related issues of water drainage, filtration and dynamic loading with regard to complications of earth quake can be further explained and analyzed. There has to be some compelling reason to select geotextiles over conventional dam construction materials. The principal advantages are lower costs, and ease and rapidity of construction.

6. REFERENCES

Amhara National Regional State Water*, Irrigation and Energy Development Bureau (ANRSWIEDB) Feasibility Study and Detail Design of Ajima Earth Dam and large Scale Irrigation Project* Volume VI: Dam and Appurtenant Structures Design Final Draft Report April, 2017 Dessie, Ethiopia

Ashenafi Yilekal Bogale (2015) *ANALYSIS OF GIDABO EARTH FILL DAM BY INTRODUCING GEOTEXTILE REINFORCEMENT* A Thesis Submitted to School of Graduate Studies in Partial Fulfillment of the Requirements for Degree of Master of Science in Civil Engineering, Addis Ababa University

Castro, G. And Christian, J. T. (1976). " Shear Strength of Soils and Cyclic Loading," Journal of Geotechniques Engineering Division, ASCE, 102, pp. 887-894

Dr Hadush (2002), "Tendaho dam dynamic analysis" draft report,73 pages

Federal Emergency Management Agency, Geotextiles in Embankment Dams Status Report on the Use of Geotextiles in Embankment Dam Construction and Rehabilitation April, 2008

Golze, A.R. (ed), 1977, Hand book of Dam Engineering, Van Nostrand Reinhold, New York.

ICOLD (1983). Seismicity and dam design, International Commission on Large dam

Koerner.R.M. 2005 *Designing with Geosynthetics* fifth ed. Pearson Prentice Hall, New Jersey

Kramer, S. L. (1996). Geotechnical Earthquake Engineering, university of Washington, Prentice Hall, New Jersey

Kumar, Yatindra, 2018 International Journal of Management, Technology and engineering, a Technical Note on Modern Soil improvement techniques, vol 8

Issue VII, July 2018

PERFORMANCE OF GEOTEXTILE-REINFORCED SOIL STRUCTURES
By Jorge Gabriel Zomberg(1994)

P. Novak, A.I.B. Moffat and C.Nalluri and R. Narayanan,(2007). Hydraulic Structures, fourth edition, UK.

Proceeding of One Day International Workshop on Reinforced Soil and Geosynthetics Engineering, 16th Dec, 2012

Seed, H.B., Idriss I. M. (1967). "Slope Stability During Earthquakes," Journal of Soil Mechanics and Foundation Division, ASCE, 109, pp. 299-323

Seed, H.B., Idriss I. M. (1979). "Simplified Procedure for Evaluating Embankment Response," Journal of Geotechnical Engineering, ASCE, 105, pp.1427-1434

Thakare et al *Performance of Geotextile Reinforced Slopes of Earthen Dam* International Journal of Engineering Science Invention ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726 www.ijesi.org Volume 3 Issue 7ǁ July 2014 ǁ PP.18-22

United States Bureau of Reclamation, USBR, (1987). Design of small dams, 3rd edition, a water resources technical publication

7. APPENDIXES

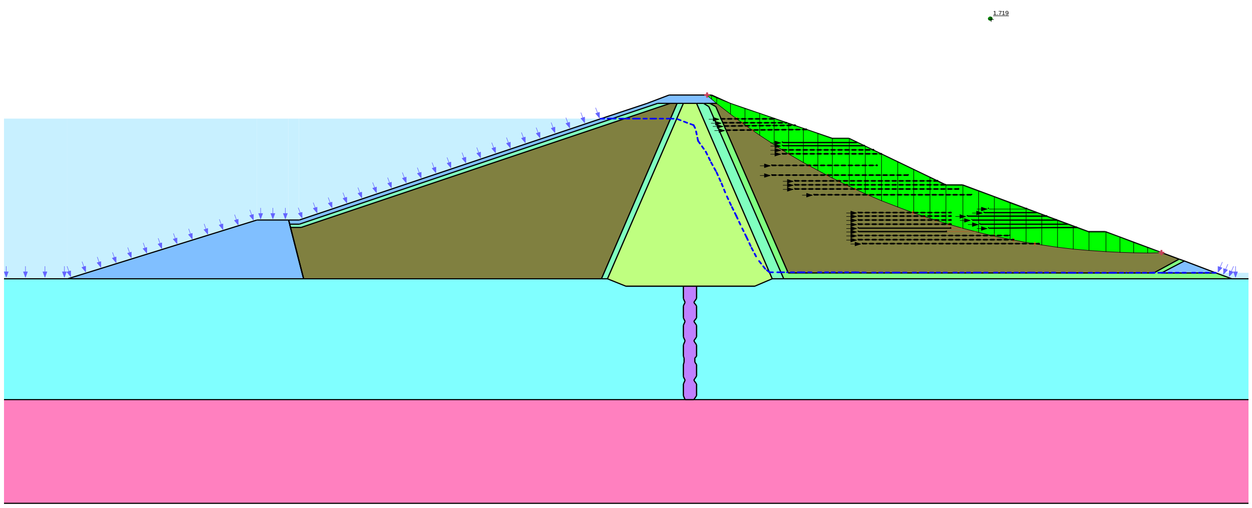


Figure 27: Stability analysis of downstream slope under steady state condition (reinforced: 2.25 H: 1V below two berm 2.5 H:1V Slope case)

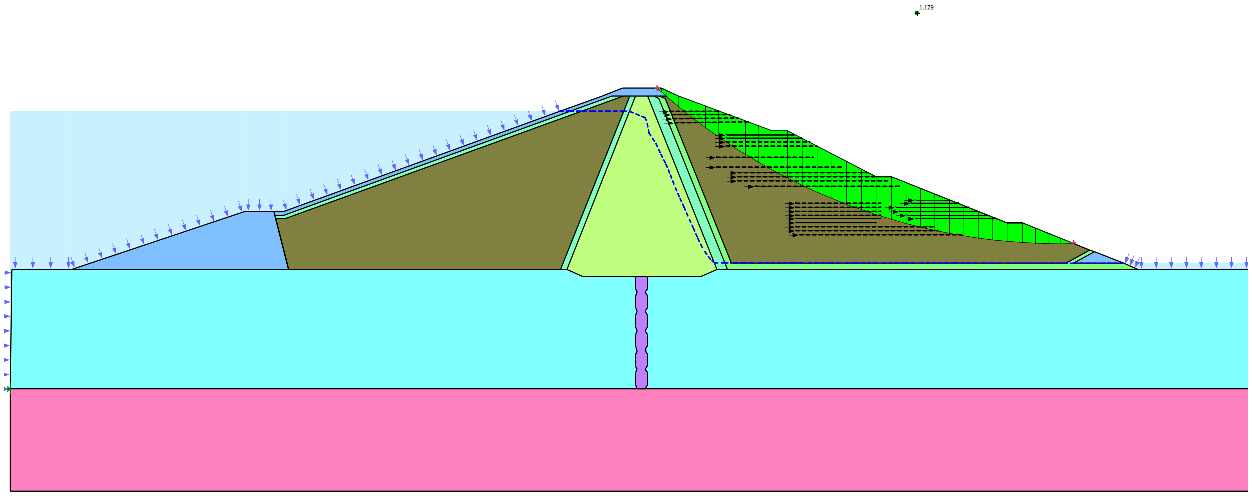


Figure 28: Stability analysis of downstream slope under steady state condition with earthquake (reinforced: 2.25 H: 1V below two berm 2.5 H:1V Slope case)

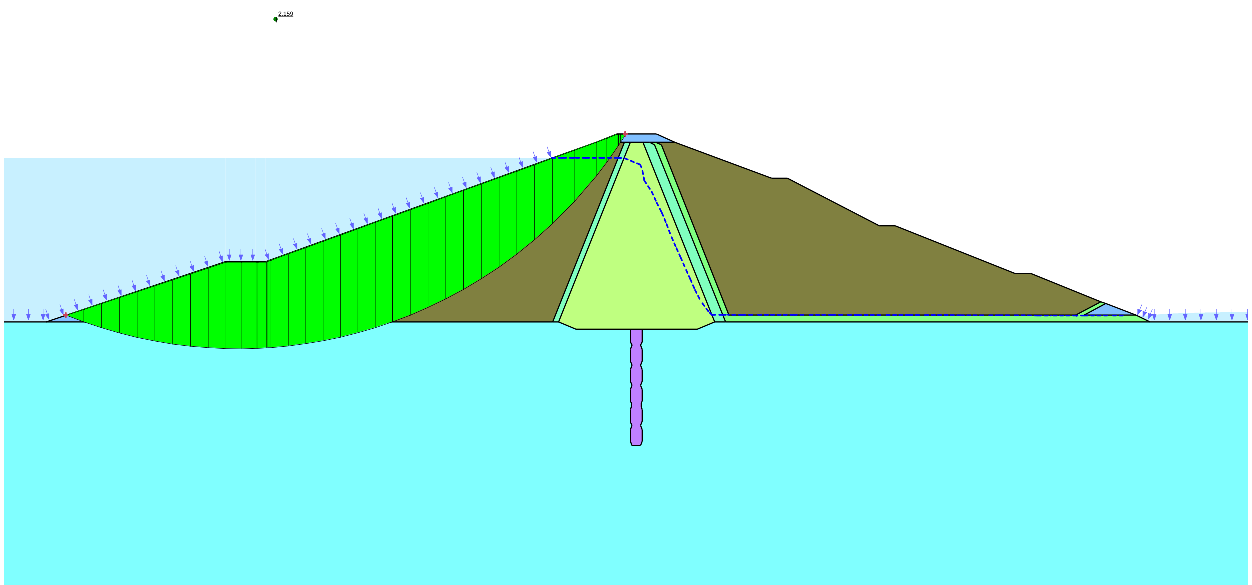


Figure 29: Stability analysis of upstream slope under steady state condition (unreinforced: 2.75 H: 1V Slope case)

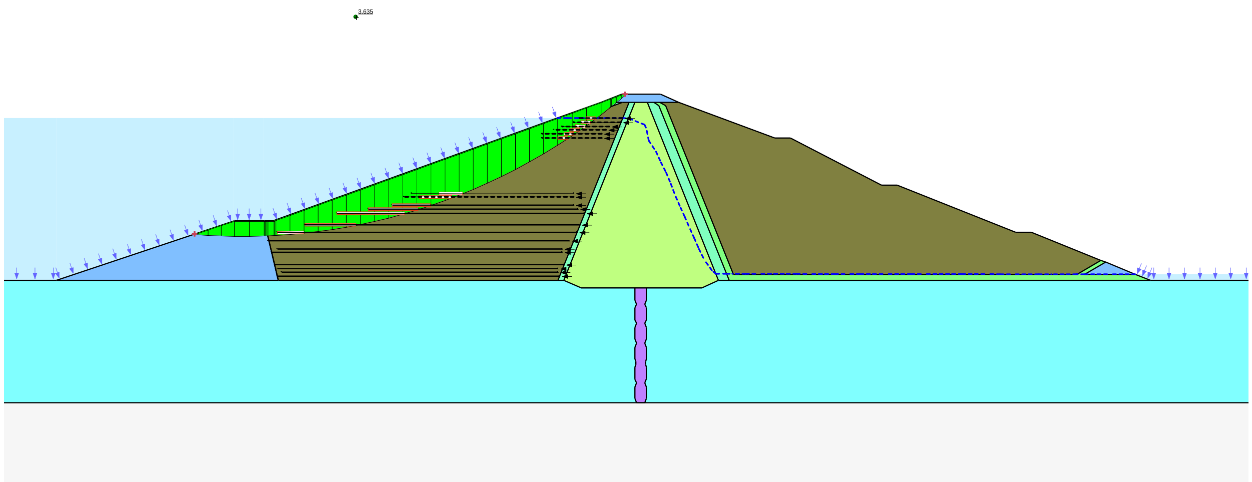


Figure 30: Stability analysis of upstream slope under steady state condition (reinforced: 2.75 H: 1V Slope case)

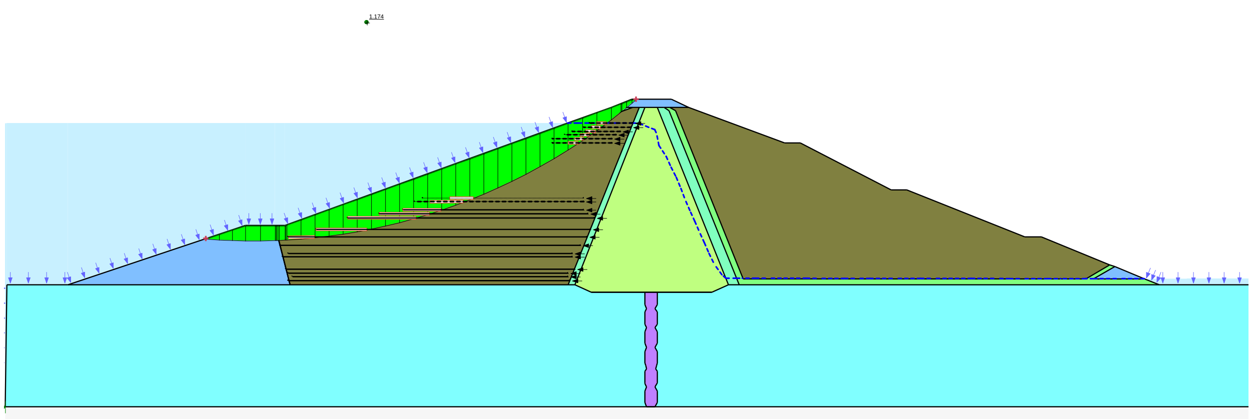


Figure 31: Stability analysis of upstream slope under steady state condition with earthquake (reinforced: 2.75 H: 1V Slope case)

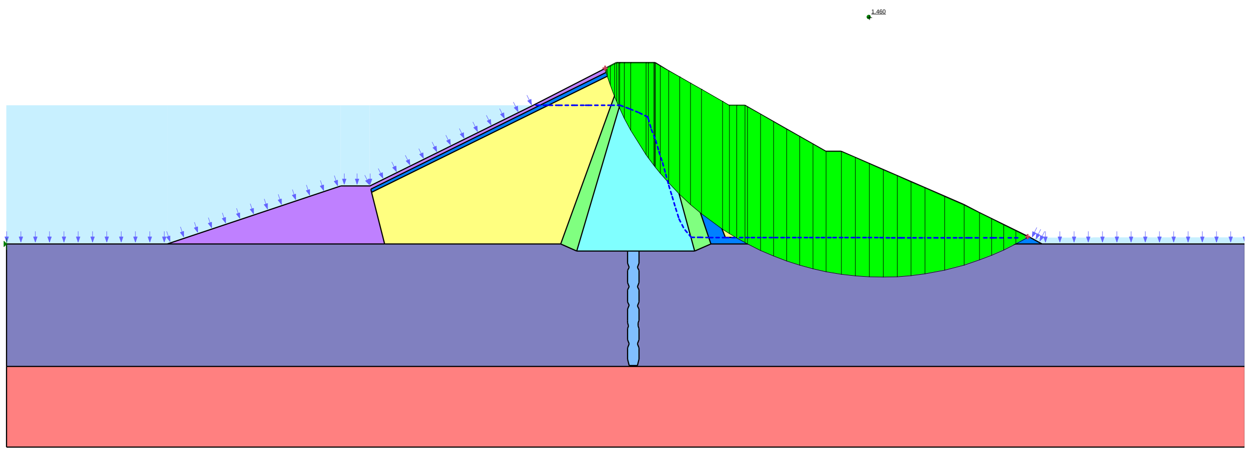


Figure 32: **Stability analysis of downstream slope under steady state condition (unreinforced: 2.0H: 1V & 1:2.25 below berm Slope case)**

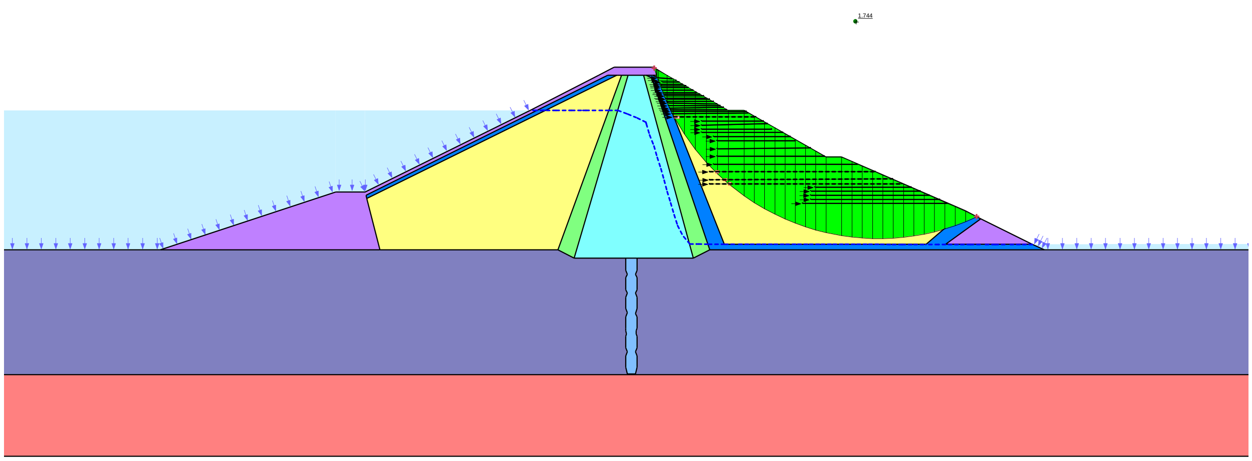


Figure 33: **Stability analysis of downstream slope under steady state condition (reinforced: 2.0H: 1V & 1:2.25 below berm Slope case)**

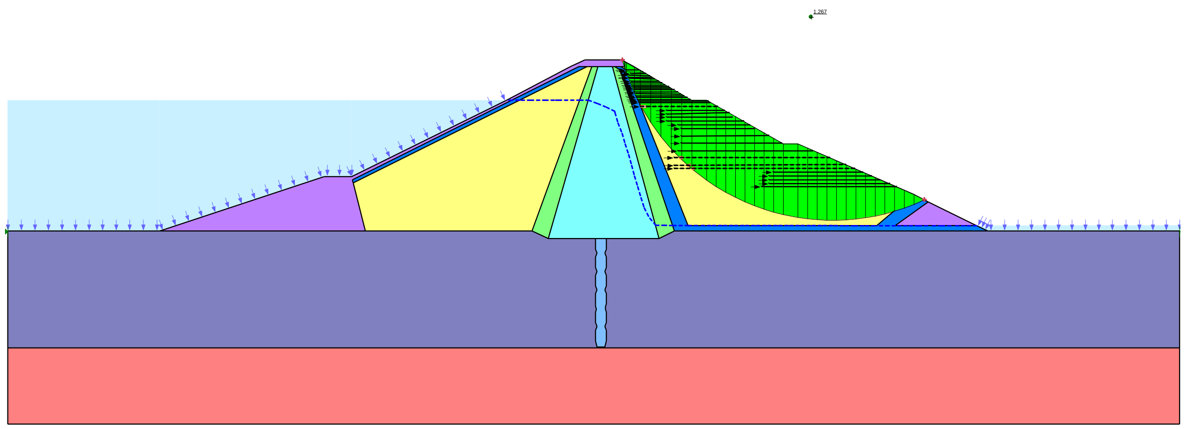


Figure 34: Stability analysis of downstream slope under steady state condition with earthquake (reinforced: 2.0H: 1V & 1:2.25 below berm Slope case)

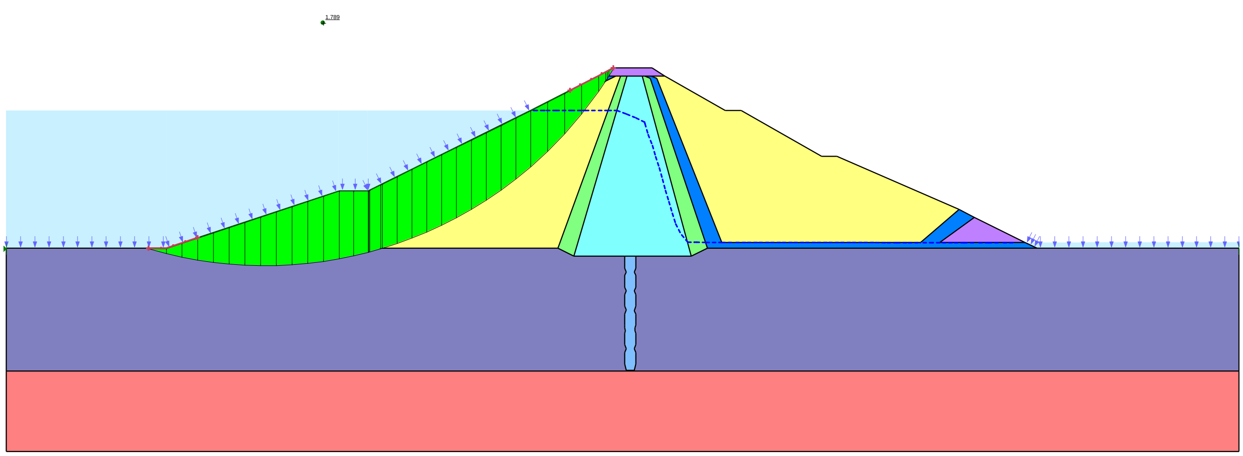


Figure 35: Stability analysis of upstream slope under steady state condition (unreinforced: 2.25H: 1V Slope case)

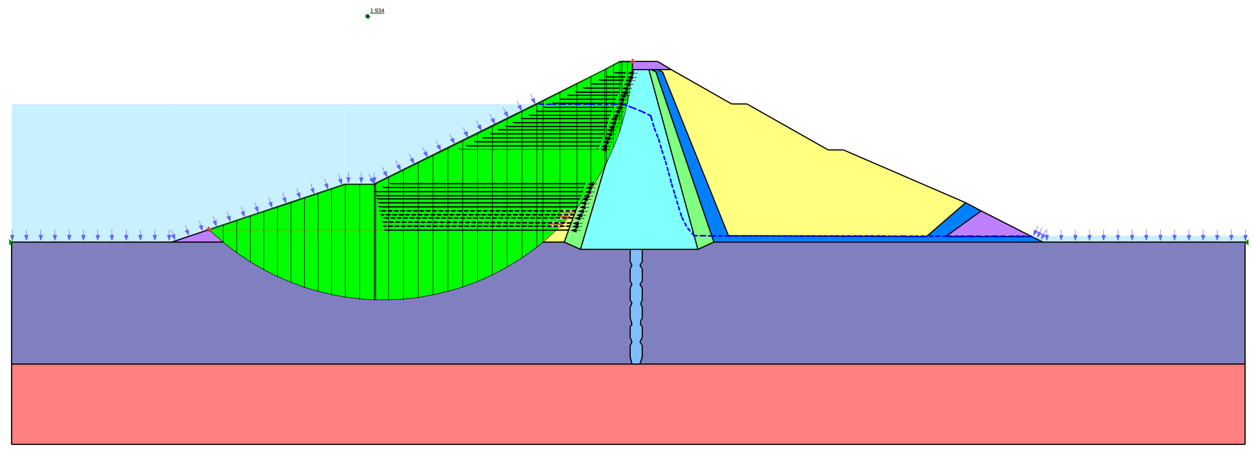


Figure 36: Stability analysis of upstream slope under steady state condition (reinforced: 2.25H: 1V Slope case) For slope 1:2 u/s

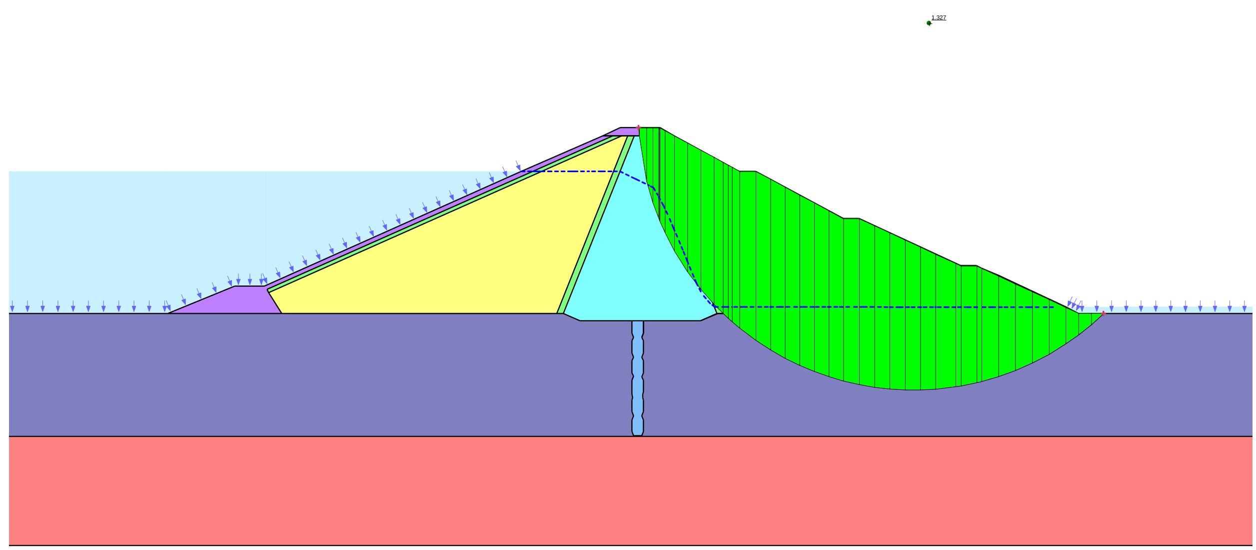


Figure 37: Stability analysis downstream slope under steady state condition (unreinforced 1.75H: 1V & 1:1.85 below berm Slope case)

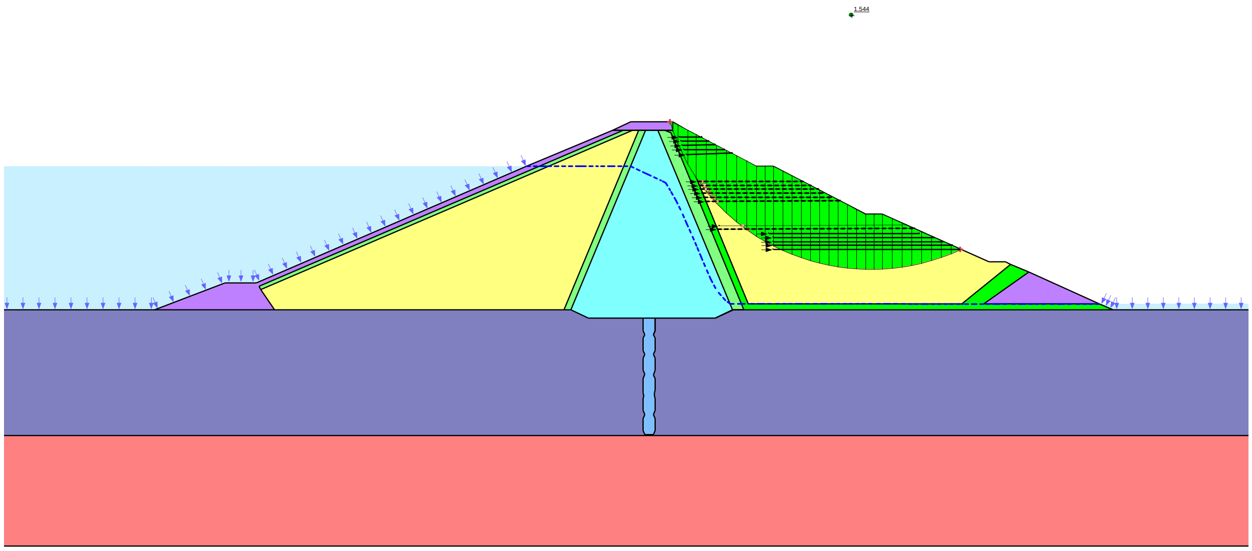


Figure 38: Stability analysis downstream slope under steady state condition (reinforced 1.75H: 1V & 1:1.85 below berm Slope case)

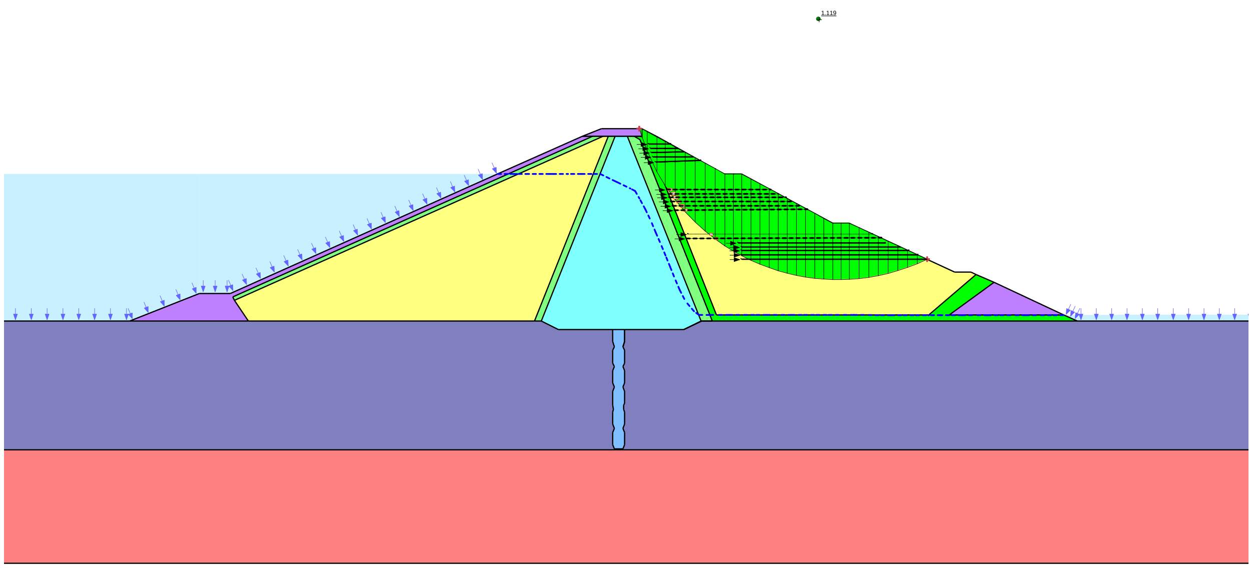


Figure 39: Stability analysis downstream slope under steady state condition with earthquake (reinforced 1.75H: 1V & 1:1.85 below berm Slope case)

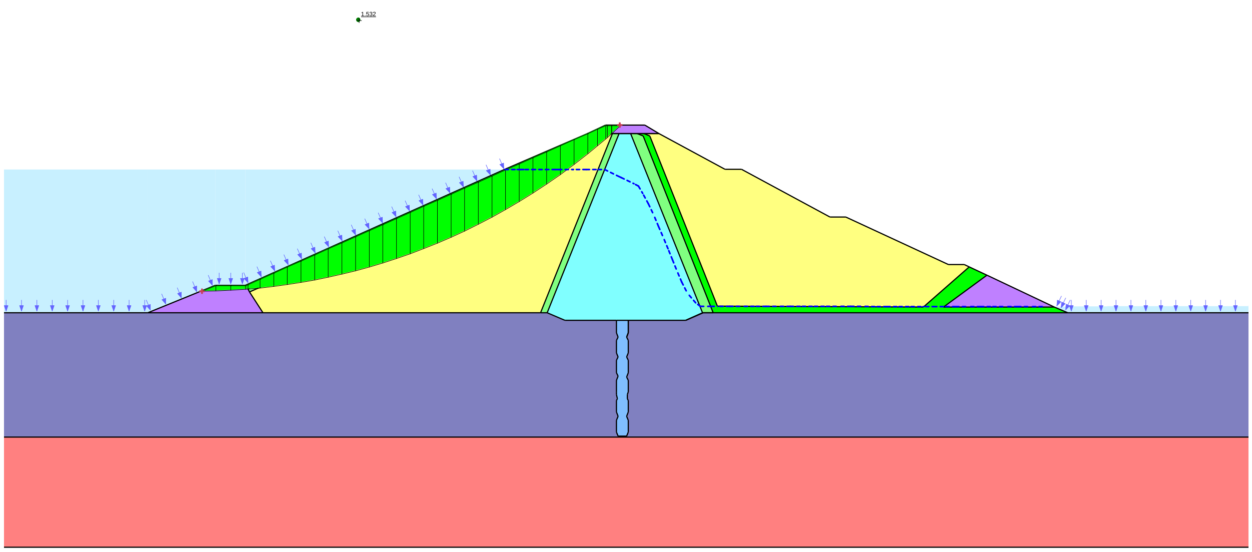


Figure 40: Stability analysis upstream slope under steady state condition (unreinforced 2H:1V Slope case)

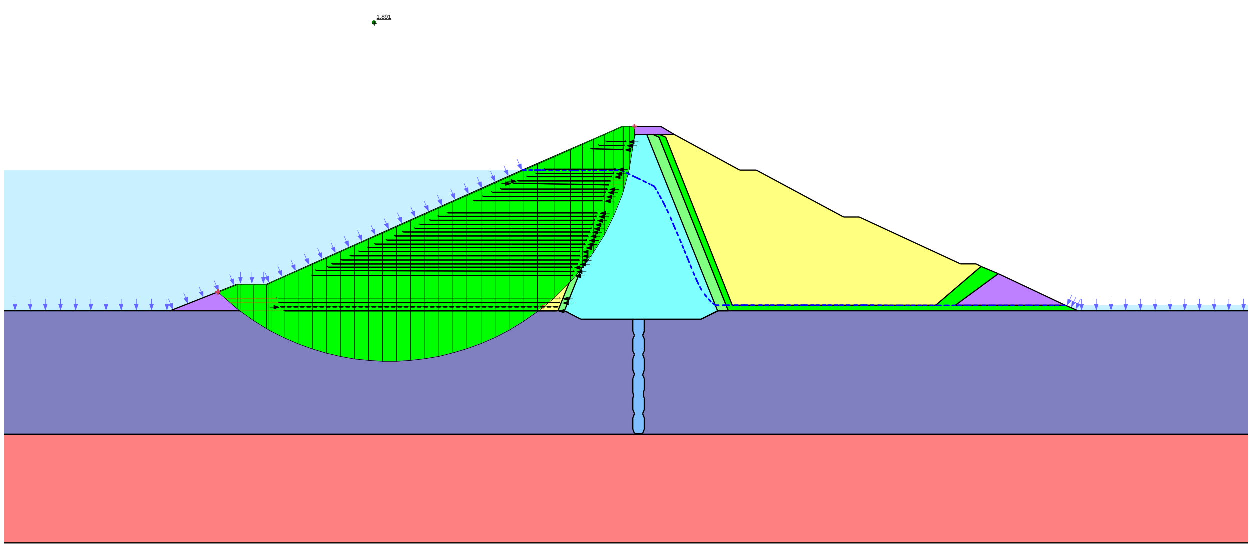


Figure 41: Stability analysis upstream slope under steady state condition (reinforced 2H:1V Slope case)

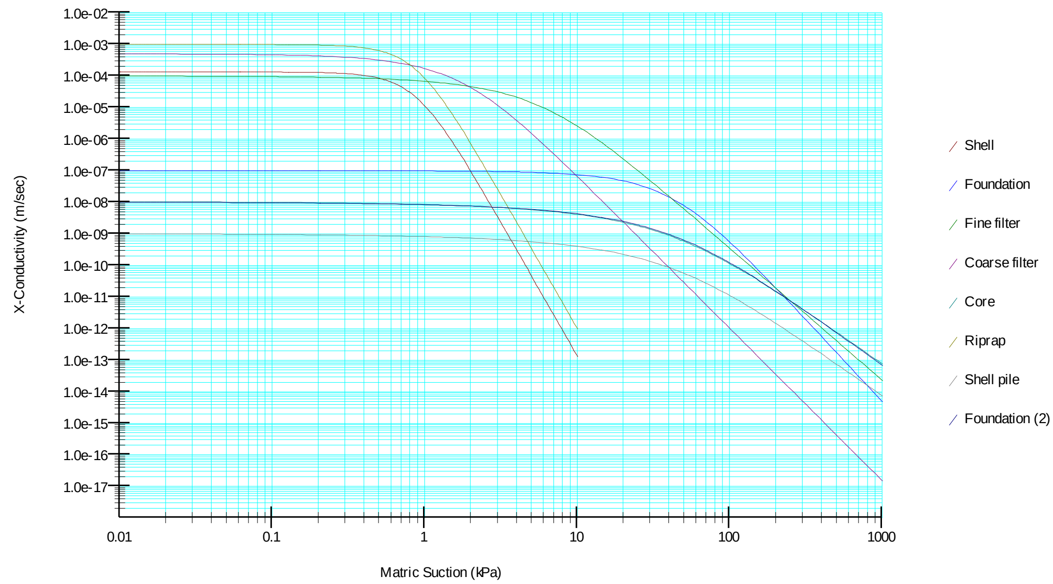


Figure 42: Hydraulic conductivity for slope 1V:2.25 for upstream and 1V:2H

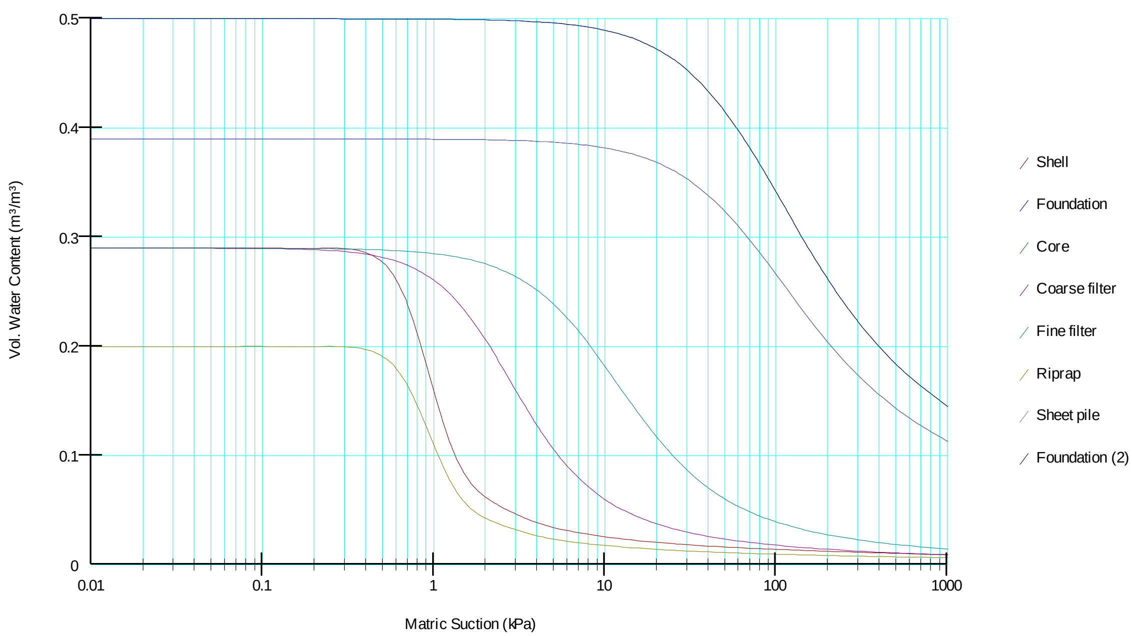


Figure 43: Volumetric water content

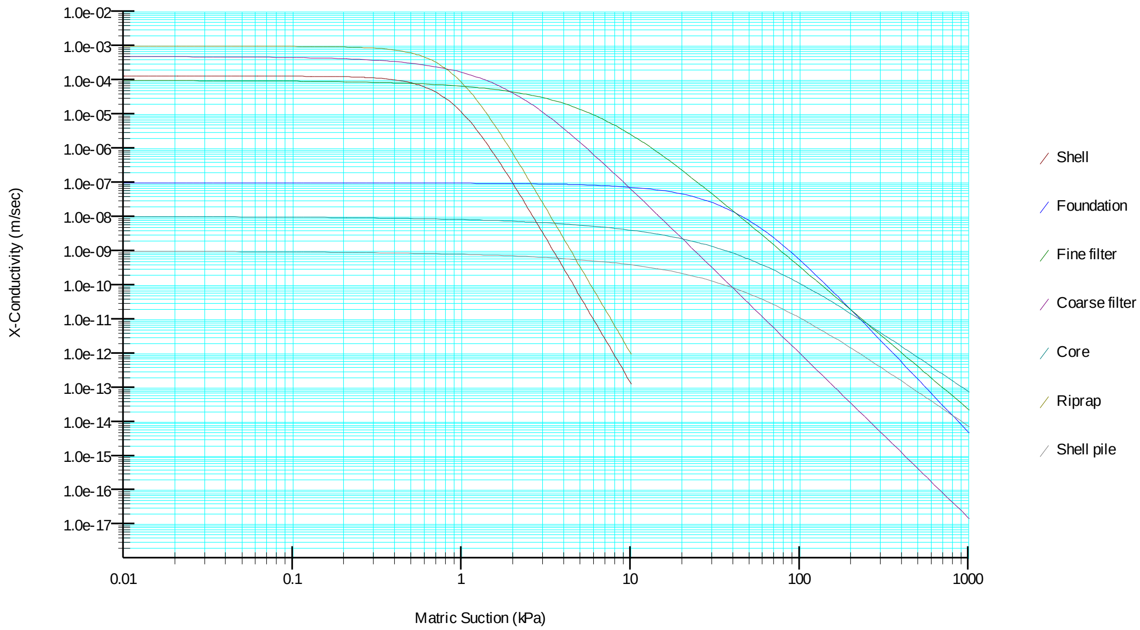


Figure 44: Hydraulic conductivity for slope 1V:2.0 H for upstream and 1V:1.75 for downstream

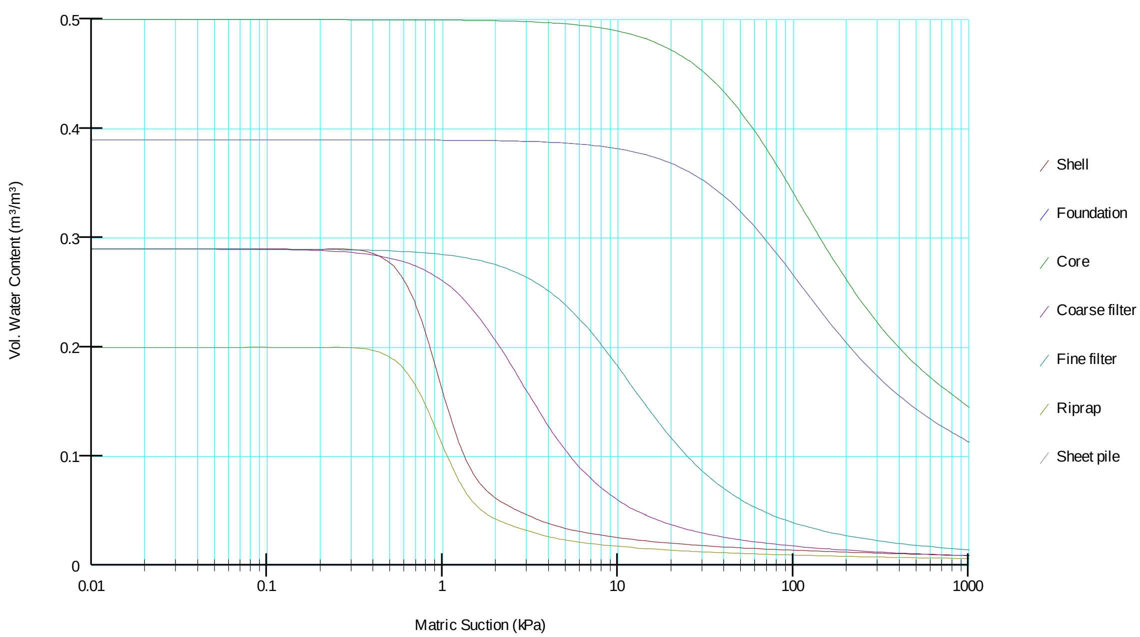


Figure 45: Volumetric water content

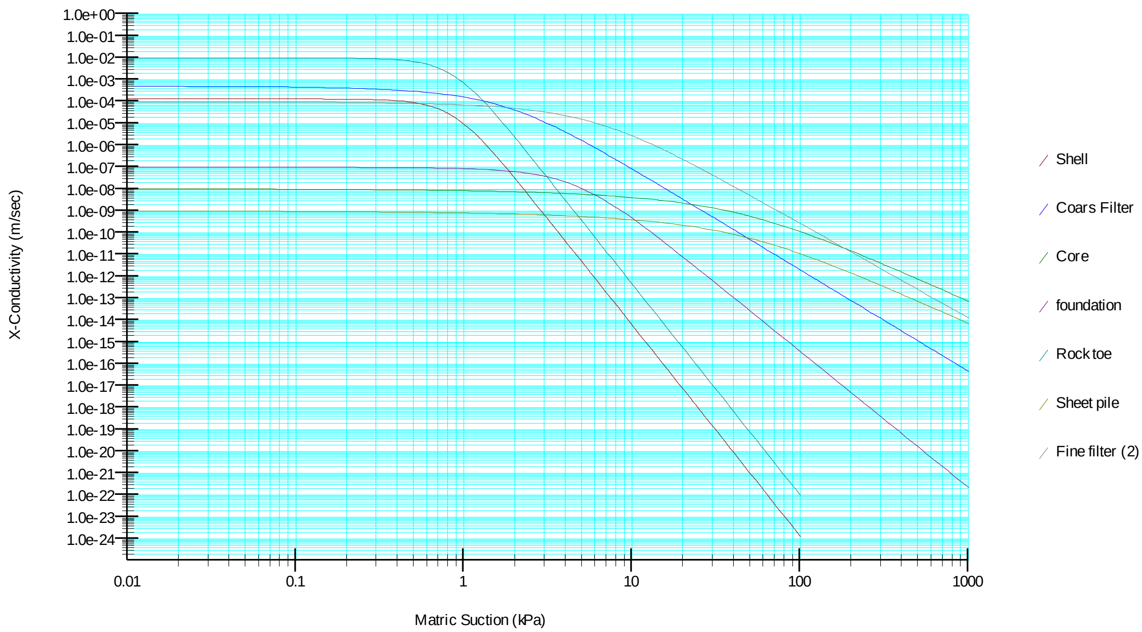


Figure 46: Hydraulic conductivity for slope 1V:2.75H for upstream and 1V:2.25H for downstream

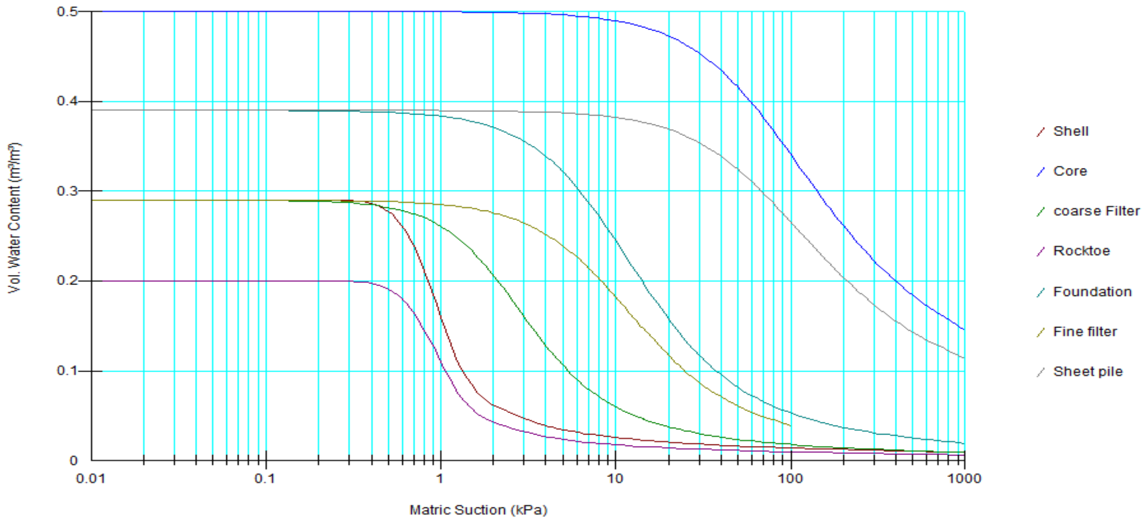


Figure 47: Volumetric water content

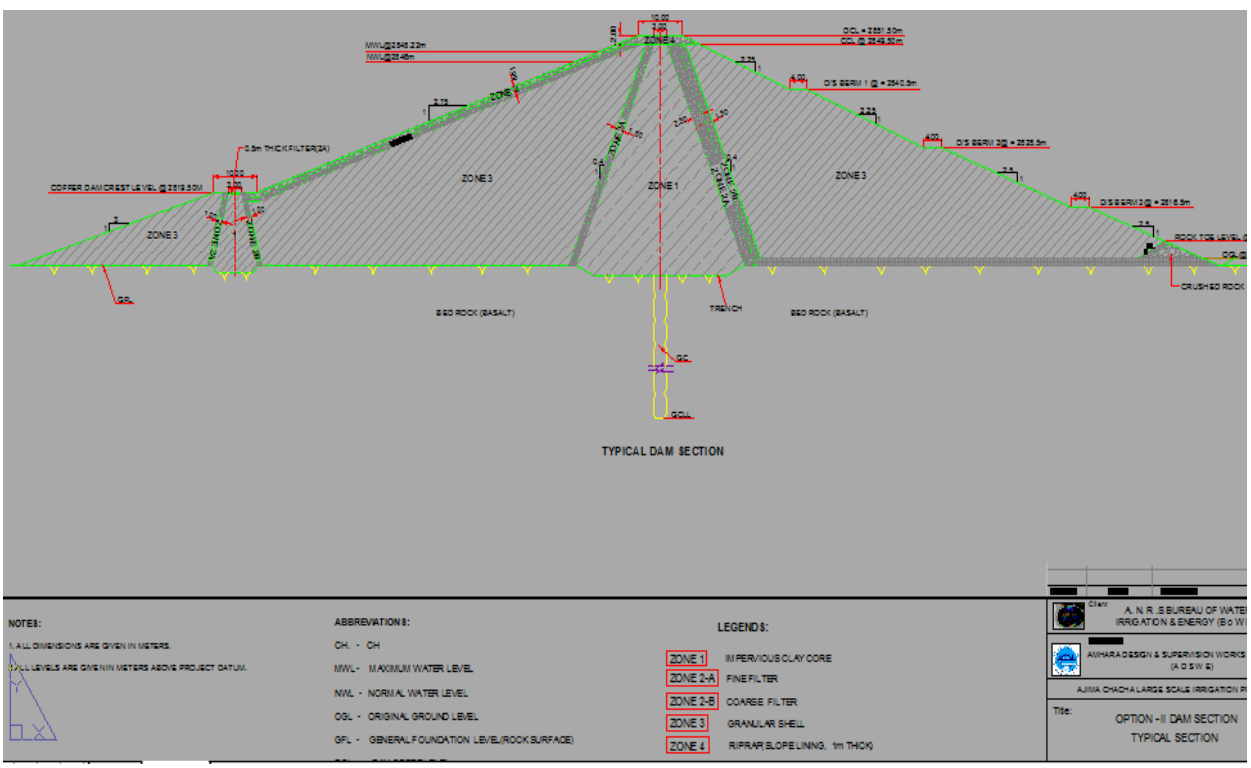


Figure 48: as built dam cross section

Appendixes b

Table 9: Ground motion amplitude in percentage of gravity (%g) for rock and soil sites at different periods of motion and for different return periods at the Ajima Irrigation Project Site

Return Period in years	Ground Motion Amplitude in % of g for Boore-Joyner-Fumal (1993,1997)					
	Period =0.2sec		Period =1.0sec		Period =2.0sec	
	Rock	Soil	Rock	Soil	Rock	Soil
100	20.85	22.12	6.18	7.11	3.63	4.10
500	40.44	42.22	11.75	13.64	6.45	7.41
1000	48.52	50.99	15.50	18.06	8.26	9.56
2500	61.74	65.44	22.17	25.75	11.46	13.38
10000	88.90	95.46	36.61	41.81	18.79	22.02