AUGUST,2012 M.Sc in Civil Engineering ALPER AYDEMİR

UNIVERSITY OF GAZIANTEP

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# RISK ASSESSMENT OF SMALL DAMS

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BY

ALPER AYDEMİR

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# Risk Assessment of Small Dams

**M. Sc. Thesis**

**In**

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**Supervisor**

**Assoc.Prof.Dr. AYTAÇ GÜVEN**

**by**

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Alper AYDEMİR

**ABSTRACT**
**Risk Assessment of Small Dams**

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Importance of renewable energy resources are increasing nowadays. Effective use of water resources can play important role on economics. One of most efficient way to manage water resources is using dams to collect water so that construction of dams is being an important subject for collecting, storage and distribution of water in the future.

Dams store water for irrigation, flood control, hydropower and inland navigation. Besides these important benefits, dam failures can cause vital and financial losses. Dam safety risk analysis must be performed for each dam and monitoring of dams should be done continually.

In this study, an excel based software which was developed by Federal Emergency Management Agency (FEMA) is used to perform risk analysis of a number of existing earthfill dams in Turkey. New empirical models were added to the standard risk analysis tool and it was substantially modified. Basicly, the added models are computing the dam breach parameters such as parameters are breach width, dam failure time, breach side slope and peak breach discharge.

The risk of failure of a dam was classified as low, significant and high. Then this tool was used to classify three dams in Turkey. The dams were found to have high risk for piping failure mode. The proposed tool could help risk assessment of existing and project-stage dams.

**Keywords:** Dam Safety, Risk, Failure, Dam Breach, Risk Analysis

**ÖZ**

**Küçük Barajların Risk Değerlendirmesi**

AYDEMİR, Alper

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Yenilenebilir enerji kaynaklarının önemi günümüzde artmıştır. Su kaynaklarının verimli kullanılması ülke ekonomisinde önemli rol oynamaktadır. Su kaynaklarının yönetmenin en verimli yollarından bir tanesi barajlardır bu nedenle suyun gelecekte kullanmak için toplanması, depolanması ve dağıtılması için baraj yapımı önemli bir konudur.

Barajlarda, sulama, taşkın kontrolü, hidroelektrik ve ülke içi navigasyon amaçları için su depolanmaktadır. Bu önemli yararlarının dışında, baraj yıkılmaları can ve mal kaybına yol açabilmektedir. Baraj güvenliğinde risk analizleri yapılarak, barajların durumu sürekli incelenmelidir.

Bu çalışmada, Federal Emergency Management Agency (FEMA) tarafından geliştirilen excel tabanlı bir yazılım Türkiyedeki mevcut birkaç barajın risk analizlerinde kullanılmıştır. Yeni ampirik modeler standart risk analizi yazılımına eklenmiş ve yazılım geliştirilmiştir. Basit olarak eklenen yöntemler baraj yıkılma parametrelerini hesaplamaktadır, bu parametreler gedik genişliği, baraj yıkılma süresi, gedik şev eğimi ve çıkan en büyük debidir.

Yıkılma riskleri az, orta ve yüksek olmak üzere sınıflandırılmıştır. Daha sonra bu program Türkiye’den üç barajın sınıflandırılması için kullanılmıştır. Bu üç barajında sızma riskinin yüksek olduğu sonucuna varılmıştır. Önerilen bu yazılım mevcut barajların ve proje aşamasındaki barajların risk değerlemesinde kullanılabilir.

**Anahtar Kelimeler:** Baraj Güvenliği, Risk, Yıkılma, Baraj Yıkılması, Risk Analizi

*To My Family*

## ACKNOWLEDGEMENTS

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# CHAPTER 1

# 1 INTRODUCTION

## 1.1 General

Although water covers more than 70% of the Earth, only 1% of the Earth's water is available as a source of drinking. Water makes up 50 to 90 percent of the weight of living things so it is vital for humans and also for all known forms of life in world.

Renewable energy is energy which comes from natural sources. For example sunlight, wind, rain, tides and geothermal heat are most common sources of renewable energy. Wind power, hydropower, solar energy, biomass, biofuel, geothermal energy are mainstream forms of renewable energy. Water is much more denser than air, even a slow flowing stream of water can yield considerable amounts of energy.

Global warming is the rise of average temperature of atmosphere and oceans. Increase of average temperature in global temperature will cause rise of sea levels, and the amount and pattern of precipitation will change accordingly. Nowadays the importance of renewable energy sources are increased because of global warming.

Water play vital role in all known forms of life, so the effective use of water resources is an important subject for human life. Agriculture, drinking water, washing, transportation, chemical uses, fire extinction, recreation, industrial applications are the most common use of water.

A dam is defined as a barrier or structure which is constructed across a stream, river or waterway to control the flow of water and store water behind that barrier. One of the most efficient way to manage water resource is using the dams to collect water. Hence, dams are being an important subject for storage and future distribution.

Dams store water for many purposes such as irrigation, flood control, hydropower. But besides these benefits if the water stored behind dam is released suddenly as a result of dam failure, there would likely be loss of life, significant social and economic losses, as well.. To prevent this kind of catastrophic accidents dams should be constructed within engineering standards of design and construction. Operation, maintenance and surveillance steps must be under continual control. For this purpose many countries have different regulations and standards for dams. (Pisaniello et al., 2006)

In this study an Excel software based risk analysis tool is used, which was developed by FEMA. The main dam parameters such as dam height, body type, spillway capacity are the inputs to the tool. Population who live downstream of dam will be called as population at risk. Population at risk values will be provided from maps and cencus data. It is also aimed to add new empirical dam breach methods to the standard and the modified and the standard tools' results will be presented in tabular and graphical form.

## 1.2 Scope of the Thesis

The main aim of this thesis is to to develop a risk analysis tool and examine the safety of dams. New dam breach computing models will be added to a risk analysis toll developed by FEMA, and the risk assessment of three existing dams in Turkey will be carried out.

## 1.3 Contribution of the Thesis

This study is expected to contribute to the dam safety researches in Turkey. A new tool will be developed for this purpose. The proposed tool will help the users to identify the risk values for different failure modes. Dam breach parameters will be also identified in this thesis. Comparison of most the most common methods and the resulting graphics of risk assessment for the dams under consideration will be presented.

## 1.4 Layout of the Thesis

This thesis is composed of seven chapters. The contents of the chapters are summarized below:

**Chapter Two:** This chapter includes information about dams. Types of dams, history of dams, benefits of dams and definition of small dams are given. Other terms such as risk, hazard and vulnerability are explained in this chapter. Failure modes of dams and literature review of risk assessment of small dams subject are explained.

**Chapter Three:** The Risk Prioritization Tool, process outline of the tool and definition of the terms in risk tool is given. Initial data input methods, failure mode evaluation and consequence assessment are other topics explained in this chapter.

**Chapter Four:** Development of Modified Risk Tool (MRT) is explained in this chapter. New parameters added to the standard risk tool are explained.

**Chapter Five:** Three case studies are performed in this chapter. Modified Risk Tool is used for risk assessment evaluation of these case studies.

**Chapter Six:** This chapter contains results, discussion of the case studies, and the graphical outputs.

**Chapter Seven:** This chapter includes the conclusions of this research and the recommendations for future studies.

CHAPTER 2

# 2 RISK ASSESSMENT OF SMALL DAMS

## 2.1 Definition of Dams

A dam is defined as a barrier or structure across a stream, river or waterway to confine and than control the flow of water.Dams vary in size from small earth embakments often for farm use to high massive concrete structures generally used for water supply,hydro-power and irrigation. (ICOLD; 2007)

The construction of a dam usually requires the relocaton of existing villages, individual houses, farms, highways, raildroads and utilities from the river valley to a higher elevation above the reservoir. (ICOLD; 2007)

Figure 2-1 Town of Old Halfeti after dam construction

Halfeti can be a good example for showing the effect of dam construction over human life. As part of the Southeastern Anatolia Project, aka GAP, several dams were constructed in the area and surrounding regions as part of a larger agricultural and economic initiative by the Turkish Government. The town of Halfeti was among those settlements, ancient and contemporary, that would remain under the rising water levels of the local dams and rivers following the execution of the GAP.

Until the area was flooded in 1999, the people lived from fishing in the Euphrates and farming on the riverbank, especially growing peanuts and the area's famous black roses. Then the waters came and 'new' Halfeti was built. Some buildings, including the jail, were pulled down and rebuilt in the new town. Figure 2-1 Town of Old Halfeti after dam construction shows effect of dam construction in Halfeti.

## 2.2 History of Dams

The history of dam building dates back to antiquity, and is bound up with the earlier civilizations of the Middle East and the Far East. The dam build at Sadd-el-Kafara, Egypt, around 2600 BC, is generally accepted as the oldest known dam of real significance. Constructed with an earthfill central zone flanked by rock shoulders and with rubble masonry face protection, Sadd-el-Kafara was completed to a height of 14m. The dam breached, probably in consequence of flood overtopping, after a relatively short period of service. (Novak et al., 2007)

Du Jiang Yan is the oldest surviving irrigation system in China that included a dam that directed water flow. It was finished in 251 B.C. A large earthen dam, made by the Prime Minister of Chu (state), Sunshu Ao, flooded a valley in modern-day northern Anhui province that created an enormous irrigation reservoir 100 km (62 mi) in circumference), a reservoir that is still present today. (Needham and Joseph, 1986)

The Grand Anicut, also known as the Kallanai is an ancient dam built on the Kaveri River in the state of Tamil Nadu in Southern India. It was built by the Chola king Karikalan around the 2nd Century AD and is considered one of the oldest water-diversion or water-regulator structures in the world, which is still in use. (Signh et al., 2003)

Recent archaeological findings indicate that simple earth dams and networks of canals were constructed as far back as 2000 BC to provide people with the realiable source of water they need to live. The building of the Marib Dam in Yemen began around 750 BC and took 100 years to complete. It consisted of an earth embankment 4 meters in height and stone sluices to regulate discharges for irrigation in domestic use. In 1986, the existing dam was raised to a height of 38 meters that creates a reservoir of 98 million cubic meters of water. (ICOLD; 2007)

### 2.2.1 History of Dams by type

*Gravity dams:* Gravity dam is designed with equilibrium of forces caused by water and weight force of dam body. Gravity dams build without cement were constructed thousands of years before Christ. According to information obtained from wrecks, first constructed gravity dams, foundation width was four times bigger than height of dam. (Ağıralioğlu; 2007)

*Earth fill dams**:*** It is known that one of first earth fill dam was 17,6 km length and with height of 21 m which was constructed by year of B.C. 504 in Sri Lanka island near south of India. (Ağıralioğlu; 2007)

*Rock fill dams**:*** Rock fill dams are used since 1800s. From end of 19th Century to 1930's many rock fill dams are constructed. This type of dam construction was descreased after 1930. Because search and settelement of rock type material was expensive.After 1960's construction projects of rock fill dams increased.

*Arch dams:* Princible of arch design has been used since year B.C. 2000, according to engineering history first arch dam was Pantalto dam in Austria which is build in 1611. But first arch dam with height of 78 m was built in Denver (USA) in 20th Century. Number of arch dams build between these years is not more than 100. (Ağıralioğlu; 2007)

*Butress dams**:*** Fist concrete buttress dam was Ambursen (USA) build in 1903.So that these kinds of dams are called Ambursen dams. (Ağıralioğlu; 2007)

*Roller compacted concrete dams**:*** Construction of roller compacted concrete dams are started during Second World War. Besides that, Shimajigana Dam in Japan was first roller compacted concrete dam completed in 1980. After Shimajigana Dam, in 1982, Willow Creek Dam in USA was another example for this type of dam. (Ağıralioğlu; 2007)

### 2.2.2 History of Dams in Turkey

Anatolia's oldest dam is Hitit Dam which is at age of 3250 .Hittite dam and spring temple constructed near Konya, in Turkey. According to texts with cuneiform writing, Alaca Höyük is reported to be a city rich in water resources. In historical site it is possible to see clean and waste water canals at age of 3250. Especially dimensions of the main waste water canals are magnificent even when they are compared with dimensions of today's canals. (Inal 2007) Figure Figure 2-2 Hitit Dam- First dam in Anatolia.

Figure 2-2 Hitit Dam- First dam in Anatolia

First hydropower dam in Turkey was built in Tarsus. This dam was completed in 15 September 1902. Transmission gained from a water mill was converted to 2 Kw electricity and this energy was used in lights of Tarsus streets.

## 2.3 Benefits of Dams

Water has a vital part for all living organisms on world. As the World population continues to grow every year, so does demand of water. But water resource on earth is not enough for worlds demand. One of most efficient way to manage water resources is using dams to collect water so that construction of dams is being an important subject for storage and future distribution.The primary benefit of dams and reservoirs in the World is water supply. Other key purposes and benefits include:

- Irrigation for agriculture (food supply)
- Flood Control
- Hydropower
- Inland navigation
- Recreation (ICOLD, 1999)

Federal Emergency Management Agency classifies benefits of dams as :

- Irrigation
- Electrical Generation
- Flood Control
- Renewable, clean energy
- Water storage
- "Black Start" capabilities
- Sediment/hazardous material control
- Navigation
- Fisheries
- Recreation
- Mining (Fema; 2007)

Most common benefits of dams are flood control, irrigation and hydropower.

### 2.3.1 Flood Control

Dams are critical feature of the Nation's ability to reduce the effects of flooding along river courses. (FEMA; 2007) The number of dams and their water control management plans are established by comprehensive planning for economic development and with public involvement. Flood control is a significant purpose for many of the existing dams and continues as a main purpose for some of the major dams of the world currently under construction. (ICOLD, 1999)

### 2.3.2 Hydropower

Hydropower is the world's largest source of renewable energy and has an important role to play responding to challenges facing the world because of climate change. As a clean and renewable energy source, hydropower can help to reduce climate change by cutting our dependence on carbon-based fuels. (IHA; 2012)

Turkey has an economic capacity of 128 billion kWh per year hydroelectric energy potential. However, Turkey is using 36% of this capacity, currently generating 46 billion kWh per year electricity from hydroelectric power plants. Another 11 billion kWh per year capacity is under construction by the private and the public sector. Turkey's geography, a rectangular plateau peninsula surrounded on three sides by seas, is highly conducive to hydroelectric power generation; Turkey has about 1% of the total world hydroelectric potential. There are many rivers in Turkey and five separate watersheds. (Turkey Electricity; 2012)

### 2.3.3 Irrigation

One of the biggest uses of water on a worldwide scale is agricultural irrigation. It is estimated that 80% of additional food production by the year 2025 will come from irrigated land. Most of the areas in need of irrigation are in arid zones, which represent a major portion of the developing countries. (ICOLD, 1999)

## 2.4 Classification of Dams

Dams can be classified in various ways

- Classification of dams on size
- Classification of dams by height
- Classification of dams by construction purpose
- Classification of dams by functions of dam
- Classification of dams by design of dam body
- Classification of dams by hydraulic properties
- Classification of dams by body material (Ağıralioğlu; 2007)

### 2.4.1 Classification of dams on size

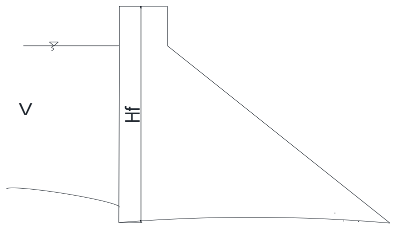



Figure 2-3 Dam size parameters

V = Reservoir Volume $H_f$ = Height of Dam

- Large Dam : $H_f > 15$ m

Or
$10 \text{ m} \leq H_f \leq 15 \text{ m}$
$V > 10^6 \text{ m}^3$
$L > 500$ m

- High Dam : $H_f > 50$ m
- Small Dam : $H_f < 10$ m (Yanmaz; 2006)

International Comission of Large Dams (ICOLD) classifies dams in 2 ways:

- Large Dams: A dam above 15 m in height measured or a dam between from the lowest portion of the general foundation area to the crest, or a dam between 10 m and 15 m in height provided it complies with at least one of the following conditions :
  - The length of the crest of the dam to be not less than 500 m
  - The capacity of the reservoir formed by the dam to be not less than one million $m^3$
  - The maximum flood discharge dealt with by the dam to be less than 2000 $m^3/s$
  - The dam has specially difficult foundation problems or the dam is of unusual design

  - Small Dams: A dam below 15 m in height measured is called as definition of small dam which given by ICOLD.

### 2.4.2 Classification of dams by height

- If height of dam is above than 100 m these kinds of dams called as high dams.
- If height of dam is between 50 m and 100 m than these dams are classified as average height dams.
- If height of dam is less than 50 m these are called as low dams. (Ağıralioğlu; 2007)

### 2.4.3 Classification of dams by construction purpose

Single purpose

- Storage Dams
- Diversion Dams
- Detention Dams
- Hydropower Dams

Multiple purpose: Serves for all or most of the above purposes. (Ağıralioğlu; 2007)

### 2.4.4 According to hydraulic design

- Overflow Dams : diversion dams
- Non-overflow Dams : earth fill,rock fill dams (Ağıralioğlu; 2007)

### 2.4.5 According to functions of dams

- Water storage
- Flood detention
- Raise water level (Ağıralioğlu; 2007)

### 2.4.6 Classification of dams by design of dam body

- Gravity dams
- Concrete gravity
- Pre-stressed concrete
- Roller compacted concrete
- Hard fill
- Arch dams
    - Constant-angle arch
    - Constant-center arch
    - Variable-angle, variable center arch
- Butress Dam
    - Flat-slab butress
    - Multiple-arch butress
- Embankment ( fill) dams
    - Earth fill
    - Rock fill (Yanmaz; 2006)

### 2.4.7 Classification of dams by body material

- Embankment dams
- Masonry and rubble dams
- Concrete dams
- Steel and timber dams (Ağıralioğlu; 2007)

## 2.5 Dams in World

The World data as of 2000 indicates that there are about 50,000 large dams in operation. Embankment dams are predominant type followed by gravity and arch dams.

Table 2-1Number of dams by height (meters): (ICOLD; 2007) showing when the world's large dams were placed into operation, their distribution by height and distribution by geographic areas are shown below:

Table 2-1Number of dams by height (meters): (ICOLD; 2007)

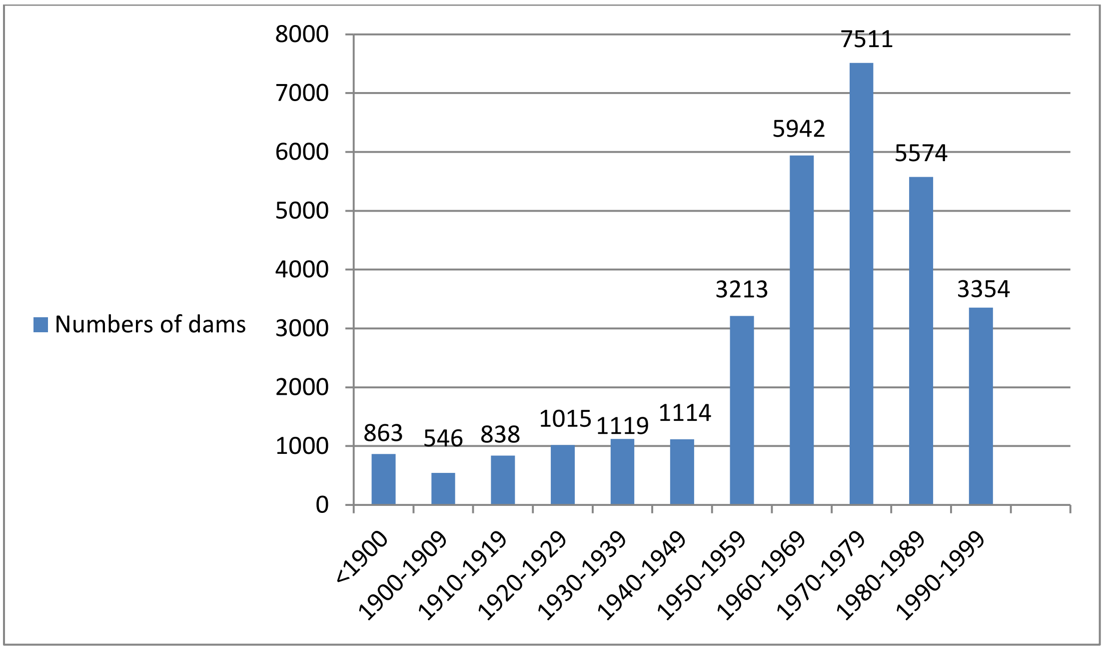
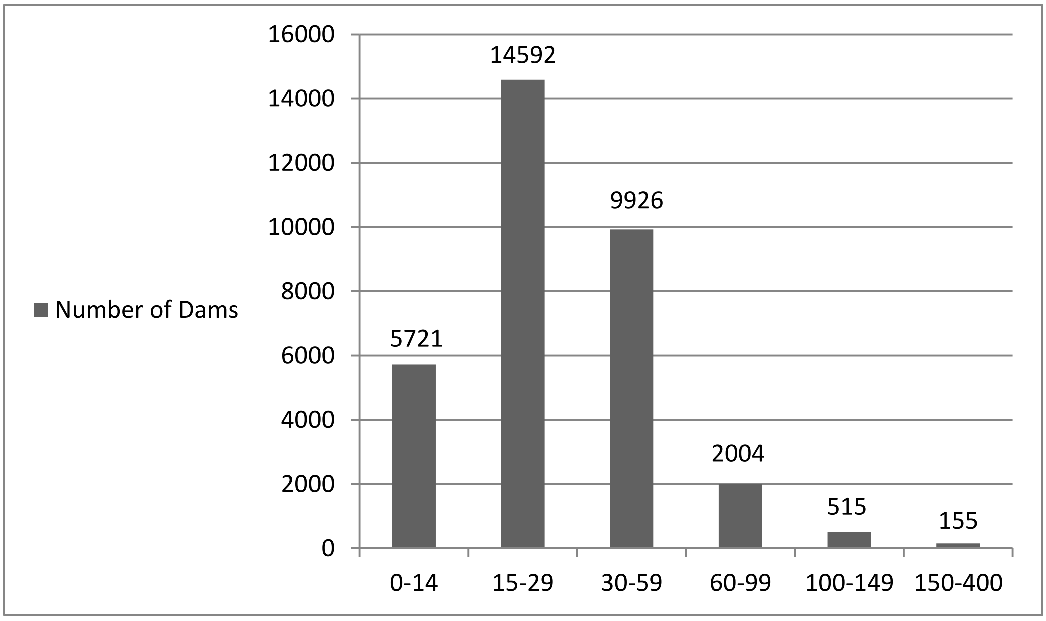



Table 2-2 Number of Dams by age



Distribution of large dams vary between continents. Most of large dams are located in Asia. Figure 2-4 Distribution of large dams by geographical area.

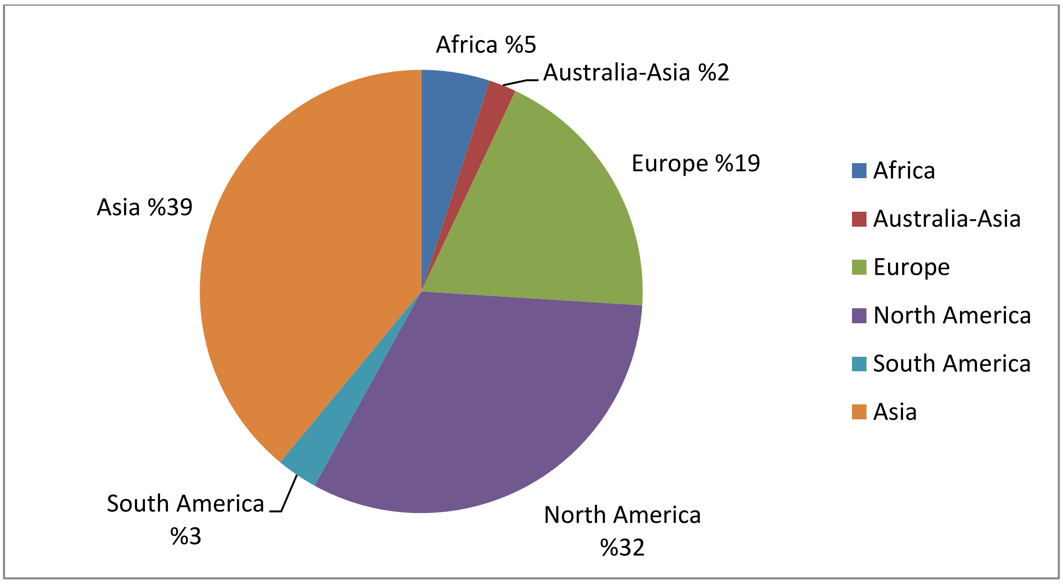



Figure 2-4 Distribution of large dams by geographical area

Nuber of large dams according to countries and years are given in Table 2-3 Number of large dams according to countries and years (Ağıralioğlu; 2007):. After 9 countries total of large dams numbers changing between 500-600 are: Turkey, Brazil, France, Italy and England. (Ağıralioğlu; 2007)

Table 2-3 Number of large dams according to countries and years (Ağıralioğlu; 2007):

| **Country** | **Number of Large dams (Completed)** | | | **Under Construction (1999)** |
|---|---|---|---|---|
| | **1950** | **1982** | **1999** | |
| **China** | 8 | 19595 | 26094 | 330 |
| **USA** | 1543 | 5338 | 6775 | 42 |
| **India** | 202 | 1085 | 3796 | 650 |
| **Japan** | 1173 | 2142 | 2560 | 100 |

| | | | | |
|---|---|---|---|---|
| **Spain** | 205 | 690 | 1191 | 31 |
| **South Korea** | 116 | 628 | 805 | 133 |
| **Canada** | 189 | 580 | 797 | 0 |
| **South Africa** | 79 | 342 | 789 | 7 |
| **Mexico** | 109 | 487 | 615 | 2 |
| **Total of 9 country** | 3642 | 30887 | 43422 | 1295 |
| **World Total** | 5196 | 34798 | 47425 | 1648 |

## 2.6 Dams in Turkey

Depending on ICOLD standards there are 673 dams in Turkey. Dams are classified by body type and given by numbers in Turkey are:

Table 2-4 Number of dams in Turkey classified by body type (Ağıralioğlu; 2011)

| **Dam type classified by body** | **Number of dams** | **Examples** |
|---|---|---|
| **Earth and Rock fill** | 650 | |
| **Concrete Gravity** | 8 | Çubuk I, Elmalı II, Sarıyar, Kemer, Gülüç, Porsuk, Arpaçay, Karacaören |
| **Arch** | 6 | Gökçekaya, Oymapınar, Karakaya, Gezende, Sır, Berke |
| **Multiple type** | 9 | Kürtün, Birecik, Karkamış, Keban, Muratlı ,Yamula , Cindere , Dim, Torul |

First dam, which was build during Turkish Republic, is Çubuk I dam. This dam was build with purpose of drinking water for Ankara. Until 1950 two small earth fill dams were completed. (Gölbaşı and Gebere) After those especially for power generation and irrigation purposes many dams have been constructed. (Ağıralioğlu; 2007) Table2-5 Number of dams constructed or under construction in Turkey (2009) (Ağıralioğlu; 2011)

Table2-5 Number of dams constructed or under construction in Turkey (2009)

| Year 2009 | Completed | Under Construction |
|---|---|---|
| **Dam** | 673 | 146 |
| **Pond** | 657 | 44 |
| **Total** | **1330** | **190** |

(Ağıralioğlu; 2011)

## 2.7 Definition of Small Dams

A reservoir is useful where the available flow in the stream is sometimes less than the flow required for water supply or irrigation, and water can be stored from a time when there is surplus, for example, from a wet season to a dry season. In addition to the simple earth dam, alternatives to consider are using the sub-surface (groundwater) dam or using wells. These may be preferable for environmental and water-quality reasons. (Smout and Shaw; 1991)

The Zimbabwe Water Act of 1998 defines a small dam as a structure which : i.) has a vertical height of more than 8 meters but less than 15 meters measured from the non overflow crest of the wall to the lowest point on the downstream face of such or ; ii.) is capable of storing more than 500 000 m3 but less than 1 000 000 m3 of water at fully supply level. (Ngonidzashe; 2007)

Commonly small dams are constructed of earth fill,but they may be made of concrete, boulders (rockfill), or timber. For economic reasons and convenience most small dams are constructed of earth. (NZSOLD; 1997)

Canadian Dam Association (CDA) Dam Safety Guidelines (CDA Guidelines), 2007, which defines a dam as:

A barrier which is constructed for the retention of wateri water containing any other substance, fluid waste, or tailings, provided the barrier is capable of impounding at least 30 000 m3 of liquid and is at least 2.5m high. Height is measured vertically to top of the barrier, as follows:

i. From the natural bed of the stream or watercourse at the downstream to of the barrier, in the case of a barrier across a stream or watercourse; or
ii. From the lowest elevation at the outside limit of the barrier, in the case of a barrier that is not across a stream or watercourse. (Grapel; 2009)

In France, a "large dam" is frequently considered as being more than 20 meters high, because since 1966, they must be submitted to the Permanent Technical Committee on Dams (CTPB); yet the relevant regulations do not use the term large dams.

ICOLD classification is most common and general used classification method worldwide. According to classifications made by ICOLD small dams are defined as dams which has height below 15 m. In this study definition of ICOLD is used for small dams.

### 2.8 Positive and Negative Impacts of Dams on the Environment

While preparing the water resources projects, it is important to make clear what the environmental impacts of the project may be when it is executed. The environmental impacts of the dams have been written down below in numerical order. These are;

1. As a result of dam construction and holding of sediments in reservoirs, sediment feeding of downstream channel or shore beaches is prevented. Corrosions may occur. As the transfer of sediments is avoided by this way, the egg lying zone of the fishes living in the stream ecosystem is restricted, too.

2. Archeological and historical places in company with geological and topographical places that are rare with their exceptional beauties, disappear after lying under the reservoir.

3. Reproduction of migrating fishes is hindered by the floods that harm the egg beds. Or the egg gravel beds can be destructed while the excavation and coating works in the stream beds.

4. Temperature of water, salt and oxygen distribution may change vertically as a consequence of reservoir formation. This may cause the generation of new living species.

5. Normal passing ways of territorial animals are hindered since the dam works as a barrier. Meantime the upstream fish movement aiming ovulation and feeding is prevented and thus fish population decreases significantly

6. The fishes can be damaged while passing trough the floodgates, turbines and pumps of the high bodied dams. Drainage of marsh and other water accumulations and the excavation works causing changes in the stream bed structures affect the creatures living here negatively; even result in their death.

7. There will be serious changes in the water quality as a result of drainage water returning from irrigation that was done based on the irrigation projects. In other words, over transfer of food and the increase in salt density can raise water lichens and may change water living species.

8. The species may change parallel to the erosion caused by the human activities or the permanent increase in the water turbidity as an outcome of the dam construction.

9. Discharge of toxic matters (pesticides, toxic metals etc.) and their condensation in food chain may affect sensitive animals immediately; all living organisms may expire when the stream becomes unable to recover itself.

10. The water regime may change as a result of destruction of nature, unexpected floods may occur and consequently vegetation and natural structures in the riverbanks can be damaged.

11. Some increase in earthquakes may occur because of filling of big dam reservoirs.

12. Rise in evaporation loses may be expected as a result of the increase in the water surface area.

13. Microclimatic and even some regional climate changes may be observed re-

lated to the changes in air moisture percentage, air temperature, air movements in big scale and the changes in the region topography caused by the stagnant, big scaled mass of water.

14. Water-soil-nutrient relations, which come into existence downstream related to the floods occuring from time to time in a long period of time, change. Depending on this fact, compulsary changes come into existence in the agricultural habits of the people living in this region and also in the flora and fauna.

15. Dams may cause increases in water sourced illnesses like typhus, typhoid fever, malaria and cholera.

16. Dams affect the social, cultural and economical structure of the region considerably. Especially forcing people, whose settlement areas and lands remain under water to migrate, affect their psychology negatively. (Tahmiscioglu; 2007)

## 2.9 Risk,Hazard and Vulnerability

### 2.9.1 Definition of Risk

Many definitions of what risk means can be found in the literature, so that this section aims to give general definitions and a theoretical overview as well as the definition of risk used in this thesis.

Risk is the chance of something happening that will have an impact upon objectives. It is measured in terms of consequences and likelihood. (AS/NSZ; 1999)

Oxford dictionary defines risk as “a situation involving exposure to danger”. (Oxford; 2012)

The ISO 31000 (2009) /ISO Guide 73:2002 definition of risk is the 'effect of uncertainty on objectives'.

In economics, different main meanings are attributed to risk. Firstly, risk is generally associated with a deviation from an expected value (of return). In the second definition based on the work of Basel Committee) it is defined as: risk is quantifiable likelihood of loss or less than expected return. Within the insurance sector risk is treated as expected loss, which is similar to definition used in some other sectors. (Jonkman; 2007)

Fema's definition about risk is "A measure of the likelihood and severity of adverse consequences." Risk is estimated by the mathematical expectation of the consequences of an adverse event occurring, i.e., the product of the probability of occurrence and the consequence, or alternatively, by the triplet of scenario, probability of occurrence, and the consequence. (FEMA; 2003)

Another general definition of risk was explained in Canadian Standard which is "the chance of injury or loss as defined as a measure of the probability and severity of an adverse effect to health, property, the environment, or other things of value." (CSA; 1997)

In the context of dam safety practice, risk is generally and simply defined as follows:

Risk = Probability of dam failure per year x consequence of realized failure
(Stewart; 2000)

Uncertainty is part of everyday life, since we are unable to accurately predict the future. The amount of uncertainty and how we can handle this uncertainty could, however, be defined and structured. Risk is closely connected to uncertainty and a commonly used term in all kinds of contexts, but is often related to the negative outcome of a certain event. (Simu; 2006)

The definition applied in the research on natural hazards, often define risk in terms of hazard and vulnerability. Hazard refers to a source of danger or alternatively to something that can cause risk. The difference between the hazard and risk concepts is that most risk definitions explicitly include the probability or likelihood of an undesired event. Vulnerability relates to potential consequences in case of an event. (Jonkman; 2007)

### 2.9.2 Hazard

Fema explains hazard as "a situation that creates the potential for adverse consequences such as loss of life, property damage, or other adverse impacts. And hazard potential is the possible adverse incremental consequences that result from the release of water or stored contents due to failure of the dam or misoperation of the dam or appurtenances. Impacts may be for a defined area downstream of a dam from flood waters released through spillways and outlet works of the dam or waters released by partial or complete failure of dam. (FEMA; 2003)

Hazard is a source of potential harm or a situation with a potential to cause loss. (AS/NSZ; 1999)

#### 2.9.2.1 Hazard Potential

The possible adverse incremental consequences that result from the release of water or stored contents due to failure of the dam or mis-operation of the dam or appurtenances is called hazard potential. (FEMA; 2004)

#### 2.9.2.2 Hazard Potential Classification System

Hazard potential classification is a system that categorizes dams according to the degree of adverse incremental consequences of a failure or mis-operation of a dam. The hazard potential classification does not reflect in any way on the current condition of the dam (e.g., safety, structural integrity, flood routing capacity). (FEMA; 2004)

Three classification levels are adopted as follows: LOW, SIGNIFICANT, and HIGH, listed in order of increasing adverse incremental consequences. The classification levels build on each other, i.e., the higher order classification levels add to the list of consequences for the lower classification levels, as noted in the table on the following page.

This hazard potential classification system should be utilized with the understanding that the failure of any dam or water-retaining structure, no matter how small, could represent a danger to downstream life and property. Whenever there is an uncontrolled release of stored water, there is the possibility of someone, regardless of how unexpected, being in its path.

A primary purpose of any classification system is to select appropriate design criteria. In other words, design criteria will become more conservative as the potential for loss of life and/or property damage increases. However, postulating every conceivable circumstance that might remotely place a person in the inundation zone whenever a failure may occur should not be the basis for determining the conservatism in dam design criteria.

This hazard potential classification system categorizes dams based on the probable loss of human life and the impacts on economic, environmental, and lifeline interests. Improbable loss of life exists where persons are only temporarily in the potential inundation area. For instance, this hazard potential classification system does not contemplate the improbable loss of life of the occasional recreational user of the river and downstream lands, passer-by, or non-overnight outdoor user of downstream lands. It should be understood that in any classification system, all possibilities cannot be defined. High usage areas of any type should be considered appropriately. Judgment and common sense must ultimately be a part of any decision on classification. Further, no allowances for evacuation or other emergency actions by the population should be considered because emergency procedures should not be a substitute for appropriate design, construction, and maintenance of dam structures. (FEMA; 2004)

#### 2.9.2.2.1 Low Hazard Potential

Dams assigned the low hazard potential classification are those where failure or misoperation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the owner’s property. (FEMA; 2004)

#### 2.9.2.2.2 Significant Hazard Potential

Dams assigned the significant hazard potential classification are those dams where failure or mis-operation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns. Significant hazard potential classification dams are often located in predominantly rural or agricultural areas but could be located in areas with population and significant infrastructure. (FEMA; 2004)

#### 2.9.2.2.3 High Hazard Potential

Dams assigned the high hazard potential classification are those where failure or mis-operation will probably cause loss of human life. (FEMA; 2004)

## 2.10 Risk Assessment

Risk assessment is the overall process of risk analysis and risk evaluation. (AS/NSZ; 1999) Risk assessment is a careful examination of what could cause harm to people so that decisions can be made about what is reasonably practicable to reduce or prevent harm.Risk Assessment Procedure

• Think of possible hazards. A hazard is anything that has the potential to cause harm

• Decide who might be affected and how.

• Evaluate the level of risk and consider preventive measures. Risk is the likelihood of a hazard causing harm.

• Discuss with school staff/parents/carers/and child as appropriate.

• Formulate into a written plan.

• Put measures into practice.

• Review and revise as necessary. (Devon; 2005)

## 2.11 Dam Safety

Dams store water for many purposes such as irrigation, flood control, hydropower. But besides these benefits if the water stored behind dam is released suddenly as the result of a dam failure, there would likely be loss of life, significant social and economic loss. To prevent this kind of catastrophic accidents dams must be constructed to engineering standards and design, construction, operation, maintenance, surveillance steps must be controlled. For this purpose many countries have different regulations and standards for dams.

Dam safety is a serious issue worldwide. However, in many countries, for example, China and Australia, although much attention is being devoted to the medium to large-scale dams, little or no attention is being paid to the serious potential problems associated with smaller dams, particularly the potential "cumulative domino effect" failure risk to the larger public dams. Farmers in Australia have often overlooked the common law obligation to review/design dams in line with current standards because of high engineering consulting costs. This leaves them vulnerable to litigation if their dam fails and the downstream community is susceptible to unacceptable risk levels. To overcome this problem, an innovative Australian-developed cost-effective spillway design/review procedure has been developed to minimise cost burdens to dam owners and encourage better dam safety management. (Pisaniello et al.; 2006)

Very small dams can represent a real danger to human life. It should be noted that the requirements as regards design, construction and operation of small dams are, as a rule, by far less stringent than in case of large ones. Furthermore, some protective measures, as warning systems, are not very adequate for small dams.

Usually, the number of small dams, in each country, is an impressive number. It could be, for instance, more than ten times the number of large dams. Sometimes, the number of small dams is not even known. It is impossible, for economic reasons (that include availability of human resources and possibilities of organization) to pay attention to a so large number of dams. This fact, this absolute need of concentrating efforts, is recognized by several authors (for instance, Chemaly and Nortjé, 1994). Therefore, the choice of dams to be included in dam safety programs is a very important problem. (Viseu and Martins; 1998)

The objectives of the United States National Dam Safety Program are to:

• ensure that new and existing dams are safe through the development of technologically and economically feasible programs and procedures for national dam safety hazard reduction;

• encourage acceptable engineering policies and procedures to be used for dam site investigation,

design, construction, operation and maintenance, and emergency preparedness;

• encourage the establishment and implementation of effective dam safety programs in each state based on state standards;

• develop and encourage public awareness projects to increase public acceptance and support of state dam safety programs;

• develop technical assistance materials for federal and state dam safety programs;

• develop mechanisms with which to provide federal technical assistance for dam safety to the non-federal sector; and

• develop technical assistance materials, seminars, and guidelines to improve security for dams in the United States. (FEMA; 2009)

## 2.12 Failure Modes of Dams

Failure mode means process resulting from an existing inadequacy or defect leading to dam failure and uncontrolled release of the reservoir. (KSDA; 2011)

Most common failure modes are described as flood, earthquake, overtoping, piping and normal stability.

### 2.12.1 Flood

Ideally, dams should be able to safely accommodate flood flows in a manner that will not increase the danger to life and property downstream. However, this situation is not always the case, and may not always be achievable. There are various methods or reasons for selecting the inflow design flood and determining whether the dam can safely accommodate the flood. The method chosen may be determined by the amount of time and/or funds available to conduct an evaluation. For example, if time and funds are scarce, a conservative inflow design flood (e.g.,the PMF) can be selected. (FEMA; 2007)

### 2.12.2 Earthquake

In order to prevent the uncontrolled rapid release of water from the reservoir of a storage dam during a strong earthquake, the dam must be able to withstand the strong ground shaking from even an extreme earthquake, which is referred to as the Safety Evaluation Earthquake (SEE) or the Maximum Credible Earthquake (MCE). Large storage dams are generally considered safe if they can survive an event with a return period of 10,000 years, i.e. having a one percent chance of being exceeded in 100 years. It is very difficult to predict what can happen during such a rare event as very few earthquakes of this size have actually affected dams. Therefore it is important to refer to the few such observations that are available. The main lessons learnt from the large Wenchuan and Chile earthquakes will have an impact on the seismic safety assessment of existing dams and the design of new dams in the future. (ICOLD; 2010)

### 2.12.3 Overtopping

Overtopping as a result of exceeding the reservoir capacity is the most common mode of failure for embankment dams. Although this is generally considered a hydrotechnical storage or discharge capacity issue, settlement of the dam crest can be a contributing factor.

Once overtopping occurs, the uncontrolled flow may cause the dam to breach, depending on the erodibility of the materials exposed along the flow path. The rate of breaching is also dependent on this erodibility. (CDA; 2007)

### 2.12.4 Piping

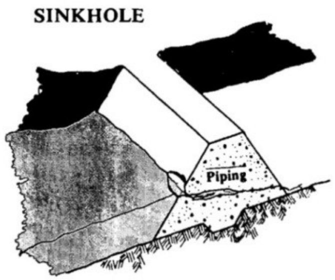
Loss of material due to internal erosion and piping is the second most common cause of embankment dam failure. Internal erosion and piping occur as a result of concentrated, excessive particle migration caused by seepage flow. Particle migration can occur when (i) seepage passes from a fine-grained material into an exceedingly coarser grained material; or (ii) perhaps more critically, material is carried into or through cracks or discontinuities in the dam, foundation, or abutments. Differential settlement and hydraulic fracturing are the most common causes of cracking in embankment dams. Hydraulic fracturing occurs when internal hydraulic pressures exceed the minor principal stresses inherent in the embankment material. Well-designed granular filters strategically placed within the embankment and between the embankment and the foundation have proven to be the best defence against internal erosion and piping failure. (CDA; 2007)

### 2.12.5 Normal Stability

The dam embankment and abutment slopes must be adequately stable to withstand all foreseeable loading conditions. In general, a limit equilibrium analysis should be sufficient to verify the stability of the slopes under normal operating conditions. Acceptance criteria are usually described in terms of factors of safety. A factor of safety in this case is defined as the ratio of available shear resistance along a potential plane of failure to the activating shear forces along the same plane. (CDA; 2007)

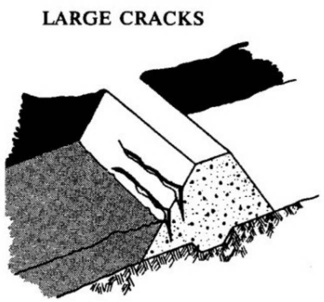
## 2.13 Problems and solutions for urgent action recommended situations

The guideline tables provide a quick reference to be used in assessing observed conditions, their probable cause and possible consequences, and remedial actions. The guidelines also point out the hazardous problems where evaluation by and engineer is required. (FEMA; 1987)




| | Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|---|
| | Piping or internal erosion of embankment materials or foundation causes a sinkhole. The cave-in of an eroded cavern can result in a sink hole. A small hole in the wall of an outlet pipe can develop a sink hole. Dirty water at the exit indicates erosion of the dam. | **HAZARDOUS** Piping can empty a reservoir through a small hole in the wall or can lead to failure of a dam as soil pipes erode through the foundation or a pervious part of the dam. | Inspect other parts of the dam for seepage or more sink holes. Identify exact cause of sink holes. Check seepage and leakage outflows for dirty water. A qualified engineer should inspect the conditons and recommend further actions to be taken. **ENGINEER REQUIRED** |

Figure 2-5 Sinkhole




| Probable Cause | Possible Consequence | Recommended Actions |
| --- | --- | --- |
| A portion of the embankment has moved because of loss of strength, or the foundation may have moved, causing embankment movement. | **HAZARDOUS** Indicates onset of massive slide or settlement caused by foundation failure. | Depending on embankment involved, draw reservoir level down. A qualified engineer should inspect the conditions and recommend further actions to be taken. **ENGINEER REQUIRED** |

Figure 2-6 Large Cracks


Figure 2-7 Slide, Slump or Slip

| Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|
| Earth or rocks move down the slope along a slippage surface becuase of too steep a slope, or the foundation moves. Also, look for slides movement in reservoir basin | **HAZARDOUS**<br>A series of slides can lead to obstruction of the outlet or failure of the dam | Evaluate extent of the slide. Monitor slide. Draw the reservoir level down if safety of dam is threatened. A qualified engineer should inspect the conditons and recommend further actions to be taken.<br>**ENGINEER REQUIRED** |

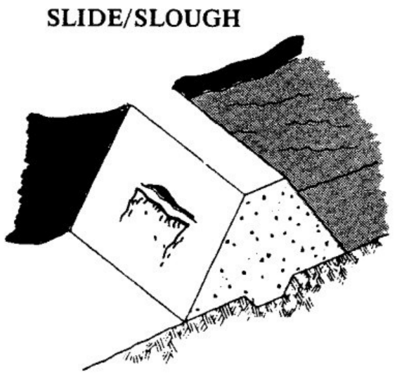



Figure 2-8 Slide or Slough

| Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|
| 1. Lack of or loss of strength of embankment material.<br>2. Loss of strength can be attributed to infiltration of water into the embankment or loss of support by the foundation. | **HAZARDOUS**<br>Massive slide cuts through crest or upstream slope reducing freeboard and cross section. Structural collapse or overtopping can result. | 1. Measure extent and displacement of slide.<br>2. If continued movement is seen, begin lowering water level until movement stops.<br>3. Have a qualified engineer inspect the condition and recommend further action.<br>**ENGINEER REQUIRED** |

TRANSVERSE CRACKING

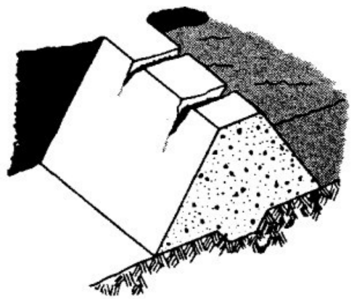


Figure 2-9 Traverse Cracking

| Probable Cause | Possible Consequence | Recommended Actions |
| --- | --- | --- |
| Differential settlement of the embankment also leads to tranverse cracking (e.g. , center settles more than abutments). | **HAZARDOUS** settlement or shrinkage cracks can kead to seepage of reservoir water through the dam. Shrinkage cracks allow water to enter the embankment. This promotes saturation and increases freeze-thaw action. | 1. If necessary, plug upstream end of crack to prevent flows from the reservoir. 2. A qualified engineer inspect the condition and recommend further action. **ENGINEER REQUIRED** |

CAVE IN/COLLAPSE

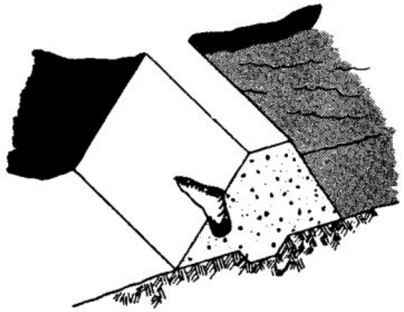


Figure 2-10 Cave in or Collapse

| Probable Cause | Possible Consequence | Recommended Actions |
| --- | --- | --- |
| 1. Uneven settlement between adjacent sections or zones within the embankment. 2. Foundation failure causing loss of support to embankment. 3. İnitial stages of embankment slide. | **HAZARDOUS**<br>1. Creates local area of low strength within embankment. Could be the point of initiation of future structural movement, deformation or failure.<br>2. Provides entrance point for surface run-off into embankment, allowing saturation of adjacent embankment area and possible lubrication which could lead to localized failure. | 1. İnspect crack and carefully record location, length, depth, width, alignment and other pertinent physical features. İmmediately stake out limits of cracking. Monitor frequently.<br>2. Engineer should determine cause of cracking and supervise steps necessary to reduce danger to dam and correct condition.<br>3. Effectively seal the cracks at the crest's surfaceto prevent infilttation by surface water. 4. Continue to routinely monitor crest for evidence of further cracking.<br>**ENGINEER REQUIRED** |

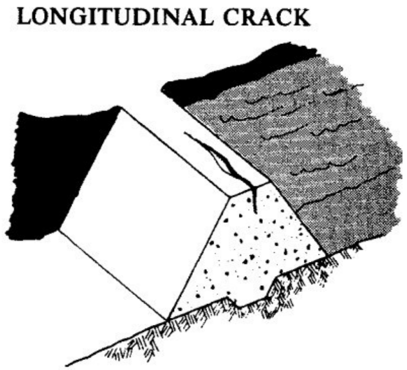



Figure 2-11 Longitudinal Crack

| Probable Cause | Possible Consequence | Recommended Actions |
| --- | --- | --- |
| 1. Lack of adequate compaction.<br>2. Rodent hole below.<br>3. Piping through embankment or foundation. | **HAZARDOUS**<br>Indicates possible wash out of embankment. | 1. Inspect for and immediately repair rodent holes. Control redents to prevent future damage.<br>2. A qualified engineer inspect the condition and recommend further action.<br>**ENGINEER REQUIRED** |

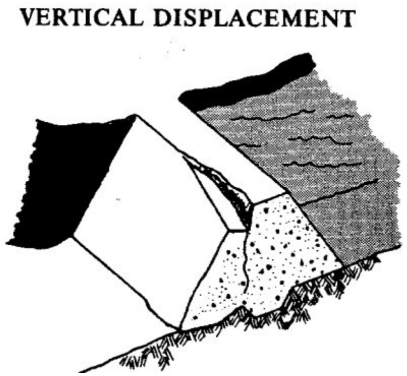



Figure 2-12 Vertical Displacement

| Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|
| 1. Vertical movement between adjacent sections of the embankment.<br>2. Structural deformation or failure caused by structural stress or instability or by failure of the foundation. | HAZARDAOUS<br>1. Provides local area of low strength within embankment which could cause future movement.<br>2. Leads to structural instability or failure.<br>3. Provides entrance point for surface water that could further lubricate plane.<br>4. Reduces available embankment cross section. | 1. Carefully inspect displacement and record its location, vertical and horizontal displacement, length and other physical features. İmmediately stake out limits of cracking.<br>2. Engineer should determine cause of displacement, length and supervise all steps necessary to reduce danger to dam and correct condition.<br>3. Excavate area to the bottom of the displacement. Bacfill excavation using competent materai and correct construction techniques and under supervision of engineer.<br>4. Continue to monitor areas routinelyfor evidence of future cracking or movement.<br>**ENGINEER REQUIRED** |

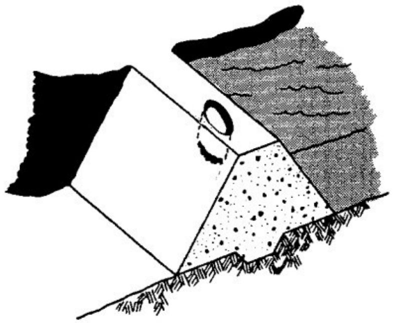



Figure 2-13 Cave-In on Crest

| Probable Cause | Possible Consequence | Recommended Actions |
| --- | --- | --- |
| 1. Rodent activity.<br>2.Hole in outlet conduit is causing erosion of embankment material.<br>3. İnternal erosion or piping of embankment material by seepage.<br>4. Breakdown of dispersive clays within embankment by seepage waters. | **HAZARDOUS**<br>1. Void within dam could cause localized craving, sloughing, instability or reduced embankment cross section. 2.Entrance point for surfacewater. | 1. Carefully inspect and record location physical characteristics(depth, width, length) of cave in.<br>2. Engineer should determine cause of cave in and supervise all steps necessary to reduce threat to dam and correct condition.<br>3. Excavate cave in slope sides of excavation and backfill hole with competent material using proper constuction techniques. This should be supervised by engineer.<br>**ENGINEER REQUIRED** |

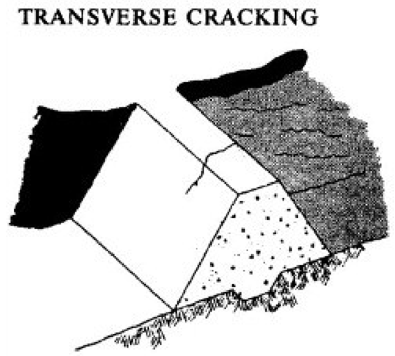



Figure 2-14 Traverse Cracking

| Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|
| 1. Uneven movement between adjacent segments of the embankment. 2. Deformation caused by structural stress or instability. | HAZARDOUS 1. Can provide a path for seepage through the embankment cross section. 2. Provides local area of low strength within embankment. Future structural movement deformation or failure could begin. 3. Provides entrance point for surface runoff to enter embankment. | 1. İnspect crack and carefully record crack location, length, depth, width and other pertinent physical features. Stake out limits of cracking. 2. Engineer should determine cause of crackingand supervise all steps necessary to reduce danger to dam and correct condition. 3. Excavate crest along crack to a point below the bottom of the crack. Then backfilling excavationusing competent material and correct construction techniques. This will seal the crack against seepage and surface runoff. This should be supervised by engineer. 4. Continue to monitor crest routinely for evidence of future cracking. ENGINEER REQUIRED |


Figure 2-15 Excessive Quantity and/or Muddy Water Exiting From a Point

**Probable Cause**

1. Water has created an open pathway, channel or pipe through the dam. The water is eroding and carrying embankment material.
2. Large amounts of water have accumulated in downstream slope. Water and embankment materials are exiting at one point. Surface agitation may be causing the muddy water.
3. Rodents, frost action or poor construction have allowed water to create an open pathway or pipe through the embankment.

**Possible Consequence**

HAZARDOUS

1. Continued flows can saturate parts of the embankment andlead to slides in the aera.
2. Continued flows can further erode embankment materials and lead to failure of the dam.

**Recommended Actions**

1. Beginmeasuring outflow quantity and establishing whether water is getting muddier, staying the same or clearing up.
2. If quantity of flow is increasing the water level in the reservoir should be lowered until the flow stabilizes or stops.
3. Search for opening on upstream side and plug if possible.
4. A qualified engineer should inspect the condition and recommend further actions to be taken.

ENGINEER REQUIRED

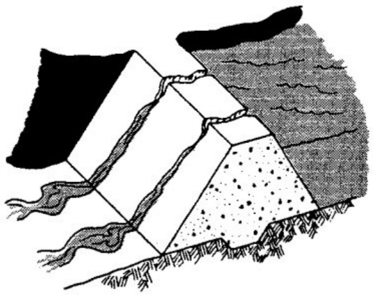



Figure 2-16 Stream of Water

Exiting Through

Cracks Near the Crest

| Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|
| 1. Severe drying has caused shrinkage of embankment material.<br>2. Settlement in the embankment or foundation is causing the transverse cracks. | 1. Flow through the crack can cause failure of the dam. | 1. Plug upstream side of the crack to stop the flow.<br>2. The water level in the reservoir should be lowered until it is below the level of the cracks.<br>3. A qualified engineer should inspect the condition and recommend further actions to be taken. |


Figure 2-17 Seepage Water Exiting As a Boil in the Foundation

| Probable Cause | Possible Consequence | Recommended Actions |
| --- | --- | --- |
| Some part of the foundation material is supplying a flow path. This could be caused by a sand or gravel layer in the foundation. | HAZARDOUS<br>Increased flows can lead to erosion of the foundation and failure of the dam. | 1. Examine the boil for transportation of foundation materials.<br>2. If soil particles are moving downstream, sandbags or earth should be used to create a dike around the boil. The pressures created by the water level within the dike may control flow velocities and temporarily prevent further erosion.<br>3. If erosion is becoming greater, the reservoir level should be lowered.<br>4. A qualified engineer should inspect the condition and recommend further actions to be taken.<br>ENGINEER REQUIRED |


Figure 2-18 Seepage Exiting at

Abutment Contact

| Probable Cause | Possible Consequence | Recommended Actions |
| --- | --- | --- |
| 1. Water flowing through pathways in the abutment.<br>2. Water flowing through the embankment. | HAZARDOUS<br>1. Can lead to erosion of embankment materials an failure of the dam. | 1. Study leakage area to determine quantityof flow and extent of saturation.<br>2. Inspect daily fr developing slides.<br>3. Water level in reservoir may need to be lowered to assure the safety of the embankment. 4. A qualified engineer should inspect the conditions and recommend further actions to be taken. ENGİNEER REQUIRED |


Figure 2-19 Large Area Wet

or Producing Flow

| Probable Cause | Possible Consequence | Recommended Actions |
| --- | --- | --- |
| 1. A seepage path has developed through the abutment or embankment materials and failure of the dam can occur. | HAZARDOUS<br>1. Increased flows could lead to erosion of embankment material and failure of the dam. 2. Saturation of the embankment can lead to local slides which could cause failure of the dam. | 1. Stake out saturated area and monitor for growth or shrinking.<br>2. Measureany outflows as accurately as possible.<br>3. Reservoir level may need to be lowered if saturated areas increase in size at a fixed storage level or if flow increases.<br>4. A qualified engineer should inspect the condition and recommend further actions to be taken.<br>ENGINEER REQUIRED |


Figure 2-20Bulge in Large Wet Area

| Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|
| 1. Downstream embankment materials have begun to move. | HAZARDOUS<br>1. Failure of the embankment result from massive sliding can follow these early movements. | 1. Compare embankment cross section to the end of construction condition to see if observed condition may reflect end of construction.<br>2. Stake out affected area and accurately measure outflow.<br>3. A qualified engineer should inspect the condition and recommend further actions to be taken.<br>ENGINEER REQUIRED |

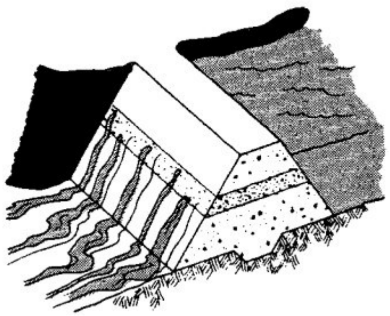



Figure 2-21 Wet Area in

Horizontal Band

| Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|
| Frost layer or layer of sandy material in original construction. | HAZARDOUS<br>1. Wetting of areas below the area of excessive seepage can led to localized instability of the embankment. (SLİDES)<br>2. Excessive flows can lead to accelerated erosion of embankment materials and failure of the dam. | 1. Determine as closely as possible the flow being produced.<br>2. If flow increases, reservoir level should be reduced until flow stabilizes or stops.<br>3. Stake out the exact area involved.<br>4. Using hand tools, try to identify the material allowing the flow.<br>5. A qualified engineer should inspect the condition and recommend further actions to be taken.<br>ENGINEER REQUIRED |

**LARGE INCREASE IN FLOW OR SEDIMENT IN DRAIN OUTFALL**

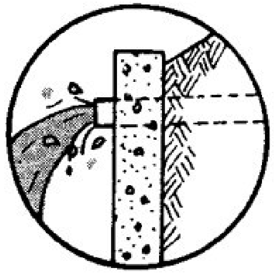


Figure 2-22 Large Increase in Flow or Sediment in Drain Outfall

| Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|
| A shortened seepage path or increased storage levels. | HAZARDOUS<br>1. Higher velocity flows can cause erosion of drain then embankment materials.<br>2. Can lead to piping failure. | 1. Accurately measures outflow quantity and determine amount of increase over previous flow.<br>2. Collect  jar samples to compare turbidity.<br>3. If either quantity or turbidity has increased by 25%, a qualified engineer should evaluate the condition and recommend further actions. ENGINEER REQUIRED |

**END OF SPILLWAY CHUTE UNDERCUT**

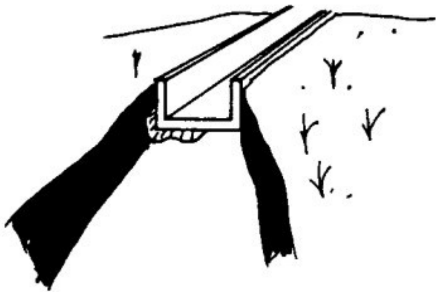


Figure 2-23 End of Spillway Chute Undercut

| Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|
| 1. Poor configuration of stilling basin area. Highly erodible materials. Absence of cutoff wall at end of chute. | HAZARDOUS<br>1. Structural damage to spillway structure; collapse of slab and wall lead to costly repair. | 1. Dewater affected area; clean out eroded area and properly backfill. Improve stream channel below chute; provide properly sized riprap in stilling basin area. Install cutoff wall. |

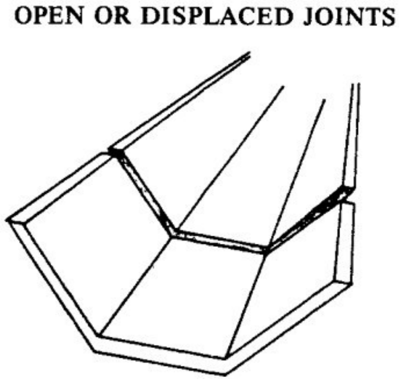



Figure 2-24 Open or Displaced Joints

| Probable Cause | Possible Consequence | Recommended Actions |
| --- | --- | --- |
| 1. Excessive and uneven settlement of foundation; sliding of concrete slab; consturction joint too wide and left unsealed. Sealant deteriorated and washed away. | HAZARDOUS<br>1. Erosion of foundation material may weaken support and cause further cracks, pressure induced bu water flowing over displaced joints may wash away wall or slab or cause extensive undermining. | 1. Construction joint should be no wider than 1/2 inch. All joints should be sealed with asphalt or other flexible materials. Waterstops should be used where feasible. Clean the joint, replace eroded materials and seal the joint. Foundation should be properly drained and prepared. Underside of chute slabs should have ribs of enough depth to prevent sliding. Avoid steep chute slope. ENGINEER REQUIRED |

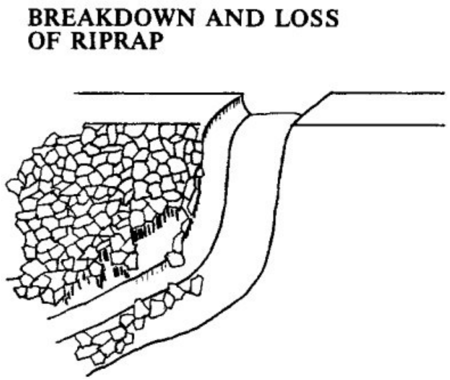



Figure 2-25 Breakdown and Loss of Riprap

| Probable Cause | Possible Consequence | Recommended Actions |
| --- | --- | --- |
| 1. Slope too steep; material poorly graded; failure of subgrade; flow velocity too high; improper placement of material; bedding material or foundation washed away. | HAZARDOUS<br>1. Erosion of channel bottom and banks; failure of spillway. | 1. Design a stable slope for channel bottom and banks. Riprap material should be well graded (the material should contain small, medium and large particles). Sub-grade should be properly prepared before placement of riprap. Install filter fabric if necessary. Control flow velocity in the spillway by proper design. Riprap should be placed according to specification. Services of an engineer are recommended. ENGINEER REQUIRED |


Figure 2-26 Leakage in or Around Spillway

| Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|
| 1. Cracks and joints in geologic formation at spillway are permitting seepage.<br>2. Gravel or sand layers at spillway are permitting seepage. | HAZARDOUS<br>1. Could lead to excessive loss of stored water.<br>2. Could lead toprogressive failure if velocitiesare high enough to cause erosion of natural materials. | 1. Examine exit area to see if type of material can explain leakage.<br>2. Measure flow quantitiy and check for erosion of natural materials.<br>3. If flow rate or amount of eroded materials increases rapidly reservoir level should be lowered until flow stabilizes or stops.<br>4. A qualified engineer should inspect the condition and recommend further actions to be taken.<br>ENGINEER REQUIRED |

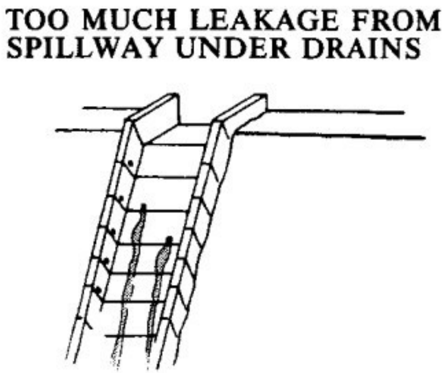



Figure 2-27 Too Much Leakage From Spillway Under Drains

| Probable Cause | Possible Consequence | Recommended Actions |
| --- | --- | --- |
| 1. Drain or cutoff may have failed. | HAZARDOUS<br>1. Excessive flows under the spillway could lead to erosion of foundation material and collapse of parts of the spillway.<br>2. Uncontrolled flows could lead to loss of stored water. | 1. Examine exit area to see if type of material can explain leakage.<br>2. Measure flow quantitiy and check for erosion of natural materials.<br>3. If flow rate or amount of eroded materials increases rapidly reservoir level should be lowered until flow stabilizes or stops.<br>4. A qualified engineer should inspect the condition and recommend further actions to be taken.<br>ENGINEER REQUIRED |

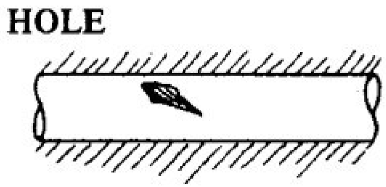



Figure 2-29 Hole

| Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|
| 1. Rust (steel pipe)<br>2. Erosion (concrete pipe)<br>3. Cavitation | HAZARDOUS<br>1. Excessive seepage, possible internal erosion. | 1. Tap pipe vicinity of damaged area, listening for hollow sound which shows a void has formed along the outside of the conduit. |

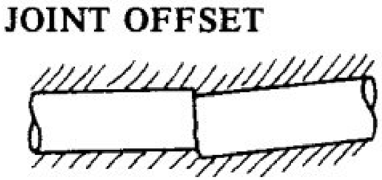



Figure 2-28 Joint Offset

| Probable Cause | Possible Consequence | Recommended Actions |
|---|---|---|
| 1. Settlement or poor construction practice. | HAZARDOUS<br>1. Provides passageway for water to exit or enter pipe, resulting in erosion of internal materials of the dam. | 1. If a progressive failure is suspected, request engineering advice. |

## FAILURE OF CONCRETE OUTFALL STRUCTURE

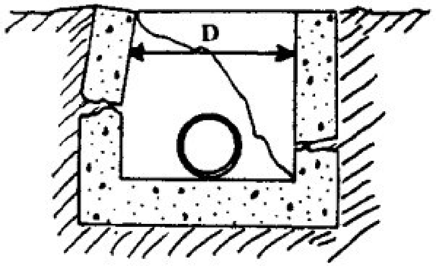



Figure 2-30 Failure of Concrete Outfall Structure

**Probable Cause**

1. Excessive side pressures on nonreinforce concrete structure. Poor concrete quality.

**Possible Consequence**

HAZARDOUS

1. Loss of outfall structure exposes embankment to erosion by outlet releases.

**Recommended Actions**

1. Check for progressive failure by monitoring typical dimension, such as "D" shown in figure.
2. Repair by patching cracks and supplying drainage around concrete structure. Total replacament of outfall structure may be needed.

## OUTLET RELEASES ERODING TOE OF DAM

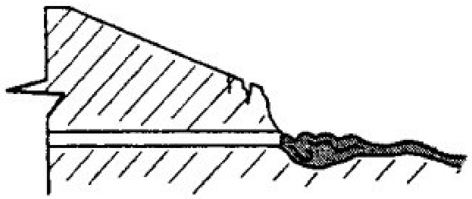


Figure 2-31 Outlet Releases Eroding Toe of Dam

**Probable Cause**

1. Outlet pipe too short.Lack or energydissipating pool or structure at downstream end of conduit.

**Possible Consequence**

HAZARDOUS

1. Erosion of toe oversteepens downstream slope, causing progressive sloughing.

**Recommended Actions**

1. Extend pipe beyond toe (use a pipe of same size and material and form watertight connection to existing conduit). 2. Protect embankment with riprap over suitable bedding.


Figure 2-32Seepage Water Exiting From a Point Adjacent to the Outlet

| Probable Cause | Possible Consequence | Recommended Actions |
| --- | --- | --- |
| 1. A break in the outlet pipe.<br>2. A path for flow has developed along the outside of the outlet pipe. | HAZARDOUS<br>1. Continued flows can lead to raid erosion of embankment materials and failure of the dam. | 1. Thoroughly investigate the area by probing and/or shovelling to see if the cause can be determined.<br>2. Determine if leakage water is carrying soil particles.<br>3. Determine quantity of flow. 4. If flow increases or is carrying embankmet materials reservoir level should be lowered until leakage stops.<br>5. A qualified engineer should inspect the condition and recommend further actions to be taken.<br>ENGINEER REQUIRED |

## CHAPTER 3

# 3 RISK PRIORIZATION TOOL for DAMS

## 3.1 General

Dam safety regulations generally include three classes based on estimated loss of life and downstream damage from a dam failure:

i. High Hazard: Probable loss of life;
ii. Significant Hazard: Possible loss of life, major damage;
iii. Low Hazard: No loss of life, minor image.

## 3.2 Process Outline

Process of risk assessment covers the most important failure modes for each type of dam.So that overall dam risk can be compared with risk tolerability criteria.The below figure show steps of risk categorization process.

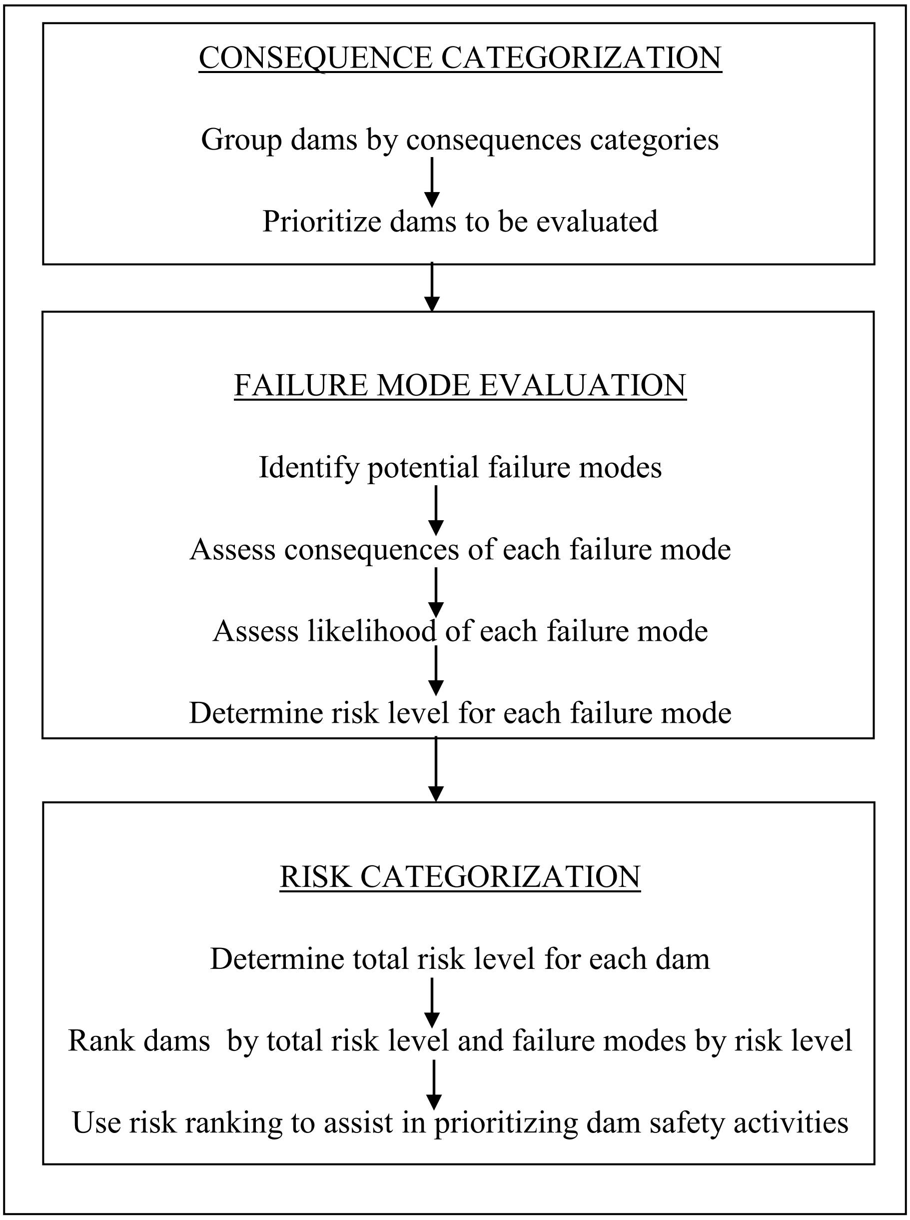



Figure 3-1 Risk Categorization Process

Consequence categorization step starts with data input about foundation properties, height, spillways capacity etc. (depending on type and properties of dam).

Failure mode evaluation step can be computed depending on dam elements.Such as rock fill dam,concrete dam,ungated spillway etc.These failure modes changes risk level for each condition.Risk categorization step can be explained as calculation of total risk level and compare of acceptable risk criterias.

## 3.3 Definitions of Terms in Risk Tool

Definitions of Terms used in risk tool are given below: (Fema; 2008)

*Abutment Outflanking: Abutment Outflanking* – During a flood, flows pass over the reservoir perimeter beyond the limits of the dam structure, probably over the abutments.

*As Low As Reasonably Practical (ALARP):* The risk has been reduced as low as reasonably practicable. This reasonableness test reflects society's aversion to incidents that can potentially cause large loss of life but recognizes that there is a point of diminished returns. ALARP is defined as the point where additional risk reduction is not possible without a disproportionate investment for the benefit gained.

*Concrete Core Wall:* Early 20$^{th}$ century dam building design when a concrete wall serves as the core with surrounding shells of embankment soils.

*Dam Element:* a feature of the subject dam which could potentially fail for one of the reasons indicated by the element's failure modes (i.e. earth dam, unlined spillway, outlet works, etc).

*Dam Risk Profile:* an individual dam's collection of Elements and LLP worksheets. The Dam Risk Profile is an Excel workbook.

*Failure Mode:* a method (i.e. piping for an earth dam, earthquake for a concrete dam, etc.) by which a Dam Element could fail resulting in an uncontrolled release of the reservoir.

*Failure Probability (F):* a User judged value representing the probability that a particular failure mode will cause failure of the Dam Element. The F value is illustrated as 1 in 100, 1 x 10 or 0.01, for example.

*Life Loss Potential (LLP)* – the number of lives potentially lost given failure of a Dam Element. The LLP value is equal to the estimated population at risk multiplied by a depending upon distance from the dam. Sometimes referred as "Loss of Life Potential."

*Maximum Design Earthquake (MDE):* An extreme design earthquake for which the dam could sustain damage but not catastrophic release of the reservoir. The return period may range from 1 in 5,000 to 1 in 100,000, or may be taken as the deterministic maximum credible earthquake (MCE).

*Operating Basis Earthquake (OBE):* An unusual design earthquake expected during the life of the structure with a return period of about 1 in 500 years that does not disrupt the operation of the reservoir.

*Population at Risk (PAR):* the estimated number of people within the inundation zone from a dam failure. The value is based on assumed people within dwellings, cars, factories, camping areas, etc that are inside the inundation zone that will get their feet wet.

*Risk Portfolio:* a collection of User created Dam Risk Profiles. The Risk Portfolio is a Microsoft Excel Workbook which manages the Dam Risk Profile workbooks.

*Risk Tool:* The combination of Excel spreadsheets (riskportfolio.xls and template.xls) that together comprise the dam risk prioritization program.

*Threshold Failure Flood (TFF):* The flood where there is just enough overtopping of the dam to cause breach failure by erosion overturning, sliding, or collapse.

*Workbook:* A workbook is an excel file that contains one or more worksheets, user forms and macro code. The Risk Portfolio application is an Excel workbook as is each Dam Risk Profile.

*Worksheet:* A worksheet is a single page within a workbook that contains data arranged in rows and columns.

*The National Inventory of Dams (NID)* : is a congressionally authorized data-base, which documents dams in the U.S. and its territories.

### 3.4 Initial Data Input

The figure 3-2 shows Initial Data Input Worksheet. This table allows user to enter specific input values like hydraulic height,max storage volume,drainage area etc.Through this table user can enter probability of the dam impounding water in any one year which is generally %100 for most dams.This value can change according due to dry or wet conditions of dam reservoir.Storage pools volume effects probability of the dam impounding water in any one year.For example; if a significant storage pool is likely once every 10 years, then the probability of the dam impounding water in any one year is 10%.Use of this factor can be subjective for dams with small normal storage capacities but very large flood capacities. Therefore, unless the impoundment is dry, the User should input a value of 100%. (Fema; 2008)

| NID Data | |
|---|---|
| Dam Name: | |
| Federal Dam ID: | |
| State: | |
| Region: | |
| Hydraulic Height (feet): | |
| NID Spillway Capacity (cfs): | |
| Max. Storage Volume (ac-ft): | |
| Max. Reservoir Area (acres): | |
| Probability of dam impounding water in any one year: | |
| NID Hazard: | |
| EAP Available: | |
| Drainage Area (sq.mi.): | |
| Owner: | |
| **Other Data** | |
| Basin Slope (feet/mile): | |
| Mean Basin Elevation (feet): | |
| Mean Annual Precipitation (inches): | |
| Main Stream Length (miles): | |
| **Evaulator Data** | |
| Evaluator Name: | |
| Organization: | |
| Address: | |
| City: | |
| State: | |
| Zip: | |
| Phone: | |
| Cell: | |
| Fax: | |
| Email: | |
| Date of Evaluation: | |
| Last Run Date: | |

Figure 3-2 Initial data input worksheet (Fema; 2008)

### 3.5 Building a Dam Through Elements

After input data users must input primary features of dams.Such as earthfill section, concrete ungated spillway and outlet tower.Selection of most proper features is critical while calculating important risk values. If too few or too many dam elements were initially selected, the Risk Tool allows the user to add or delete dam elements at any time.Dam elements were prepared for the following types of dam features :

- Concrete Gravity Dam
- Concrete Arch Dam
- Masonry Dam (being updated)
- Earthfill Dam
- Earth – Rockfill Dam
- Concrete Face Rockfill Dam
- Timber Crib Dam
- Tailings Dam
- Lined Impoundment
- Outlet Tower and Conduit
- Concrete Gated Spillway (being updated)
- Ungated Spillway (multiple selections permitted)

### 3.6 Failure Mode Evaluation

Each dam element contains a series of three or four likely failure modes. These failure modes represent physical mechanisms that could result in failure of the dam and an uncontrolled release of the impounded reservoir. The Failure Modes Table is typically comprised of four vertical columns of failure mode bins such as Earthquake, Flood, Piping and Normal Stability. In each column are bins of descriptors which aid in selecting the order of magnitude of failure probability F ranging from 1 to 1 x 10-6. In addition there is a column of specific observations which provide clues about which bin might be appropriate. General descriptions in making subjective judgements of failure probability are provided below. (Fema; 2008)

Table 3-1 Failure Mode Evaluation (Barneich et Al; 1996)

| Description of Event or Condition | Order of Magnitude of Probability Assigned |
|---|---|
| Occurences of the condition or event are observed in the available databese. | $10^{-1}$ |
| The occurrence of the condition or event is not observed,or is observed in one isolated instance,in the available database;however,several potential failure scenarios can be identified. | $10^{-2}$ |
| The occurrence of the condition or event is not observed in the available database.It is difficult to think about any plausible failure scenario;however,a single scenario could be identified after considerable effort. | $10^{-3}$ |
| The condition or event has not been observed,and no plausible scenario could be identified,even after considerable effort. | $10^{-4}$ |

Probability estimates should be input in scientific notation such as “1 E –3” for 1 in 1,000 years.Other notations such as 5% in 100 years should be converted to “2 E-3.”

### 3.7 Failure Mode Descriptions and Evaluation

Visual observations section in Failure Modes worksheet (see Fig. 3.3) shows different conditions for dam. Generally these conditions are observed by dam engineers or foundation conditions can be used in visual observations section

Failure mode section includes most general types of failures of dams elements such as :

- Normal Stability

- Piping
- Normal Flood
- Extreme Flood
- Earhquakes
- Gates
- Valves
- Outlet Tower Stability

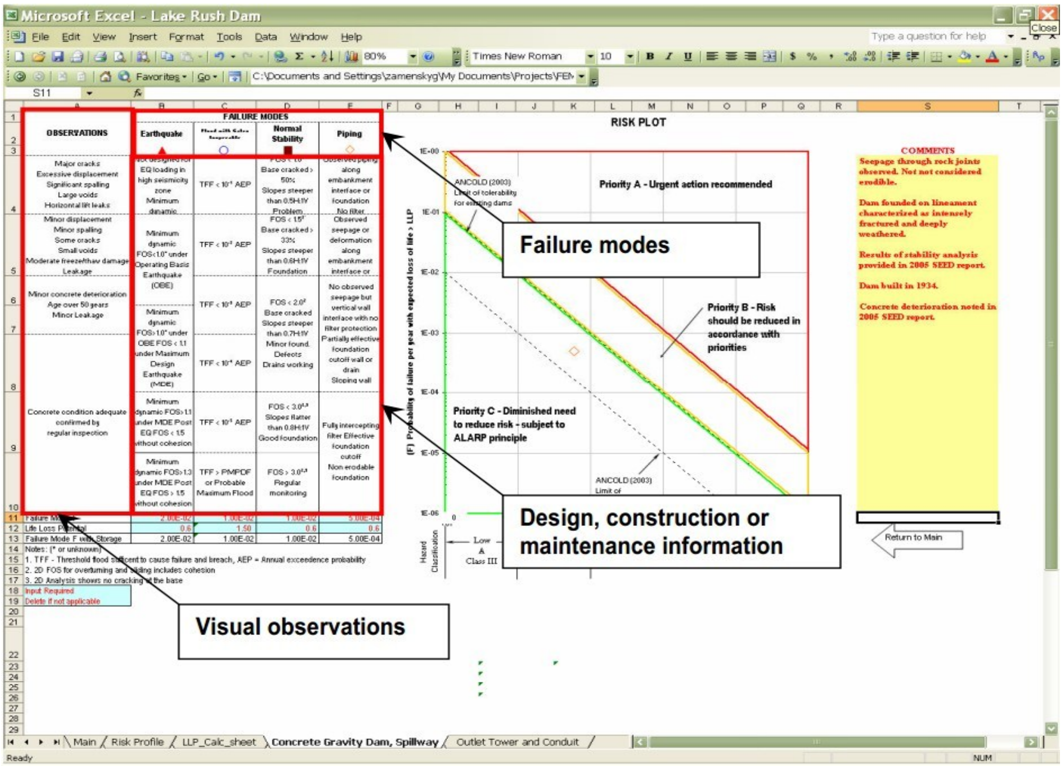



Figure 3-3 Failure Modes Worksheet (Fema; 2008)

Design, construction or maintenance information section allows user to select proper situation for failure modes.For example, under piping failure mode there are 5 different conditions like seepage, filter condition, cutoff wall, sloping wall etc.

Each failure mode is characterized by a column of physical observations, geometric details, analysis results and other pertinent information. The columns are made up of bins with ranges of failure probability corresponding to the noted information about the dam in each bin.

### 3.7.1 Piping

Piping is perhaps the most difficult failure mode, so the Historical Performance Method developed by Dr. Mark Foster while he was at the University of New South Wales (UNSW) hasbeen used to guide the binning process. The paper (Foster et al;1998) has been appended to assist the User in selecting the appropriate order of magnitude. The UNSW method provides guidance on the adjustments to the failure probabilities based on whether various conditions are better or worse then the average.

This coloum provides descriptions based on historical precedent of conditions.The first bin covers the range of annual failure probabilty of $1x10^{-2}$ to 1.

For an earth fill dam piping can be most dangerous situation if there is active piping going on with turbid seepage, no filter, erodible soils and an unprotected seepage exit. The probability of failure may be as high 0.5, or 1 if failure is imminent.

According to Foster et al (1998)4, an average homogeneous earthfill dam with no filters has an annualized probability of piping failure of 2 x 10-4.Risk level can be high if there are the presence of dispersive clay, observed piping.On the other hand if there is well compacted clay and a filter toe drain,than risk should be low.

### 3.7.2 Flood

Flood failure conditions are easiest to estimate.The flood recurrence probability can be change due to type of climatological area type.In arid areas the probable maximum precipitation (PMP) is controlled by freak storms, the PMF may be projected to occur only once in a million years ($1x10^{-6}$). Where as in more temperatee climates PMF might have a return period of 1 in 10,000 or $1x10^{-4}$. (Fema; 2008)

### 3.7.3 Earthquake

Some judgment of whether liquefaction might be a problem for earthquake failure mode.So clues such as loose sands in foundation or hydraulic fill construction would be important to identify.However,if are is quiet sismically,this failure mode can be skipped. (Fema; 2008)

### 3.7.4 Stability

If stability analyses are not available than slope angles,or telltale signs of crackings,slumps or deformation may be helpful indicators for stability.However,if factors of safety have been taken under considiration in design process of dam,than these figures should be used to select order of magnitude of failure probability. (Fema; 2008)

## 3.8 Consequence Asessment

The main focus of dam safety regulators is protecting public safety.Therefore,the type of consequence of primary interest in the prioritization too is human lives.

The main focus of state dam safety regulators is protecting public safety. Therefore, the type of consequence of primary interest in the prioritization tool is human lives. However, the method typically used for life loss estimation from dam failure requires extensive dam break modeling, which is typically not available to the regulator. (Graham, 1999)

To overcome this limitation, Wayne Graham developed a simplified procedure dated June 18,2004 entitled "A Method for Easily Estimating the Loss of Life from Dam Failures", appended to this report. A spreadsheet was developed to assist in determining the potential for loss of life based on the methodology outlined by Graham using primarily information from the NID database. The simplified approach requires several estimates of hydrologic and geographic parameters:

i. Estimation of the peak dam breach discharge ;
ii. Estimation of the peak 10-year frequency discharge;
iii. Estimation of the Population at Risk (PAR) in a given reach ;
iv. Estimation of the fatality rate in a given reach.

## 3.9 Life Loss Potential Worksheet

The below table shows ilustrated empty worksheet for life loss potential.Some values are updated from main worksheet while values like population at risk must be entered manually.

The resulting LLP values for the Flood and Sunny Day conditions are then applied to each failure mode for every Dam Element. The User must manually input the values into each failure mode at the locations shown in Figure 3.5.

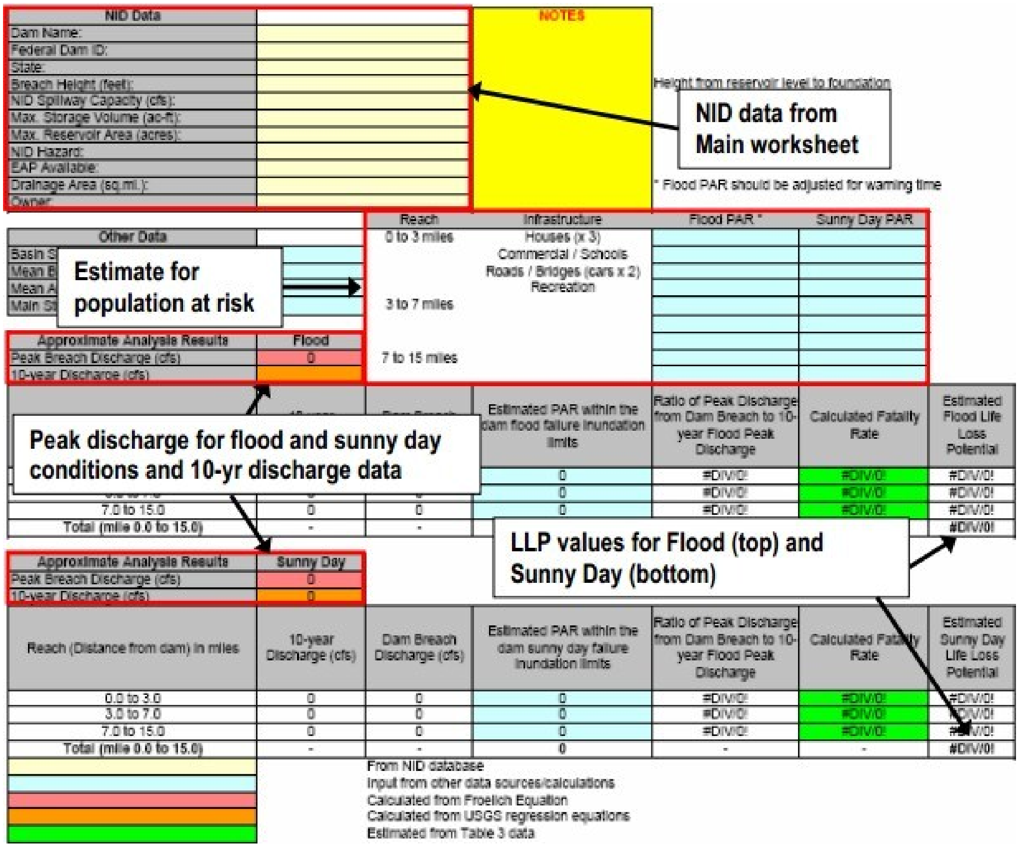



Figure 3-4 Life Loss Potential Worksheet (Fema; 2008)

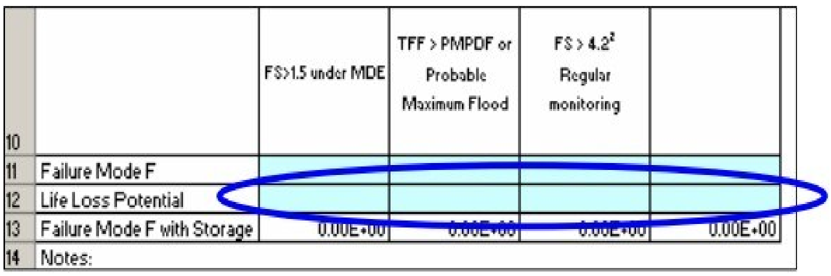



Figure 3-5 Life loss potential values for failure conditions (Fema; 2008)

Selection of the appropriate Life Loss Potential (LLP) can be diffucult to select in some conditions.For example,failure of a valve on an outlet works facility would not result in an uncontrolled relase of water but the resulting discharge may or may not be a hazard.Application of the LLP value can be provided in the Table 3-2.

Table 3-2 Failure Modes and LLP Consideration (Fema; 2008)

| Failure Mode | LLP Consideration |
| --- | --- |
| Earthquake | Sunny Day |
| Flood | Flood |
| Normal Stability | Sunny Day |
| Piping | Sunny Day |
| Seepage | Sunny Day |
| Training Walls | Flood – can failure of training walls lead to catastrophic breach and release of reservoir? |
| Abutment Outflanking | Flood |
| Lined Chute and Dissipator | Flood – can spillway channel erosion lead to catastrophic breach and release of the reservoir ? |
| Unlined Channel | Flood – can spillway channel erosion lead to catastrophic breach and release of the reservoir ? |
| Conduits | Sunny Day |
| Gates | Flood – can gate failure lead to catastrophic breach and release of the reservoir ? |
| Valves | Sunny Day - can valve failure lead to catastrophic breach and release of the reservoir ? |

### 3.10 Estimating Peak Dam Breach Discharge

Practical application of this methodology is in the estimating peak dam breach discharge. Risk tool calculates 2 different peak dam breach discharges for sunny day condition and for flood condition. If user doesn't have any detailed information about dam breach discharges, risk tool uses simplistic approach to estimating peak dam breach discharge. This method is known as Froelich equation:

$$Q_p=0,607\ (S)^{0,295}\ H_w^{\ 1,24}$$

When user manually input Main Worksheet data (as shown below) than risk tool automatically computes peak dam breach discharge by using Froelich equation. The calculated value can be changed manually by user so that user can input updated data or any other alternative discharge.

| NID Data | |
|---|---|
| Dam Name: | Old Timbers Lake Dam |
| Federal Dam ID: | IN03021 |
| State: | Indiana |
| Region: | 3 |
| Hydraulic Height (feet): | 52.7 |
| NID Spillway Capacity (cfs): | 12100 |
| Max. Storage Volume (ac-ft): | 5126 |
| Max. Reservoir Area (acres): | 295 |
| Probability of dam impounding water in any one year: | 100.00% |
| NID Hazard: | High |
| EAP Available: | Yes |
| Drainage Area (sq.mi.): | 5.1 |
| Owner: | USFWS |
| Other Data | |

Figure 3-6 NID Data input example (Fema; 2008)

# CHAPTER 4

## 4 DEVELOPMENT OF MODIFIED RISK TOOL

In this thesis Risk Tool software is used for risk assessment of small dams. This software mainly based on Froelich equation, this software only calculates peak breach discharge. Other methods for peak breach discharge added to software. These methods are:

- Soil Conservation Method
- Macdonald and Langridge-Monopolis Method
- Costa Method

New Life Loss Potential Worksheets prepared for each method. New Risk Profiles drawn for all conditions.

Other breach parameters like breach width, failure time, breach side slope factor formulas added to software in first worksheet of Risk Tool.

Breach width prediction methods added to software are:

- Johnson and Illes (1976)
- Singh and Snorrason (1982,84)
- Fereral Energy Regulatory Comission (1987)
- US Bureau of Reclamation Formula (1988)

Failure time formulations added to software are:

- Singh and Snorrason (1982,84)
- Fereral Energy Regulatory Comission (1987)
- US Bureau of Reclamation Formula (1988)
- Von Thun and Gillette (1990)
- Froelich Method (1995)

Breach Side Slope Factor formulas added to software are:

- Freral Energy Regulatory Commission Formula
- Froelich Method
- Singh and Scarlatos Method
- Von Thun and Gillette Method

These methods are used for calculation of breach parameters. The standard tool uses the Froelich Method for calculating dam breach discharge. Other 3 methods aren't available in the standard version of the tool. In this study all available breach discharge calculation methods were added and made available in the Modified Risk Tool (MRT)

Failure time is important for safety of population living near dam. During a failure it can save many lifes if there is failure of calculations made for risk analysis. For this purpose 4 main methods were added to the Failure Time Worksheet of the standard tool.

## 4.1 Implementation of New Parameters to the Standart Risk Tool

The main purpose of this thesis is to modify and improve the capabilities of the standard Risk Tool developed by FEMA. Since, for calculating dam breach risk values, some dam breach parameters must be calculated first. These parameters can be found by some models or some empirical formulae can be used for calculations. For this reason, some additional dam breach models are added.

## 4.2 Some Important Variables

Dam breach parameters can be calculated by using some important variables. These variables are:

Water height passing over dam (d)

Height between breach base and top of embankment (H)

Water height in reservoir before failure ($H_w$)

Dam Height (H)

Volume of water in reservoir during dam failure (S)

Volume of water over top of dam during dam failure (V)

Breach width (B)

## 4.3 Calculation and implementation of the model parameters

### i. Water height passing over dam , d:

Changes between 0,3m and 1,5m (Ağıralioğlu; 2011)

### ii. Water height in reservoir before failure (Hw)

Water height can be calculated with this formula :

$$H_w = H + d$$

### iii. Volume of water over top of dam during dam failure (V):

Top of the reservoir can be assumed as rectangular. This value can be calculated with: (Ağıralioğlu; 2011)

$$V = d \times A$$

#### iv. Volume of water in reservoir during dam failure (S) :

Volume of water in reservoir during dam failure can be between 2 values. These values are calculated with sum of volume and Vmin or Vmax. Volume of water can be calculated with formula :

$S_1$=v + $V_{min}$

$S_2$=v+ $V_{max}$

Where;

$S_1$=minimum value of Volume of water in reservoir during dam failure

v=Storage volume of reservoir

$S_2$=maximum value of Volume of water in reservoir during dam failure

$V_{min}$= minimum value of Volume of water over top of dam during dam failure

$V_{max}$=maximum value of Volume of water over top of dam during dam failure (Ağıralioğlu; 2011)

Breach width (B) Average width between breach base and top of embankment : According to calulations in Timberlake Dam (USA) breach width found between 27,4 and 54,8m. If these values are accepted as minimum and maximum values of width so that average width can be found as 41,1m. Generally breach width assumed that can change between 30m and 48m. (Ağıralioğlu; 2011)

## 4.4 Peak Breach Discharge

### 4.4.1 Soil Conservation Method :

Soil Conservation Service (SCS) offered two different methods.

If $H_w$ > 30m;

$$Q=16,6(H_w)^{1,85}$$

If $H_w$<30m;

$$Q=4,2x10^{-4}[SxH_w/(BxH)]^{1,35}$$ (Ağıralioğlu; 2011)

### 4.4.2 Macdonald and Langridge-Monopolis Method:

Macdonald and Langridge-Monopolis offered below formula for maximum discharge :

$$Q=1,175(SxH_w)^{0,41}$$ (Ağıralioğlu; 2011)

### 4.4.3 Costa Method:

Costa offered

$$Q=0,763(SxH_w)^{0,42}$$

formulation for calculating peak breach discharge (Ağıralioğlu; 2011)

### 4.4.4 Froelich Method:

Froelich (1995) offered

$$Q=0,607(S)^{0,295}(H_w)^{1,24}$$

Formulation. (Ağıralioğlu; 2011)

## 4.5 Breach Width

It refers, depending on each model, to the top, lower or average width of the breach.It seems that the changes in breach width is more effective for large dams because it produced larger changes (35-87%)in peak outflow and smaller changes (6-50%) for small reservoirs (Wahl; 1998)

**i. Johnson and Illes (1976)**

They were the first to predict failure shapes for earth, gravity, and arch concrete dams. For earth dams, their proposition was that the breach shape begins as a triangle and ends as a trapezoid (Wahl; 1998). They also realized that failure width (general) B is given by:

$0.5h < B < 3h$ for earthfill dams (Ağıralioğlu; 2011)

**ii. Singh and Snorrason (1982,84)**

Their study was conducted on 20 case studies and they came up with the

following. (Wahl; 1998) The breach width is constrained by:

$2h<B<5h$ (Ağıralioğlu; 2011)

**iii. Federal Energy Regulatory Comission (1987)**

Federal Energy Regulatory Comission (FERC,1987) offered $2h<B<4h$formula for embankment dam breach width (Ağıralioğlu; 2011)

**iv. US Bureau of Reclamation Formula (1988)**

US Bureau of Reclamation offered that breach width can be calculated with $B=3H_w$ (Ağıralioğlu; 2011)

## 4.6 Failure Time

Researchers found that if failure time were reduced by half its initial value, the peak outflow for a PMF hydrograph would increase by 13 to 83 %. But for large reservoirs, the change in peak outflow was much smaller showing a variation of only 1 to 5 % (Wahl; 1998)

### i. Singh and Snorrason (1982,84)

Singh and Snorrason offered that failure time Tf changes between 0,25 hours and 1 hour.

$0,25h < T_f < 1h$

### ii. FERC (1987)

Fereral Energy Regulatory Comission (FERC,1987) offered that failure time $T_f$ changes between 0,1 hours and 0,5hour. (Ağıralioğlu; 2011)

$0,1h<T_f<0,5h$

### iii. Froelich (1995):

Froelich offered below formula for time of failure :

$$Tf=2,54x10^{-3}(S)^{0,53}(H_w)^{-0,59}$$ (Ağıralioğlu; 2011)

### iv. US Bureau of Reclamation Formula

US Bureau of Reclamation (USBR,1988) offered that time of failure changes with breach width and they offered below formula:

$$T_f=0,011\ B$$

Where;

$T_f$=Failure time

B= Breach width (Ağıralioğlu; 2011)

**v. Von Thun and Gillette (1990)**

Von Thun and Gillette offered 2 formulas for failure time.These methods are dependent on the amount of erosion that occurs : (Wahl; 1998)

$t_f$= 0.020h + 0.25 (hr) (erosion resistant)

$t_f$= 0.015x$h_w$ (hr) (easily erodible)

Where $t_f$ should be in hours and $H_w$ in meters. (Ağıralioğlu; 2011)

### 4.7 Breach Side Slope Factor

**i. Freral Energy Regulatory Commission Formula**

Fereral Energy Regulatory Comission (FERC,1987) found that breach side slope for failure of embankment dams change between 1 and 2. (Ağıralioğlu; 2011)

$1<z<2$

**ii. Froelich Method**

Froelich offered that, if water doesnt pass over dam crest than side slope should be equal to 1,4 (Ağıralioğlu; 2011)

Z=1,4

**iii. Singh and Scarlatos Method**

They found that side slope factor changes between 0,09 and 1,12 (Ağıralioğlu; 2011)

$0,09<z<1,12$

**iv. Von Thun and Gillette Method**

In their work, they assumed that side slopes of breach are 1H: 1V except for dams that have cohesive shells or very wide cohesive cores, where slopes of 1:2 or 1:3 (H: V) are more acceptable. (Atallah; 2002)

Z=1

# CHAPTER 5

# 5 CASE STUDIES

## 5.1 General

In this chapter modified risk tool (MRT) is used for risk assessment of three dams in Turkey. These are Kayacık dam in Gaziantep, Karaova and Çoğun dams in Kırşehir. All dams used in the case studies are earth-fill dam, owned by the Stae of Hydraul,c Works (DSİ) of Turkey.

## 5.2 Kayacık Dam

Kayacık Dam is located in Gaziantep, Turkey. The dam was constructed between 1993 and 2006 as part of the Southeastern Anatolia Project (GAP). Coordinates of dam are 36˚ 38’ - 36˚ 56’ latitude and 37˚ 11’ - 37˚ 42’ lontitude. Kayacık Project is only surrounded by small mountains which lay in north of area. These are : Barak Mountain (663 m) Şehbilcan Mountain (694 m) and Tüzel Mountain (760 m). Project area covers some part of Gaziantep Plain. Height in project area changes between 500 m and 560 m. The Kayacık Dam impounds the Ayfinar Creek, one of the two streams that join south of Gaziantep to form the Sacir River. Both rivers are getting together 3 km near Syria Border. There isn’t any lake or swap near project area. Summers are very hot and dry, winters are warm and rainy. Project area is in 4$^{th}$ Seismic zone of Turkey according to Turkey Seismic Zones Map.

There are 20 residential units within the project area. According to census in 1980 total population is 4239. Lentils, cotton, sesame, onion, pistachio are main agricultural products in area. General problems before dam construction was insufficient water resources and lack of irrigation. Project area, in general words places near dam, isn’t industrialized enough. Industry products are provided from Gaziantep and Kilis.

In the project area main trade activities are based on agricultural products. There arent any historical buildings or touristic places build in project area so that improvement of tourism isn't expected. Project area is located 500-560m above sea level. General soil properties are heavy textured soils.

Dam body type has been chosen earth fill dam because of general geological situation and material needs. Height of dam is 56,5m. Maximum spillway capacity is 548,89 $m^3/s$. It has a reservoir capacity of 116760 $m^3$ and total reservoir area is 194438 $m^2$. Drainage area capacity of dam is 4,56 $km^2$. Main purpose of dam is irrigation.

### 5.2.1 Implementation of Kayacık Dam Characteristics into Modified Risk Tool

Initial input data for Kayacık Dam is given in Table 5-1. This table shows main dam characteristics used for first step of risk analysis.

Table 5-1 Kayacık Dam Input Data

| **Input Data (metric)** | |
|---|---|
| Dam Name | Kayacık |
| Dame Code | |
| State: | |
| Region | |
| Hydaulic Height : (m) | 44,5 |
| Spillway Capacity : ($m^3/s$) | 548,89 |
| Max.Storage Volume($m^3$) | 116760000 |
| Max. Reservoir Area ($m^2$) | 13100000 |
| Probability of dam impounding water in any one year: | 100,00% |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area ($m^2$): | 456000000 |

| | |
|---|---|
| Owner | DSİ |
| **Other Input** | |
| Basin Slope | 0,1 |
| Mean Basin Elevation : (m) | 560 |
| Mean Annual Precipitation : (mm) | 425,9 |
| Main Stream Length : (m) | 50125 |
| Q10 ($m^3$/s) | 612 |

Table 5-2 Kayacık Dam Breach Variables

| **Variable** | **Definition** |
|---|---|
| d | Water passing over dam |
| H | Height from breach base to top of embakment |
| Hw | Height of water in reservoir before breach.Measured from breach base |
| H | Height of dam |
| S | Total water volume during dam failure |
| V | Water volume over dam crest during dam failure |
| B | Average width between breach base and top of embakment.Breach width |

For calculating breach parameters user must calculate some variables for using as input data in breach parameters calculations. Table 5-3 shows Kayacık Dam breach variables.

Table 5-3 Kayacık Dam Breach Variables Calculations

| **Variable** | **Min Value** | **Max Value** | **Value** | |
|---|---|---|---|---|
| d (m) | 0,3 | 1,5 | 1,5 | m |
| h (m) | 44,5 | | 44,5 | m |
| Hw (m) | 44,8 | 46 | 46 | m |
| H (m) | 44,5 | | 44,5 | m |
| S ($m^3$) | 116896800 | 117444000 | 117444000 | $m^3$ |
| V (m3) | 136800 | 684000 | 684000 | $m^3$ |
| B (m) | 89,00 | 222,50 | 222,5 | m |

In risk analysis most dangerous stuation is important for safety. For this reason variable values such as average width was taken as maximum value. Dam breach variables are given in Table 5-4

Table 5-4 Kayacık Dam Breach Variable Values

| Variable | Choosen Value | |
|---|---|---|
| d (m) | 1,5 | m |
| h (m) | 44,5 | m |
| Hw (m) | 46 | m |
| H (m) | 44,5 | m |
| S (m3) | 117444000 | m3 |
| V (m3) | 684000 | m3 |
| B max(m) | 220 | m |
| B min(m) | 89 | m |

Dam breach calculations are made by using Johnson and Illes Formula, Singh and Snorrason Formula, Federal Energy Regulatory Commission Formula, US Bureau of Reclamation Formula. Results of these calculations are given in Table 5-5

Peak breach discharges are used for calculation flood and sunny day conditions. Different values for peak breach discharges are calculated by using empirical formulations. Kayacık Dam peak breach discharge values are given in Table 5-6.

Table 5-5 Kayacık Dam Breach Width

| Dam Breach Formulation | | |
|---|---|---|
| Johnson and Illes Formula | | |
| 0,5h<B<3h | $B_{min}$ (m) | 22,25 |
| | $B_{max}$ (m) | 133,50 |
| Singh and Snorrason Formula | | |
| 2h<B<5h | $B_{min}$ (m) | 89,00 |
| | $B_{max}$ (m) | 222,50 |
| Federal Energy Regulatory Commission Formula | | |
| 2h<B<4h | $B_{min}$ (m) | 89,00 |
| | $B_{max}$ (m) | 178,00 |
| US Bureau of Reclamation Formula | | |
| B=3Hw | B (m) | 138,00 |

Table 5-6 Kayacık Dam Peak Breach Discharge

| **Peak Breach Discharge Formulation** | **Peak Breach Discharge Value** |
|---|---|
| Soil Conservation Service Method | |
| Hw>30m Q=16,6*(Hw)1,85 | 18602,62 ($m^3/s$) |
| Hw<30m Q=4,2*10-4*[S*Hw/(BxH)]1,35 | |
| Macdonald and Langridge-Monopolis Method | |
| Q=1,175*(S*Hw)0,41 | 11492,10 ($m^3/s$) |
| Costa Method | |
| Q=0,763*(S*Hw)0,42 | 9337,10 ($m^3/s$) |
| Froelich Equation | |
| Q=0,607*(S)0,295*(Hw)1,24 | 16811,58 ($m^3/s$) |

Failure time is important for early warning systems. Effects of dam failures can be reduced with help of estimation of failure time. Kayacık Dam failure time estimations are given in Table 5-7.

Table 5-7 Kayacık Dam Failure Time

| **Failure Time Formulas** | **Failure Time (hour)** | | **Failure Time (minute)** | |
|---|---|---|---|---|
| Singh and Snorrason Formula | | | | |
| 0,25 hour < T < 1 hour | $T_{min}$ | 0,25 | $T_{min}$ | 15 |
| | $T_{max}$ | 1 | $T_{max}$ | 60 |
| Federal Energy Regulatory Commission Formula | | | | |
| 0,1 hour < T < 0,5 hour | $T_{min}$ | 0,1 | $T_{min}$ | 6 |
| | $T_{max}$ | 0,5 | $T_{max}$ | 30 |
| Froelich Equation | | | | |
| T=2,54*10-3*(S)0,53*(Hw)-0,59 | T | 5,02 | $T_{min}$ | 301,3 |
| US Bureau of Reclamation Formula | | | | |
| T=0,011*B | T | 0,98 | T | 58,74 |
| Von Thun and Gillette Method | | | | |
| T=0,02*Hw+0,25 | $T_{min}$ | 1,17 | $T_{min}$ | 70,2 |
| T=0,015*Hw | $T_{max}$ | 0,69 | $T_{max}$ | 41,4 |

The breach side slope defines shape of breach and breach side slope for Kayacık Dam is given in Table 5-8.

Table 5-8 Kayacık Dam Slide Slope

| Federal Energy Regulatory Commission Formula | |
|---|---|
| $Z_{min}$ | 1 |
| $Z_{max}$ | 2 |
| Froelich Method | |
| Z | 1,4 |
| Singh and Snorrason Method | |
| $Z_{min}$ | 0,09 |
| $Z_{max}$ | 1,12 |
| Von Thun and Gillette Method | |
| Z | 1 |

Table 5-9 shows initial input data for Froelich Method. Hydraulich height, spillway capacity, max storage volume, max reservoir area, drainage area and existence of emergency action plans are main input data for NID Data table.

Table 5-9 Kayacık Dam Froelich Method Life Loss Potential Calculations NID Data

| **NID Data** | |
|---|---|
| Dam Name: | KAYACIK |
| Federal Dam ID: | |
| State: | |
| Hydraulic Height (feet): | 145,9974 |
| NID Spillway Capacity (cfs): | 19.383,8671 |
| Max. Storage Volume (ac-ft): | 94.658,8499 |
| Max. Reservoir Area (acres): | 3.237,0805 |
| Probability of having dam fill in any one year: | 1,0000 |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area (sq.mi.): | 176,0625 |
| Peak Breach Discharge : | 21.612,5757 |

Population living near Kayacık Dam was calculated by using maps and census data. Table 5-10 shows population at risk near Kayacık Dam.

Table 5-10 Kayacık Dam Froelich Method Life Loss Potential Calculations Population at Risk (PAR) Data

| | | Reach | Infrastructure | Flood PAR | Sunny Day PAR |
|---|---|---|---|---|---|
| **Other Data** | | 0 to 3 miles | Houses (x 3) | 303 | 303 |
| Basin Slope (feet/mile): | 0,1000 | | Commercial / Schools | | |
| Mean Basin Elevation (feet): | 1.837,2703 | | Roads / Bridges (cars x 2) | | |
| Mean Annual Precipitation (inches): | 16,7677 | | Recreation | | |
| Main Stream Length (miles): | 31,1462 | 3 to 7 miles | | 1.045 | 1.045 |
| | | 7 to 15 miles | | 2.891 | 2.891 |

Kayacık Dam risk assessment was made by using Froelich Method. This method makes calculations for both flood and sunny day conditions. Table 5-11 shows calculations for flood conditions and Table 5-12 shows sunny day conditions for Froelich Method.

Table 5-11 Kayacık Dam Froelich Method Life Loss Potential Calculation for Flood Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge | 593.695,2910 | | | | | |
| 10-year Discharge (cfs) | 21.612,5757 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 21.612,5757 | 593.695,2910 | 303,0000 | 27,4699 | 0,2 | 60,6000 |
| 3.0 to 7.0 | 21.612,5757 | 593.695,2910 | 1.045,0000 | 27,4699 | 0,15 | 156,7500 |
| 7.0 to 15.0 | 21.612,5757 | 593.695,2910 | 2.891,0000 | 27,4699 | 0,1 | 289,1000 |
| **Total (mile 0.0 to 15.0)** | - | - | **4.239,0000** | - | - | **506,4500** |

Table 5-12 Kayacık Dam Froelich Method Life Loss Potential Calculations for Sunny Day Conditions

| **Approximate Analysis Results** | **Sunny Day** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 568.721,6922 | | | | | |
| 10-year Discharge (cfs) | 21.612,5757 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam sunny day failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Sunny Day Life Loss Potential |
| 0.0 to 3.0 | 21.612,5757 | 568.721,6922 | 303,0000 | 26,3144 | 0,2 | 60,6000 |
| 3.0 to 7.0 | 21.612,5757 | 568.721,6922 | 1.045,0000 | 26,3144 | 0,15 | 156,7500 |
| 7.0 to 15.0 | 21.612,5757 | 568.721,6922 | 2.891,0000 | 26,3144 | 0,1 | 289,1000 |
| **Total (mile 0.0 to 15.0)** | - | - | **4.239,0000** | - | - | **506,4500** |

Main failure modes used for Froelich Method are earthquake, flood, piping and normal stability. For each failure mode observations were used for input data and life loss potential values were taken from population at risk tables. Kayacık Dam Froelich Method Failure Modes and values of life loss potential are given in Table 5-13.

Table 5-13 Kayacık Dam Froelich Method Failure Modes

| OBSERVATIONS | FAILURE MODES | | | |
|---|---|---|---|---|
| | **Earthquake** [2]<br>▲ | **Flood**[1]<br>○ | **Piping**<br>■ | **Normal Stability**<br>◇ |
| Significant deformation<br>and<br>transverse cracking<br>Concentrated seepage<br>with turbidity<br>Large slumps<br>Large Trees | Not designed<br>for EQ loading<br>in high hazard<br>area<br>Soils liquefy<br>FS<1.0* in EQ<br>AEP $10^{-1}$ | TFF < $10^{-1}$ | Observed piping of<br>embankment<br>or foundation<br>Erodable / poorly<br>compacted / dry and<br>brittle soils* and<br>Incompatible or<br>Internally unstable<br>soils<br>No filter<br>Unprotected<br>seepage exit with<br>high gradient | FS < 1.0*<br>Slopes steeper than<br>1.5H:1V<br>High Pore Pressures<br>Very weak<br>foundation |
| Observed deformation<br>and cracking,<br>steep or stepped<br>abutments<br>Significant seepage or<br>wet areas<br>Trees on slope or toe | Loose soils<br>present in fdn or<br>embankment<br>Soils liquefy or<br>FS<1.0* under<br>Operating Basis<br>Earthquake<br>(OBE) | TFF < $10^{-2}$ | | FS < 1.1*<br>Slopes steeper than<br>2H:1V<br>High phreatic<br>surface<br>Poor foundation |
| Infrequent Inspection<br>(none in last 10 years)<br>Limited Cracking<br>Small Trees<br>Minor Animal Burrows | Marginal soils<br>FS>1.0* under<br>OBE FS<1.0*<br>for Maximum | TFF < 10-3 | Compacted clay<br>core | FS < 1.2*<br>Slopes steeper than |
| | | TFF < $10^{-4}$ | No observed piping<br>Uncertain Filter<br>Compatibility | FS < 1.3<br>Slopes steeper than<br>3H:1V |
| Embankment condition<br>satisfactory<br>confirmed by regular<br>inspection<br>**(Note: with<br>embankment concrete<br>corewall or cutoff wall<br>reduce by one order of<br>magnitude)** | Dense<br>foundation or<br>compacted<br>embankment<br>soils<br>FS>1.1 under<br>MDE | TFF < $10^{-5}$ | No known cracks<br>Modern, fully<br>penetrating filter<br>Full Foundation<br>Cutoff<br>Modern Foundation<br>Treatment | FS > 1.3<br>Regular monitoring<br>Slopes flatter than<br>3H:1V<br>Good foundation |
| | FS>1.3 under<br>MDE | TFF > PMPDF<br>or Probable<br>Maximum Flood | Wide filter and<br>blanket drain<br>Extensive<br>monitoring | FS > 1.5<br>Regular monitoring |
| Failure Mode F | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-04 |
| Life Loss Potential | 506 | 506 | 506 | 506 |
| Failure Mode F with Stor | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-04 |

Notes: (* or unknown)

1. TFF - threshold failure flood flood which overtops sufficent to cause breach

2. Skip earthquake failure mode if in low seismicity area where Maximum Design Earthquake (MDE) pg

Input Required
Ignore if not applicable

Risk values are classified in three important zones. These are Priority A (given with red triangle) Priority B (Yellow area) and Priority C (green triangle). Figure 5-2 shows failure mode risk values and life loss potential risk plot.

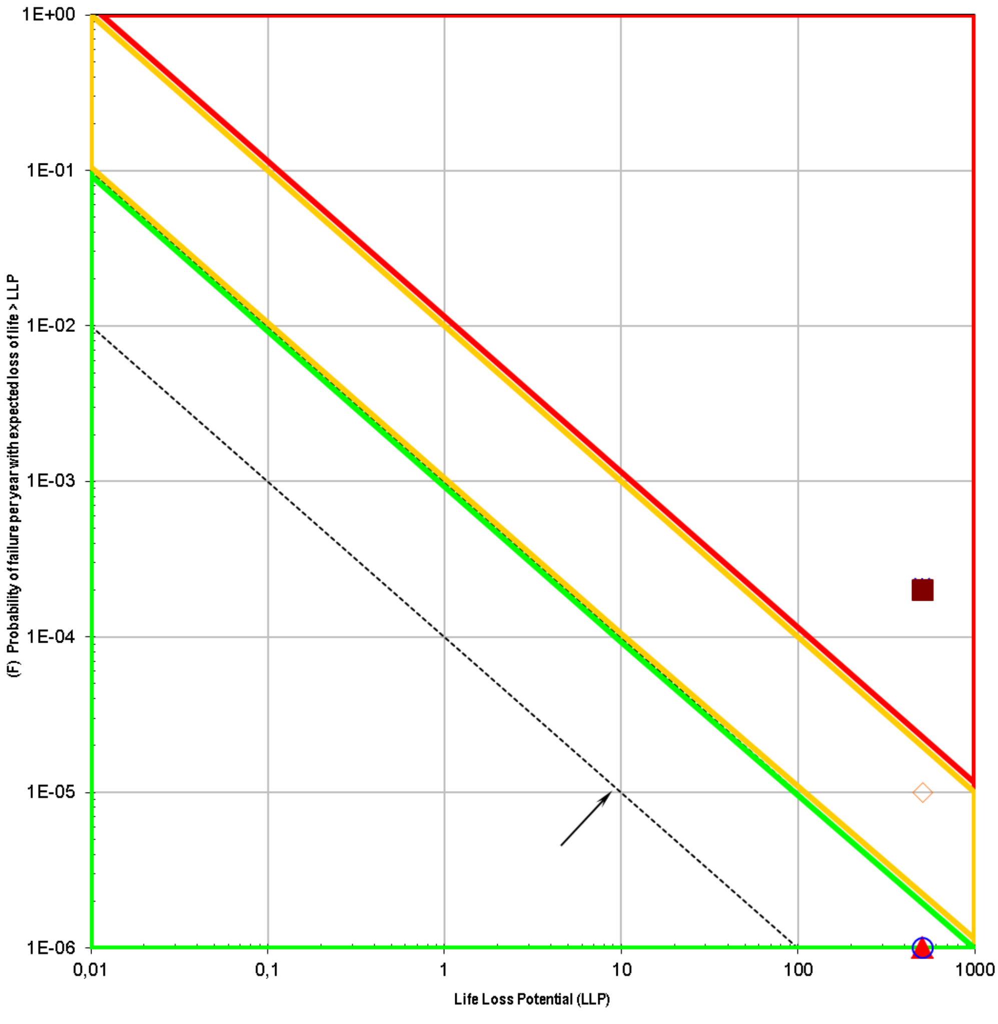



Figure 5-1 Kayacık Dam Froelich Method Risk Plot

Soil Conservation Service Method is used as second risk analysis method for Kayacık Dam. Parameters such as hydraulic height, spillway capacity, max storage volume etc. are used for Soil Conservation Service Method as same as Froelich Method. These initial input datas are given in Table 5-14.

Table 5-14 Kayacık Dam Soil Conservation Service Method Life Loss Potential Calculations NID Data

| **NID Data** | |
|---|---|
| Dam Name: | KAYACIK |
| Federal Dam ID: | |
| State: | |
| Hydraulic Height (feet): | 146,0 |
| NID Spillway Capacity (cfs): | 19.384 |
| Max. Storage Volume (ac-ft): | 94.659 |
| Max. Reservoir Area (acres): | 3.237 |
| Probability of having dam fill in any one year: | 1 |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area (sq.mi.): | 176,06 |
| Peak Breach Discharge: | 21.612,58 |

Table 5-15 shows Population at risk data for Soil Conservation Service Method. As seen in table number of people living in 0-3 miles is 303, in 3-7 miles is 1045 and between 7-15 miles is 2891.

Table 5-15 Kayacık Dam Soil Conservation Service Method Life Loss Potential Calculations Population at Risk (PAR) Data

| | | Reach | Infrastructure | Flood PAR | Sunny Day PAR |
|---|---|---|---|---|---|
| **Other Data** | | 0 to 3 miles | Houses (x 3) | 303 | 303 |
| Basin Slope (feet/mile): | 0 | | Commercial / Schools | | |
| Mean Basin Elevation (feet): | 1.837 | | Roads / Bridges (cars x 2) | | |
| Mean Annual Precipitation (inches): | 17 | | Recreation | | |
| Main Stream Length (miles): | 31 | 3 to 7 miles | | 1045 | 1045 |
| | | 7 to 15 miles | | 2891 | 2891 |

Peak breach discharge and 10-year discharge is used for flood conditions. Estimated PAR within the dam flood failure inundation limits coloumb shows people at risk and values are taken from population at risk table. Flood Conditions are given in Table 5-16 and sunny day condition calculations are given in Table 5-17.

Table 5-16 Kayacık Dam Soil Conservation Service Method Life Loss Potential Calculations for Flood Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 656.945 | | | | | |
| 10-year Discharge (cfs) | 21612,57572 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 21.613 | 656.945 | 303 | 30,4 | 0,25 | 76 |
| 3.0 to 7.0 | 21.613 | 656.945 | 1.045 | 30,4 | 0,2 | 209 |
| 7.0 to 15.0 | 21.613 | 656.945 | 2.891 | 30,4 | 0,13 | 376 |
| **Total (mile 0.0 to 15.0)** | - | - | **4.239** | - | - | **661** |

Table 5-17 Kayacık Dam Soil Conservation Service Method Life Loss Potential Calculations for Sunny Day Conditions

| **Approximate Analysis Results** | **Sunny Day** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 568.722 | | | | | |
| 10-year Discharge (cfs) | 21612,57572 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam sunny day failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Sunny Day Life Loss Potential |
| 0.0 to 3.0 | 21.613 | 568.722 | 303 | 26,3 | 0,2 | 61 |
| 3.0 to 7.0 | 21.613 | 568.722 | 1.045 | 26,3 | 0,15 | 157 |
| 7.0 to 15.0 | 21.613 | 568.722 | 2.891 | 26,3 | 0,1 | 289 |
| **Total (mile 0.0 to 15.0)** | - | - | **4.239** | - | - | **506** |

Life Loss Potential was calculated for flood and sunny day conditions. According to observations in dam site, earthquake and risk value was taken 1,00E-06, piping risk value was taken 2.00E-04 and for normal stability failure mode risk value was taken 1.00E-04. These values are given in Table 5-18.

Table 5-18 Kayacık Dam Soil Conservation Service Method Failure Modes

| | **FAILURE MODES** | | | |
|---|---|---|---|---|
| **OBSERVATIONS** | **Earthquake** [2] ▲ | **Flood**[1] ○ | **Piping** ■ | **Normal Stability** ◇ |
| Significant deformation<br>and<br>transverse cracking<br>Concentrated seepage<br>with turbidity<br>Large slumps<br>Large Trees | Not designed<br>for EQ loading<br>in high hazard<br>area<br>Soils liquefy<br>FS<1.0* in EQ<br>AEP $10^{-1}$ | TFF < $10^{-1}$ | Observed piping of<br>embankment<br>or foundation<br>Erodable / poorly<br>compacted / dry and<br>brittle soils* and<br>Incompatible or<br>Internally unstable<br>soils<br>No filter<br>Unprotected<br>seepage exit with<br>high gradient | FS < 1.0*<br>Slopes steeper than<br>1.5H:1V<br>High Pore Pressures<br>Very weak<br>foundation |
| Observed deformation<br>and cracking,<br>steep or stepped<br>abutments<br>Significant seepage or<br>wet areas<br>Trees on slope or toe | Loose soils<br>present in fdn or<br>embankment<br>Soils liquefy or<br>FS<1.0* under<br>Operating Basis<br>Earthquake<br>(OBE) | TFF < $10^{-2}$ | | FS < 1.1*<br>Slopes steeper than<br>2H:1V<br>High phreatic<br>surface<br>Poor foundation |
| Infrequent Inspection<br>(none in last 10 years)<br>Limited Cracking<br>Small Trees<br>Minor Animal Burrows | Marginal soils<br>FS>1.0* under<br>OBE FS<1.0*<br>for Maximum | TFF < 10-3 | Compacted clay<br>core | FS < 1.2*<br>Slopes steeper than |
| | | TFF < $10^{-4}$ | No observed piping<br>Uncertain Filter<br>Compatibility | FS < 1.3<br>Slopes steeper than<br>3H:1V |
| Embankment condition<br>satisfactory<br>confirmed by regular<br>inspection<br>**(Note: with** | Dense<br>foundation or<br>compacted<br>embankment<br>soils | TFF < $10^{-5}$ | No known cracks<br>Modern, fully<br>penetrating filter<br>Full Foundation<br>Cutoff | FS > 1.3<br>Regular monitoring<br>Slopes flatter than<br>3H:1V<br>Good foundation |
| **embankment concrete<br>corewall or cutoff wall<br>reduce by one order of<br>magnitude)** | FS>1.3 under<br>MDE | TFF > PMPDF<br>or Probable<br>Maximum Flood | Wide filter and<br>blanket drain<br>Extensive<br>monitoring | FS > 1.5<br>Regular monitoring |
| Failure Mode F | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-04 |
| Life Loss Potential | 661 | 661 | 661 | 661 |
| Failure Mode F with Stor | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-04 |

Notes: (* or unknown)

1. TFF - threshold failure flood flood which overtops sufficent to cause breach
2. Skip earthquake failure mode if in low seismicity area where Maximum Design Earthquake (MDE) pg

| |
|---|
| Input Required<br>Ignore if not applicable |

Earthquake and flood failure mode risk values are equal. Piping failure mode has biggest value and lowest risk value is for normal stability failure mode. Risk plot of these values for Soil Conservation Service Method are given in Figure 5-2

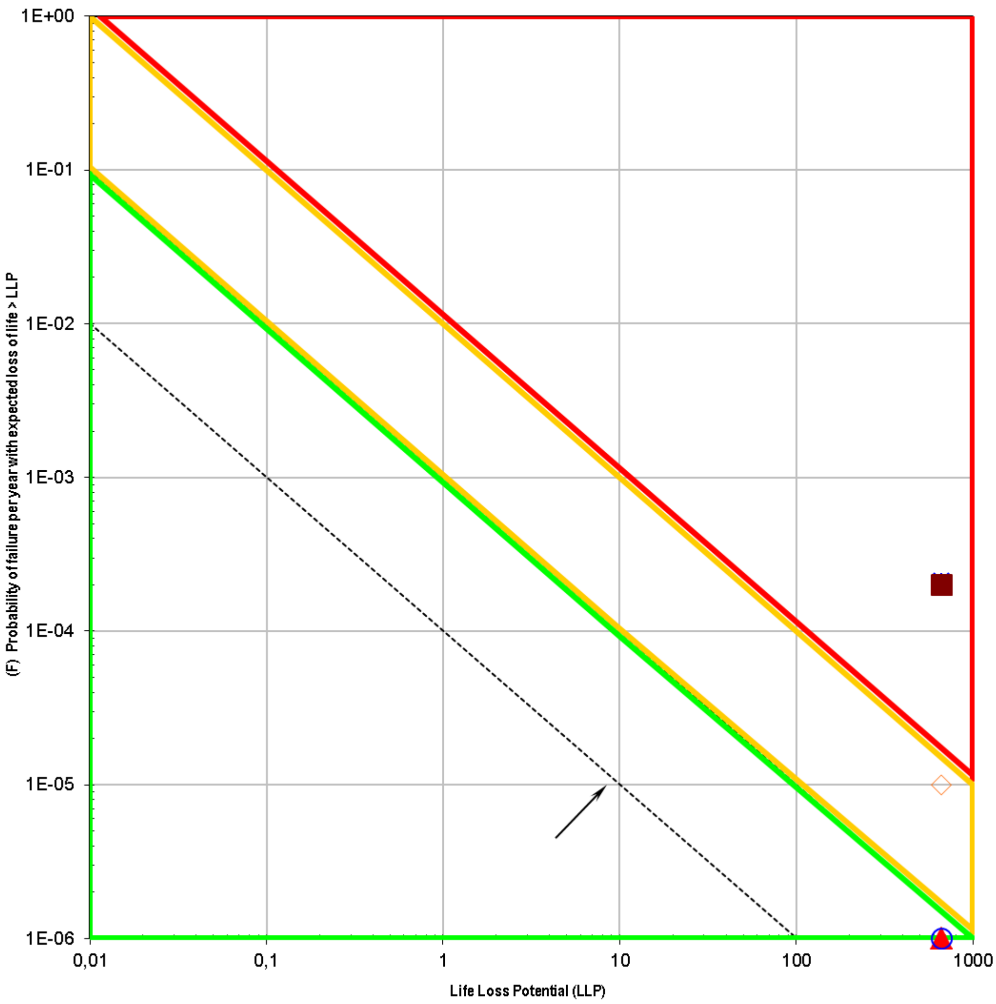



Figure 5-2 Kayacık Dam Soil Conservation Service Method Risk Plot

Third method used for risk analysis is Macdonald and Langridge-Monopolis Method. Main characteristics of Kayacık Dam were used in this method. These characteristic values are given in Table 5-19.

Table 5-19 Kayacık Dam Macdonald and Langridge-Monopolis Method Life Loss Potential Calculations NID Data

| **NID Data** | |
|---|---|
| Dam Name: | KAYACIK |
| Federal Dam ID: | |
| State: | |
| Hydraulic Height (feet): | 145,9974 |
| NID Spillway Capacity (cfs): | 19.383,8671 |
| Max. Storage Volume (ac-ft): | 94.658,8499 |
| Max. Reservoir Area (acres): | 3.237,0805 |
| Probability of having dam fill in any one year: | 1,0000 |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area (sq.mi.): | 176,0625 |
| Peak Breach Discharge : | 405.839,5104 |

Population at risk data is same as used in Froelich Method and Soil Conservation Service Method. According to this population at risk in first 3 miles is 303, in next 4 miles 1045 and for next 8 miles is 2891. These values and other input data values are given in Table 5-20.

Table 5-20 Kayacık Dam Macdonald and Langridge-Monopolis Method Life Loss Potential Calculations Population at Risk (PAR) Data

| | | Reach | Infrastructure | Flood PAR | Sunny Day PAR |
|---|---|---|---|---|---|
| **Other Data** | | 0 to 3 miles | Houses (x 3) | 303 | 303 |
| Basin Slope (feet/mile): | 0,1000 | | Commercial / Schools | | |
| Mean Basin Elevation (feet): | 1.837,2703 | | Roads / Bridges (cars x 2) | | |
| Mean Annual Precipitation (inches): | 16,7677 | | Recreation | | |
| Main Stream Length (miles): | 31,1462 | 3 to 7 miles | | 1.045 | 1.045 |
| | | 7 to 15 miles | | 2.891 | 2.891 |

Ratio between peak breach discharge and 10 year discharge is very low so that calculated fatality rates are lower than 1. As a result of this situation estimated flood life loss potential was calculated as 0,4. Calculations for flood and sunny day conditions of Macdonald and Langridge-Monopolis Method are given in tables 5-21 and 5-22.

Table 5-21 Kayacık Dam Macdonald and Langridge-Monopolis Method Life Loss Potential Calculations for Flood Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge | 405.839,5104 | | | | | |
| 10-year Discharge (cfs) | 21.612,5757 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 21.612,5757 | 405.839,5104 | 303,0000 | 18,7779 | 0,0010 | 0,3030 |
| 3.0 to 7.0 | 21.612,5757 | 405.839,5104 | 1.045,0000 | 18,7779 | 0,0001 | 0,1045 |
| 7.0 to 15.0 | 21.612,5757 | 405.839,5104 | 2.891,0000 | 18,7779 | 0,0000 | 0,0000 |
| **Total (mile 0.0 to 15.0)** | - | - | **4.239,0000** | - | - | **0,4075** |

Table 5-22 Kayacık Dam Macdonald and Langridge-Monopolis Method Life Loss Potential Calculations for Sunny Day Conditions

| **Approximate Analysis Results** | **Sunny Day** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 405.839,5104 | | | | | |
| 10-year Discharge (cfs) | 21.612,5757 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam sunny day failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Sunny Day Life Loss Potential |
| 0.0 to 3.0 | 21.612,5757 | 11.492,0953 | 303,0000 | 0,5317 | 0,0010 | 0,3030 |
| 3.0 to 7.0 | 21.612,5757 | 11.492,0953 | 1.045,0000 | 0,5317 | 0,0001 | 0,1045 |
| 7.0 to 15.0 | 21.612,5757 | 11.492,0953 | 2.891,0000 | 0,5317 | 0,0000 | 0,0000 |
| Total (mile 0.0 to 15.0) | - | - | 4.239,0000 | - | - | 0,4075 |

Failure modes for Macdonald and Langridge-Monopolis Method are same as other methods. Earthuqake, flood, piping and normal stability risk values are calculated using observations. Table 5-23 shows Macdonald & Langridge-Monopolis Method Failure Modes

Table 5-23 Kayacık Dam Macdonald and Langridge-Monopolis Method Failure Modes

| **OBSERVATIONS** | **FAILURE MODES** | | | |
|---|---|---|---|---|
| | **Earthquake** [2]<br>▲ | **Flood**[1]<br>○ | **Piping**<br>■ | **Normal Stability**<br>◇ |
| Significant deformation<br>and<br>transverse cracking<br>Concentrated seepage<br>with turbidity<br>Large slumps<br>Large Trees | Not designed<br>for EQ loading<br>in high hazard<br>area<br>Soils liquefy<br>FS<1.0* in EQ<br>AEP $10^{-1}$ | TFF < $10^{-1}$ | Observed piping of<br>embankment<br>or foundation<br>Erodable / poorly<br>compacted / dry and<br>brittle soils* and<br>Incompatible or<br>Internally unstable<br>soils<br>No filter<br>Unprotected<br>seepage exit with<br>high gradient | FS < 1.0*<br>Slopes steeper than<br>1.5H:1V<br>High Pore Pressures<br>Very weak<br>foundation |
| Observed deformation<br>and cracking,<br>steep or stepped<br>abutments<br>Significant seepage or<br>wet areas<br>Trees on slope or toe | Loose soils<br>present in fdn or<br>embankment<br>Soils liquefy or<br>FS<1.0* under<br>Operating Basis<br>Earthquake<br>(OBE) | TFF < $10^{-2}$ | | FS < 1.1*<br>Slopes steeper than<br>2H:1V<br>High phreatic<br>surface<br>Poor foundation |
| Infrequent Inspection<br>(none in last 10 years)<br>Limited Cracking<br>Small Trees<br>Minor Animal Burrows<br>Clear, Consistent<br>Seepage | | TFF < 10-3 | Compacted clay<br>core | FS < 1.2*<br>Slopes steeper than |
| | Marginal soils<br>FS>1.0* under<br>OBE FS<1.0*<br>for Maximum<br>Design<br>Earthquake | TFF < $10^{-4}$ | No observed piping<br>Uncertain Filter<br>Compatibility<br>Uncertain<br>Foundation | FS < 1.3<br>Slopes steeper than<br>3H:1V |
| Embankment condition<br>satisfactory<br>confirmed by regular<br>inspection<br>**(Note: with embankment concrete corewall or cutoff wall reduce by one order of magnitude)** | Dense<br>foundation or<br>compacted<br>embankment<br>soils<br>FS>1.1 under<br>MDE | TFF < $10^{-5}$ | No known cracks<br>Modern, fully<br>penetrating filter<br>Full Foundation<br>Cutoff<br>Modern Foundation<br>Treatment | FS > 1.3<br>Regular monitoring<br>Slopes flatter than<br>3H:1V<br>Good foundation |
| | FS>1.3 under<br>MDE | TFF > PMPDF<br>or Probable<br>Maximum Flood | Wide filter and<br>blanket drain<br>Extensive<br>monitoring | FS > 1.5<br>Regular monitoring |
| Failure Mode F | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-04 |
| Life Loss Potential | 0 | 0 | 0 | 0 |
| Failure Mode F with Stor | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-04 |

Notes: (* or unknown)

1. TFF - threshold failure flood flood which overtops sufficent to cause breach
2. Skip earthquake failure mode if in low seismicity area where Maximum Design Earthquake (MDE) pg

Input Required
Ignore if not applicable

Population at risk was calculated as 0,4 so that points of failure modes in risk plot are in safe zone. Life loss potential and probability of failure per year with expected loss of life graphic is given in Figure 5-3.

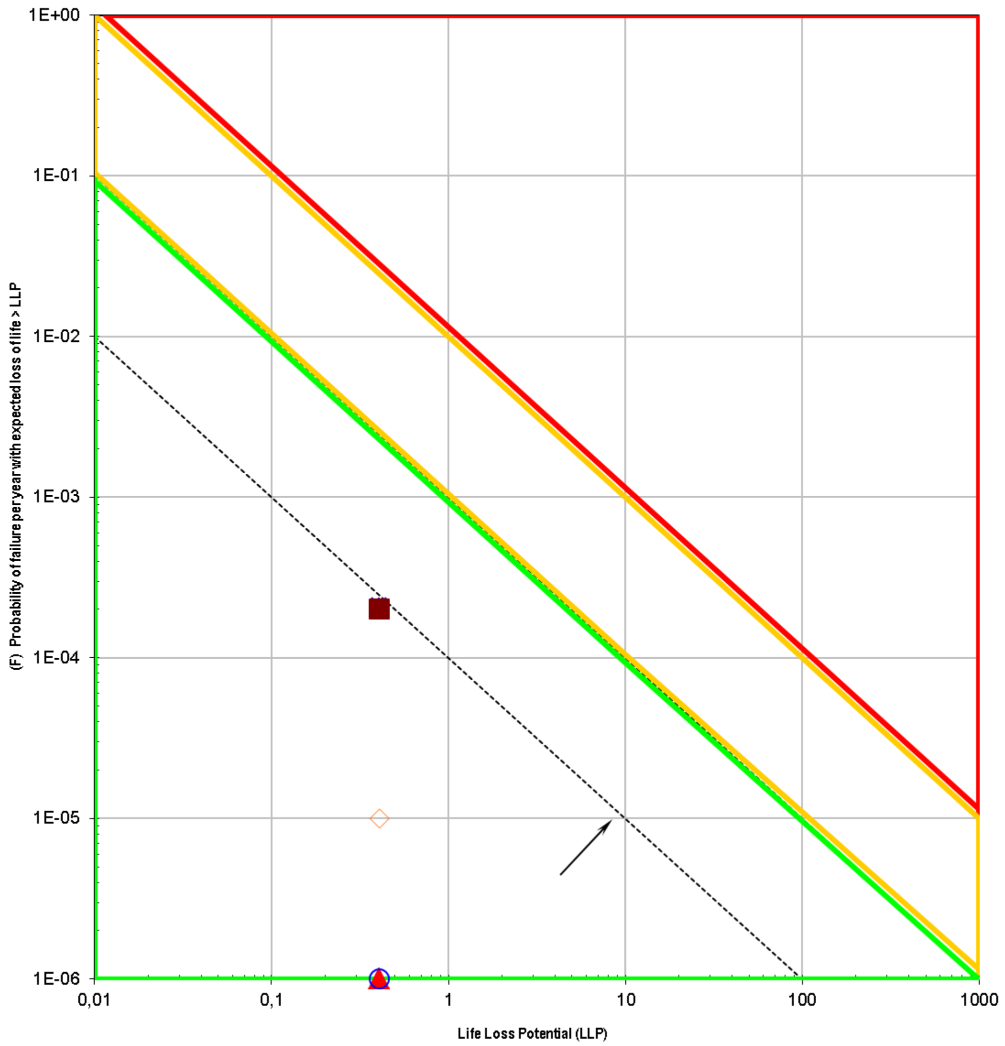



Figure 5-3 Kayacık Dam Macdonald and Langridge-Monopolis Method Risk Plot

Costa Method is used as forth risk analysis method for Kayacık Dam. Hydraulic height, reservoir area and other main dam characteristics are used for initial data. Table 5-24 shows Kayacık Dam Costa Method Life Loss Potential data.

Table 5-24 Kayacık Dam Costa Method Life Loss Potential NID Data

| **NID Data** | |
|---|---|
| Dam Name: | KAYACIK |
| Federal Dam ID: | |
| State: | |
| Hydraulic Height (feet): | 146,0 |
| NID Spillway Capacity (cfs): | 19.384 |
| Max. Storage Volume (ac-ft): | 94.659 |
| Max. Reservoir Area (acres): | 3.237 |
| Probability of having dam fill in any one year: | 1 |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area (sq.mi.): | 176,06 |
| Peak Breach Discharge | 329736,3934 |

Census data and maps of Kayacık dam were used for Population at risk calculations. Flood and sunny day population at risk values are taken as same value. People who live in houses are counted as 3 people, cars on roads and bridges are calculated as 2 people and other population data was calculated for each building. These values are given in Table 5-25.

Table 5-25 Kayacık Dam Costa Method Loss Potential Calculations Population at Risk (PAR) Data

| | | Reach | Infrastructure | Flood PAR | Sunny Day PAR |
|---|---|---|---|---|---|
| **Other Data** | | 0 to 3 miles | Houses (x 3) | 303 | 303 |
| Basin Slope (feet/mile): | 0 | | Roads / Bridges (cars x 2) Recreation | | |
| Mean Basin Elevation (feet): | 1.837 | 3 to 7 miles | | 1045 | 1045 |
| Mean Annual Precipitation (inches): | 17 | 7 to 15 miles | | 2891 | 2891 |
| Main Stream Length (miles): | 31 | | | | |

Flood and sunny day calculations were made for Costa Method as same as other methods. These calculations and estimated life loss potentials are given in Table 5-26 for flood and in Table 5-27 for sunny day conditions.

Table 5-26 Kayacık Dam Costa Method Life Loss Potential Calculations for Flood Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 329.736 | | | | | |
| 10-year Discharge (cfs) | 21612,57572 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 21.613 | 329.736 | 303 | 15,3 | 0,1 | 30 |
| 3.0 to 7.0 | 21.613 | 329.736 | 1.045 | 15,3 | 0,08 | 84 |
| 7.0 to 15.0 | 21.613 | 329.736 | 2.891 | 15,3 | 0,05 | 145 |
| Total (mile 0.0 to 15.0) | - | - | 4.239 | - | - | 258 |

Table 5-27 Kayacık Dam Costa Method Life Loss Potential Calculations for Sunny Day Conditions

| **Approximate Analysis Results** | **Sunny Day** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 329.736 | | | | | |
| 10-year Discharge (cfs) | 21612,57572 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam sunny day failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Sunny Day Life Loss Potential |
| 0.0 to 3.0 | 21.613 | 329.736 | 303 | 15,3 | 0,1 | 30 |
| 3.0 to 7.0 | 21.613 | 329.736 | 1.045 | 15,3 | 0,08 | 84 |
| 7.0 to 15.0 | 21.613 | 329.736 | 2.891 | 15,3 | 0,05 | 145 |
| Total (mile 0.0 to 15.0) | - | - | 4.239 | - | - | 258 |

Same observation risk values are used for Costa Method which are 1E-06 for flood and earthquake failure modes, 2E-04 for piping failure mode and 1E-04 for normal stability failure mode. These values and life loss potential values for each failure mode are given in Table 5-28.

Table 5-28 Kayacık Dam Costa Method Failure Modes

| OBSERVATIONS | FAILURE MODES | | | |
|---|---|---|---|---|
| | **Earthquake** [2] ▲ | **Flood**[1] ○ | **Piping** ■ | **Normal Stability** ◇ |
| Significant deformation and transverse cracking<br>Concentrated seepage with turbidity<br>Large slumps<br>Large Trees | Not designed for EQ loading in high hazard area<br>Soils liquefy FS<1.0* in EQ AEP $10^{-1}$ | TFF < $10^{-1}$ | Observed piping of embankment or foundation<br>Erodable / poorly compacted / dry and brittle soils* and Incompatible or Internally unstable soils<br>No filter<br>Unprotected seepage exit with high gradient | FS < 1.0*<br>Slopes steeper than 1.5H:1V<br>High Pore Pressures<br>Very weak foundation |
| Observed deformation and cracking, steep or stepped abutments<br>Significant seepage or wet areas<br>Trees on slope or toe | Loose soils present in fdn or embankment<br>Soils liquefy or FS<1.0* under Operating Basis Earthquake (OBE) | TFF < $10^{-2}$ | | FS < 1.1*<br>Slopes steeper than 2H:1V<br>High phreatic surface<br>Poor foundation |
| Infrequent Inspection (none in last 10 years)<br>Limited Cracking<br>Small Trees<br>Minor Animal Burrows | | TFF < 10-3 | Compacted clay core | FS < 1.2*<br>Slopes steeper than |
| | Marginal soils FS>1.0* under OBE FS<1.0* for Maximum | TFF < $10^{-4}$ | No observed piping<br>Uncertain Filter Compatibility | FS < 1.3<br>Slopes steeper than 3H:1V |
| Embankment condition satisfactory confirmed by regular inspection<br>**(Note: with embankment concrete corewall or cutoff wall reduce by one order of magnitude)** | Dense foundation or compacted embankment soils<br>FS>1.1 under MDE | TFF < $10^{-5}$ | No known cracks<br>Modern, fully penetrating filter<br>Full Foundation Cutoff<br>Modern Foundation Treatment | FS > 1.3<br>Regular monitoring<br>Slopes flatter than 3H:1V<br>Good foundation |
| | FS>1.3 under MDE | TFF > PMPDF or Probable Maximum Flood | Wide filter and blanket drain<br>Extensive monitoring | FS > 1.5<br>Regular monitoring |
| Failure Mode F | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-04 |
| Life Loss Potential | 114 | 114 | 114 | 114 |
| Failure Mode F with Stor | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-04 |

Notes: (* or unknown)
1. TFF - threshold failure flood flood which overtops sufficent to cause breach
2. Skip earthquake failure mode if in low seismicity area where Maximum Design Earthquake (MDE) pg

Input Required
Ignore if not applicable

Figure 5-4 shows Kayacık Dam Costa Method Risk Plot. In this figure piping failure mode is in Priority A which means urgent action recommended for this failure mode.

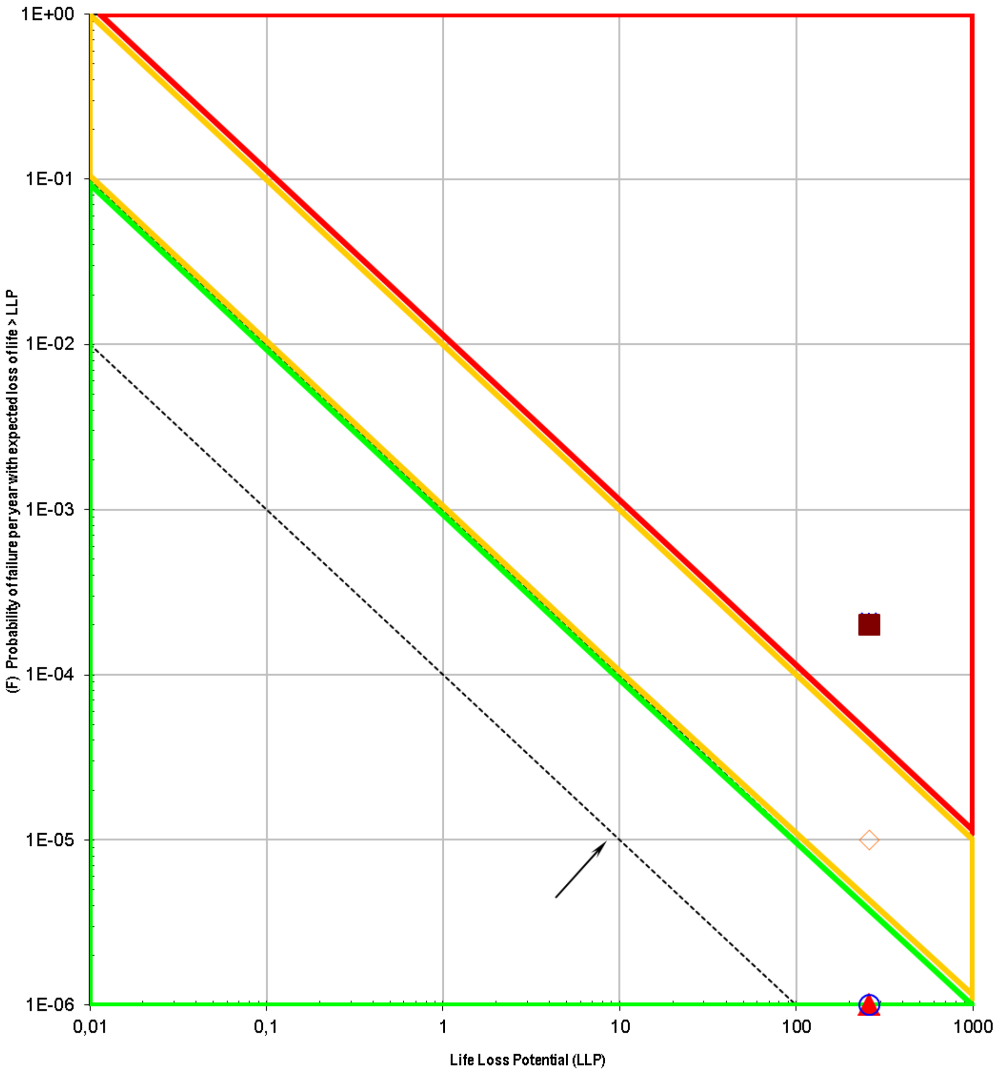



Figure 5-4 Kayacık Dam Costa Method Risk Plot

## 5.3 Karaova Dam

Karaova Dam is located in Kırşehir, Turkey. The dam was constructed between 1991 and 1998. Coordinates of dam are 39˚ 32' - 39˚ 52' 30" latitude and 33˚ 51' 30" - 34˚ 01' 30" longitude. Dam is located in Deliceırmak basin. Project area is rugged. There aren't any big plains in area. Main water resource is Kılıçözü creek. According to flow value Mahanözü stream is biggest river in basin. 29 earthquakes bigger than 4,3 magnitude are recorded between 1900-1970. Project area is in second earthquake zone. Winters are cold and rainy, summers are hot and dry. Average precipitation is 439,7 mm and average temperature is 10,4 ˚C. Temperature differences between day-night and winter-summer are very high. Population growth in the field of project is not available. Agriculture is main economic activity in area. There isn't any industrial facility in project area. Important markets for trade are Keskin, Kırıkkale and Kaman. There are no touristic places in area. Transportation and communication facilities are very good in project area. Dam is 55 km away from Kırşehir and 132 km from Ankara.

Karaova is an earth-fill dam. Height of dam is 53 m. Total volume of reservoir is $64897x10^6$ $m^3$. Normal reservoir area is $3465x10^6$ $m^2$. Maximum spillway capacity is 723 $m^3/s$. Main purpose of dam is irrigation.

### 5.3.1 Implementation of Dam Characteristics into Modified Risk Tool

Main dam characteristics of Karaova dam are given in Table 5-29. These values are used in risk analysis tool as data input values.

Table 5-29 Karaova Dam Data Input

| **Input Data (metric)** | |
|---|---|
| Dam Name | Karaova |
| Dame Code | |
| State: | |
| Region | |
| Hydaulic Height : (m) | 53 |
| Spillway Capacity : ($m^3/s$) | 660 |
| Max.Storage Volume($m^3$) | 64897000 |
| Max. Reservoir Area ($m^2$) | 3565000 |
| Probability of dam impounding water in any one year: | 100,00% |
| NID Hazard: | Low-significant-high |
| EAP Available: | Yes-no-unknown |
| Drainage Area ($m^2$): | 479100000 |
| Owner | DSİ |
| Basin Slope | 0,1 |
| Mean Basin Elevation : (m) | 825 |
| Mean Annual Precipitation : (mm) | 362,9 |
| Main Stream Length : (m) | 71000 |
| Q10 ($m^3/s$) | 723 |

Table 5-30 Karaova Dam Breach Variables

| **Variable** | **Definition** |
|---|---|
| d | Water passing over dam |
| H | Height from breach base to top of embakment |
| Hw | Height of water in reservoir before breach.Measured from breach base |
| H | Height of dam |
| S | Total water volume during dam failure |
| V | Water volume over dam crest during dam failure |
| B | Average width between breach base and top of embakment.Breach width |

Karaova Dam breach variables are calculated in risk analysis tool and results are given in Table 5-31.

Table 5-31 Karaova Dam Breach Variables Calculations

| **Variable** | **Min Value** | **Max Value** | **Value** | |
|---|---|---|---|---|
| d (m) | 0,3 | 1,5 | 1,5 | m |
| h (m) | 53 | | 53 | m |
| Hw (m) | 53,3 | 54,5 | 54,5 | m |
| H (m) | 53 | | 53 | m |
| S ($m^3$) | 65040730 | 65615650 | 65615650 | $m^3$ |
| V (m3) | 143730 | 718650 | 718650 | $m^3$ |
| B (m) | 106,00 | 265,00 | 265 | m |

Breach variables are calculated as maximum and minimum values. Table 5-33 shows Choosen values for Karaova Dam breach variables.

Table 5-32 Karaova Dam Breach Variables Choosen Value

| **Variable** | **Choosen Value** | |
|---|---|---|
| d (m) | 1,5 | m |
| h (m) | 53 | m |
| Hw (m) | 54,5 | m |
| H (m) | 53 | m |
| S ($m^3$) | 65615650 | $m^3$ |
| V (m3) | 718650 | $m^3$ |
| B max(m) | 260 | m |
| B min(m) | 106 | m |

Empirical methods are used for Dam Breach Width calculations. Results are given in Table 5-33.

Table 5-33 Karaova Dam Breach Width

| **Dam Breach Formulation** | | |
|---|---|---|
| Johnson and Illes Formula | | |
| 0,5h<B<3h | $B_{min}$ (m) | 26,50 |
| | $B_{max}$ (m) | 159,00 |
| Singh and Snorrason Formula | | |
| 2h<B<5h | $B_{min}$ (m) | 106,00 |
| | $B_{max}$ (m) | 265,00 |
| Federal Energy Regulatory Commission Formula | | |
| 2h<B<4h | $B_{min}$ (m) | 106,00 |
| | $B_{max}$ (m) | 212,00 |
| US Bureau of Reclamation Formula | | |
| B=3Hw | B (m) | 163,50 |

Peak breach discharges are given in Table 5-34 for Karaova Dam. Costa Method and Macdonald and Langridge-Monopolis Method given close values while Soil Conservation service method given biggest value.

Table 5-34 Karaova Dam Peak Breach Discharge

| **Peak Breach Discharge Formulation** | **Peak Breach Discharge Value** |
| --- | --- |
| Soil Conservation Service Method | |
| Hw>30m Q=16,6*(Hw)1,85 | 25705,05 ($m^3/s$) |
| Hw<30m Q=4,2*10-4*[S*Hw/(BxH)]1,35 | |
| Macdonald and Langridge-Monopolis Method | |
| Q=1,175*(S*Hw)0,41 | 9703,61 ($m^3/s$) |
| Costa Method | |
| Q=0,763*(S*Hw)0,42 | 7851,53 ($m^3/s$) |
| Froelich Equation | |
| Q=0,607*(S)0,295*(Hw)1,24 | 17471,80 ($m^3/s$) |

Estimation of failure time is important for public safety. People who live near dam area or in downstream of the dam are called population at risk so the early warning is an important subject. Table 5-35 shows Karaova Dam failure time estimation.

Table 5-35 Karaova Dam Failure Time

| **Failure Time Formulas** | **Failure Time (hour)** | | **Failure Time (minute)** | |
|---|---|---|---|---|
| Singh and Snorrason Formula | | | | |
| 0,25 hour < T < 1 hour | $T_{min}$ | 0,25 | $T_{min}$ | 15 |
| | $T_{max}$ | 1 | $T_{max}$ | 60 |
| Federal Energy Regulatory Commission Formula | | | | |
| 0,1 hour < T < 0,5 hour | $T_{min}$ | 0,1 | $T_{min}$ | 6 |
| | $T_{max}$ | 0,5 | $T_{max}$ | 30 |
| Froelich Equation | | | | |
| T=2,54*10-3*(S)0,53*(Hw)-0,59 | T | 3,33 | $T_{min}$ | 200,3 |
| US Bureau of Reclamation Formula | | | | |
| T=0,011*B | T | 1,166 | T | 69,96 |
| Von Thun and Gillette Method | | | | |
| T=0,02*Hw+0,25 | $T_{cr}$ | 1,34 | $T_{cr}$ | 80,4 |
| T=0,015*Hw | $T_{ec}$ | 0,82 | $T_{ec}$ | 49,05 |

Dam slide slope is used for normal stability calculations. Slide slope values are given in Table 5-36 for Karaova Dam.

Table 5-36 Karaova Dam Slide Slope

| Federal Energy Regulatory Commission Formula | |
|---|---|
| $Z_{min}$ | 1 |
| $Z_{max}$ | 2 |
| Froelich Method | |
| $Z$ | 1,4 |
| Singh and Snorrason Method | |
| $Z_{min}$ | 0,09 |
| $Z_{max}$ | 1,12 |
| Von Thun and Gillette Method | |
| $Z$ | 1 |

Karaova Dam risk assessment was made by using Froelich Method. For this method hydraulic height, spillway capacity, max storage volume, max reservoir area, dam breach discharge values are used. Table 5-37 shows Life Loss Potential Calculations NID Data for Karaova Dam.

Table 5-37 Karaova Dam Froelich Method LLP Calculations NID Data

| **NID Data** | |
|---|---|
| Dam Name: | Karaova |
| Federal Dam ID: | |
| State: | |
| Hydraulic Height (feet): | 173,8845 |
| NID Spillway Capacity (cfs): | 23.307,6797 |
| Max. Storage Volume (ac-ft): | 52.612,8416 |
| Max. Reservoir Area (acres): | 880,9307 |
| Probability of having dam fill in any one year: | 1,0000 |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area (sq.mi.): | 184,9815 |
| Peak Breach Discharge : | 25.532,5037 |

Population at risk means people who can be effected from rapid release of water caused by dam failure. Number of people who live near Karaova Dam are calculated from census data and maps of area. Table 5-38 shows population at risk calculations. Froelich Method life loss potential calculations for flood conditions are given in Table 5-39. As seen in table estimated flood life loss was found 144,45 people.Table 5-40 shows Karaova Dam Froelich Method life loss calculations for sunny day conditions.

Table 5-38 Karaova Dam Froelich Method Life Loss Potential Calculations Population at Risk (PAR) Data

| | | Reach | Infrastructure | Flood PAR | Sunny Day PAR |
|---|---|---|---|---|---|
| **Other Data** | | 0 to 3 miles | Houses (x 3) | 117 | 117 |
| Basin Slope (feet/mile): | 0,1000 | | Commercial / Schools | | |
| Mean Basin Elevation (feet): | 2.706,6929 | | Roads / Bridges (cars x 2) | | |
| Mean Annual Precipitation (inches): | 14,2874 | | Recreation | | |
| Main Stream Length (miles): | 44,1174 | 3 to 7 miles | | 457 | 457 |
| | | | | | |
| | | | | | |
| | | 7 to 15 miles | | 525 | 525 |

Table 5-39 Karaova Dam Froelich Method Life Loss Potential Calculation for Flood Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 617.010,6397 | | | | | |
| 10-year Discharge (cfs) | 25.532,5037 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 25.532,5037 | 617.010,6397 | 117,0000 | 24,1657 | 0,2 | 23,4000 |
| 3.0 to 7.0 | 25.532,5037 | 617.010,6397 | 457,0000 | 24,1657 | 0,15 | 68,5500 |
| 7.0 to 15.0 | 25.532,5037 | 617.010,6397 | 525,0000 | 24,1657 | 0,1 | 52,5000 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.099,0000** | **-** | **-** | **144,4500** |

Table 5-40 Karaova Dam Froelich Method Life Loss Potential Calculation for Sunny Day Conditions

| **Approximate Analysis Results** | **Sunny Day** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 594.004,8157 | | | | | |
| 10-year Discharge (cfs) | 25.532,5037 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam sunny day failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Sunny Day Life Loss Potential |
| 0.0 to 3.0 | 25.532,5037 | 594.004,8157 | 117,0000 | 23,2647 | 0,2 | 23,4000 |
| 3.0 to 7.0 | 25.532,5037 | 594.004,8157 | 457,0000 | 23,2647 | 0,15 | 68,5500 |
| 7.0 to 15.0 | 25.532,5037 | 594.004,8157 | 525,0000 | 23,2647 | 0,1 | 52,5000 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.099,0000** | **-** | **-** | **144,4500** |

Karaova Dam main failure modes used for risk assessment are earthquake, flood, piping and normal stability. As calculated in population at risk tables life loss potentials are taken 144 people for all conditions. Table 5-41 shows Karaova Dam Froelich Method Failure Modes

Table 5-41 Karaova Dam Froelich Method Failure Modes

| OBSERVATIONS | FAILURE MODES | | | |
|---|---|---|---|---|
| | **Earthquake** [2]<br>▲ | **Flood**[1]<br>○ | **Piping**<br>■ | **Normal Stability**<br>◇ |
| Significant deformation and transverse cracking<br>Concentrated seepage with turbidity<br>Large slumps<br>Large Trees | Not designed for EQ loading in high hazard area<br>Soils liquefy FS<1.0* in EQ AEP $10^{-1}$ | TFF < $10^{-1}$ | Observed piping of embankment or foundation<br>Erodable / poorly compacted / dry and brittle soils* and Incompatible or Internally unstable soils<br>No filter<br>Unprotected seepage exit with high gradient | FS < 1.0*<br>Slopes steeper than 1.5H:1V<br>High Pore Pressures<br>Very weak foundation |
| Observed deformation and cracking,<br>steep or stepped abutments<br>Significant seepage or wet areas<br>Trees on slope or toe | Loose soils present in fdn or embankment<br>Soils liquefy or FS<1.0* under Operating Basis Earthquake | TFF < $10^{-2}$ | | FS < 1.1*<br>Slopes steeper than 2H:1V<br>High phreatic surface<br>Poor foundation |
| Infrequent Inspection (none in last 10 years)<br>Limited Cracking<br>Small Trees<br>Minor Animal Burrows | Marginal soils<br>FS>1.0* under OBE FS<1.0* for Maximum | TFF < 10-3<br>TFF < $10^{-4}$ | Compacted clay core<br>No observed piping<br>Uncertain Filter Compatibility | FS < 1.2*<br>Slopes steeper than<br>FS < 1.3<br>Slopes steeper than 3H:1V |
| Embankment condition satisfactory confirmed by regular inspection<br>**(Note: with embankment concrete corewall or cutoff wall reduce by one order of magnitude)** | Dense foundation or compacted embankment soils<br>FS>1.1 under MDE | TFF < $10^{-5}$ | No known cracks<br>Modern, fully penetrating filter<br>Full Foundation Cutoff<br>Modern Foundation Treatment | FS > 1.3<br>Regular monitoring<br>Slopes flatter than 3H:1V<br>Good foundation |
| | FS>1.3 under MDE | TFF > PMPDF or Probable Maximum Flood | Wide filter and blanket drain<br>Extensive monitoring | FS > 1.5<br>Regular monitoring |
| Failure Mode F | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |
| Life Loss Potential | 144 | 144 | 144 | 144 |
| Failure Mode F with Storage | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |

Notes: (* or unknown)

1. TFF - threshold failure flood flood which overtops sufficent to cause breach
2. Skip earthquake failure mode if in low seismicity area where Maximum Design Earthquake (MDE) pga < 0.1

Input Required
Ignore if not applicable

Figure 5-5 Karaova Dam Froelich Method Risk Plot is given in Figure 5-5. Horizontal axis shows life loss potential (LLP) and vertical axis shows probability of failure per year with expected loss of life.

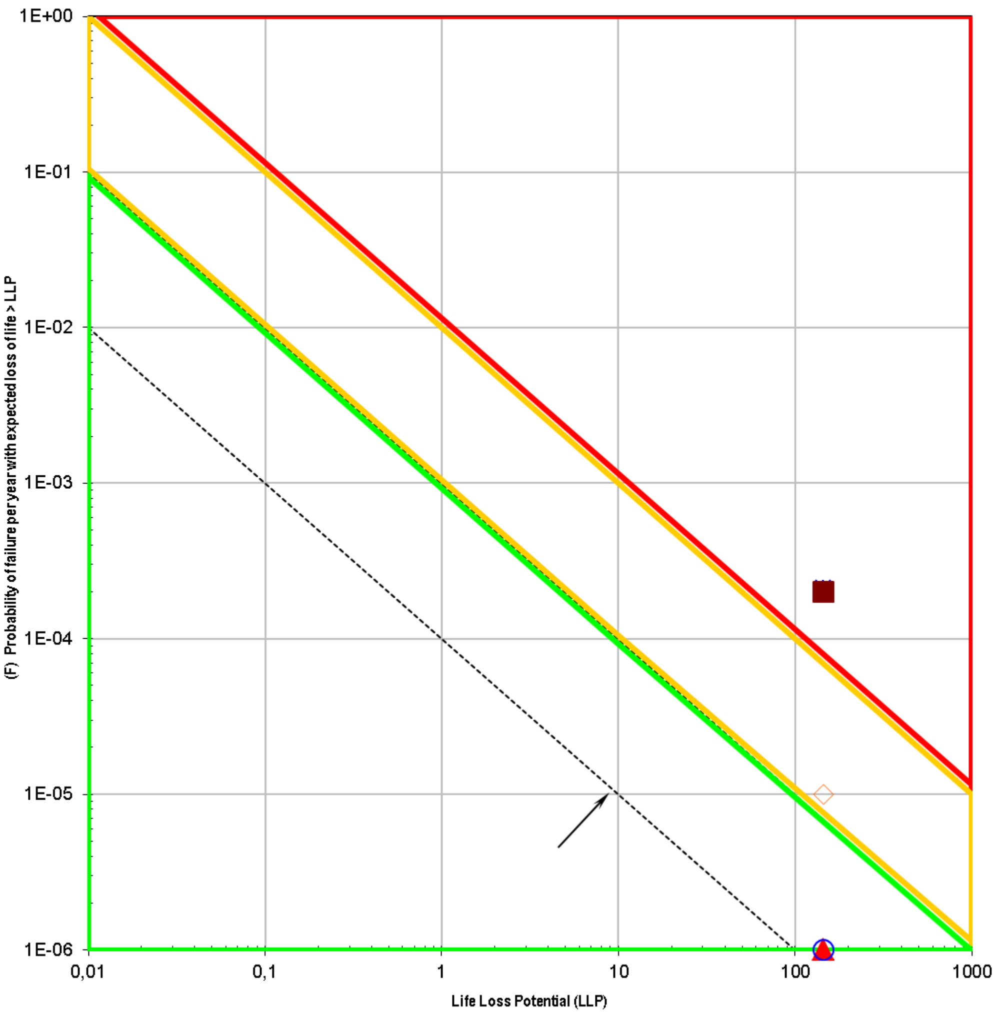



Figure 5-5 Karaova Dam Froelich Method Risk Plot

Second method was used for risk analysis of Karaova Dam is Soil Conservation Service Method. Table 5-42 shows initial data input of Karaova Dam for Soil Conservation Service Method.

Table 5-42 Karaova Dam Soil Conservation Service Method Life Loss Potential Calculations NID Data

| **NID Data** | |
|---|---|
| Dam Name: | Karaova |
| Federal Dam ID: | |
| State: | |
| Hydraulic Height (feet): | 173,9 |
| NID Spillway Capacity (cfs): | 23.308 |
| Max. Storage Volume (ac-ft): | 52.613 |
| Max. Reservoir Area (acres): | 881 |
| Probability of having dam fill in any one year: | 1 |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area (sq.mi.): | 184,98 |
| Peak Breach Discharge: | 25.532,50 |

Population at risk values are taken as same as Froelich Method. People who live near dam or in downstream of valley are calculated. Table 5-43 shows Population at risk data for Karaova Dam.

Table 5-43 Karaova Dam Soil Conservation Service Method Life Loss Potential Calculations Population at Risk (PAR) Data

| | | Reach | Infrastructure | Flood PAR | Sunny Day PAR |
|---|---|---|---|---|---|
| **Other Data** | | 0 to 3 miles | Houses (x 3) | 117 | 117 |
| Basin Slope (feet/mile): | 0 | | Commercial / Schools | | |
| Mean Basin Elevation (feet): | 2.707 | | Roads / Bridges (cars x 2) | | |
| Mean Annual Precipitation (inches): | 14 | | Recreation | | |
| Main Stream Length (miles): | 44,1174 | 3 to 7 miles | | 457 | 457 |
| | | | | | |
| | | | | | |
| | | 7 to 15 miles | | 525 | 525 |
| | | | | | |

Karaova Dam Soil Conservation Service Method Life Loss Potential Calculations for flood conditions are given in Table 5-44. Last column of table shows estimated flood life loss potential.

Table 5-44 Karaova Dam Soil Conservation Service Method Life Loss Potential Calculations for Flood Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 907.765 | | | | | |
| 10-year Discharge (cfs) | 25532,50367 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 25.533 | 907.765 | 117 | 35,6 | 0,25 | 29 |
| 3.0 to 7.0 | 25.533 | 907.765 | 457 | 35,6 | 0,2 | 91 |
| 7.0 to 15.0 | 25.533 | 907.765 | 525 | 35,6 | 0,13 | 68 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.099** | **-** | **-** | **189** |

Table 5-45 shows Karaova Dam Soil Conservation Service Method Life Loss Potential Calculations for Sunny Day Conditions. For sunny day conditions peak breach discharge was taken 594.005 cfs. Than ratio of peak discharge from dam breach to 10 year flood peak discharge values are change and as a result of this estimated sunny day life loss potential was calculated as 144 people.

Table 5-45 Karaova Dam Soil Conservation Service Method Life Loss Potential Calculations for Sunny Day Conditions

| **Approximate Analysis Results** | **Sunny Day** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 594.005 | | | | | |
| 10-year Discharge (cfs) | 25532,50367 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam sunny day failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Sunny Day Life Loss Potential |
| 0.0 to 3.0 | 25.533 | 594.005 | 117 | 23,3 | 0,2 | 23 |
| 3.0 to 7.0 | 25.533 | 594.005 | 457 | 23,3 | 0,15 | 69 |
| 7.0 to 15.0 | 25.533 | 594.005 | 525 | 23,3 | 0,1 | 53 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.099** | **-** | **-** | **144** |

Risk values for earthquake and flood are taken 1E-06, piping risk value was taken 2E-04 and normal stability failure mode risk value was taken 1E-05. Table 5-46 shows Karaova Dam Soil Conservation Service Method Failure Modes.

Table 5-46 Karaova Dam Soil Conservation Service Method Failure Modes

| **OBSERVATIONS** | **FAILURE MODES** | | | |
|---|---|---|---|---|
| | **Earthquake** [2] ▲ | **Flood**[1] ○ | **Piping** ■ | **Normal Stability** ◇ |
| Significant deformation and transverse cracking<br>Concentrated seepage with turbidity<br>Large slumps<br>Large Trees | Not designed for EQ loading in high hazard area<br>Soils liquefy FS<1.0* in EQ AEP $10^{-1}$ | TFF < $10^{-1}$ | Observed piping of embankment or foundation<br>Erodable / poorly compacted / dry and brittle soils* and Incompatible or Internally unstable soils<br>No filter<br>Unprotected seepage exit with high gradient | FS < 1.0*<br>Slopes steeper than 1.5H:1V<br>High Pore Pressures<br>Very weak foundation |
| Observed deformation and cracking, steep or stepped abutments<br>Significant seepage or wet areas<br>Trees on slope or toe | Loose soils present in fdn or embankment<br>Soils liquefy or FS<1.0* under Operating Basis Earthquake (OBE) | TFF < $10^{-2}$ | | FS < 1.1*<br>Slopes steeper than 2H:1V<br>High phreatic surface<br>Poor foundation |
| Infrequent Inspection (none in last 10 years)<br>Limited Cracking<br>Small Trees<br>Minor Animal Burrows | Marginal soils FS>1.0* under OBE FS<1.0* for Maximum | TFF < 10-3 | Compacted clay core | FS < 1.2*<br>Slopes steeper than |
| | | TFF < $10^{-4}$ | No observed piping<br>Uncertain Filter Compatibility | FS < 1.3<br>Slopes steeper than 3H:1V |
| Embankment condition satisfactory confirmed by regular inspection<br>**(Note: with embankment concrete corewall or cutoff wall reduce by one order of magnitude)** | Dense foundation or compacted embankment soils | TFF < $10^{-5}$ | No known cracks<br>Modern, fully penetrating filter<br>Full Foundation Cutoff | FS > 1.3<br>Regular monitoring<br>Slopes flatter than 3H:1V<br>Good foundation |
| | FS>1.3 under MDE | TFF > PMPDF or Probable Maximum Flood | Wide filter and blanket drain<br>Extensive monitoring | FS > 1.5<br>Regular monitoring |
| Failure Mode F | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |
| Life Loss Potential | 189 | 189 | 189 | 189 |
| Failure Mode F with Stora | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |

Notes: (* or unknown)
1. TFF - threshold failure flood flood which overtops sufficent to cause breach
2. Skip earthquake failure mode if in low seismicity area where Maximum Design Earthquake (MDE) pga <

Input Required
Ignore if not applicable

Risk plot for Soil Conservation Service Method is given in Figure 5-6. Piping failure mode is in urgent action needed zone, earthquake and flood failure modes are in safe zone. Normal stability risk value is in Priority B.

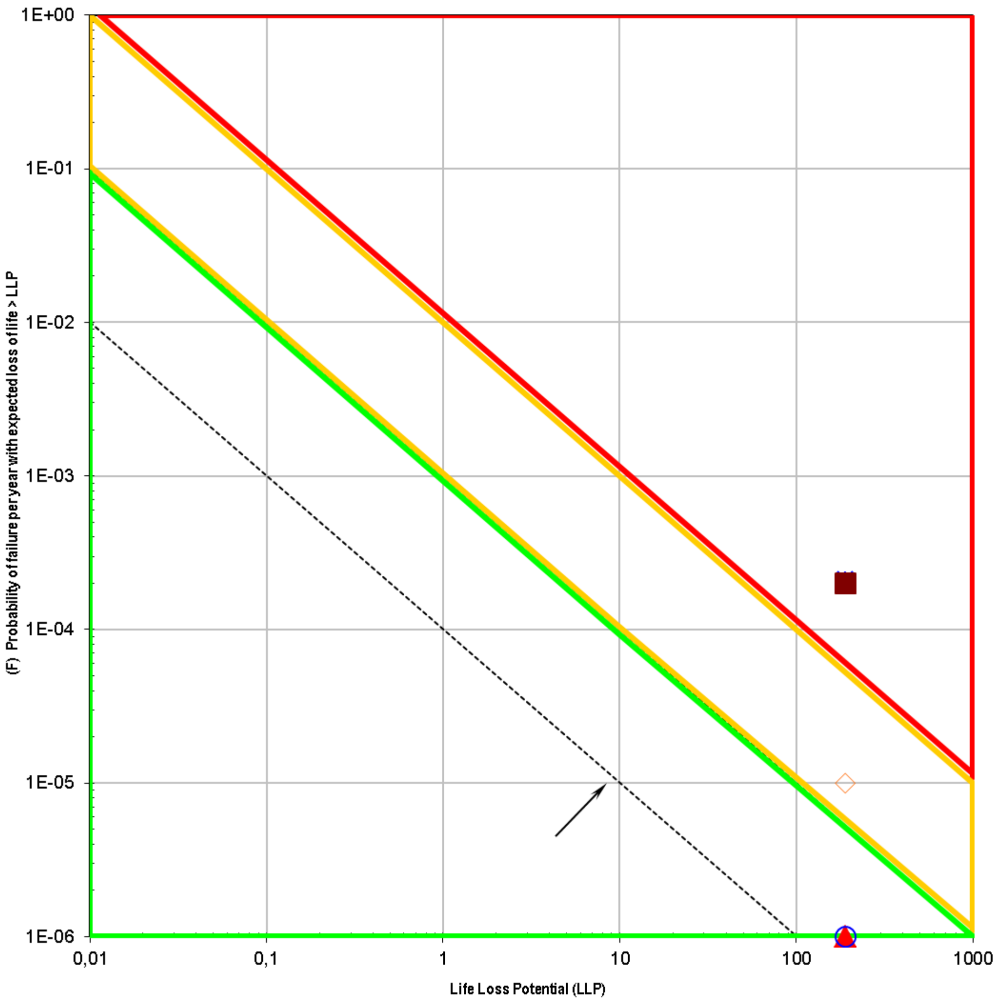



Figure 5-6 Karaova Dam Soil Conservation Service Method Risk Plot

Third method used for risk assessment of Karaova Dam is Macdonald and Langridge-Monopolis Method. Initial data input for this method is given in Table 5-47.

Table 5-47 Karaova Dam Macdonald and Langridge-Monopolis Method Life Loss Potential Calculations NID Data

| **NID Data** | |
|---|---|
| Dam Name: | Karaova |
| Federal Dam ID: | |
| State: | |
| Hydraulic Height (feet): | 173,8845 |
| NID Spillway Capacity (cfs): | 23.307,6797 |
| Max. Storage Volume (ac-ft): | 52.612,8416 |
| Max. Reservoir Area (acres): | 880,9307 |
| Probability of having dam fill in any one year: | 1,0000 |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area (sq.mi.): | 184,9815 |
| Peak Breach Discharge : | 342.679,8647 |

Number of people who live in 0-3 miles away from dam was calculated 117, in 3-7 miles 457, in 7-15 miles was calculated 525. Table 5-48 shows Population at Risk Data for Karaova Dam.

Table 5-48 Karaova Dam Macdonald and Langridge-Monopolis Method Life Loss Potential Calculations Population at Risk (PAR) Data

| | | Reach | Infrastructure | Flood PAR | Sunny Day PAR |
|---|---|---|---|---|---|
| **Other Data** | | 0 to 3 miles | Houses (x 3) | 117 | 117,0000 |
| Basin Slope (feet/mile): | 0,1000 | | Commercial / Schools | | |
| Mean Basin Elevation (feet): | 2.706,6929 | | Roads / Bridges (cars x 2) | | |
| Mean Annual Precipitation (inches): | 14,2874 | | Recreation | | |
| Main Stream Length (miles): | 44,1174 | 3 to 7 miles | | 457 | 457,0000 |
| | | | | | |
| **Approximate Analysis Results** | **Flood** | | | | |
| Peak Breach Discharge (cfs) | 9.703,6133 | 7 to 15 miles | | 525 | 525,0000 |
| 10-year Discharge (cfs) | 25.532,5037 | | | | |

Estimated life loss potentials were calculated for flood and sunny day conditions. Table 5-49 shows flood conditions and Table 5-50 shows sunny day conditions of Karaova Dam.

Table 5-49 Karaova Dam Macdonald and Langridge-Monopolis Method Life Loss Potential Calculations for Flood Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 9.703,6133 | | | | | |
| 10-year Discharge (cfs) | 25.532,5037 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 25.532,5037 | 9.703,6133 | 117,0000 | 0,3800 | 0,0010 | 0,1170 |
| 3.0 to 7.0 | 25.532,5037 | 9.703,6133 | 457,0000 | 0,3800 | 0,0001 | 0,0457 |
| 7.0 to 15.0 | 25.532,5037 | 9.703,6133 | 525,0000 | 0,3800 | 0,0000 | 0,0000 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.099,0000** | **-** | **-** | **0,1627** |

Table 5-50 Karaova Dam Macdonald and Langridge-Monopolis Method Life Loss Potential Calculations for Sunny Day Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 9.703,6133 | | | | | |
| 10-year Discharge (cfs) | 25.532,5037 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 25.532,5037 | 9.703,6133 | 117,0000 | 0,3800 | 0,0010 | 0,1170 |
| 3.0 to 7.0 | 25.532,5037 | 9.703,6133 | 457,0000 | 0,3800 | 0,0001 | 0,0457 |
| 7.0 to 15.0 | 25.532,5037 | 9.703,6133 | 525,0000 | 0,3800 | 0,0000 | 0,0000 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.099,0000** | **-** | **-** | **0,1627** |

Life loss potentials were calculated as 0,1627 for sunny day and flood conditions. Failure modes observations were used for risk values and results are shown in Table 5-51.

Table 5-51 Karaova Dam Macdonald and Langridge-Monopolis Method Failure Modes

| OBSERVATIONS | FAILURE MODES | | | |
|---|---|---|---|---|
| | **Earthquake** [2] ▲ | **Flood**[1] ○ | **Piping** ■ | **Normal Stability** ◇ |
| Significant deformation and transverse cracking<br>Concentrated seepage with turbidity<br>Large slumps<br>Large Trees | Not designed for EQ loading in high hazard area<br>Soils liquefy FS<1.0* in EQ AEP $10^{-1}$ | TFF < $10^{-1}$ | Observed piping of embankment or foundation<br>Erodable / poorly compacted / dry and brittle soils* and Incompatible or Internally unstable soils<br>No filter<br>Unprotected seepage exit with high gradient | FS < 1.0*<br>Slopes steeper than 1.5H:1V<br>High Pore Pressures<br>Very weak foundation |
| Observed deformation and cracking, steep or stepped abutments<br>Significant seepage or wet areas<br>Trees on slope or toe | Loose soils present in fdn or embankment<br>Soils liquefy or FS<1.0* under Operating Basis Earthquake (OBE) | TFF < $10^{-2}$ | | FS < 1.1*<br>Slopes steeper than 2H:1V<br>High phreatic surface<br>Poor foundation |
| Infrequent Inspection (none in last 10 years)<br>Limited Cracking<br>Small Trees<br>Minor Animal Burrows<br>Clear, Consistent Seepage | Marginal soils<br>FS>1.0* under OBE FS<1.0* for Maximum Design Earthquake | TFF < 10-3 | Compacted clay core | FS < 1.2*<br>Slopes steeper than |
| | | TFF < $10^{-4}$ | No observed piping<br>Uncertain Filter Compatibility<br>Uncertain Foundation | FS < 1.3<br>Slopes steeper than 3H:1V |
| Embankment condition satisfactory confirmed by regular inspection<br>**(Note: with embankment concrete corewall or cutoff wall reduce by one order of magnitude)** | Dense foundation or compacted embankment soils<br>FS>1.1 under MDE | TFF < $10^{-5}$ | No known cracks<br>Modern, fully penetrating filter<br>Full Foundation Cutoff<br>Modern Foundation Treatment | FS > 1.3<br>Regular monitoring<br>Slopes flatter than 3H:1V<br>Good foundation |
| | FS>1.3 under MDE | TFF > PMPDF or Probable Maximum Flood | Wide filter and blanket drain<br>Extensive monitoring | FS > 1.5<br>Regular monitoring |
| Failure Mode F | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |
| Life Loss Potential | 0 | 0 | 0 | 0 |
| Failure Mode F with Stora | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |

Notes: (* or unknown)

1. TFF - threshold failure flood flood which overtops sufficent to cause breach

2. Skip earthquake failure mode if in low seismicity area where Maximum Design Earthquake (MDE) pga <

Input Required
Ignore if not applicable

Karaova Dam Macdonald and Langridge-Monopolis Method Risk Plot is given in Figure 5-7. Life loss values are calculated below 1 so as seen in figure all failure modes risk values are in safe zone.

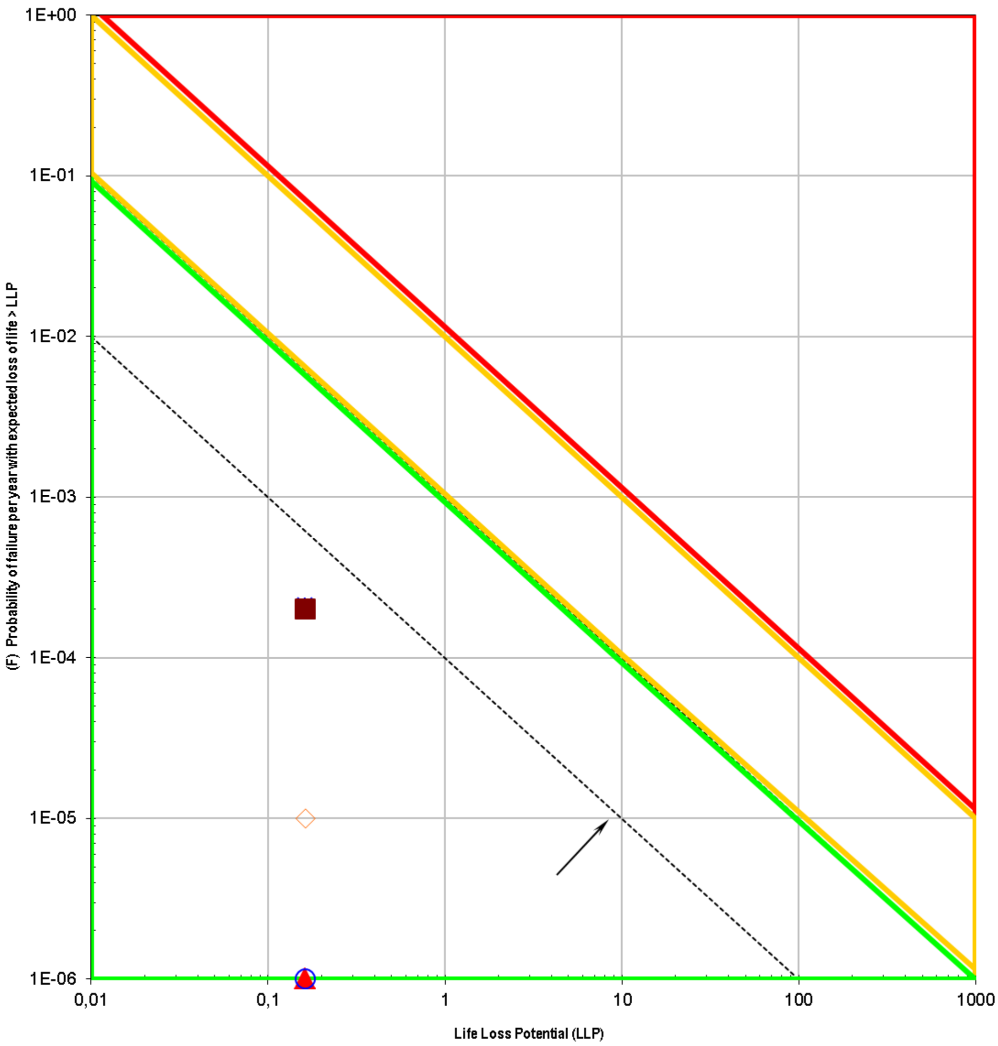



Figure 5-7 Karaova Dam Macdonald and Langridge-Monopolis Method Risk Plot

Last method used for risk analysis of Karaova Dam is Costa Method. Data input was given in Table 5-52.

Table 5-52 Karaova Dam Costa Method Life Loss Potential Calculations NID Data

| **NID Data** | |
|---|---|
| Dam Name: | Karaova |
| Federal Dam ID: | |
| State: | |
| Hydraulic Height (feet): | 173,9 |
| NID Spillway Capacity (cfs): | 23.308 |
| Max. Storage Volume (ac-ft): | 52.613 |
| Max. Reservoir Area (acres): | 881 |
| Probability of having dam fill in any one year: | 1 |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area (sq.mi.): | 184,98 |
| Peak Breach Discharge | 277274,0957 |

Population at risk values are same as in other methods. First 3 miles 117, next 4 miles 457 and last 8 miles 525 people. Table 5-53 shows population at risk values. Consta Method calculations for flood conditions are given in Table 5-54 and for sunny day conditions are given in Table 5-55.

Table 5-53 Karaova Dam Costa Method Life Loss Potential Calculations Population at Risk (PAR) Data

| | | Reach | Infrastructure | Flood PAR | Sunny Day PAR |
|---|---|---|---|---|---|
| **Other Data** | | 0 to 3 miles | Houses (x 3) | 117 | 117 |
| Basin Slope (feet/mile): | 0 | | Commercial / Schools | | |
| Mean Basin Elevation (feet): | 2.707 | | Roads / Bridges (cars x 2) | | |
| Mean Annual Precipitation (inches): | 14 | | Recreation | | |
| Main Stream Length (miles): | 44 | 3 to 7 miles | | 457 | 457 |
| | | | | | |
| | | | | | |
| | | 7 to 15 miles | | 525 | 525 |

Table 5-54 Karaova Dam Costa Method Life Loss Potential Calculations for Flood Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 277.274 | | | | | |
| 10-year Discharge (cfs) | 25532,50367 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 25.533 | 277.274 | 117 | 10,9 | 0,1 | 12 |
| 3.0 to 7.0 | 25.533 | 277.274 | 457 | 10,9 | 0,08 | 37 |
| 7.0 to 15.0 | 25.533 | 277.274 | 525 | 10,9 | 0,05 | 26 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.099** | **-** | **-** | **75** |

Table 5-55 Karaova Dam Costa Method Life Loss Potential Calculations for Sunny Day Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 277.274 | | | | | |
| 10-year Discharge (cfs) | 25532,50367 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 25.533 | 277.274 | 117 | 10,9 | 0,1 | 12 |
| 3.0 to 7.0 | 25.533 | 277.274 | 457 | 10,9 | 0,08 | 37 |
| 7.0 to 15.0 | 25.533 | 277.274 | 525 | 10,9 | 0,05 | 26 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.099** | **-** | **-** | **75** |

For Costa Method life loss values are 75 people. Failure modes observations and life loss values are given in Table 5-56.

Table 5-56 Karaova Dam Costa Method Failure Modes

| **OBSERVATIONS** | **FAILURE MODES**<br>**Earthquake** [2]<br>▲ | <br>**Flood**[1]<br>○ | <br>**Piping**<br>■ | <br>**Normal Stability**<br>◇ |
|---|---|---|---|---|
| Significant deformation and<br>transverse cracking<br>Concentrated seepage with turbidity<br>Large slumps<br>Large Trees | Not designed for EQ loading in high hazard area<br>Soils liquefy FS<1.0* in EQ AEP $10^{-1}$ | TFF < $10^{-1}$ | Observed piping of embankment or foundation<br>Erodable / poorly compacted / dry and brittle soils* and<br>Incompatible or Internally unstable soils<br>No filter<br>Unprotected seepage exit with high gradient | FS < 1.0*<br>Slopes steeper than 1.5H:1V<br>High Pore Pressures<br>Very weak foundation |
| Observed deformation and cracking,<br>steep or stepped abutments<br>Significant seepage or wet areas<br>Trees on slope or toe | Loose soils present in fdn or embankment<br>Soils liquefy or FS<1.0* under Operating Basis Earthquake (OBE) | TFF < $10^{-2}$ | | FS < 1.1*<br>Slopes steeper than 2H:1V<br>High phreatic surface<br>Poor foundation |
| Infrequent Inspection (none in last 10 years)<br>Limited Cracking<br>Small Trees<br>Minor Animal Burrows | Marginal soils FS>1.0* under OBE FS<1.0* for Maximum | TFF < 10-3<br>TFF < $10^{-4}$ | Compacted clay core<br>No observed piping<br>Uncertain Filter Compatibility | FS < 1.2*<br>Slopes steeper than<br>FS < 1.3<br>Slopes steeper than 3H:1V |
| Embankment condition satisfactory confirmed by regular inspection<br>**(Note: with embankment concrete corewall or cutoff wall reduce by one order of magnitude)** | Dense foundation or compacted embankment soils<br>FS>1.1 under MDE | TFF < $10^{-5}$ | No known cracks<br>Modern, fully penetrating filter<br>Full Foundation Cutoff<br>Modern Foundation Treatment | FS > 1.3<br>Regular monitoring<br>Slopes flatter than 3H:1V<br>Good foundation |
| | FS>1.3 under MDE | TFF > PMPDF or Probable Maximum Flood | Wide filter and blanket drain<br>Extensive monitoring | FS > 1.5<br>Regular monitoring |
| Failure Mode F | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |
| Life Loss Potential | 75 | 75 | 75 | 75 |
| Failure Mode F with Stora | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |

Notes: (* or unknown)

1. TFF - threshold failure flood flood which overtops sufficent to cause breach
2. Skip earthquake failure mode if in low seismicity area where Maximum Design Earthquake (MDE) pga <

Input Required
Ignore if not applicable

Piping failure mode risk values are in Priority A. Other failure modes are in safe zone. Risk plot for costa method is given in Figure 5-8.

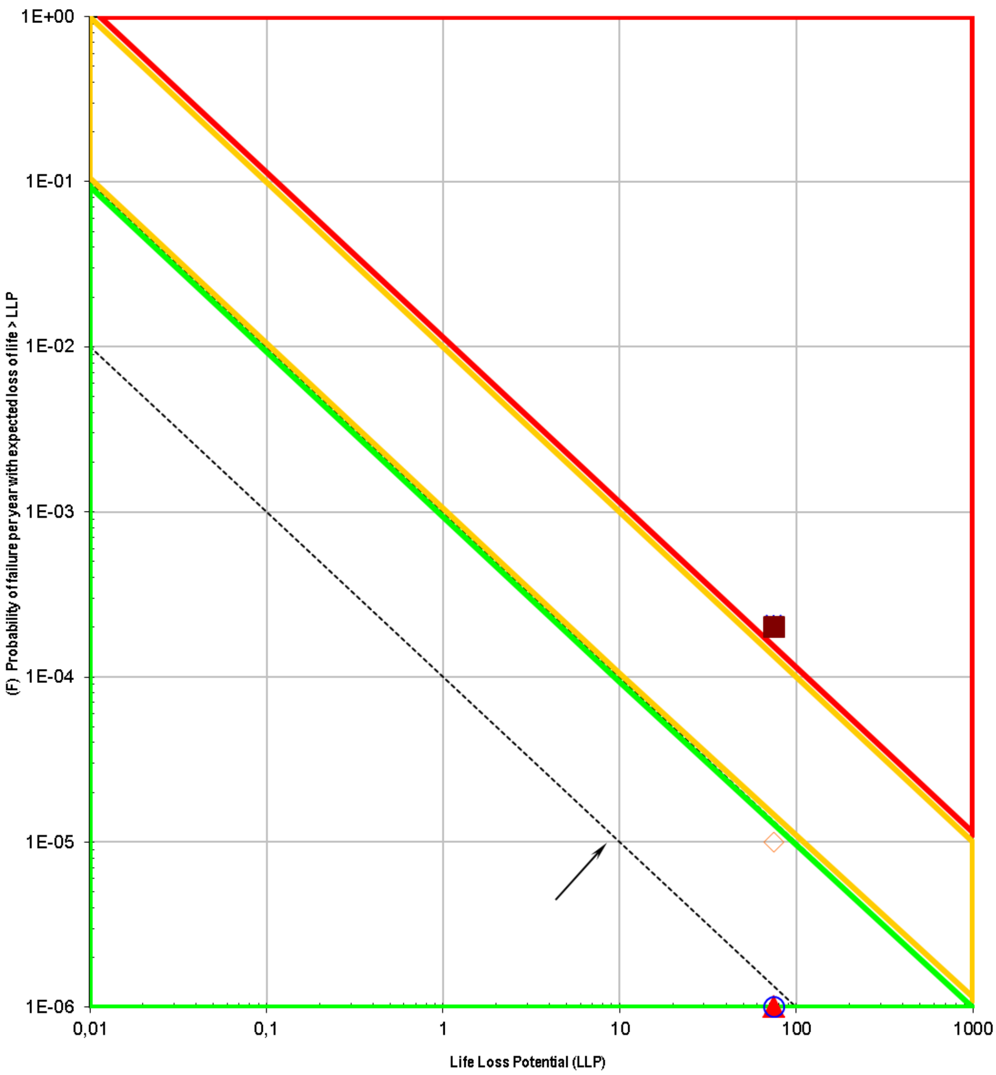



Figure 5-8 Karaova Dam Costa Method Risk Plot

## 5.4 Çoğun Dam

Çoğun Dam is located in Kırşehir, Turkey. The dam was constructed between 1963 and 1976. Coordinates of dam are 39˚ 00’ - 39˚ 30’ latitude and 33˚ 45’ - 34˚ 15’ longitude. Total area of the project is 1500 $km^2$. Project area is surrounded by mountains and hills. These are : In west of basin : Naldöken mountain (1516 m), Üçkuyu hill (1600 m), Bozçal hill(1645 m), Tümsoygun hill (1808 m), Keçikale hill (1783 m), Gökçer hill (1565 m), and Kırtis hill (1514 m). In north of basin : Çamlık hill (1526 m), Boztepe (1416 m), Buzluk hill (1706 m), Baldak hill (1460 m) and Ziyaret hill (1464 m). East of project area is surrounded with Seyfe plain (1100 m) and Kervansaray mountains (1670 m). Main water resource in basin is Kılıçözü creek. Source of this creek is near Sofular – Kurancılı villages. This streams path is connecting to Kızılırmak river in south of area. There are some small plains in project area. Sofular – Çoğun plateau and Kılıçözü valley are main agriculture areas. Kılıçözü valley is very narrow and long valley. Minimum width of valley is 300 m and maximum width is 2 km. Project area has general characteristics of Orta Anadolu weather conditions. Winters are cold and rainy, summers are hot and dry. Average annual precipitation in basin is 365.2 mm. About 20 days in a year are snowy. Maximum snow height is 60 cm and average temperature is 11,3 ˚C.

Project area is near Özbağ, Kızılcaköy, Kışlapınar, Çoğun, Çayağzı and Güzler villages. Main economic activity is agriculture in area. Vineyards, farms and orchards are general agricultural areas. Industrial facilities are flour mill, wine cellar, carpet looms and quarry. Most important trade center is Kırşehir. Mucur, Hacıbektaş and Kaman are second important markets. Ahievran Türbesi, Cacabey Mosque, Aşıkpaşa Türbesi, İlhani Kümbeti and Melikgazi Kümbeti are historical buildings in area. Terma and Karakurt hot springs are modern facilities for tourists.

Height of Çoğun Dam from river bed is 28 m. Body type of dam is rock-earth fill. Main purpose of dam are flood control and irrigation.

### 5.4.1 Implementation of Çoğun Dam Characteristics into Modified Risk Tool

Initial input data for Çoğun Dam is given in Table 5-57. This table shows main dam characteristics of dam.

Table 5-57 Çoğun Dam Data Input

| **Input Data (metric)** | |
|---|---|
| Dam Name | Çoğun |
| Dame Code | |
| State: | |
| Region | |
| Hydaulic Height : (m) | 28 |
| Spillway Capacity : ($m^3$/s) | 718 |
| Max.Storage Volume($m^3$) | 22000000 |
| Max. Reservoir Area ($m^2$) | 669160000 |
| Probability of dam impounding water in any one year: | 100,00% |
| NID Hazard: | Low-significant-high |
| EAP Available: | Yes-no-unknown |
| Drainage Area ($m^2$): | 238000000 |
| Owner | DSİ |
| **Other Input** | |
| Basin Slope | 0,02 |
| Mean Basin Elevation : (m) | 1312,34 |
| Mean Annual Precipitation : (mm) | 365,3 |
| Main Stream Length : (m) | 10000 |
| Q10 ($m^3$/s) | 1040 |

Table 5-58 Çoğun Dam Breach Variables

| **Variable** | **Definition** |
|---|---|
| d | Water passing over dam |
| H | Height from breach base to top of embakment |
| Hw | Height of water in reservoir before breach.( from breach base) |
| H | Height of dam |
| S | Total water volume during dam failure |
| V | Water volume over dam crest during dam failure |
| B | Average width between breach base and top of embakment.Breach width |

Breach variables for Çoğun Dam are given in Table 5-59. Maximum values of breach variables are taken for breach parameter calculations. Table 5-60 shows breach variables choosen values and these variables are used for dam breach width calculations. Table 5-61 shows Çoğun Dam breach width.

Table 5-59 Çoğun Dam breach variables calculations

| **Variable** | **Min Value** | **Max Value** | **Value** | |
|---|---|---|---|---|
| d (m) | 0,3 | 1,5 | 1,5 | m |
| h (m) | 28 | | 28 | m |
| Hw (m) | 28,3 | 29,5 | 29,5 | m |
| H (m) | 28 | | 28 | m |
| S ($m^3$) | 22071400 | 22357000 | 22357000 | $m^3$ |
| V (m3) | 71400 | 357000 | 357000 | $m^3$ |
| B (m) | 56,00 | 140,00 | 140 | m |

Table 5-60 Çoğun Dam Breach Variables Choosen value

| **Variable** | **Choosen Value** | |
|---|---|---|
| d (m) | 1,5 | m |
| h (m) | 28 | m |
| Hw (m) | 29,5 | m |
| H (m) | 28 | m |
| S ($m^3$) | 22357000 | $m^3$ |
| V (m3) | 357000 | $m^3$ |
| B max(m) | 140 | m |
| B min(m) | 56 | m |

Table 5-61 Çoğun Dam Breach Width

| **Dam Breach Formulation** | | |
|---|---|---|
| Johnson and Illes Formula | | |
| 0,5h<B<3h | $B_{min}$ (m) | 14 |
| | $B_{max}$ (m) | 84 |
| Singh and Snorrason Formula | | |
| 2h<B<5h | $B_{min}$ (m) | 56 |
| | $B_{max}$ (m) | 140 |
| Federal Energy Regulatory Commission Formula | | |
| 2h<B<4h | $B_{min}$ (m) | 56 |
| | $B_{max}$ (m) | 112 |
| US Bureau of Reclamation Formula | | |
| B=3Hw | B (m) | 91,50 |

Soil Conservation Service Method, Macdonald and Langridge-Monopolis Method, Costa Method and Froelich Equation peak breach dishcarges are given in Table 5-62.

Table 5-62 Çoğun Dam Peak Breach Discharge

| **Peak Breach Discharge Formulation** | **Peak Breach Discharge Value** |
|---|---|
| Soil Conservation Service Method | |
| Hw>30m Q=16,6*(Hw)1,85 | 7894,97 ($m^3$/s) |
| Hw<30m Q=4,2*10-4*[S*Hw/(BxH)]1,35 | |
| Macdonald and Langridge-Monopolis Method | |
| Q=1,175*(S*Hw)0,41 | 4940,22 ($m^3$/s) |
| Costa Method | |
| Q=0,763*(S*Hw)0,42 | 3932,02 ($m^3$/s) |
| Froelich Equation | |
| Q=0,607*(S)0,295*(Hw)1,24 | 6210,89 ($m^3$/s) |

Dam failure times are important during a dam failure. Early warning can save many people life. Çoğun Dam failure time calculations are given in Table 5-63.

Table 5-63 Çoğun Dam Failure Time

| **Failure Time Formulas** | **Failure Time (hour)** | | **Failure Time (minute)** | |
|---|---|---|---|---|
| Singh and Snorrason Formula | | | | |
| 0,25 hour < T < 1 hour | $T_{min}$ | 0,25 | $T_{min}$ | 15 |
| | $T_{max}$ | 1 | $T_{max}$ | 60 |
| Federal Energy Regulatory Commission Formula | | | | |
| 0,1 hour < T < 0,5 hour | $T_{min}$ | 0,1 | $T_{min}$ | 6 |
| | $T_{max}$ | 0,5 | $T_{max}$ | 30 |
| Froelich Equation | | | | |
| T=2,54*10-3*(S)0,53*(Hw)-0,59 | T | 2,67 | $T_{min}$ | 160,3 |
| US Bureau of Reclamation Formula | | | | |
| T=0,011*B | T | 0,61 | T | 36,96 |
| Von Thun and Gillette Method | | | | |
| T=0,02*Hw+0,25 | $T_{cr}$ | 0,86 | $T_{cr}$ | 51,6 |
| T=0,015*Hw | $T_{ec}$ | 0,44 | $T_{ec}$ | 27,45 |

Slide slope values are calculated by using Federal Energy Regulatory Commission Formula, Froelich Method, Singh and Snorrason Method and Von Thun and Gillette Method. These values are given in Table 5-64 for Çoğun Dam.

Table 5-64 Çoğun Dam Slide Slope

| Federal Energy Regulatory Commission Formula | |
|---|---|
| $Z_{min}$ | 1 |
| $Z_{max}$ | 2 |
| Froelich Method | |
| Z | 1,4 |
| Singh and Snorrason Method | |
| $Z_{min}$ | 0,09 |
| $Z_{max}$ | 1,12 |
| Von Thun and Gillette Method | |
| Z | 1 |

First step of Froelich Method calculations is data input of Çoğun Dam. Main dam characteristics are implemented to software. Table 5-65 shows NID Data for Çoğun Dam.

Table 5-65 Çoğun Dam Froelich Method Life Loss Potential Calculations NID Data

| **NID Data** | |
|---|---|
| Dam Name: | Çoğun |
| Federal Dam ID: | |
| State: | |
| Hydraulic Height (feet): | 91,8635 |
| NID Spillway Capacity (cfs): | 25.355,9303 |
| Max. Storage Volume (ac-ft): | 17.835,6860 |
| Max. Reservoir Area (acres): | 165.353,0371 |
| Probability of having dam fill in any one year: | 1,0000 |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area (sq.mi.): | 91,8923 |
| Peak Breach Discharge : | 36.727,2529 |

Population at risk is important for measuring effect of dam failure. Life loss potential values are calculated with help of population at risk values. Table 5-66 shows population at risk calculations.

Table 5-66 Çoğun Dam Froelich Method Life Loss Potential Calculations Population at Risk (PAR) Data

| | | Reach | Infrastructure | Flood PAR | Sunny Day PAR |
|---|---|---|---|---|---|
| **Other Data** | | 0 to 3 miles | Houses (x 3) | 258 | 258,0000 |
| Basin Slope (feet/mile): | 0,0200 | | Commercial / Schools | | |
| Mean Basin Elevation (feet): | 4.305,5774 | | Roads / Bridges (cars x 2) | | |
| Mean Annual Precipitation (inches): | 14,3819 | | Recreation | | |
| Main Stream Length (miles): | 6,2137 | 3 to 7 miles | | 364 | 364,0000 |
| | | | | | |
| | | | | | |
| | | 7 to 15 miles | | 1.000 | 1.000,0000 |

Life loss potential caclulations were made first for flood conditions.Fatality rate changes between 0,02 and 0,01. Calculation of estimated flood life loss potential is given in Table 5-67.

Table 5-67 Çoğun Dam Froelich Method Life Loss Potential Calculations for Flood Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 209.797,3929 | | | | | |
| 10-year Discharge (cfs) | 36.727,2529 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 36.727,2529 | 219.335,6568 | 258,0000 | 5,9720 | 0,02 | 5,1600 |
| 3.0 to 7.0 | 36.727,2529 | 219.335,6568 | 364,0000 | 5,9720 | 0,015 | 5,4600 |
| 7.0 to 15.0 | 36.727,2529 | 219.335,6568 | 1.000,0000 | 5,9720 | 0,01 | 10,0000 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.622,0000** | **-** | **-** | **20,6200** |

As same as flood conditions estimated life loss potential and fatality rates are calculated for sunny day conditions. Table 5-68 shows life loss calculations for sunny day conditions.

Table 5-68 Çoğun Dam Froelich Method Life Loss Potential Calculations for Sunny Day Conditions

| **Approximate Analysis Results** | **Sunny Day** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 195.691,6405 | | | | | |
| 10-year Discharge (cfs) | 36.727,2529 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam sunny day failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Sunny Day Life Loss Potential |
| 0.0 to 3.0 | 36.727,2529 | 195.691,6405 | 258,0000 | 5,3282 | 0,02 | 5,1600 |
| 3.0 to 7.0 | 36.727,2529 | 195.691,6405 | 364,0000 | 5,3282 | 0,015 | 5,4600 |
| 7.0 to 15.0 | 36.727,2529 | 195.691,6405 | 1.000,0000 | 5,3282 | 0,01 | 10,0000 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.622,0000** | **-** | **-** | **20,6200** |

Earthquake and flood risk values are 1E-06, piping failure mode risk value is 2E-04 and normal stability is 1E-05. Table 5-69 shows failure modes for Froelich Method.

Table 5-69 Çoğun Dam Froelich Method Failure Modes

| **OBSERVATIONS** | **FAILURE MODES** | | | |
|---|---|---|---|---|
| | **Earthquake** [2] ▲ | **Flood**[1] ○ | **Piping** ■ | **Normal Stability** ◇ |
| Significant deformation and transverse cracking<br>Concentrated seepage with turbidity<br>Large slumps<br>Large Trees | Not designed for EQ loading in high hazard area<br>Soils liquefy FS<1.0* in EQ AEP $10^{-1}$ | TFF < $10^{-1}$ | Observed piping of embankment or foundation<br>Erodable / poorly compacted / dry and brittle soils* and Incompatible or Internally unstable soils<br>No filter<br>Unprotected seepage exit with high gradient | FS < 1.0*<br>Slopes steeper than 1.5H:1V<br>High Pore Pressures<br>Very weak foundation |
| Observed deformation and cracking,<br>steep or stepped abutments<br>Significant seepage or wet areas<br>Trees on slope or toe | Loose soils present in fdn or embankment<br>Soils liquefy or FS<1.0* under Operating Basis Earthquake | TFF < $10^{-2}$ | | FS < 1.1*<br>Slopes steeper than 2H:1V<br>High phreatic surface<br>Poor foundation |
| Infrequent Inspection<br>(none in last 10 years)<br>Limited Cracking<br>Small Trees<br>Minor Animal Burrows | | TFF < 10-3 | Compacted clay core | FS < 1.2*<br>Slopes steeper than |
| | Marginal soils<br>FS>1.0* under OBE FS<1.0* for Maximum | TFF < $10^{-4}$ | No observed piping<br>Uncertain Filter Compatibility | FS < 1.3<br>Slopes steeper than 3H:1V |
| Embankment condition satisfactory confirmed by regular inspection<br>**(Note: with embankment concrete corewall or cutoff wall reduce by one order of magnitude)** | Dense foundation or compacted embankment soils<br>FS>1.1 under MDE | TFF < $10^{-5}$ | No known cracks<br>Modern, fully penetrating filter<br>Full Foundation Cutoff<br>Modern Foundation Treatment | FS > 1.3<br>Regular monitoring<br>Slopes flatter than 3H:1V<br>Good foundation |
| | FS>1.3 under MDE | TFF > PMPDF or Probable Maximum Flood | Wide filter and blanket drain<br>Extensive monitoring | FS > 1.5<br>Regular monitoring |
| Failure Mode F | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |
| Life Loss Potential | 21 | 21 | 21 | 21 |
| Failure Mode F with Storage | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |

Notes: (* or unknown)

1. TFF - threshold failure flood flood which overtops sufficent to cause breach
2. Skip earthquake failure mode if in low seismicity area where Maximum Design Earthquake (MDE) pga < 0.1

Input Required
Ignore if not applicable

Piping failure mode risk value is in Priority B. Other failure modes are in safe zone. Risk plot for Froelich Method is given in Figure 5-9.

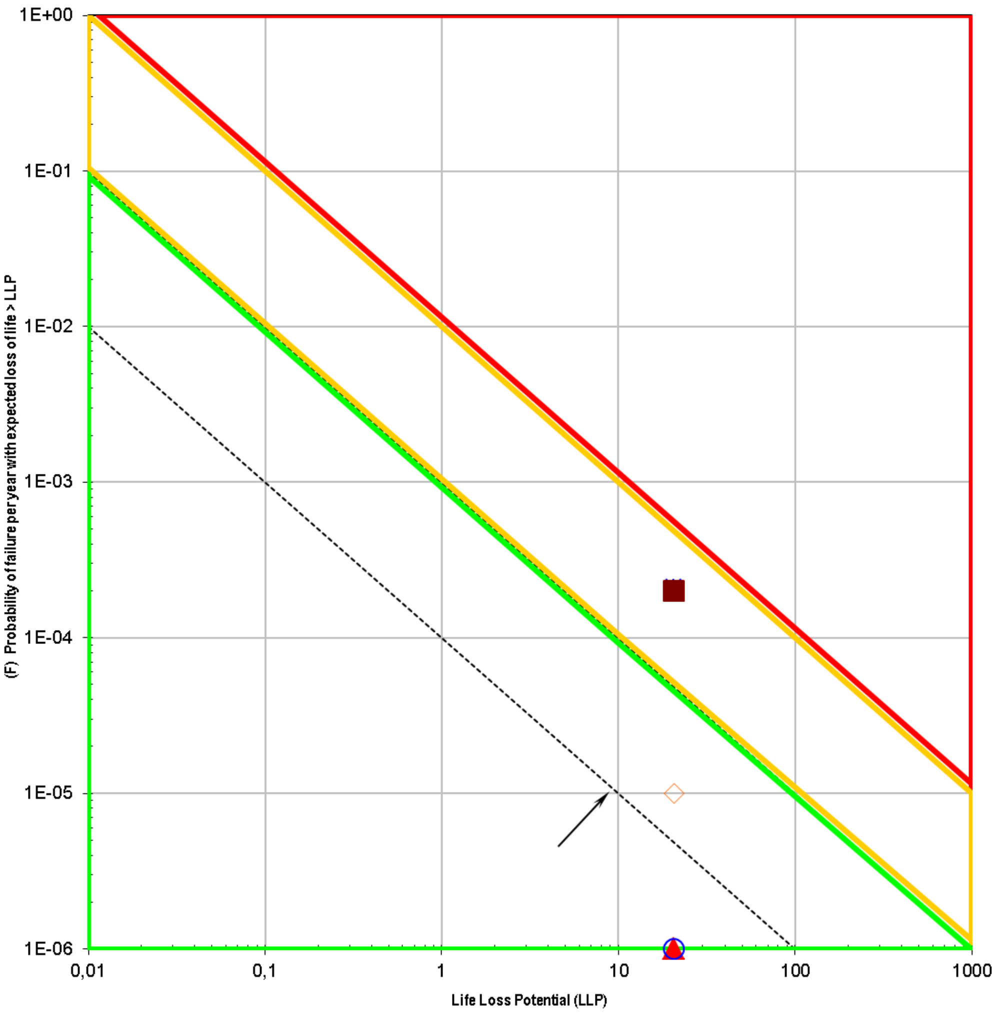



Figure 5-9 Çoğun Dam Froelich Method Risk Plot

First method  used for risk assessment of Çoğun Dam is Froelich Method. For calculations hydraulic height, spillway capacity, max storage volume, max reservoir area, dam breach discharge values are used. Table 5-70 shows Life Loss Potential Calculations NID Data for Çoğun Dam.

Table 5-70 Çoğun Dam Soil Conservation Service Method Life Loss Potential Calculations NID Data

| **NID Data** | |
|---|---|
| Dam Name: | Çoğun |
| Federal Dam ID: | |
| State: | |
| Hydraulic Height (feet): | 91,9 |
| NID Spillway Capacity (cfs): | 25.356 |
| Max. Storage Volume (ac-ft): | 17.836 |
| Max. Reservoir Area (acres): | 165.353 |
| Probability of having dam fill in any one year: | 1 |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area (sq.mi.): | 91,89 |
| Peak Breach Discharge: | 36.727,25 |

Population at risk data for Çoğun Dam is given in Table 5-71. As seen in table 258 people live in first 3 miles, 364 in next 4 miles and 1000 people live in last 8 miles away from dam. Table 5-72 shows flood conditions and Table 5-73 shows sunny day conditions estimated life loss calculations.

Table 5-71 Çoğun Dam Soil Conservation Service Method Life Loss Potential Calculations Population at Risk (PAR) Data

| | | Reach | Infrastructure | Flood PAR | Sunny Day PAR |
|---|---|---|---|---|---|
| **Other Data** | | 0 to 3 miles | Houses (x 3) | 258 | 258 |
| Basin Slope (feet/mile): | 0 | | Commercial / Schools | | |
| Mean Basin Elevation (feet): | 4.306 | | Roads / Bridges (cars x 2) | | |
| Mean Annual Precipitation (inches): | 14 | | Recreation | | |
| Main Stream Length (miles): | 6 | 3 to 7 miles | | 364 | 364 |
| | **Flood** | | | | |
| | 168.359 | 7 to 15 miles | | 1000 | 1000 |
| | 36727,25286 | | | | |

Table 5-72 Çoğun Dam Soil Conservation Service Method Life Loss Potential Calculations for Flood Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 168.359 | | | | | |
| 10-year Discharge (cfs) | 36727,25286 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 36.727 | 278.808 | 258 | 7,6 | 0,02 | 5 |
| 3.0 to 7.0 | 36.727 | 278.808 | 364 | 7,6 | 0,015 | 5 |
| 7.0 to 15.0 | 36.727 | 278.808 | 1.000 | 7,6 | 0,01 | 10 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.622** | **-** | **-** | **21** |

Table 5-73 Çoğun Dam Soil Conservation Service Method Life Loss Potential Calculations for Sunny Day Conditions

| **Approximate Analysis Results** | **Sunny Day** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 195.692 | | | | | |
| 10-year Discharge (cfs) | 36727,25286 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam sunny day failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Sunny Day Life Loss Potential |
| 0.0 to 3.0 | 36.727 | 195.692 | 258 | 5,3 | 0,02 | 5 |
| 3.0 to 7.0 | 36.727 | 195.692 | 364 | 5,3 | 0,015 | 5 |
| 7.0 to 15.0 | 36.727 | 195.692 | 1.000 | 5,3 | 0,01 | 10 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.622** | **-** | **-** | **21** |

Main failure modes and life loss values are given in Table 5-74. This table shows earthquake, flood, piping and normal stability failure modes for Soil Conservation Service Method.

Table 5-74 Çoğun Dam Soil Conservation Service Method Faiure Modes

| **OBSERVATIONS** | **FAILURE MODES** | | | |
|---|---|---|---|---|
| | **Earthquake** [2] ▲ | **Flood**[1] ○ | **Piping** ■ | **Normal Stability** ◇ |
| Significant deformation and transverse cracking<br>Concentrated seepage with turbidity<br>Large slumps<br>Large Trees | Not designed for EQ loading in high hazard area<br>Soils liquefy FS<1.0* in EQ AEP $10^{-1}$ | TFF < $10^{-1}$ | Observed piping of embankment or foundation<br>Erodable / poorly compacted / dry and brittle soils* and Incompatible or Internally unstable soils<br>No filter<br>Unprotected seepage exit with high gradient | FS < 1.0*<br>Slopes steeper than 1.5H:1V<br>High Pore Pressures<br>Very weak foundation |
| Observed deformation and cracking, steep or stepped abutments<br>Significant seepage or wet areas<br>Trees on slope or toe | Loose soils present in fdn or embankment<br>Soils liquefy or FS<1.0* under Operating Basis Earthquake (OBE) | TFF < $10^{-2}$ | | FS < 1.1*<br>Slopes steeper than 2H:1V<br>High phreatic surface<br>Poor foundation |
| Infrequent Inspection (none in last 10 years)<br>Limited Cracking<br>Small Trees<br>Minor Animal Burrows | Marginal soils FS>1.0* under OBE FS<1.0* for Maximum | TFF < 10-3 | Compacted clay core<br>No observed piping<br>Uncertain Filter Compatibility | FS < 1.2*<br>Slopes steeper than |
| | | TFF < $10^{-4}$ | | FS < 1.3<br>Slopes steeper than 3H:1V |
| Embankment condition satisfactory confirmed by regular inspection<br>**(Note: with embankment concrete corewall or cutoff wall reduce by one order of magnitude)** | Dense foundation or compacted embankment soils | TFF < $10^{-5}$ | No known cracks<br>Modern, fully penetrating filter<br>Full Foundation Cutoff | FS > 1.3<br>Regular monitoring<br>Slopes flatter than 3H:1V<br>Good foundation |
| | FS>1.3 under MDE | TFF > PMPDF or Probable Maximum Flood | Wide filter and blanket drain<br>Extensive monitoring | FS > 1.5<br>Regular monitoring |
| Failure Mode F | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |
| Life Loss Potential | 21 | 21 | 21 | 21 |
| Failure Mode F with Stora | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |

Notes: (* or unknown)

1. TFF - threshold failure flood flood which overtops sufficent to cause breach
2. Skip earthquake failure mode if in low seismicity area where Maximum Design Earthquake (MDE) pga <

| |
|---|
| Input Required<br>Ignore if not applicable |

Piping failure mode value is 2E-04, earthquake and flood failure modes are 1E-06 and normal stability failure mode risk value is 1E-05. Risk plot of Soil Conservaion Service Method is given in Figure 5-10.

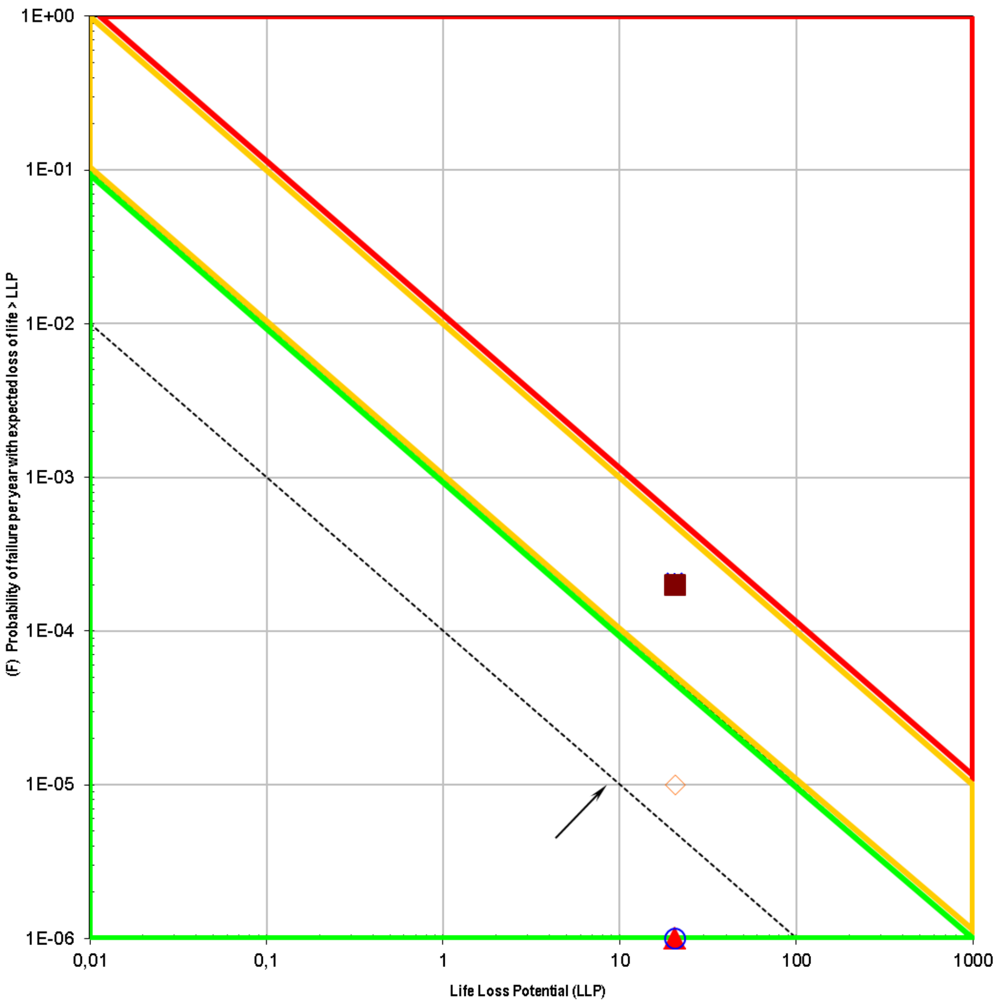



Figure 5-10 Çoğun Dam Soil Conservation Service Method Risk Plot

Other method used for risk analysis of Çoğun Dam is Macdonald and Langridge-Monopolis Method. Table 5-75 shows input data of this method.

Table 5-75 Çoğun Dam Macdonald and Langridge-Monopolis Method Life Loss Potential Calculations NID Data

| **NID Data** | |
|---|---|
| Dam Name: | Çoğun |
| Federal Dam ID: | |
| State: | |
| Hydraulic Height (feet): | 91,8635 |
| NID Spillway Capacity (cfs): | 25.355,9303 |
| Max. Storage Volume (ac-ft): | 17.835,6860 |
| Max. Reservoir Area (acres): | 165.353,0371 |
| Probability of having dam fill in any one year: | 1,0000 |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area (sq.mi.): | 91,8923 |
| Peak Breach Discharge : | 174.462,0488 |

Population at risk was calculated with help of census statistics and maps of area. Table 5-76 shows population at risk values. Two main conditions are used for estimated life loss calculations. First is flood conditions and second sunny day conditions. Table 5-77 shows flood conditions and Table 5-78 shows calculations of sunny day conditions.

Table 5-76 Çoğun Dam Macdonald and Langridge-Monopolis Method Life Loss Potential Calculations NID Data

| | | Reach | Infrastructure | Flood PAR | Sunny Day PAR |
|---|---|---|---|---|---|
| **Other Data** | | 0 to 3 miles | Houses (x 3) | 258,0000 | 258,0000 |
| Basin Slope (feet/mile): | 0,0200 | | Commercial / Schools | | |
| Mean Basin Elevation (feet): | 4.305,5774 | | Roads / Bridges (cars x 2) | | |
| Mean Annual Precipitation (inches): | 14,3819 | | Recreation | | |
| Main Stream Length (miles): | 6,2137 | 3 to 7 miles | | 364,0000 | 364,0000 |
| | | | | | |
| | | | | | |
| | | 7 to 15 miles | | 1000,0000 | 1000,0000 |

Table 5-77 Çoğun Dam Macdonald and Langridge-Monopolis Method Life Loss Potential Calculations for Flood Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 174.462,0488 | | | | | |
| 10-year Discharge (cfs) | 36.727,2529 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 36.727,2529 | 174.462,0488 | 258,0000 | 4,7502 | 0,0010 | 0,2580 |
| 3.0 to 7.0 | 36.727,2529 | 174.462,0488 | 364,0000 | 4,7502 | 0,0001 | 0,0364 |
| 7.0 to 15.0 | 36.727,2529 | 174.462,0488 | 1.000,0000 | 4,7502 | 0,0000 | 0,0000 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.622,0000** | **-** | **-** | **0,2944** |

Table 5-78 Çoğun Dam Macdonald and Langridge-Monopolis Method Life Loss Potential Calculations for Sunny Day Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 4.940,2151 | | | | | |
| 10-year Discharge (cfs) | 36.727,2529 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 36.727,2529 | 174.462,0488 | 258,0000 | 4,7502 | 0,0010 | 0,2580 |
| 3.0 to 7.0 | 36.727,2529 | 174.462,0488 | 364,0000 | 4,7502 | 0,0001 | 0,0364 |
| 7.0 to 15.0 | 36.727,2529 | 174.462,0488 | 1.000,0000 | 4,7502 | 0,0000 | 0,0000 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.622,0000** | **-** | **-** | **0,2944** |

Life loss values are around 1 for Macdonald and Langridge-Monopolis Method. Failure modes and observations are given in Table 5-79.

Table 5-79 Çoğun Dam Macdonald and Langridge-Monopolis Method Failure Modes

| OBSERVATIONS | FAILURE MODES | | | |
|---|---|---|---|---|
| | **Earthquake** [2]<br>▲ | **Flood**[1]<br>○ | **Piping**<br>■ | **Normal Stability**<br>◇ |
| Significant deformation and<br>transverse cracking<br>Concentrated seepage with turbidity<br>Large slumps<br>Large Trees | Not designed for EQ loading in high hazard area<br>Soils liquefy FS<1.0* in EQ AEP $10^{-1}$ | TFF < $10^{-1}$ | Observed piping of embankment or foundation<br>Erodable / poorly compacted / dry and brittle soils* and Incompatible or Internally unstable soils<br>No filter<br>Unprotected seepage exit with high gradient | FS < 1.0*<br>Slopes steeper than 1.5H:1V<br>High Pore Pressures<br>Very weak foundation |
| Observed deformation and cracking, steep or stepped abutments<br>Significant seepage or wet areas<br>Trees on slope or toe | Loose soils present in fdn or embankment<br>Soils liquefy or FS<1.0* under Operating Basis Earthquake (OBE) | TFF < $10^{-2}$ | | FS < 1.1*<br>Slopes steeper than 2H:1V<br>High phreatic surface<br>Poor foundation |
| Infrequent Inspection (none in last 10 years)<br>Limited Cracking<br>Small Trees<br>Minor Animal Burrows<br>Clear, Consistent Seepage | Marginal soils<br>FS>1.0* under OBE FS<1.0* for Maximum Design Earthquake | TFF < 10-3 | Compacted clay core | FS < 1.2*<br>Slopes steeper than |
| | | TFF < $10^{-4}$ | No observed piping<br>Uncertain Filter Compatibility<br>Uncertain Foundation | FS < 1.3<br>Slopes steeper than 3H:1V |
| Embankment condition satisfactory confirmed by regular inspection<br>**(Note: with embankment concrete corewall or cutoff wall reduce by one order of magnitude)** | Dense foundation or compacted embankment soils<br>FS>1.1 under MDE | TFF < $10^{-5}$ | No known cracks<br>Modern, fully penetrating filter<br>Full Foundation Cutoff<br>Modern Foundation Treatment | FS > 1.3<br>Regular monitoring<br>Slopes flatter than 3H:1V<br>Good foundation |
| | FS>1.3 under MDE | TFF > PMPDF or Probable Maximum Flood | Wide filter and blanket drain<br>Extensive monitoring | FS > 1.5<br>Regular monitoring |
| Failure Mode F | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |
| Life Loss Potential | 1 | 1 | 1 | 1 |
| Failure Mode F with Stora | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |

Notes: (* or unknown)

1. TFF - threshold failure flood flood which overtops sufficent to cause breach
2. Skip earthquake failure mode if in low seismicity area where Maximum Design Earthquake (MDE) pga <

Input Required
Ignore if not applicable

Life loss estimations are calculated for each condition. Because of low life loss value all failure modes are in safe zone. Risk plot of . Macdonald and Langridge-Monopolis Method is given in Figure 5-11.

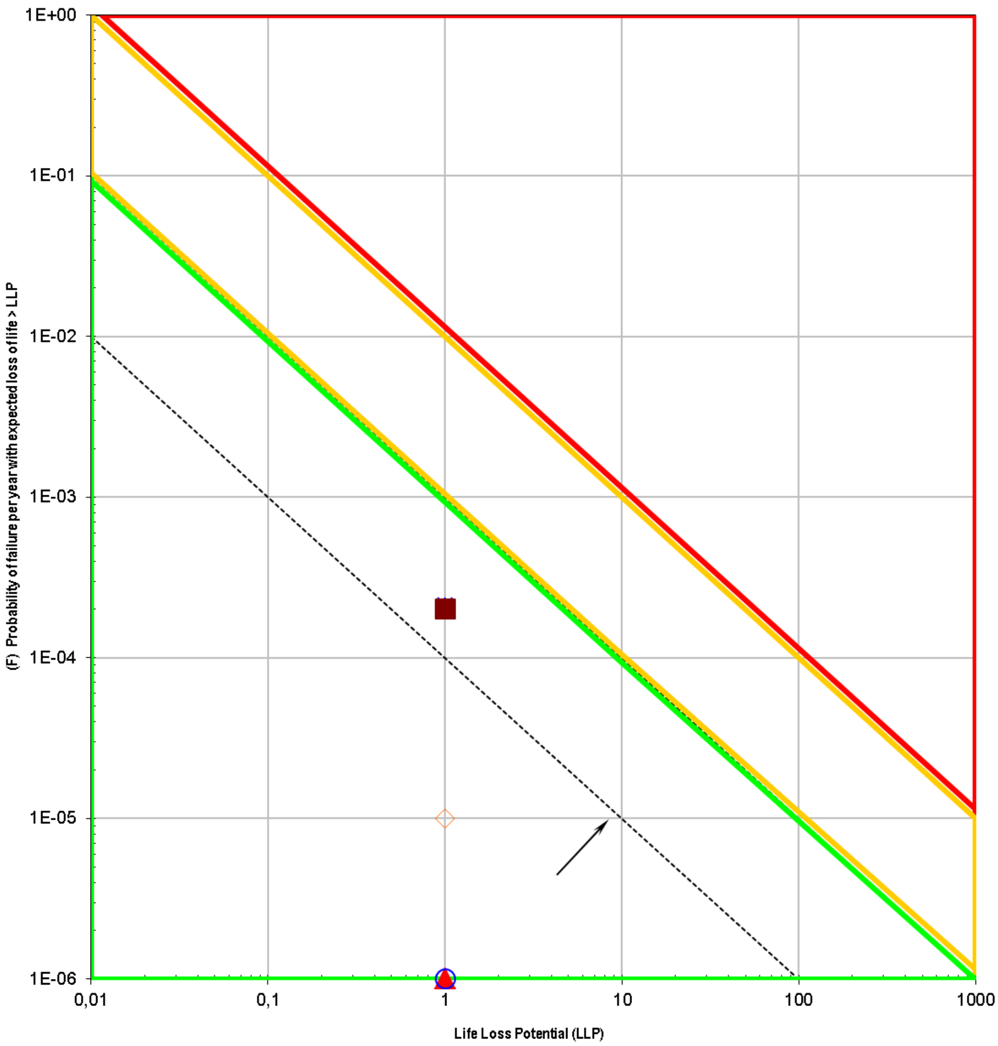



Figure 5-11 Çoğun Dam Macdonald and Langridge-Monopolis Method Risk Plot

Last method used for Çoğun Dam risk analysis is Costa Method. Input data for this method is given in Table 5-80.

Table 5-80 Çoğun Dam Costa Method Life Loss Potential Calculations NID Data

| **NID Data** | |
|---|---|
| Dam Name: | Çoğun |
| Federal Dam ID: | |
| State: | |
| Hydraulic Height (feet): | 91,9 |
| NID Spillway Capacity (cfs): | 25.356 |
| Max. Storage Volume (ac-ft): | 17.836 |
| Max. Reservoir Area (acres): | 165.353 |
| Probability of having dam fill in any one year: | 1 |
| NID Hazard: | Low |
| EAP Available: | No |
| Drainage Area (sq.mi.): | 91,89 |
| Peak Breach Discharge | 138857,9539 |

Number of people who live 3 miles away from dam is 258, 3 to 7 miles away is 364 and 7 to 15 miles away is 1000. Table 5-81 shows population at risk calculations. By usind population at risk data estimated life loss are calculated. Flood conditions life loss calculations are given in Table 5-82 and sunny day conditions are given in Table 5-83.

Table 5-81Çoğun Dam Costa Method Life Loss Potential Calculations Population at Risk (PAR) Data

| | | Reach | Infrastructure | Flood PAR | Sunny Day PAR |
|---|---|---|---|---|---|
| **Other Data** | | 0 to 3 miles | Houses (x 3) | 258 | 258 |
| Basin Slope (feet/mile): | 0 | | Commercial / Schools | | |
| Mean Basin Elevation (feet): | 4.306 | | Roads / Bridges (cars x 2) | | |
| Mean Annual Precipitation (inches): | 14 | | Recreation | | |
| Main Stream Length (miles): | 6 | 3 to 7 miles | | 364 | 364 |
| | | | | | |
| | | | | | |
| | | 7 to 15 miles | | 1000 | 1000 |

Table 5-82 Çoğun Dam Costa Method Life Loss Potential Calculations for Flood Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 136.320 | | | | | |
| 10-year Discharge (cfs) | 36727,25286 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 36.727 | 138.858 | 258 | 3,8 | 0,01 | 3 |
| 3.0 to 7.0 | 36.727 | 138.858 | 364 | 3,8 | 0,007 | 3 |
| 7.0 to 15.0 | 36.727 | 138.858 | 1.000 | 3,8 | 0,005 | 5 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.622** | **-** | **-** | **10** |

Table 5-83 Çoğun Dam Costa Method Life Loss Potential Calculations for Sunny Day Conditions

| **Approximate Analysis Results** | **Flood** | | | | | |
|---|---|---|---|---|---|---|
| Peak Breach Discharge (cfs) | 136.320 | | | | | |
| 10-year Discharge (cfs) | 36727,25286 | | | | | |
| Reach (Distance from dam) in miles | 10-year Discharge (cfs) | Dam Breach Discharge (cfs) | Estimated PAR within the dam flood failure inundation limits | Ratio of Peak Discharge from Dam Breach to 10-year Flood Peak Discharge | Calculated Fatality Rate | Estimated Flood Life Loss Potential |
| 0.0 to 3.0 | 36.727 | 138.858 | 258 | 3,8 | 0,01 | 3 |
| 3.0 to 7.0 | 36.727 | 138.858 | 364 | 3,8 | 0,007 | 3 |
| 7.0 to 15.0 | 36.727 | 138.858 | 1.000 | 3,8 | 0,005 | 5 |
| **Total (mile 0.0 to 15.0)** | **-** | **-** | **1.622** | **-** | **-** | **10** |

Earthquake, flood, piping and normal stability failure modes are choosen for dangerous situations of Çoğun Dam. Failure modes, risk values and life loss values are given in Table 5-84.

Table 5-84 Çoğun Dam Costa Method Failure Modes

| OBSERVATIONS | FAILURE MODES<br>Earthquake [2] ▲ | Flood[1] ○ | Piping ■ | Normal Stability ◇ |
|---|---|---|---|---|
| Significant deformation<br>and<br>transverse cracking<br>Concentrated seepage<br>with turbidity<br>Large slumps<br>Large Trees | Not designed<br>for EQ loading<br>in high hazard<br>area<br>Soils liquefy<br>FS<1.0* in EQ<br>AEP $10^{-1}$ | TFF < $10^{-1}$ | Observed piping of<br>embankment<br>or foundation<br>Erodable / poorly<br>compacted / dry and<br>brittle soils* and<br>Incompatible or<br>Internally unstable<br>soils<br>No filter<br>Unprotected<br>seepage exit with<br>high gradient | FS < 1.0*<br>Slopes steeper than<br>1.5H:1V<br>High Pore Pressures<br>Very weak<br>foundation |
| Observed deformation<br>and cracking,<br>steep or stepped<br>abutments<br>Significant seepage or wet<br>areas<br>Trees on slope or toe | Loose soils<br>present in fdn or<br>embankment<br>Soils liquefy or<br>FS<1.0* under<br>Operating Basis<br>Earthquake<br>(OBE) | TFF < $10^{-2}$ | | FS < 1.1*<br>Slopes steeper than<br>2H:1V<br>High phreatic surface<br>Poor foundation |
| Infrequent Inspection<br>(none in last 10 years)<br>Limited Cracking<br>Small Trees<br>Minor Animal Burrows | Marginal soils<br>FS>1.0* under<br>OBE FS<1.0*<br>for Maximum | TFF < 10-3<br>TFF < $10^{-4}$ | Compacted clay<br>core<br>No observed piping<br>Uncertain Filter<br>Compatibility | FS < 1.2*<br>Slopes steeper than<br>FS < 1.3<br>Slopes steeper than<br>3H:1V |
| Embankment condition<br>satisfactory<br>confirmed by regular<br>inspection<br>**(Note: with embankment concrete corewall or cutoff wall reduce by one order of magnitude)** | Dense<br>foundation or<br>compacted<br>embankment<br>soils<br>FS>1.1 under<br>MDE | TFF < $10^{-5}$ | No known cracks<br>Modern, fully<br>penetrating filter<br>Full Foundation<br>Cutoff<br>Modern Foundation<br>Treatment | FS > 1.3<br>Regular monitoring<br>Slopes flatter than<br>3H:1V<br>Good foundation |
| | FS>1.3 under<br>MDE | TFF > PMPDF<br>or Probable<br>Maximum Flood | Wide filter and<br>blanket drain<br>Extensive monitoring | FS > 1.5<br>Regular monitoring |
| Failure Mode F | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |
| Life Loss Potential | 10 | 10 | 10 | 10 |
| Failure Mode F with Stora | 1,00E-06 | 1,00E-06 | 2,00E-04 | 1,00E-05 |

Notes: (* or unknown)
1. TFF - threshold failure flood flood which overtops sufficent to cause breach
2. Skip earthquake failure mode if in low seismicity area where Maximum Design Earthquake (MDE) pga <

Input Required
Ignore if not applicable

Risk plot for piping, flood, earthquake and normal stability failure modes is given in Figure 5-12. Flood, earthquake and normal stability risk values are in Priority C and piping failure mode risk value is in Priority B.

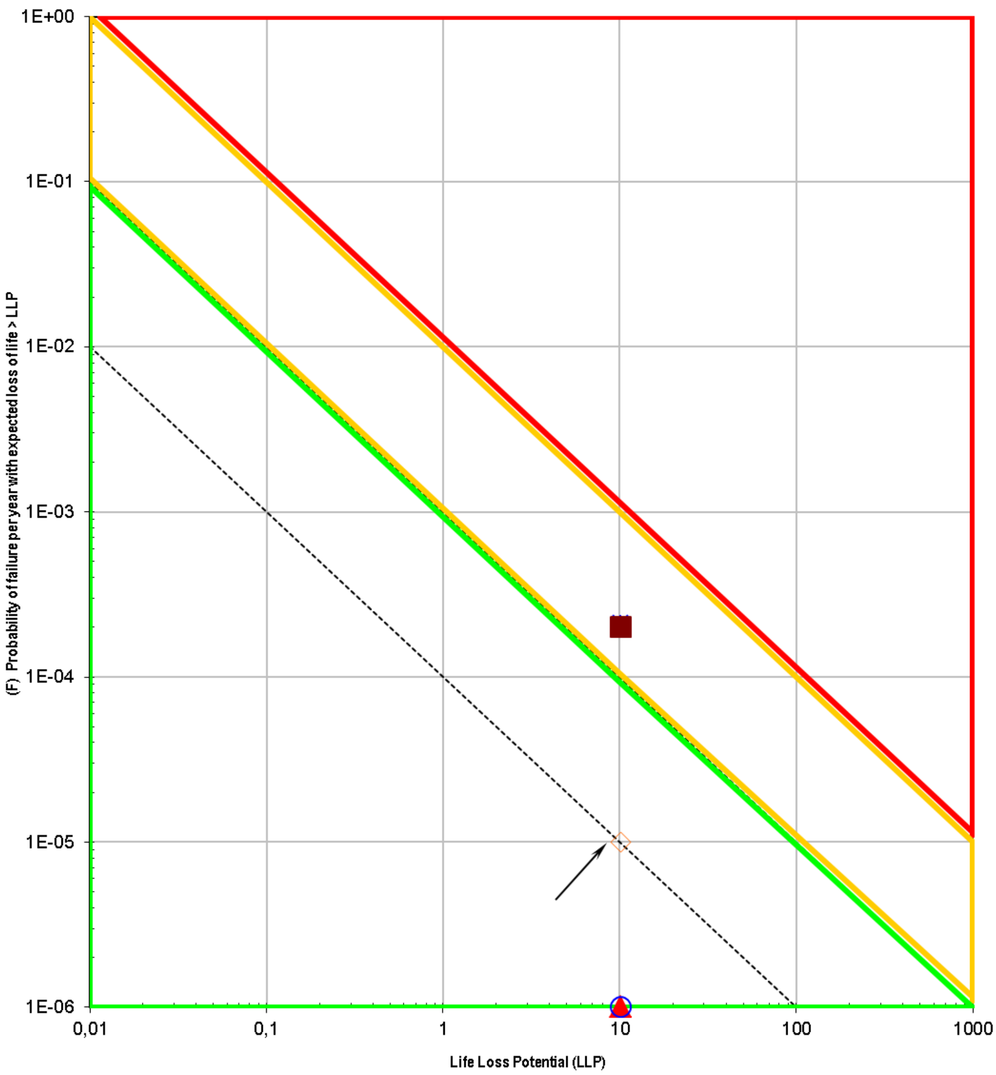



Figure 5-12 Çoğun Dam Costa Method Risk Plot

# CHAPTER 6

# 6 RESULTS AND DISCUSSIONS

## 6.1 Results

### 6.1.1 Risk Assessment Results of Kayacık Dam

Figure 6.1 shows Failure Mode-Risk Profile for Kayacık Dam based on the Froelich Method. Earthquake failure mode risk value and flood failure mode risk values are around $1x10^{-3}$ which means these values are below Priority B (the risk should be reduced in accordance with priorities). Normal stability risk value is between $1x10^{-2}$ and $1x10^{-3}$ which means risk value is in Priority B.

Piping failure mode risk level for Froelich equation is above the border of Priority A level. Piping failure is internal erosion of embankment materials or foundation that causes a sinkhole. The cave-in of an eroded cavern can result in a sink hole. A small hole in the wall of an outlet pipe can develop a sink hole.

Dirty water observation at the exit indicates erosion of the dam due to piping. Piping can empty a reservoir through a small hole in the wall or can lead to failure of a dam as soil pipes erode through the foundation or a pervious part of the dam.

Recommended actions for piping are:

- Inspect other parts of the dam for seepage or more sink holes.
- Identify exact cause of sink holes.
- Check seepage and leakage outflows for dirty water.

- A qualified engineer should inspect the conditions and recommend further actions to be taken.

Soil Conservation Service Method Dam failure mode and risk profile is shown in Figure 6-2. This figure shows that earthquake failure mode risk value and flood failure mode risk values are around $1x10^{-3}$ which means these values are below Priority B (Risk Should be Reduced in Accordance with Priorities). Normal stability risk value is below dangerous zone.

Piping failure mode risk level is above than border of Priority A level. Piping failure is internal erosion of embankment materials or foundation causes a sinkhole. The cave-in of an eroded cavern can result in a sink hole. A small hole in the wall of an outlet pipe can develop a sink hole.

Macdonald and Langridge-Monopolis Method dam failure mode-risk profile for Kayacık dam is given in Figure 6-3. Earthquake, piping and flood failure mode risk values are lower than 1x10-4, this means all failure modes risk values are in priority C (diminished needs to reduce risk subject to ALARP Principle)

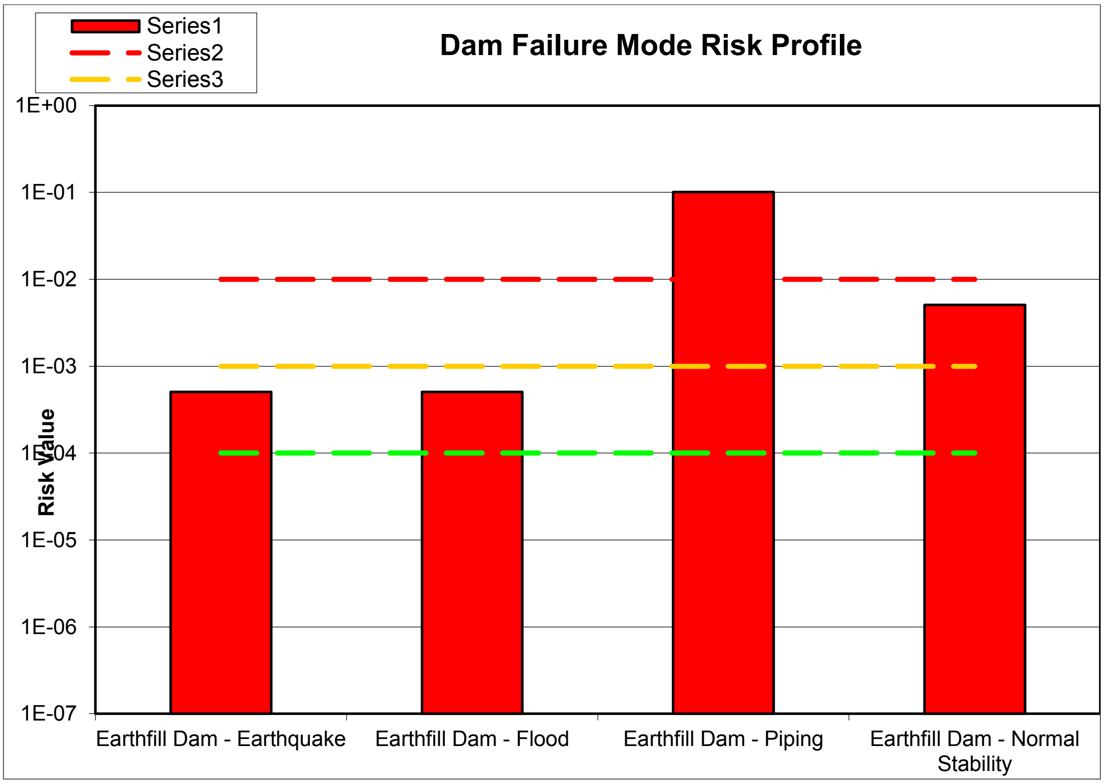


Figure 6-1 Kayacık Dam Froelich Method Dam Failure Mode-Risk Profile

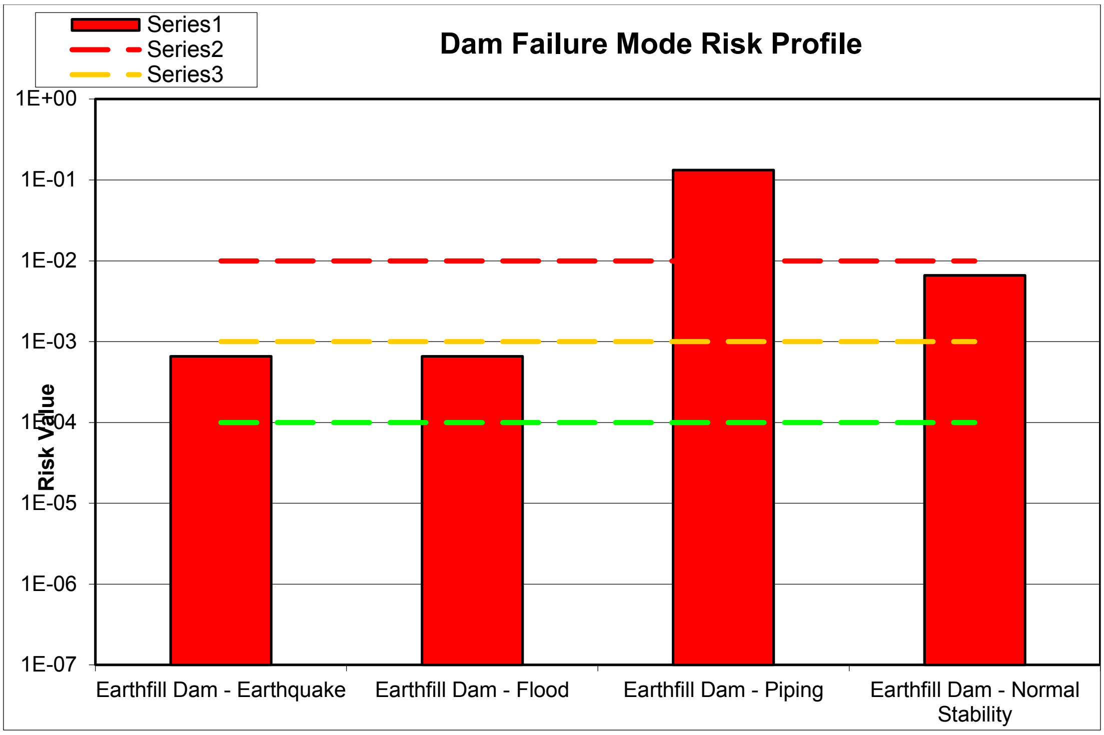



Figure 6-2 Kayacık Dam Soil Conservation Service Method Dam Failure Mode-Risk Profile

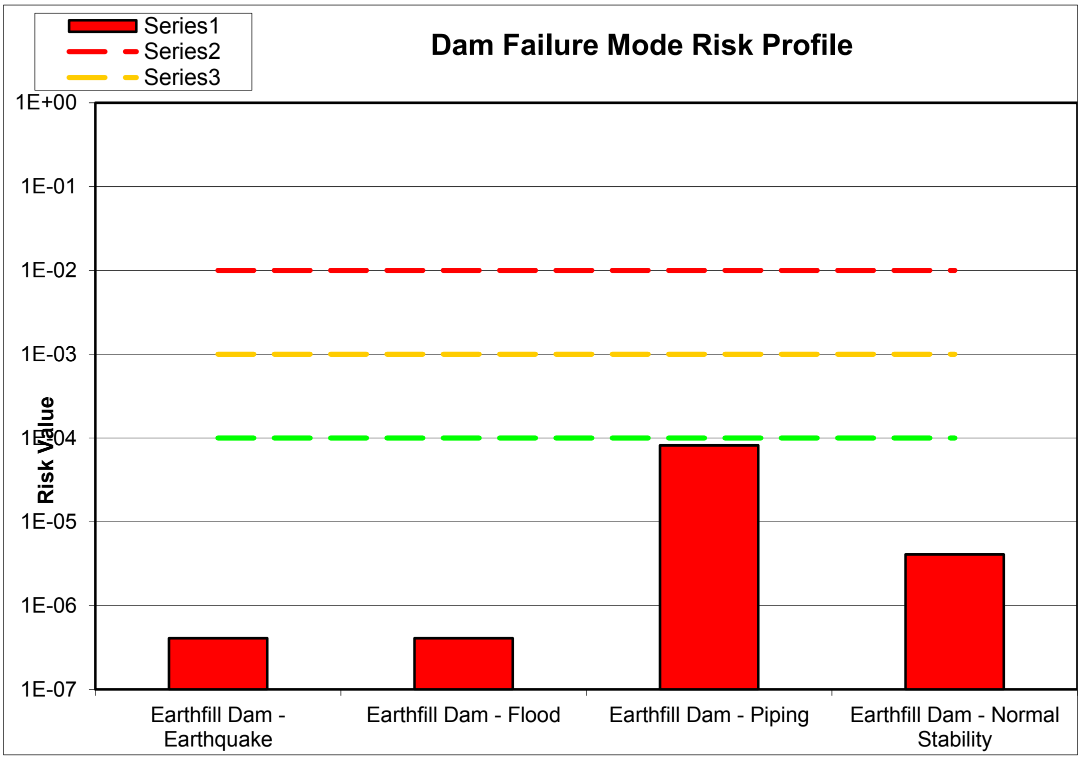



Figure 6-3 Kayacık Dam Macdonald and Langridge-Monopolis Method Dam Failure Mode-Risk Profile

Costa Method Dam failure mode and risk profile is showen in Figure 6-4. This figure shows that earthquake failure mode risk value and flood failure mode risk values are around $1x10^{-3}$ which means these values are below Priority B (risk should be reduced in accordance with priorities). Normal stability risk value is around $1x10^{-2}$.

As it is seen in Figure 6.4, piping failure mode risk level for Costa Method is above the border of Priority A level.

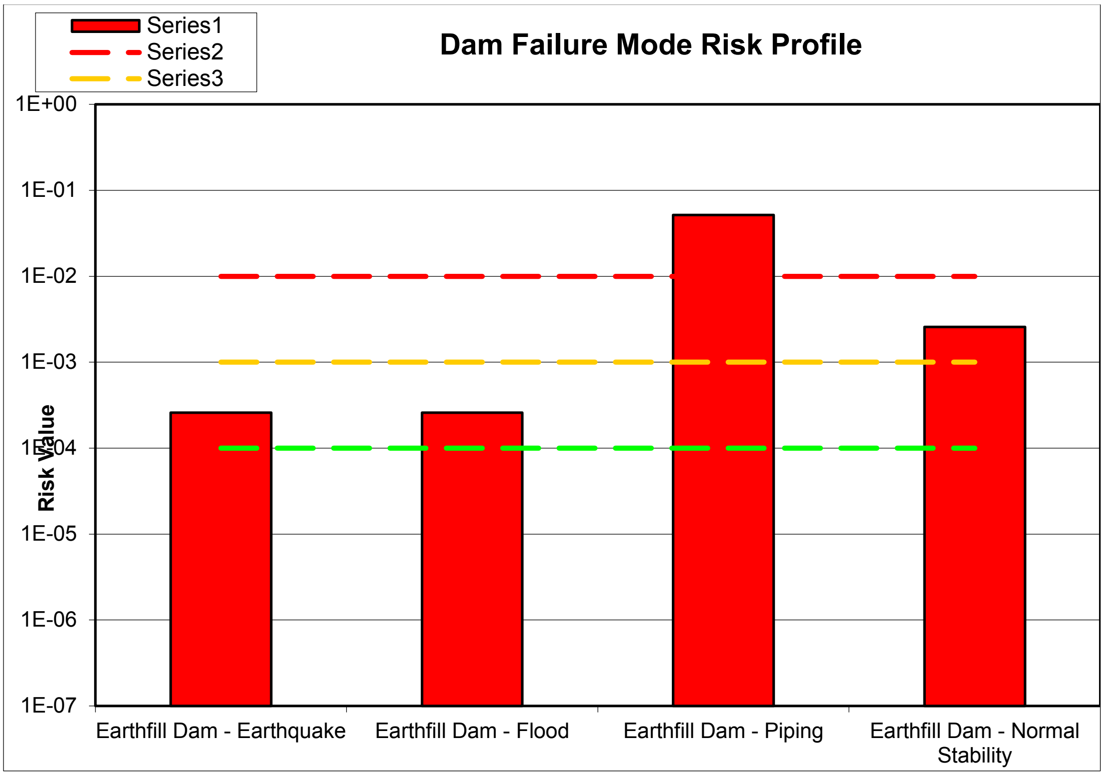



Figure 6-4 Kayacık Dam Costa Method Dam Failure Mode-Risk Profile

### 6.1.2 Risk Assessment Results of Karaova Dam

Figure 6.5 shows Froelich Method Dam failure mode and risk profile for Karaova dam. This figure shows that earthquake failure mode risk value and flood failure mode risk values are around 1x10-3 which means these values are below Priority B (Risk Should be Reduced in Accordance with Priorities). Normal stability failure mode risk value is around $1x10^{-3}$.

As it is seen in Figure 6.5, piping failure mode risk level for Froelich equation is above than border of Priority A level.

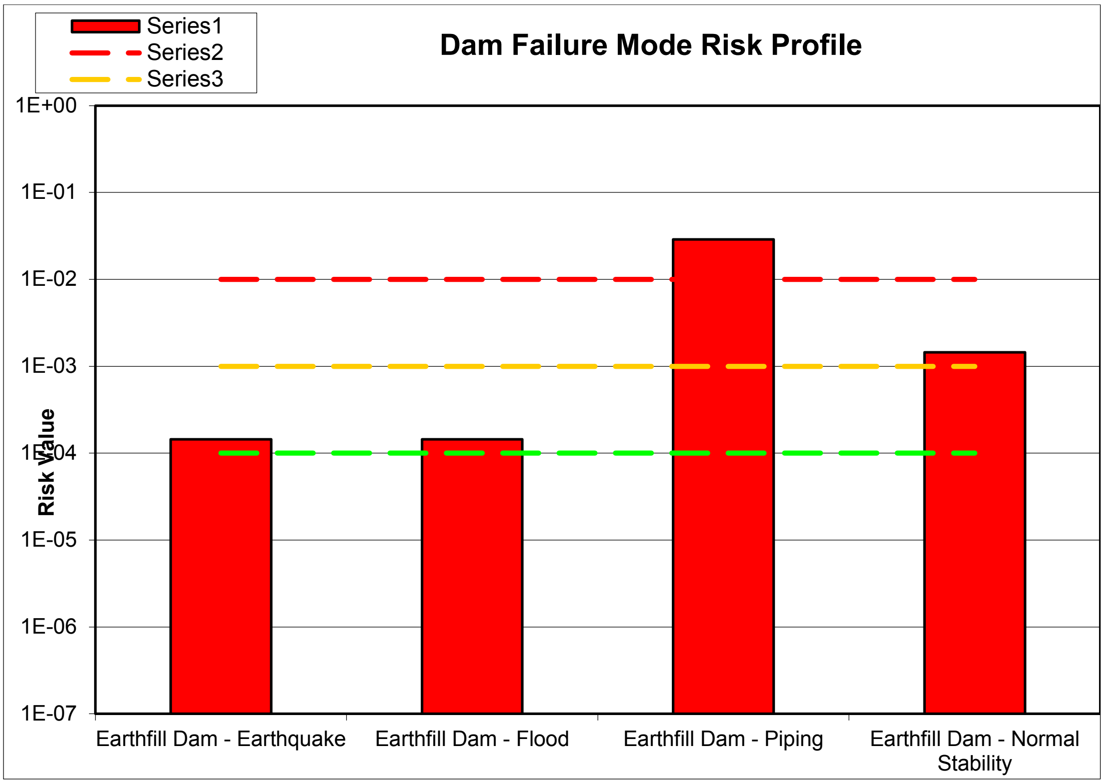



Figure 6-5 Karaova Dam Froelich Method Dam Failure Mode-Risk Profile

Figure 6.6 represents Soil Conservation Service Method Dam failure mode and risk profile for Karaova dam. This figure shows that earthquake failure mode risk value and flood failure mode risk values are around 1x10-3 which means these values are below Priority B (Risk Should be Reduced in Accordance with Priorities). Normal stability failure mode risk value is above $1x10^{-3}$. Piping failure mode risk level for Soil Conservation Service equation is above than border of Priority A level.

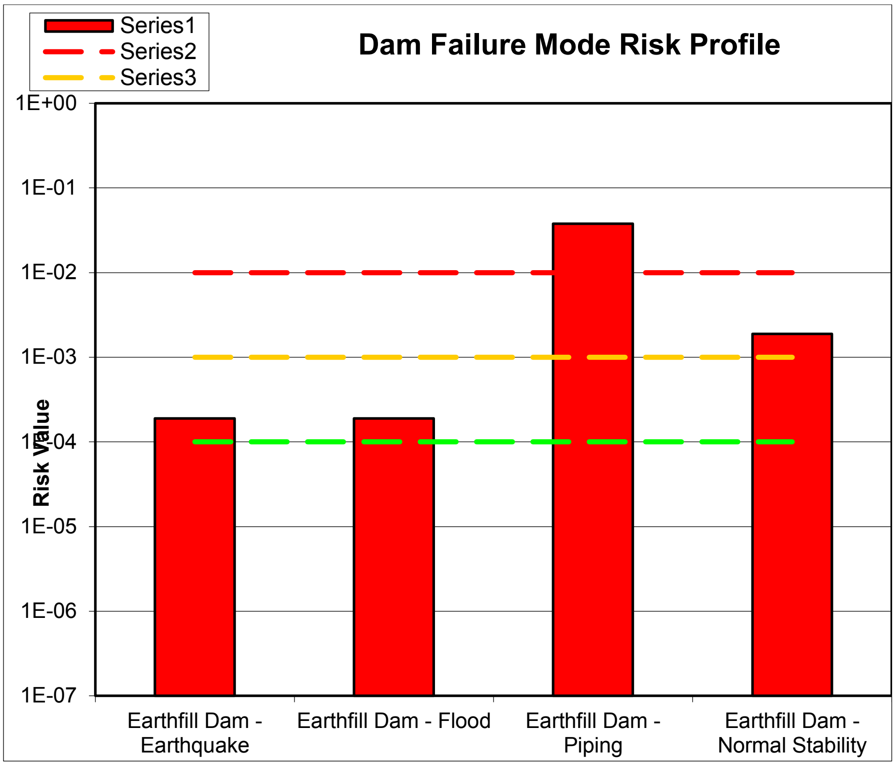



Figure 6-6 Karaova Dam Soil Conservation Service Method Dam Failure Mode-Risk Profile

Figure 6.7 shows Macdonald and Langridge-Monopolis Method dam failure mode and risk profile for Karaova dam. Earthquake, flood, piping and normal stability failure modes risk values are around 1E-0$^{6}$, which is safe zone.

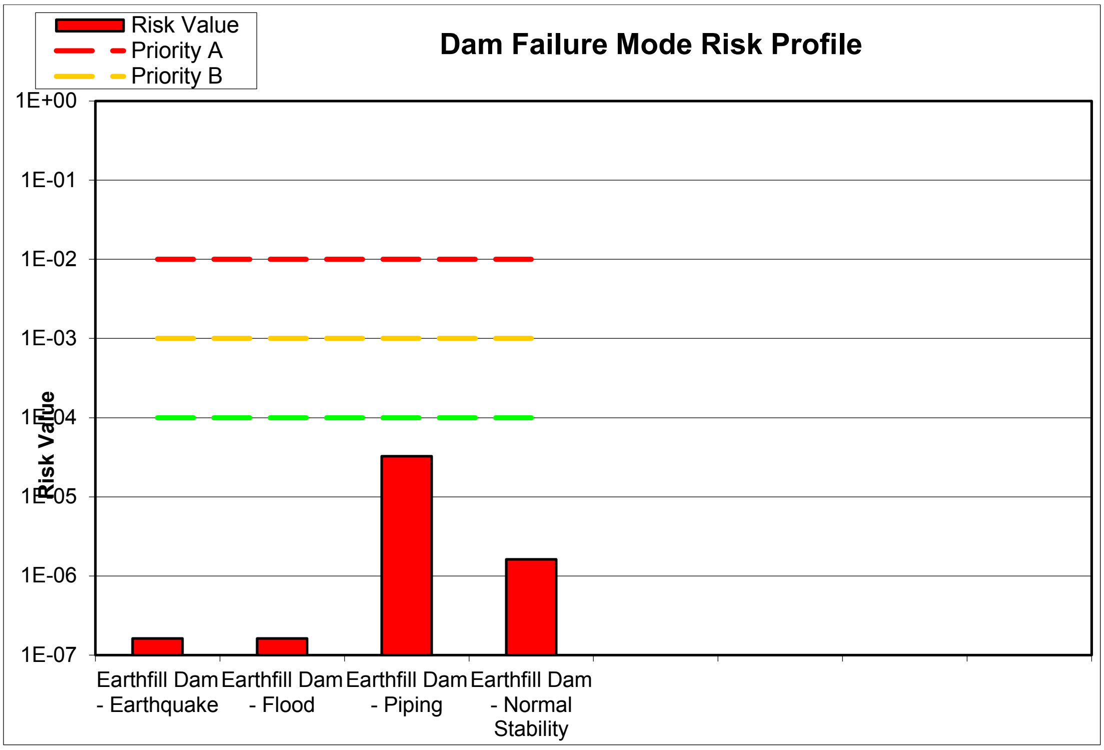



Figure 6-7 Karaova Dam Macdonald and Langridge-Monopolis Method Dam Failure Mode-Risk Profile

Costa Method Dam failure mode and risk profile for Karaova dam is given in Figure 6.8. This figure shows that earthquake failure mode risk value and flood failure mode risk values are around $1x10^{-3}$ which means these values are below Priority B (Risk Should be Reduced in Accordance with Priorities). Normal stability risk value is lower than $1x10^{-3}$. Piping failure mode risk level for Soil Conservation Service equation is above than border of Priority A level.

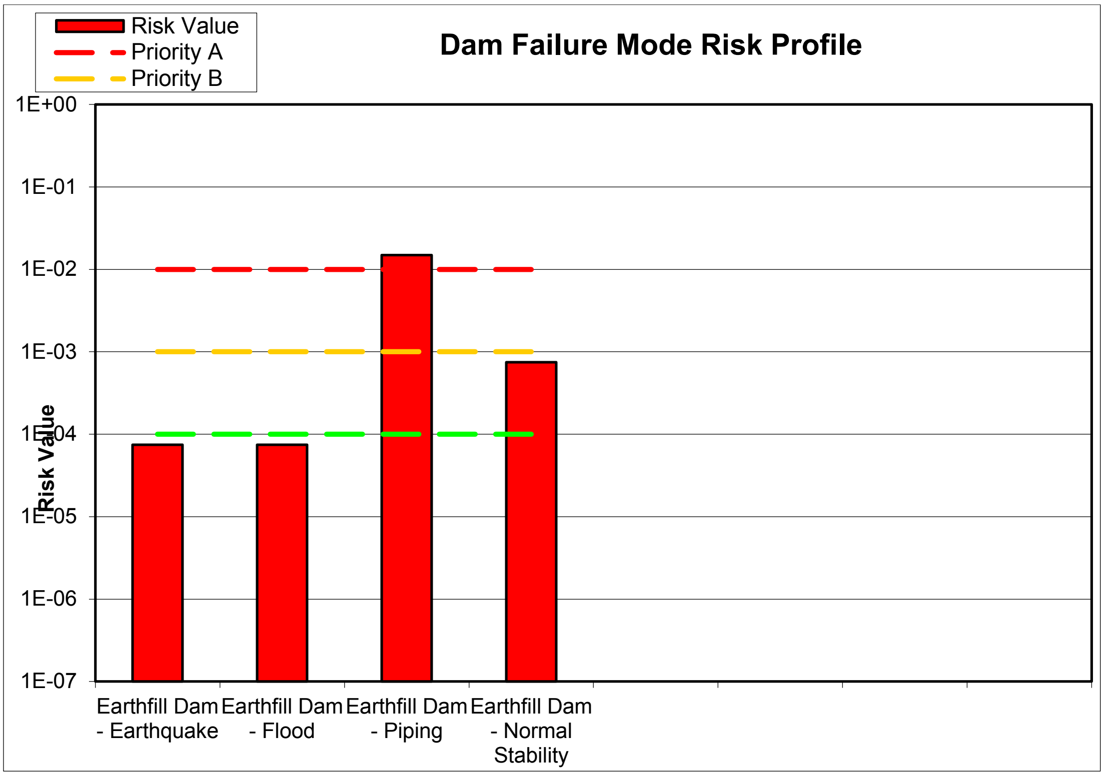



Figure 6-8 Karaova Dam Costa Method Dam Failure Mode-Risk Profile

### 6.1.3 Risk Assessment Results of Çoğun Dam

Figure 6-9 represents the dam failure mode and risk profile of Froelich Method for Çoğun Dam. According to this figure earthquake failure mode risk value and flood failure mode risk value are below priority C(Diminished Need to Reduce Risk Subject to the ALARP Principle). Normal failure mode risk value is in Priority B. Piping failure mode risk value is above priority A(Urgent action recommended.

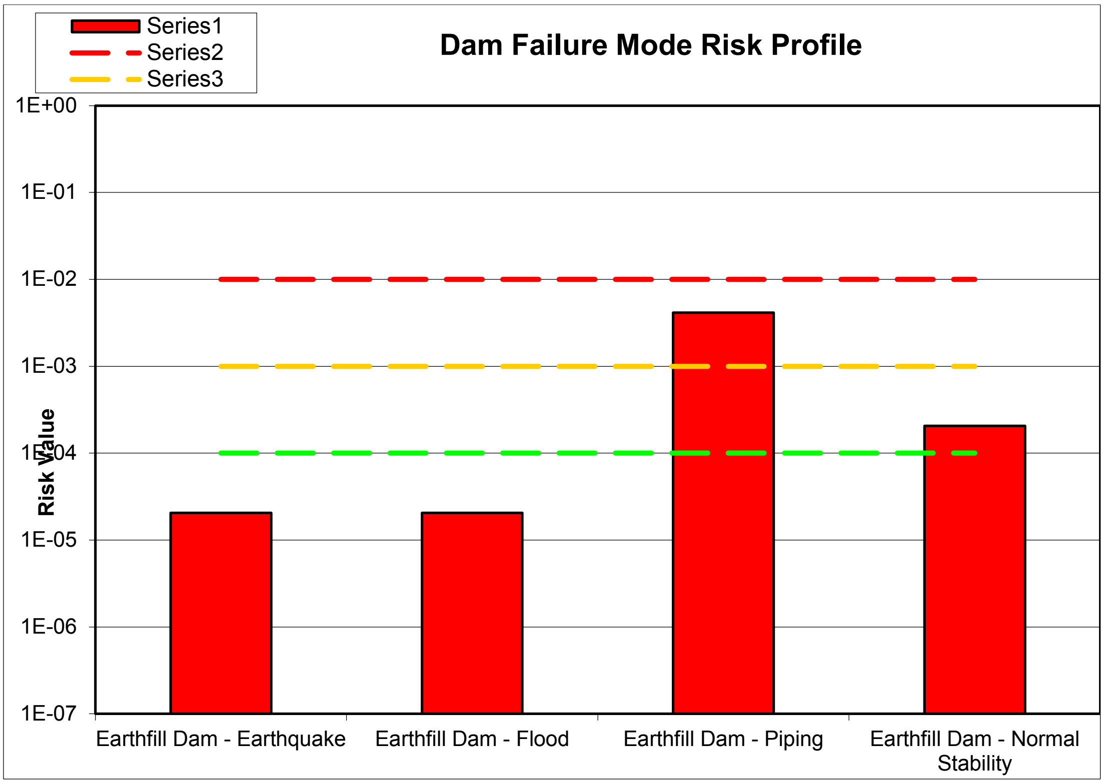



Figure 6-9 Çoğun Dam Froelich Method Dam Failure Mode-Risk Profile

Çoğun Dam Soil Conservation Service Method Dam Failure Mode-Risk Profile is given in Figure 6-10. Earthquake failure mode risk value and flood failure mode risk value are below priority C (Diminished Need to Reduce Risk Subject to the ALARPPrinciple). Normal stability risk value is in Priority B. Piping failure mode risk value is in priority B Risk Should be Reduced in Accordance with Priorities which indicates that risk level still falls above the level of 1 in 1000 or 1 x $10^{-3}$, but that the risk can be addressed in an appropriate and deliberate sequence of dams or failure modes based on their relative risk.

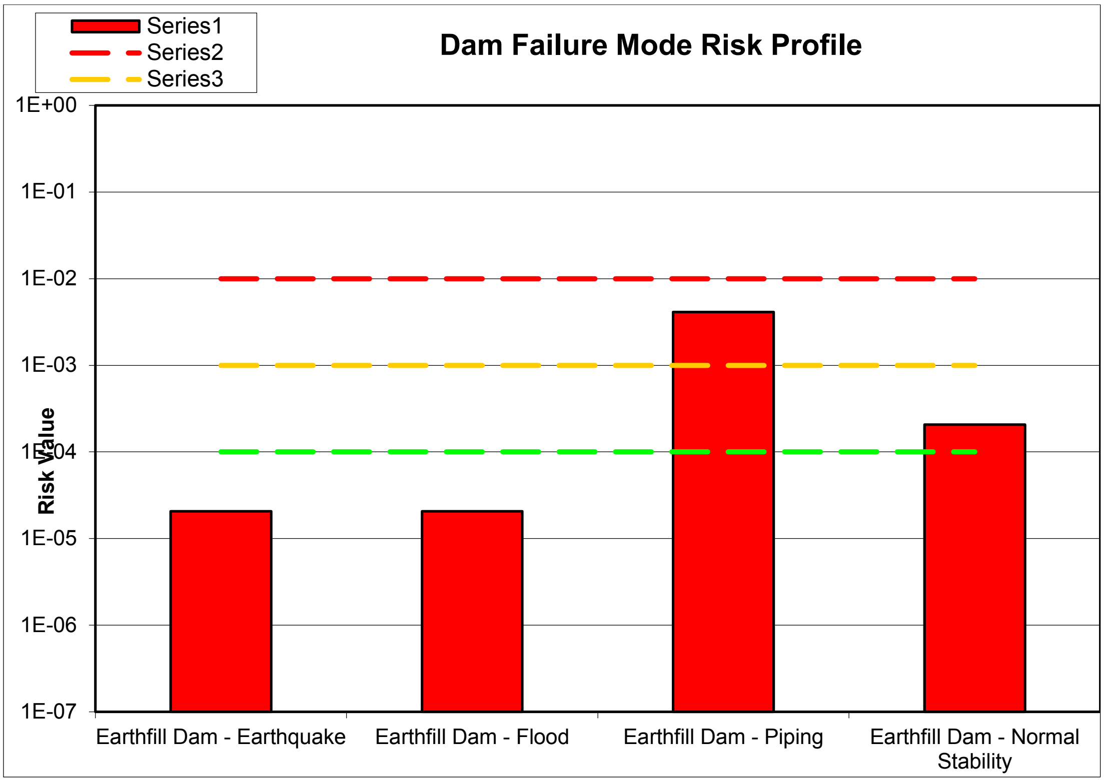



Figure 6-10 Çoğun Dam Soil Conservation Service Method Dam Failure Mode-Risk Profile

Figure 6-11 shows Macdonald and Langridge-Monopolis Method dam failure mode and risk profile for Çoğun Dam. Earthquake, flood and normal stability failure modes risk values are around 1E-06, which is safe zone. Pioing failure mode risk value is below Priority B (Risk Should be Reduced in Accordance with Priorities).

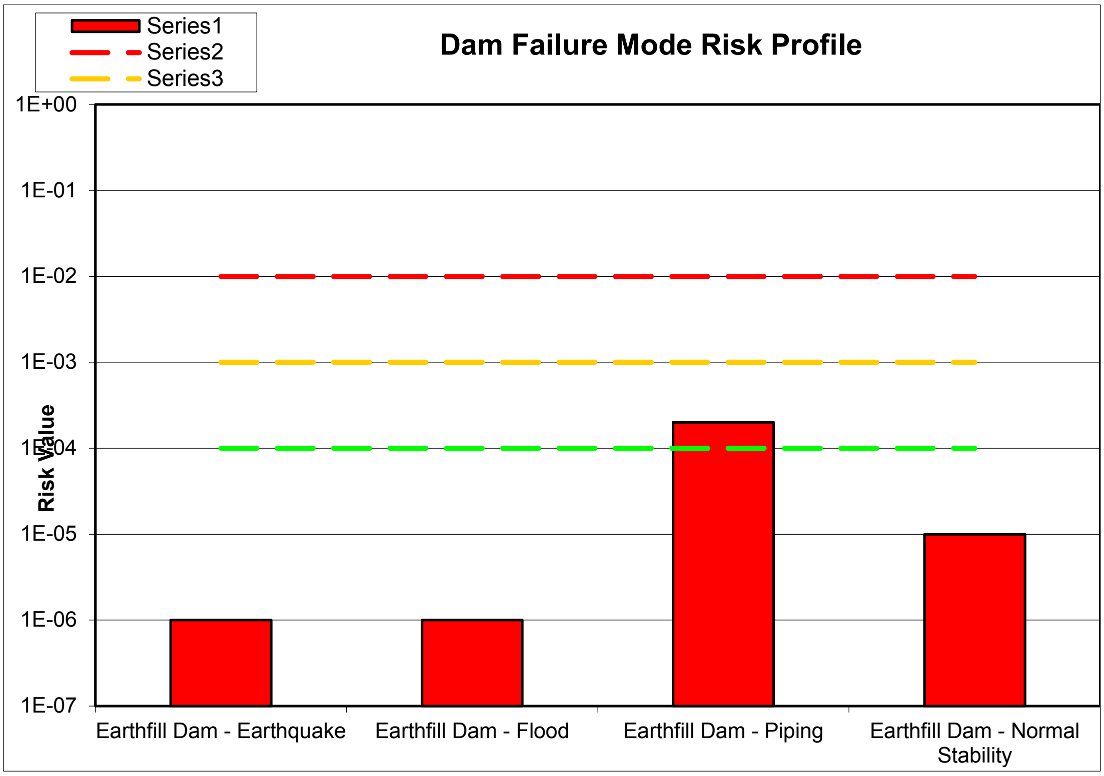



Figure 6-11 Çoğun Dam Macdonald and Langridge-Monopolis Method Dam Failure Mode-Risk Profile

Çoğun Dam Costa Method Dam Failure Mode-Risk Profile is given in Figure 6.12. Earthquake, flood, normal stability failure modes risk values are below priority C(Diminished Need to Reduce Risk Subject to the ALARPPrinciple). Piping failure mode risk value is in priority B Risk Should be Reduced in Accordance with Priorities which indicates that risk level still falls above the level of 1 in 1000 or 1 x $10^{-3}$, but that the risk can be addressed in an appropriate and deliberate sequence of dams or failure modes based on their relative risk.

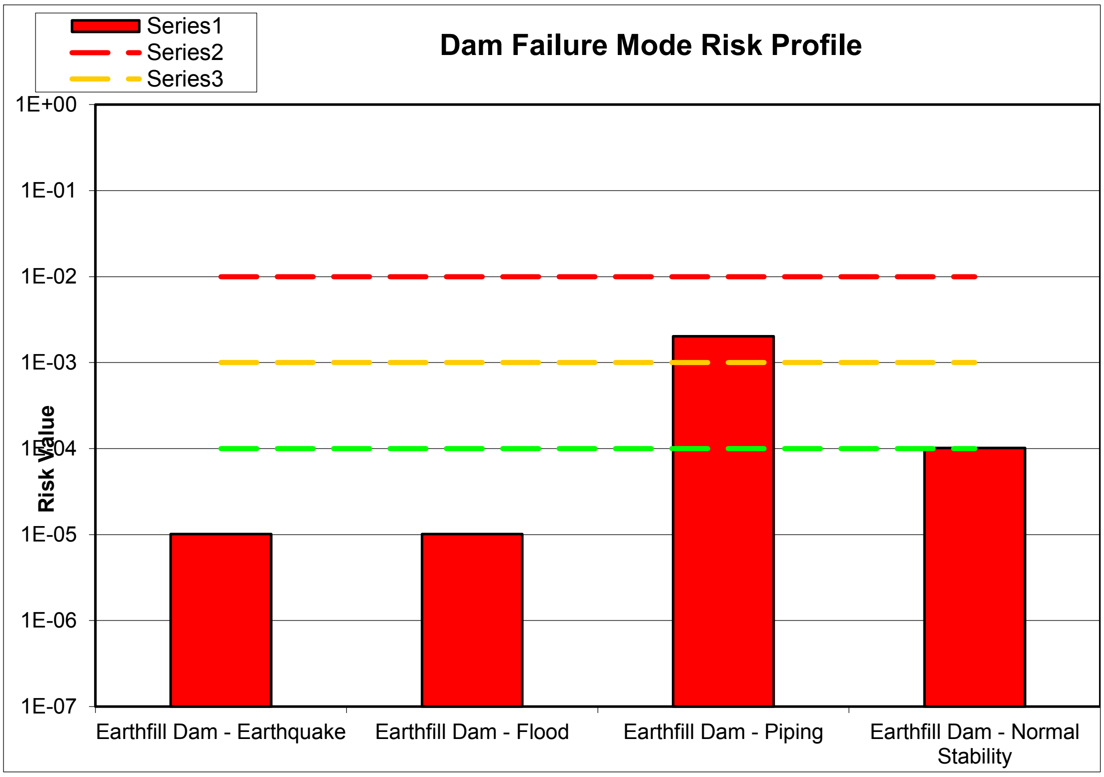



Figure 6-12 Çoğun Dam Costa Method Dam Failure Mode-Risk Profile

## 6.2 Discussion

### 6.2.1 Kayacık Dam

Soil Conservation Service Method, Froelich Method, Macdonald and Langridge-Monopolis Method and Costa Method results are shown in Figure 6-13 Comparison of Froelich, Soil Conservation Service, Macdonal & Langridge-Monopolis and Costa Methods for Kayacık Dam. In this figure first four coloumbs show earthquake failure mode, second four coloumbs show flood failure mode, third four coloumbs show piping failure mode and last four coloumbs risk values of Kayacık Dam.

For earthquake failure mode risk plot Macdonald and Langdridge-Monopolis method shows minimum value, other methods have closer risk values. Flood failure mode risk values are almost same as in earthquake failure modes. Froelich Method, Soil Conservation Service Method and Costa Method risk values for piping are above Priority A which means urgent action recommended for failure. MacDonald and Langdridge-Monopolis method risk value for piping is lower than limit of Priority C which is smallest value for piping failure. Normal stability failure risk values are close for three methods only MacDonald and Langdridge-Monopolis gives smaller value than others.

### 6.2.2 Karaova Dam

Figure 6-14 represents Soil Conservation Service Method, Froelich Method, Macdonald and Langridge-Monopolis Method and Costa Method results for Karaova Dam. In this figure first four coloumbs show earthquake failure mode, second four coloumbs show flood failure mode and last four coloumbs show piping failure mode risk values of Karaova Dam.

Macdonald and Langridge-Monopolis Method risk values for earthquake failure mode is lowest value. All other methods shows close values for earthquake failure. Flood failure mode risk values of Froelich Method, Soil Conservation Service Method and Costa Method are between $1x10^{-3}$ and $1x10^{-4}$. Flood risk value for Macdonal & Langridge-Monopolis Method is $1x10^{-6}$ which is lowest value.

Piping failure mode risk values are shown in last four coloumbs in Figure 6-14. Macdonal & Langridge-Monopolis Method risk value is in safe zone (Priority C) while other three methods risk values are bigger than $1x10^{-2}$.

Normal stability failure mode risk values are given in last four coloumbs. Froelich, Soil Conservation Service and Costa Methods given close values for this failure mode.

### 6.2.3 Çoğun Dam

Figure 6-15 Comparison of Froelich, Soil Conservation Service, Macdonal & Langridge-Monopolis and Costa Methods for Çoğun Dam represents comparision of Froelich Method, Soil Conservation Service Method, Macdonald and Langridge-Monopolis Method and Costa Method failure mode risk values for Çoğun Dam. Earthquake failure mode risk values and flood failure mode risk values are smaller than $1x10^{-4}$, which is limit value of Priority C. Macdonal & Langridge-Monopolis Method piping failure mode risk value is smallest value for piping, Froelich Method risk value is biggest value.Soil Conservaiton Service Method and Costa Method piping failure mode risk values are close. Normal stability risk values for Froelich Method and Soil Conservation Service Method are close and Costa Method results show that risk value of normal stability is lower than $1x10^{-3}$. Macdonald and Langridge-Monopolis Method risk value for normal stability is around $1x10^{-5}$.

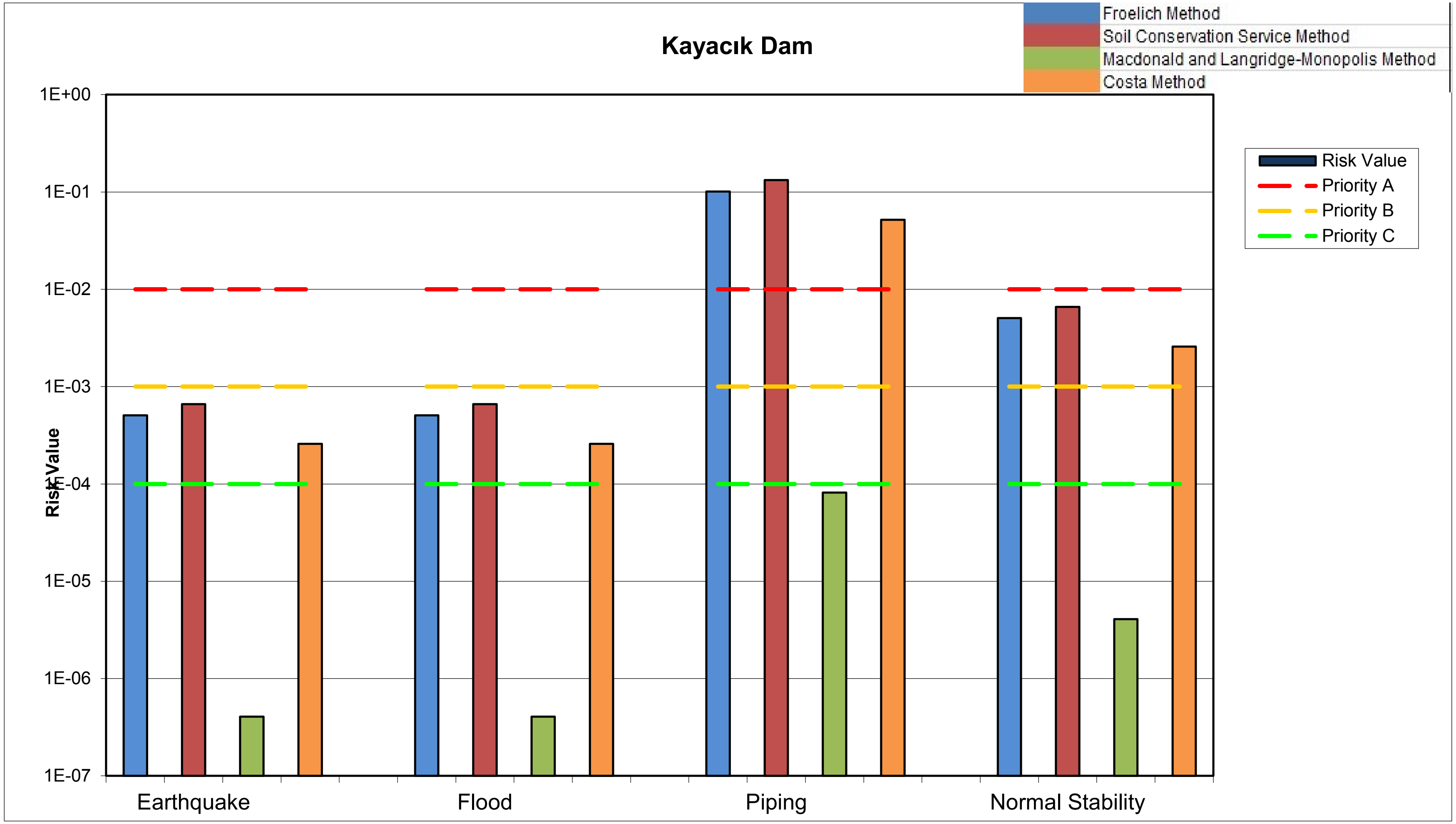



Figure 6-13 Comparison of Froelich, Soil Conservation Service, Macdonal & Langridge-Monopolis and Costa Methods for Kayacık Dam

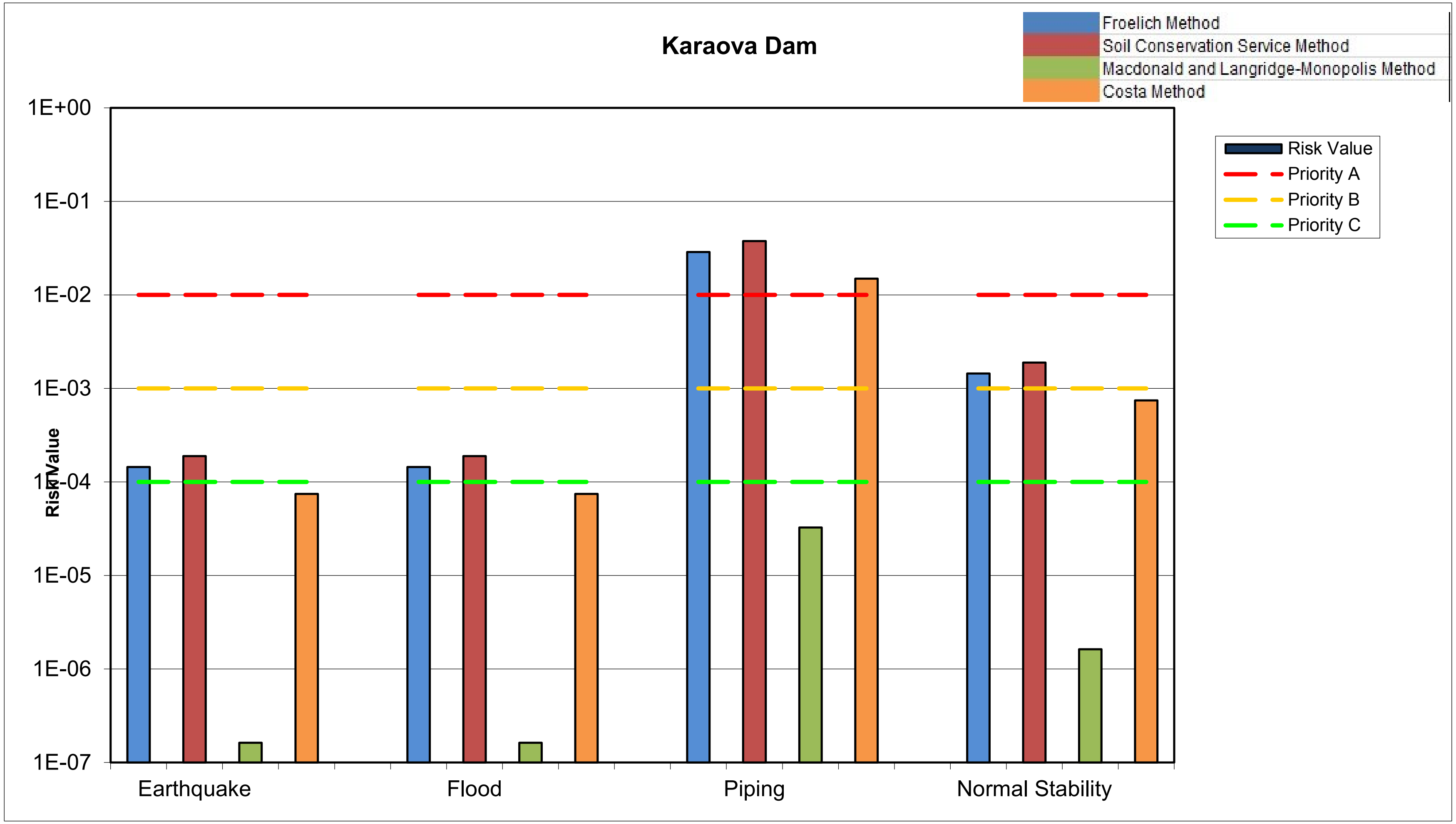



Figure 6-14 Comparison of Froelich, Soil Conservation Service, Macdonal & Langridge-Monopolis and Costa Methods for Karaova

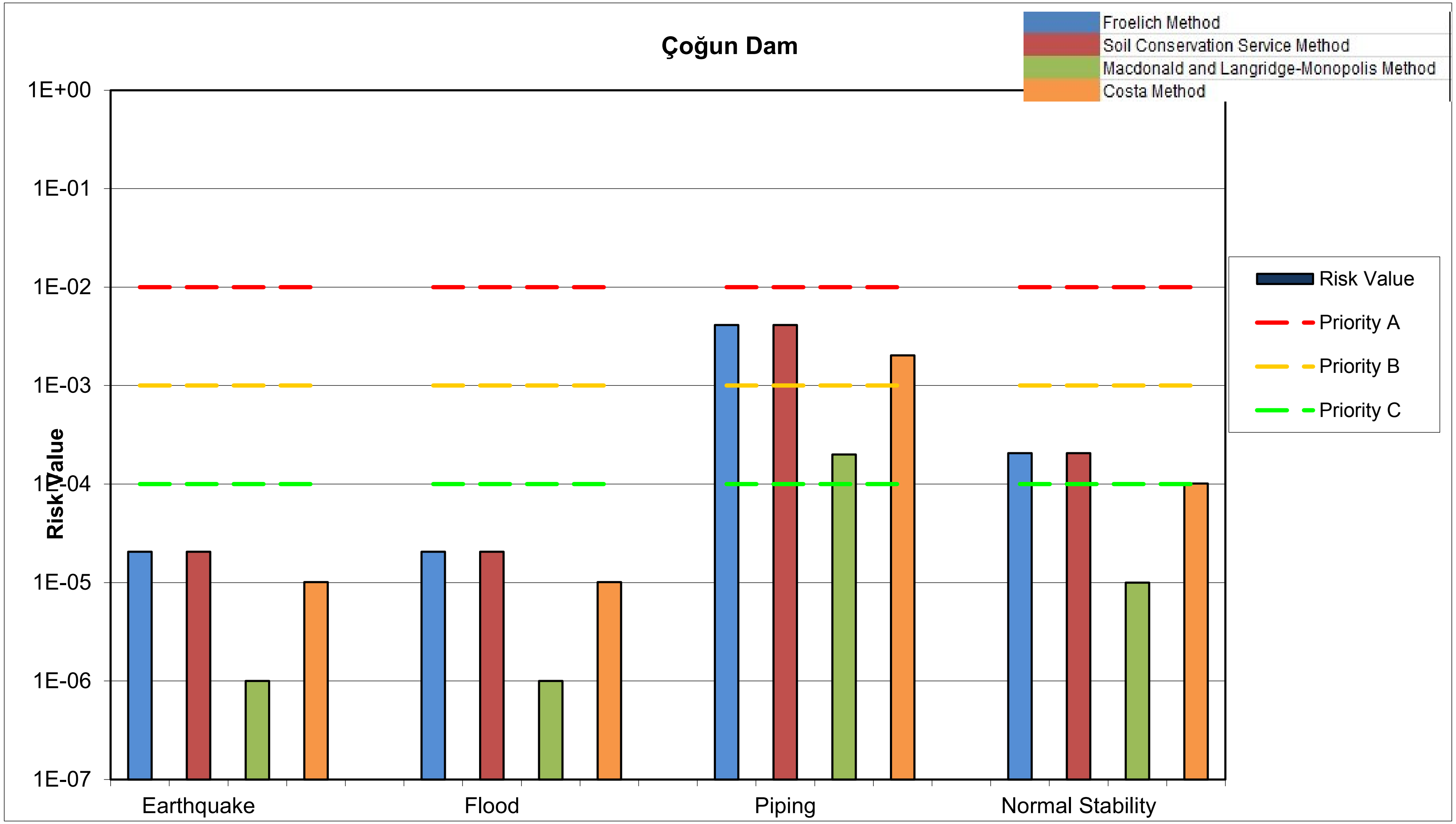



Figure 6-15 Comparison of Froelich, Soil Conservation Service, Macdonal & Langridge-Monopolis and Costa Methods for Çoğun Dam

# CHAPTER 7

# 7 CONCLUSIONS AND SUGGESTION FOR FURTHER RESEARCH

## 7.1 Conclusions

In this study, the use of a Risk Anaysis Tool was investigated. Three case studies were carried out on three existing earthfill dams in Turkey. All the dams the dams are earthfill type, since the proposed tool is capable of analyzing the risk parameters earthfill dams.

The research shows that risk analysis of existing dams is important for public safety. Building a dam in a river will change biology and ecology of the environment. Failure of a dam can be catastrophic which means dam failure can cause loss of life and money. Different failure modes for dams are discussed in this study.

For risk analysis Fema Risk tool was used which was created by UTAH State University for Federal Emergency Management Agency (Fema). This tool uses main dam characteristics and evaluates risk value for main failure modes such as earthquake, flood, piping and normal stability.

A modified extension to the standard risk tool (MRT) was also developed in this study. Empirical methods such as Froelich Method, Soil Conservation Service Method, Macdonald and Langridge-Monopolis method and Costa Method were added to the standard Risk Tool for calculating peak breach discharge. Other important breach parameters such as failure time, breach width and breach side slope were added.

In this study, risk assessment of three dams in Turkey has been made by using modified risk analysis software. New added methods are used for calculations. Result graphics are discussed for each method and recommendations for failure modes were given.

Unfortunately, all the three existing dams failed based on different risk and failure modes identified in the proposed MRT. Also, according to the risk and failure values of each case study, useful and emergent actions were recommended. The results were presented in graphical and tabular forms, and discussed based on each method for the three dam case studies.

## 7.2 Suggestion for Further Research

In this study three earth-fill dams from Turkey are used for case studies. A possible further extension of this tool can contain different types of dams and number of case studies can be improved.

Additional number of case studies will surely improve the projection capability of the proposed tool.

A guideline for risk analysis of dams should be developed by the national institutes suh as DSİ. As such a guideline is developed, regulations in this guideline could be adapted to the liabrary of the proposed MRT. More user friendly software may be developed so that more engineers can use this software easily.

A possible modification to the proposed tool might be adaptation of a more user-friendly graphical user interface based on Visual Basic macros.

People who live in downstream of dams are called population at risk. Emergency Action Plans must contain dam break maps so that the threatened areas could be in danger should be estimated easily. During a failure or early warning systems can be developed for these areas under dam breach threat.

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