FLOODING RISK ASSESSEMENT OF DAMS

A

MAJOR PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degree of

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IN

CIVIL ENGINEERING

Under the supervision of

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MAY, 2023

DECLARATION

I hereby declare that the work presented in the Project report entitled "**FLOODING RISK ASSESEMENT OF DAMS**" submitted for partial fulfillment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Dr. Sugandha Singh**. This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled "**FLOODING RISK ASSESMENT OF DAMS**" in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Shashwat Nandan Sharma (201614)** and **Saurabh Kharyal (201620)** during a period from June 2023 to May 2024 under the supervision of **Dr. Sugandha Singh,** Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

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ABSTRACT

Even while engineering expertise and construction quality have increased the safety of dams, there is no absolute guarantee against danger, and accidents can still happen as a result of human error, natural disasters, aging dams, or weakening of the dam. Dam-break flood risk management is supported and encouraged by several modern safety laws and technical guidelines, which is a significant contribution to both the preservation of the ecosystem and the public's safety in the downstream valleys. In dam-break risk management, there are two key stages: risk assessment to anticipate losses or damages and their likelihood, and mitigation strategy selection when remaining risks cannot be tolerated. The primary implications of a dam failure are estimated, the relevance of the flood hazard is assessed, and the size of the flood hazard is defined by dam-break risk assessment. In order to analyse this kind of risk, it is typically required to integrate numerical dam-break flood simulations to estimate possible damages and dam reliability analysis to determine the chance of dam collapse. Through flood modelling, the consequences can be predicted, allowing for the identification of flood-prone locations, the path and amount of the flood, and an assessment of valley vulnerabilities, losses, and damages. The goal of hazard mitigation is to coordinate the preventative measures, such as emergency preparedness plans and safety control regulations, that will be put into place in the downstream valley and at the dam site. Dam safety monitoring, disaster readiness and planning, early warning systems, and rescue and relief efforts for after-event actions are among the concerns that need to be addressed.

Keywords*: Flash floods, Dam failure, Vulnerability, Hazard and risk assessment.*

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LIST OF ACRONYMS & ABBREVIATIONS

CFRD	Concrete-face Rockfill Dams
FF	Flash Flood
FFG	Flash Flood Guidance

CHAPTER 1 - INTRODUCTION

1.1.General

Dams play a crucial role in managing rivers and water resources. They are often built to control natural floodplains of lakes and rivers. Hydrologists may intentionally flood certain areas to prevent damage to the dam or to increase water supply for agriculture, industry, or consumer use. However, balancing water storage for various purposes while preventing floods is a challenge faced by dam managers. Regular monitoring systems and accurate data are essential to better understand dams' impact on floods.

1.2.Need for study

Studying flooding risks associated with dams is imperative for safeguarding lives, ecosystems, and infrastructure. Firstly, it ensures a comprehensive understanding of potential hazards, including factors like extreme weather events, upstream development, and reservoir capacity. This knowledge aids in formulating robust emergency preparedness plans and evacuation strategies.

Secondly, a thorough assessment of flooding risks allows for the implementation of effective mitigation measures, such as improved dam design, early warning systems, and reservoir management protocols.

Lastly, studying these risks contributes to sustainable water resource management, balancing the need for reservoir storage with the imperative to prevent catastrophic dam failures, reinforcing the importance of informed decision-making in dam-related projects. Following graph shows the number of floods is maximum in Asia as compared to other continents

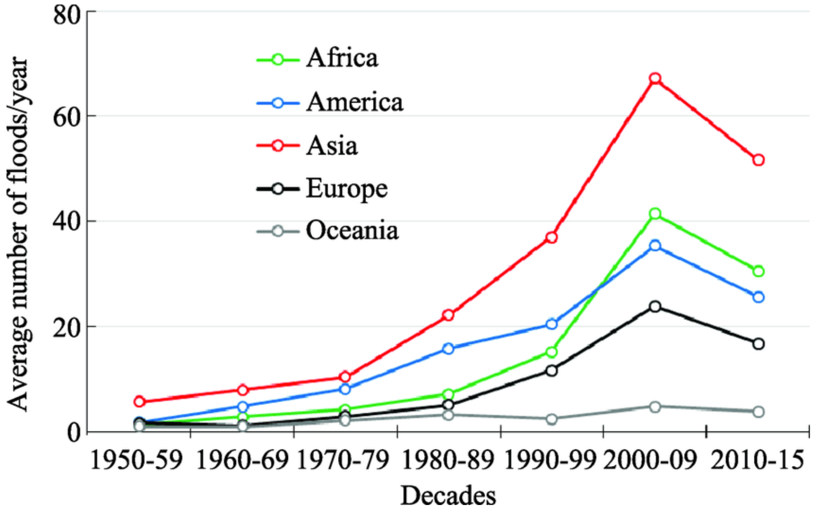

Fig 1.1: *Overview of floods per year all over the world from 1950-2015*

(Source: Wikipedia)

Following graph shows that in Asia itself, most flood prone region as India is a peninsular country which is surrounded by the Indian Ocean, Arabian sea and Bay of Bengal and hence, experiences significant maritime influence. These oceans impact the country's climate, monsoons, and trade, emphasizing the interconnectedness of India's geography and marine environments.

A lot of perennial river flow in India due to the Himalayas. This geographical placement makes the country prone to floods.

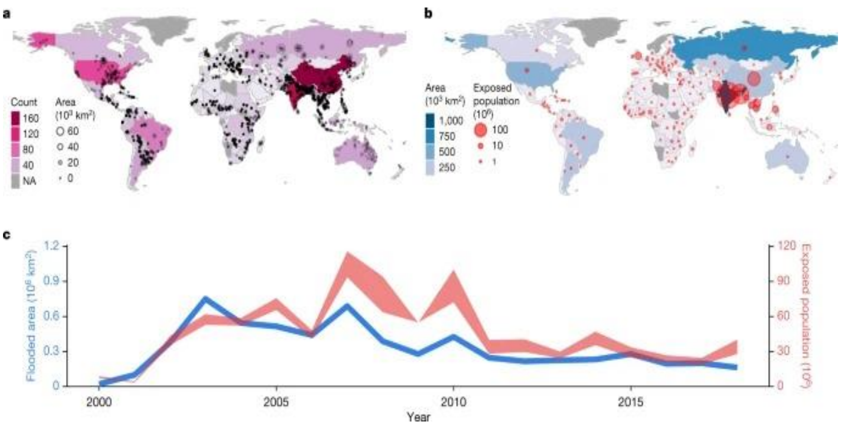

Fig 1.2: *Overview of most flood prone regions all over the world from 2000-2015*

(Source: Wikipedia)

In recent years, floods in India have unleashed a devastating menace, claiming lives, displacing communities, and causing extensive damage to infrastructure.

The escalating frequency and severity underscore the urgent need for comprehensive flood management strategies and sustainable development practices to mitigate the profound impact on both human lives and the environment.

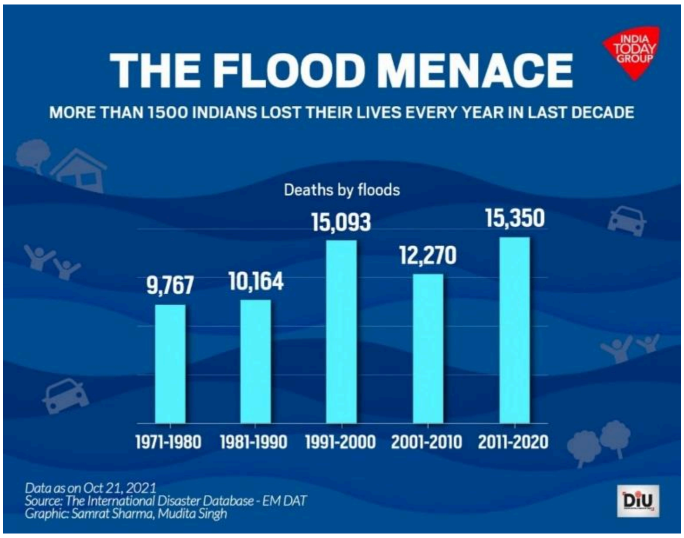

Fig 1.3: *Flood menace in India over 1971- 2020*

(Source: Wikipedia)

1.3. Types of dams in Himachal

Gravity Dams:

Gravity dams are constructed to harness water resources for hydroelectric power generation and water storage. Their design utilizes the dam's own weight and gravity to counteract the force of water, ensuring stability. Built from materials like concrete, gravity dams are ideal for locations with strong foundations. They efficiently store and release water, supporting irrigation, flood control, and sustainable energy production.

Bhakra Nangal *Dam* - It is a concrete gravity dam on the Satluj River Bhakra in Bhakra Village near Bilaspur in Bilaspur district, Himachal Pradesh in northern India

Fig 1.4: *Bhakra Nangal Dam*

(Source: Wikipedia)

Arch Dams:

Arch dams are built to utilize the arch shape, with the curved structure directing water pressure into the abutments. This design efficiently withstands the force of water. Typically made of concrete, arch dams are suitable for narrow valleys where the abutments can support the horizontal thrust.

They are commonly employed in hydroelectric projects, providing a combination of structural strength and efficient use of materials to store and regulate water.

Nathpa Jhakri Dam – Situated on the Satluj River, it is an arch dam that supports a hydroelectric project, providing substantial power to the region.

Fig 1.5: *Nathpa Jhakri Dam*

(Source: energy.economictimes.indiatimes)

Earth-fill Dams:

Earth fill dams, constructed with compacted earth or rock, are versatile and cost-effective solutions for water storage and flood control. They rely on natural materials, often featuring impermeable cores, and are strategically layered and compacted for stability, making them essential for sustainable water resource management in various environments.

Pandoh Dam - An earth-fill dam on the Beas River, it serves the purpose of diverting water for hydroelectric power generation.

Fig 1.6: *Pandoh Dam*

(Source: trawell.inhimachalmandipandoh-dam)

Rockfill Dams:

Rockfill dams are built using a combination of rock fragments and soil. Their construction involves placing these materials in layers, compacting them to create a stable structure. These dams are ideal for locations where solid bedrock is not available. They provide a flexible and cost-effective solution for water storage, flood control, and energy generation, adapting well to diverse terrains and foundation conditions.

Chamera Dam – It impounds the River Ravi and supports the hydroelectricity project in the region. It is located near the town of Dalhousie, in the Chamba district in the state of Himachal Pradesh in India. The reservoir of the dam is the Chamera Lake. Large part of its reservoir lies in Salooni sub-division of Chamba.

Fig 1.7: *Chamera Dam*

(Source: Wikipedia)

Concrete-face Rockfill Dams (CFRD):

It combines the principles of rockfill and concrete dams. A core of compacted rockfill is constructed, and its upstream face is covered with a concrete layer. This design enhances structural integrity, leveraging the strength of both materials. CFRDs are used for water storage and hydropower, offering a balance between the stability of concrete and the cost-effectiveness of rockfill construction. They're especially suitable for sites with abundant rock but where a solid concrete dam might be too costly.

Baspa Dam - Part of the Baspa Hydroelectric Project, it is a CFRD located on the Baspa River, ensuring efficient water storage and power generation.

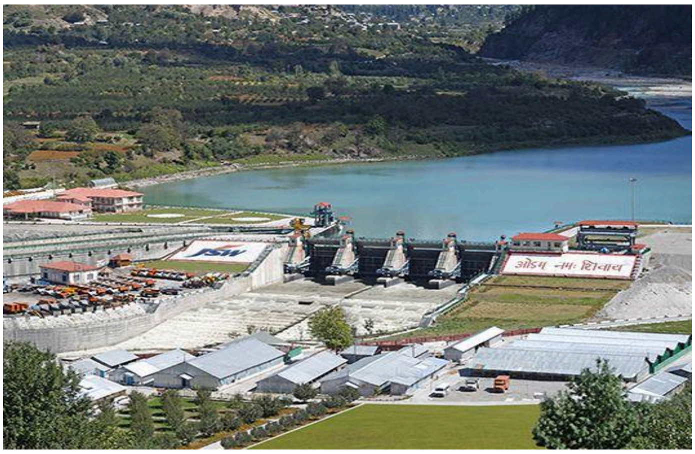

Fig 1.8: *Baspa Dam*

(Source: jsw.inenergy)

Masonry Dams:

Masonry dams are constructed using bricks, stones, or concrete blocks bonded together by mortar. These dams exhibit durability and resistance to weathering, making them suitable for water storage and irrigation. While less common than other dam types, masonry dams can be aesthetically pleasing and are historically significant. Their construction involves carefully arranging and securing masonry units, creating a solid and stable barrier for water containment in various geographical settings.

Maharana Pratap Sagar Dam / Pong Dam - Built across the Beas River, it is a masonry dam serving irrigation and power generation purposes.

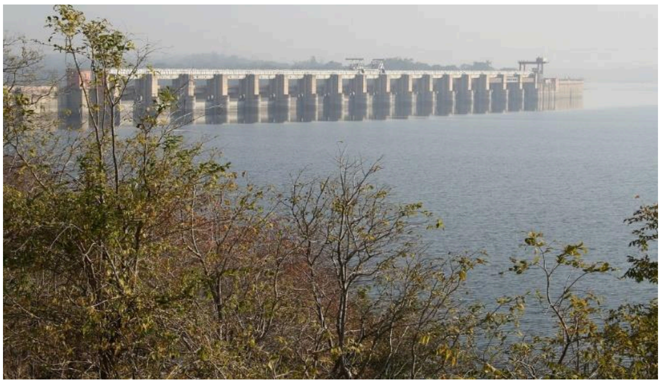

Fig 1.9: *Maharana Pratap Sagar Dam*

(Source: Wikipedia)

1.4.Major Types of Floods

Riverine Floods

Riverine floods occur when rivers overflow their banks, inundating adjacent areas. Typically triggered by heavy rainfall, snowmelt, or a combination of both, these floods pose substantial risks to communities, agriculture, and infrastructure located in floodplains. The excess water exceeds the river's capacity, leading to widespread flooding. Effective floodplain management and early warning systems are crucial to mitigate the impact of riverine floods and protect lives and property.

Fig 1.10: *(a) Rain flood in Paznaun, Tyrol, August, 2005*

(b) Ice jam flood in Vienna, Austria, March, 1830

(Source: researchgate)

Flash Floods

Flash floods are sudden, intense floods characterized by a rapid onset of high-water levels. Typically caused by heavy rainfall, dam breaks, or sudden release of water, flash floods can occur with little warning. The swift and powerful flow of water poses immediate threats to life, property, and infrastructure.

Flash floods are common in urban areas with poor drainage systems and steep terrains, emphasizing the need for robust early warning systems and community preparedness to minimize their devastating impact.

Fig 1.11: *Flash flooding at Erftstadt-Blessem, Germany, July 16, 2021*

(Source: sentinelcolorado.com)

Urban Flooding:

Urban flooding refers to the inundation of urban areas due to excessive rainfall, inadequate drainage systems, or the overflow of water bodies. Impervious surfaces, such as pavement and buildings, hinder water absorption, causing rapid runoff and increased vulnerability to flooding.

Urbanization often leads to altered land use and insufficient stormwater management, exacerbating the risk. Urban flooding can result in property damage, traffic disruptions, and health hazards. Effective urban planning, improved drainage infrastructure, and sustainable land-use practices are essential for mitigating the impact of urban flooding.

Fig 1.12: *Flooding in Bom Princípio of the Caí River in Brazil during July 2020*

(Source: Wikipedia)

Coastal Floods:

Coastal flooding occurs when seawater inundates coastal areas, often due to storm surges, high tides, or tropical cyclones. The combination of strong winds and low atmospheric pressure causes a temporary rise in sea level, flooding low-lying coastal regions. Coastal flooding poses significant threats to communities, ecosystems, and infrastructure, impacting both human and marine environments. Rising sea levels due to climate change further exacerbate this risk.

Fig 1.13: *Coastal flooding during Hurricane Lili in 2002 on Louisiana Highway*

(Source: Wikipedia)

1.5. Main Causes of Dam Failure

Dam failures are catastrophic events that can have devastating impacts on human life, property, and the environment. Understanding the primary causes of dam failures is essential for improving design, construction, maintenance practices, and ensuring the safety and functionality of these critical structures. Here are the main causes of dam failures:

1. Hydrological Failures

Overtopping: One of the most common causes of dam failure is overtopping, which occurs when water flows over the top of the dam. This can be caused by extreme weather events, such as heavy rainfall or rapid snowmelt, which exceed the dam's storage capacity. Inadequate spillway design or blocked spillways can exacerbate this issue, leading to erosion of the dam crest and eventual structural collapse.

2. Structural Failures

Foundation Defects: The stability of a dam largely depends on the strength and integrity of its foundation. Defects in the foundation, such as poor geological conditions, uneven settling, or inadequate preparation, can lead to structural instability and failure.

Construction Defects: Improper construction practices, such as using substandard materials, inadequate compaction of fill material, or poor-quality control, can compromise the structural integrity of a dam. Errors during construction, including design flaws not addressed during the building phase, can also lead to failure.

Seepage: Uncontrolled seepage through the dam body or foundation can lead to internal erosion, known as piping. If not detected and managed, seepage can create channels within the dam, leading to progressive erosion and eventual failure.

3. Operational Failures

Poor Maintenance: Lack of regular maintenance and inspection can result in undetected issues such as cracks, leaks, or mechanical failures. Over time, these issues can grow and compromise the dam's integrity. Proper maintenance routines and timely repairs are crucial for the long-term safety of a dam.

Human Error: Operational errors, such as incorrect gate operations, inadequate emergency response, or failure to implement safety protocols, can contribute to dam failure. Proper training and adherence to operational guidelines are essential to prevent such errors.

4. Geotechnical Failures

Slope Instability: Dams are particularly vulnerable to slope instability, which can be caused by factors like excessive rainfall, seismic activity, or poor construction practices. Landslides or slumping of the dam slopes can reduce the stability of the structure and lead to failure.

Earthquakes: Seismic activity can induce severe stress on dam structures, particularly in regions prone to earthquakes. Ground shaking can cause cracks, settlement, and displacement of dam materials, leading to structural failure if the dam is not designed to withstand seismic forces.

5. Environmental and External Factors

Extreme Weather Events: Climate change has increased the frequency and intensity of extreme weather events, such as intense storms and heavy rainfall. These events can exceed the design capacity of dams, leading to overtopping and subsequent failure.

Animal Activity: Burrowing animals like rodents can create tunnels within the dam structure, which can lead to increased seepage and internal erosion. Regular monitoring and control measures are necessary to mitigate this risk.

Vegetation: The growth of large trees and shrubs on a dam can pose a risk as their root systems can penetrate the dam structure, causing cracks and increasing seepage. Additionally, decaying roots can create pathways for water to flow, further weakening the dam.

6. Human-Induced Factors

Vandalism and Terrorism: Dams can be targets for vandalism or terrorism, which can lead to intentional damage and potential failure. Security measures are essential to protect these structures from deliberate attacks.

Changes in Land Use: Urbanization and changes in land use upstream of the dam can alter the hydrology of the area, increasing runoff and sedimentation. This can reduce the storage capacity and efficiency of the dam, increasing the risk of overtopping and failure.

Fig 1.14: *Heavy rain cause partial collapse of Norwegian dam*

(Source: geoengineer.org)

1.6.Flash Floods Due to Dam Failure

Flash flooding resulting from dam failure is a critical and hazardous event:

- Dam failure leads to an abrupt release of water, causing an immediate and rapid rise in downstream water levels.
- The unleashed water travels at high speeds, amplifying the force and impact of the flash flood downstream.
- Flash floods from dam failure offer minimal warning, leaving little time for affected communities to evacuate or prepare.
- Low-lying areas downstream are at high risk, with flash floods quickly inundating homes, infrastructure, and agricultural land.
- Flash flooding poses a direct threat to human lives, making swift and efficient emergency response crucial to minimizing casualties and damages.

Fig 1.15: *Teton Dam Flood - Newdale (June 5, 1976)*

(Source: WaterArchives.org)

CHAPTER 2 – LITERATURE SUMMARY

2.1. Flash Flood Disaster in Uttarakhand

Ravindra K. Pande et al. examines the most important issue confronting Uttarakhand that is cloud bursts, which cause flash floods. Flash flood tragedies are becoming more and more common as the world's population and habitation increases. The majority of settlements in Uttarakhand's hilly terrain have witnessed flash flooding as a result of heavy rains and thunderstorms. In the Okhimath area, there were two significant landslide incidents on August 11–12 and August 18–19, 1998. One of the most catastrophic days in the history of the area was marked by these slide episodes. Most of the occupants were stuck inside their homes because to the intense rains that had been raining for two or three days before the slide incidents.

Most locals fled to safer areas when the first slide happened on August 11–12, but some lost both their homes and their lives. New slides were created in the area by the intense rains that fell on August 18–19; one of the more destructive slides happened on the left bank of the Madhmaheshwar river. On August 19, 1998, from 2 a.m. to 2 p.m., this slide totally destroyed the villages of Bhenti and Paundar and stopped the Madhmaheshwar River's flow for 12 hours. Massive Devastation followed downstream. It was estimated that 422 cattle, 101 human lives, and Rs 41 million in property were lost in this disaster.

Uttrakhand has been facing flash floods for a long period of time as shown in the below table

Table 1. *Causalities in Flash Floods along the years*

Name of incident	District	Year	Casualities
Malpa	Pithoragarh	1998	300
Phata and Byung Gad	Rudraprayag	2001	21
Burakedar	Tehri	2002	28
Khetgaon	Pithoragarh	2002	5
Amparav	Nainital	2004	3
Govindghat	Chamoli	2005	11

Causes of flash floods in Uttarakhand:

- **Cloudburst:**

It is a significant factor in Uttarakhand's flash floods. It is a brief period of intense rainfall that quickly increases the seasonal streams' discharge. These streams' channels are unable to handle the discharge, which results in damage. At the slope break, the channel is regularly clogged with debris, which diverts the stream and catches individuals in safer areas off guard.

- **Landslide dam failure:**

Landslides frequently dam streams and rivers; landslide dam failure generates flash floods in downstream locations; and there were 12 occurrences of landslide dam breaches recorded in India between 1941 and 1945. Mandakini blockades, 1857; Alaknanda blockade, 1868; Birahi blockade, 1979 Alaknanda valley tragedy in 1894; Alaknanda disaster in 1970; Blockade of Madhyamaheshwar in 1998.

- **Sudden discharge or breach from man-made reservoirs.**
- **Glacial Lake breaches.**
- **Landslide into the reservoir.**
- **Melting of glaciers unexpectedly.**

Although it is impossible to prevent cloud bursts and flash floods, we may considerably lessen their impact by taking certain proactive measures. Cloud bursts/flash floods result in the loss of property, life, and the mental health of people, ultimately slowing the pace of development. If disasters cannot be avoided, disaster-related losses must be reduced.

2.2. Flash Flood Criterion

F. Lempérière et al. used the "flash flood guidance" (FFG) method which is a popular technique to flash flood warnings, in which flood warnings are only sent in the event of preventive soil moisture levels and rainfall forecast information. The technique compares the critical rainfall values with the accumulated (forecasted) rainfall in a straightforward manner. Flood warnings are issued when these rainfall thresholds which are computed once based on catchment characteristics are exceeded for the particular rain forecast.

Since flash floods frequently occur during extremely intense rainfall events that last only a short while, the FFG technique only used rainfall-runoff models for individual occurrences. As a result, the number of available events is restricted. The calibration and validation procedures took into consideration the soil moisture levels before to the incident. Nevertheless, the catchment's border circumstances for varying seasons and lengths of time were disregarded.

This study made use of the BROOK90 model, which is comparatively versatile and easy to apply in both gauged and ungauged catchments. This study explores the possible application of the BROOK90 model as a tool for FFG and suggests a modified technique of FFG that takes into consideration the shortcomings of earlier studies.

With sufficient precipitation, the Wernersbach watershed only needed 11.5 to 13.5 mm of precipitation in an hour to achieve the flooding stage, as this model successfully projected. With a prediction accuracy of more than 91%, this model accurately anticipated the critical moisture condition in the catchment of 40 chosen occurrences throughout the research period using rain gauge data.

Rico Kronenberg et al. did research on extreme flood evaluation which has been the subject of numerous researches, particularly in the past, employing a variety of ideas and techniques. The outcomes differ depending on the approach taken and who applies it; a considerable proportion of dam failures have been connected to severe underestimations. Thus, it would appear prudent to employ multiple methods to prevent notable underestimations by a single approach. If one refers to severe global statistics on rainfall and floods based on catchment area, there may be a range of magnitudes for extreme floods; Chinese data (Table 1) are extremely near to the global maximum.

- Table 2: *Chinese rainfall data (mm)*

Duration	Area (km^2)							
	Point	100	300	1 000	3 000	10 000	30 000	100 000
1 h	401	185	145	107	41			
3 h	550	447	399	297	120			
6 h	840	723	643	503	360	127		
12 h	1 400	1 050	854	675	570	212		
24 h	1 673	1 200	1 150	1 060	830	435	306	155
3 d	2 749	1 554	1 460	1 350	1 080	940	715	420
7 d	2 749	1 805	1 720	1 573	1 350	1 200	960	570

- Table 3: *World maximal floods registered*

Catchment (km^2)	1	10	100	1 000
Flood peak (m^3·s^{-1})	100	700	4 000	15 000
Flood peak (km^{-2})	100	70	40	15

Thus, a crucial component of risk is the overtopping time. There have been reports of 70 major dams operating during floods failing. Although many may not have been documented, this figure most likely represents the vast majority of severe reservoir failures or failures that resulted in several fatalities. Thus, for an average life of 50 years, the failure rate has been 0.3% or 0.4%, corresponding to an average yearly probability of roughly 6 × 10-5. For dams taller than thirty meters, this rate is roughly the same.

2.3.Flash Floods in Himachal

Vinod Kumar et al. did research on the two main problems faced by Himachal Pradesh's hilly terrain namely bank erosion brought on by steep river slopes and flash floods. Excessive river flows caused by heavy rainfall are not unusual. Consequently, reports of embankment breaches and damage to various utilities, including dwellings and irrigation/flood control systems, have been made.

The Satluj and its tributaries, including Spiti, Sangle Khad, Ali Khad, Gambhar Khad, Sirs Khad, and Swan Khad, are significant rivers for flood damage.
- The River Beas and its tributaries, Sukheti Khad and Uru.
- Yamuna River and its tributaries, Pabbar Khad, Giri, and Bata; River Ravi and its

tributaries, Sivi, etc. In Satluj, flash floods happened in 2000 during the wet season.

On the night of July 31, 2000, a massive natural disaster struck the Satluj Valley. It caused the Satluj River's water level to rise to an unprecedented degree, spanning over 250 kilometers from the Tibetan plateau to Govindsagar Lake. There was an increase in water levels of up to 60 feet above normal, according to witnesses. The quick rise and breach of the Parechu River in Chinese territory resulted in yet another huge natural disaster that struck the Satluj valley on June 26, 2005. Over the whole length of National Highway 22, it caused an extraordinary spike in the water level of the Satluj River, which originates in the Tibetan Plateau.

In certain places, the water level increased by up to 15 meters. About 350 kilometers of road from Samdo to Govindsagar/Bhakra Dam sustained significant damage as a result of it. Highways and bridges sustained major damage as a result of it. Storage reservoirs, flood embankments, drainage channels, anti-erosion works, channel enhancement works, detention basins, and other non-structural measures, like flood forecasting, flood plain zoning, flood proofing, disaster preparedness, etc., were put in place to make sure this didn't happen again in the future.

Main mitigation strategies discussed in the paper are:

Mapping of the flood prone areas

Historical records include information about the locations that have experienced flooding, as well as the duration and coverage of those events. The basic map is supplemented with additional maps and data to provide a more complete image of the flood plain. Based on the previously recorded water level heights, a warning could be issued in the event of a potential threat.

Land use control

Significant development in areas in which the flooding occurs regularly should not be allowed. It is ideal to construct significant buildings in safe areas. It is possible to create water-holding zones in lakes, ponds, and low-lying areas of cities. It is better to reduce the density in areas where neighborhoods are going to be built.

Construction of engineered structures

Structures in floodplains are being reinforced to resist seepage and storm surges. Structures ought to be built at an elevation. The goal of flood control is to lessen flood damage. Flood Reduction is one way to do this, as it lowers runoff through practices including vegetation protection, reforestation, and clearing debris from streams and other water-holding areas.

One of the states in India most vulnerable to flooding is Himachal Pradesh. Previous experiences in Himachal Pradesh have demonstrated that a number of desirable disaster mitigation measures could reduce our losses due to flooding. When it comes to flood forecasting, Himachal Pradesh has led the way. Through extensive experience and experimentation, the state has developed sound policy approaches.

Vikram Gupta et al. highlights the severe consequences of urban development that constricts natural drainage systems. The flash flood, triggered by intense rainfall, caused significant damage to infrastructure, including roads, buildings, and vehicles, and led to loss of life and livelihoods. The study emphasizes that the rapid and unplanned urbanization in the region has exacerbated the natural vulnerability to such events by blocking and narrowing natural drainage channels with construction and debris.

Key findings reveal that poor urban planning, deforestation, and encroachment on riverbanks and drainage pathways are major factors contributing to the severity of the flood. The paper calls for urgent policy measures to regulate construction activities, restore natural drainage systems, and implement sustainable urban planning practices. It also suggests enhancing community awareness and preparedness to mitigate the impacts of such disasters. The case study serves as a warning to other regions facing similar urban pressures, underlining the importance of preserving natural watercourses and implementing comprehensive flood management strategies to prevent future catastrophes.

Hanyu Li et al. performs a seepage analysis of a clay core wall dam utilizing the finite element method in ABAQUS software. It aims to evaluate seepage characteristics and potential failure mechanisms. The study focuses on the impact of various factors such as hydraulic gradients, material properties, and boundary conditions on seepage behavior. Through numerical simulations, the authors investigate seepage patterns, flow velocities, and pressure distributions within the dam structure. Results indicate the significance of proper material characterization and boundary condition selection in accurately predicting seepage behavior. The analysis highlights the importance of understanding seepage mechanisms for ensuring the stability and safety of clay core wall dams. This study contributes valuable insights for engineers and researchers involved in dam design and risk assessment, ultimately aiding in the development of effective strategies for mitigating seepage-related risks.

Hajar Nasiri et al. examines four categories of the more popular approaches of vulnerability assessment. One of the key elements of risk management and flood damage assessment is flood vulnerability. Given that vulnerability has been identified as the primary cause of disasters, it would seem vital to expand our understanding of vulnerability. Previous research has suggested that vulnerability assessment techniques can be divided into four main types, which are as follows:

The vulnerability indicators approach, which was modified to make advantage of the data that was provided in order to provide a logical picture of the location vulnerability. This approach is popular among flood vulnerability researchers and policy makers because it provides a clear picture of vulnerability across space, which can be used to prioritize actions and plan for risk response in a given area.

Method of vulnerability curves. Reliability between flood risk and vulnerable elements can be examined using empirical damage or fragility curves. This method is usually limited to homes in a certain location because it is mostly based on data from case studies that have been thoroughly documented.

The disaster loss data approach. This approach is based on gathering data from actual flood hazards and using it as a guide for future disasters. Although this procedure is straightforward, it may not be entirely accurate. The results of these methods should be handled cautiously due to inconsistently recorded data.

Approaches to modelling. Computer models can use the hydrograph's frequency, magnitude, and form to assess the depth, elevation, and velocity of a flood. One-dimensional (1D) or two-dimensional (2D) models that are based on solutions of the complete or approximative forms of the surface water equations are commonly used to calculate flood inundation. For these methods to be accurate, comprehensive information regarding the topography, hydrography, and economy of the studied region is required.

Shivakumar S. Athani et al. explores the application of the finite element method (FEM) in evaluating the performance and safety of earth dams. The study focuses on two critical aspects: seepage analysis and stability analysis, both of which are essential for the integrity and functionality of earth dams.

In seepage analysis, the FEM is employed to model the flow of water through the dam structure and its foundation. This analysis helps in identifying potential seepage paths, calculating seepage rates, and assessing the effectiveness of drainage systems. The study highlights the importance of controlling seepage to prevent issues such as internal erosion, piping, and excessive water loss, which can compromise the dam's stability.

For stability analysis, the FEM is used to evaluate the structural stability of the dam under various loading conditions, including the effects of water pressure, gravity, and seismic forces. The research emphasizes the need to ensure that the dam can withstand these forces without experiencing failure modes like slope instability or structural collapse.

The paper concludes that the finite element method provides a robust and precise tool for the comprehensive analysis of earth dams. It recommends its use for the design, evaluation, and maintenance of these structures to ensure their safety and longevity.

S. Ohadi et al. investigates the application of the finite element method (FEM) to analyze seepage behavior in earth dams, focusing on both the foundation and the dam body. Seepage, the movement of water through soil pores, is a critical factor influencing the stability and safety of earth dams. Uncontrolled seepage can lead to issues like internal erosion, piping, and eventual dam failure. This research aims to provide a detailed understanding of seepage patterns and rates, thereby enhancing dam safety and design efficiency.

The study begins with a comprehensive overview of seepage phenomena in earth dams, including the factors affecting seepage such as soil permeability, dam geometry, and hydraulic gradients. It then introduces the finite element method as a powerful numerical tool for modeling complex seepage problems. FEM allows for detailed simulations that account for heterogeneous material properties, complex boundary conditions, and variable water levels.

Key aspects of the modeling process are detailed, including the discretization of the dam and its foundation into finite elements, the assignment of material properties, and the specification of boundary conditions. The research emphasizes the importance of accurate input data, such as soil permeability coefficients, which are critical for reliable simulation results.

The results of the FEM analysis are presented through various case studies, illustrating how seepage patterns develop in different dam configurations. These results highlight the areas within the dam and its foundation that are most susceptible to high seepage pressures. The study also discusses the effectiveness of different seepage control measures, such as cutoff walls and drainage blankets, by simulating their impact on seepage patterns.

One of the key findings of the paper is the identification of critical zones where seepage is most likely to initiate structural problems. By pinpointing these zones, the study provides valuable insights for the design and retrofitting of earth dams. Additionally, the paper underscores the benefits of using FEM for continuous monitoring and assessment, allowing for timely interventions to mitigate seepage-related risks.

In conclusion, the paper demonstrates that FEM is a robust and versatile tool for seepage analysis in earth dams. It provides engineers and dam designers with detailed insights into seepage behavior, helping to ensure the structural integrity and safety of earth dams. The study advocates for the widespread adoption of FEM in the routine analysis and design of earth dam projects.

Azhar Husain et al. addresses the essential task of determining the design flood for Kol Dam, vital for the dam's safety and efficient water resource management. The hydrometeorological method integrates meteorological data and hydrological models to forecast the maximum flood potential during extreme weather conditions.

The study begins by gathering extensive hydrometeorological data, including rainfall intensity, duration, and distribution patterns in the Kol Dam catchment area. This data is crucial for understanding the precipitation characteristics that could lead to significant flood events. Using this data, researchers develop and calibrate hydrological models to simulate the catchment's response to various rainfall scenarios.

Key elements of the approach include analyzing historical rainfall records and applying statistical methods to predict extreme rainfall events. These predictions are then used in hydrological models to estimate peak discharge and flood volume. The study also takes into account the topography, soil characteristics, and land use patterns of the catchment area, which affect runoff and flood potential.

The analysis results provide an estimate of the design flood, which is the maximum flood the Kol Dam is expected to safely manage. This estimation informs the structural requirements and spillway capacity of the dam, ensuring it can withstand extreme flood events without failure.

In summary, the paper shows that the hydrometeorological approach is a dependable method for estimating design floods. By combining meteorological and hydrological data, this method offers a comprehensive understanding of flood risks, enabling the optimal design and operation of dams for safety and efficiency.

A. C. Pandey et al. examines the susceptibility and risks associated with waterlogging and floods in the Indo-Gangetic Plain, a region crucial for India's agriculture and population density. The study aims to identify the area’s most vulnerable to these hazards and assess the potential impacts on communities, infrastructure, and agricultural productivity.

The research employs a combination of remote sensing data, geographic information systems (GIS), and field surveys to map and analyze the extent of waterlogging and flood-prone areas. Factors such as soil type, topography, rainfall patterns, and drainage conditions are considered to understand the underlying causes of these hazards.

Key findings indicate that the region's flat terrain, poor drainage infrastructure, and heavy monsoon rainfall contribute significantly to waterlogging and flooding. The study highlights those areas with high population density and intensive agriculture are particularly vulnerable, leading to substantial economic losses and adverse effects on livelihoods.

The paper also assesses the effectiveness of existing flood management and mitigation measures, identifying gaps and proposing improvements. Recommendations include enhancing drainage systems, adopting sustainable agricultural practices, and implementing early warning systems to reduce the impact of floods.

In conclusion, the need for a comprehensive approach to managing waterlogging and flood risks in the Indo-Gangetic Plain.

CHAPTER 3 – METHODOLOGY

3.1.Flow chart of Methodology

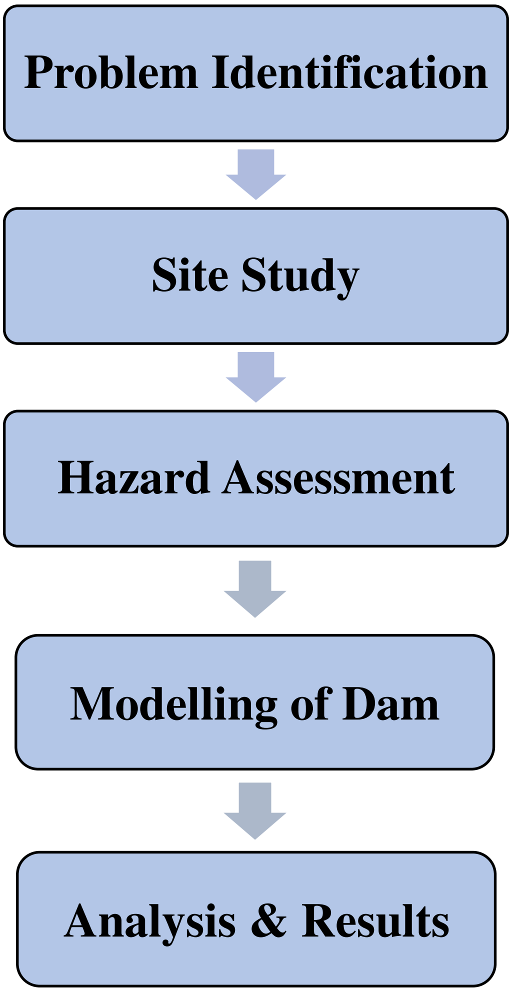

Fig 3.1: *Methodology of the Study*

3.2. Problem Identification

Contrary to common perception, hilly terrains can indeed be susceptible to flooding, and several factors contribute to this phenomenon such as:

Terrain Characteristics:

Steep slopes in hilly regions can accelerate the runoff of rainwater, causing flash floods. The fast flow of water downhill can lead to the rapid inundation of lower-lying areas.

Landslide-induced Flooding:

Heavy rainfall in hilly terrain may trigger landslides, blocking watercourses and creating temporary dams. When these dams breach, they release large volumes of water downstream, causing flooding.

Soil Saturation:

Hilly areas with limited soil permeability can experience rapid saturation during intense rainfall. This saturation reduces the soil's ability to absorb water, leading to surface runoff and increased flood risk.

High Intensity Rainfall:

Hilly regions often experience intense, localized rainfall. The combination of steep slopes and heavy rainfall can result in the quick accumulation of water, leading to flash floods and increased flood vulnerability.

Limited Floodplain Areas:

Hilly terrains may have limited flat or low-lying areas, which means there are fewer natural floodplains to absorb excess water. This lack of natural drainage exacerbates the risk of flooding.

Understanding these factors is crucial for effective flood risk management in hilly terrains. Implementing sustainable land-use practices, improving infrastructure resilience, and adopting early warning systems are essential components of mitigating flooding in such area

3.3. Critical Situation at the Koldam Power Station

Koldam situated in Bilaspur district of Himachal Pradesh is assessed for the flooding risk due to flash floods in this report.

This site was chosen due to the following 2 main reasons for the analysis:

- **On 18th August, 2019**

The highest rainfall of 252 mm was recorded in Bilaspur district, which was 2,586 per cent more than its normal level.

Due to this, the water level in the Satluj river rose drastically putting extra load on the dam (Koldam).

- **On 1st September, 2023**

Bilaspur, which received 597.2 mm rains against the normal of 316.8 -- an excess of 89 per cent.

Districts with highest rainfall in August

District	Normal rainfall	Actual rainfall	Departure
Bilaspur	316.8 mm	597.2 mm	89%
Mandi	395.3 mm	681.5 mm	72%
Solan	287.9 mm	466.1 mm	62%
Shimla	196.4 mm	253.3 mm	29%

Fig 3.2: *Districts of H.P. with highest rainfall in August, 2023*

(Source: Times of India - Sep 1, 2023)

3.4.Koldam Hydropower Station at Glance

Fig 3.3: *Koldam spillway in operation*

(Source: Wikipedia)

Location:

Located on the Sutlej River, upstream of the Dehar Power House, is the embankment dam known as Koldam Hydropower Station. The location is 18 km away from Bilaspur, close to Barmana in Himachal Pradesh, India, off the Chandigarh-Manali Highway (NH-21).

Fig 3.4: *Location of Koldam on map*

(Source: Google Maps)

Project details:

A 167-meter-tall rock and gravel fill clay core dam with a 474-meter-long and 14-meter-wide crest was built as part of the project. Moreover, it required building a downstream coffer dam and an upstream coffer dam with a maximum height of 73 meters, a crest length of 243.5 meters, and a crest width of 14 meters.

There are six 17.1-meter-wide and 17-meter-high radial gates on the left bank of the dam's chute-style spillway.

The surface powerhouse is equipped with four vertical Francis-type 200MW turbines, a 400kV conventional/surface switchyard, a 100m-long open-type tailrace canal, and a 144m hydraulic head. Two diversion tunnels, a pen stock, and an approach channel were built as ancillary project activities.

Transmission system & beneficiaries of the project:

A 400kV direct current (D/C) connection carries the Koldam hydroelectric power plant's output to the national grid. The state of Himachal Pradesh receives 15% of the power generated at bus-bar rate and 12% of it at no cost.

The project is also benefiting the states of Delhi, Haryana, Punjab, Rajasthan, Uttar Pradesh, Jammu & Kashmir, and Chandigarh in north India.

Catchment Area:

Fig 3.5: *Koldam Reservoir*

(Source: Wikipedia)

The Koldam Dam, located in Bilaspur district, Himachal Pradesh, India, has a catchment area spanning approximately 53770 Sq Km. This catchment area plays a crucial role in the dam's water storage capacity and the regulation of water flow for hydroelectric power generation.

3.5 Hazard & Risk Assessment

Hydrological Analysis:

Conduct comprehensive hydrological assessments to analyze river flow patterns, precipitation trends, and potential inflow scenarios, providing a basis for flood risk estimation.

Dam Break Analysis:

Perform dam break simulations to model potential scenarios and assess the downstream impact in the event of dam failure, enabling emergency response planning.

Topographical Mapping:

Utilize accurate topographical maps to understand the terrain, identify vulnerable areas, and assess the potential extent of flooding downstream.

Infrastructure Vulnerability Assessment:

Evaluate the vulnerability of critical infrastructure downstream, including residential areas, roads, and utilities, to estimate the potential socio-economic impact.

Climate Change Considerations:

Incorporate climate change projections into risk assessments to account for potential shifts in precipitation patterns and extreme weather events affecting flood risks.

Emergency Response Planning:

Develop and regularly update emergency response plans based on risk assessments, ensuring efficient evacuation routes, communication strategies, and coordination with relevant authorities.

Community Engagement:

Involve local communities in the risk assessment process to gather valuable insights, enhance awareness, and foster community resilience in the face of potential flooding events.

Continuous Monitoring:

Implement real-time monitoring systems to track dam conditions, river levels, and weather forecasts, facilitating timely risk assessments and immediate response measures.

Probabilistic Risk Assessment:

Use probabilistic models to assess the likelihood of different flood scenarios, incorporating uncertainties and enabling a more nuanced understanding of potential risks.

Regulatory Compliance:

Adhere to relevant regulatory standards and guidelines in the risk assessment process, ensuring that dams meet safety requirements and contribute to overall water resource management.

3.6 Rainfall Data (1990-2023) in mm

Table 4: *Rainfall data of Bilaspur district, H.P. (1990-2023)*

YEAR	MONSOON PERIOD		
	JULY	AUGUST	SEPTEMBER
1990	216.21	158.2	**279.43**
1991	84.38	**300.59**	131.84
1992	126.56	**258.49**	126.56
1993	**495.7**	137.11	189.84
1994	**406.05**	395.51	73.83
1995	200.39	**400.78**	131.84
1996	147.66	**379.69**	152.93
1997	226.76	**348.05**	26.37
1998	258.4	**263.67**	79.1
1999	**147.66**	142.38	94.92
2000	**342.77**	105.47	94.92
2001	**353.32**	184.57	42.19
2002	105.47	**210.94**	195.12
2003	**332.32**	258.4	137.11
2004	184.57	**379.63**	10.55
2005	**253.12**	152.93	200.39
2006	**326.94**	184.57	131.84

2007	216.21	**305.86**	73.83
2008	284.77	**421.88**	226.76
2009	**221.48**	205.66	142.38
2010	**495.78**	300.59	326.95
2011	290.04	**369.14**	232.03
2012	242.58	**284.77**	200.39
2013	395.51	**469.34**	68.55
2014	158.2	158.2	**332.23**
2015	**390.23**	226.76	84.38
2016	**279.49**	268.95	36.91
2017	237.3	**258.4**	105.47
2018	326.95	**379.7**	305.86
2019	221.48	**326.95**	94.92
2020	290.04	**321.68**	15.82
2021	**360.43**	196.96	238.24
2022	**465.89**	349.79	200.32
2023	324.4	**597.2**	87.9

(*Source:* *https://power.larc.nasa.gov/data-access-viewer/*)

Highlighted figures show us the maximal rainfall in a monsoon period

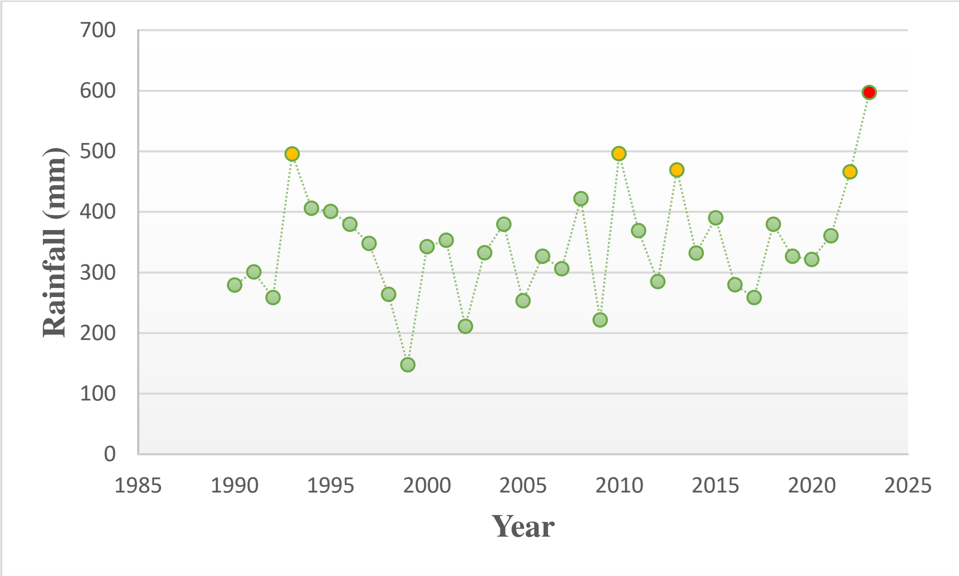

Fig 3.6: *Annual rainfall graph (1990-2023)*

Graph showing that Rainfall above 500 (mm) in the catchment area of Koldam is critical and there are chances of occurrence of floods. During the monsoon season (June to September), the Kol Dam region in the Bilaspur district of Himachal Pradesh experiences substantial rainfall. The average monthly rainfall during this period can be estimated as follows:

June: Approximately 150-200 mm

July: Approximately 300-400 mm

August: Approximately 300-400 mm

September: Approximately 200-250 mm

These estimates indicate that July and August are typically the wettest months, receiving the highest rainfall. This heavy monsoon rainfall is critical for the inflow to Kol Dam, influencing reservoir levels and the overall water management strategy for hydroelectric power generation and flood control.

3.7 Probability Density Function

• Utilizing a histogram to summarize the distribution: Start by using a histogram to transform the dataset into a discrete format. A histogram shows the number of values falling into each category by displaying categorical values on the x-axis with different bin heights. The number and width of bars in the histogram, which affect how the density is represented visually, are determined by the bin count selection, making it an important decision.

• Carrying out Probability density functions, or PDFs, bear a striking resemblance to standard functions in parametric density estimation. You may determine the kind of function that might be used to explain the data distribution by looking at the histogram's form. Determine the function's parameters in order to determine the density. You can evaluate the histogram's and the function's goodness of fit by:

Plot the density function and contrast its form with that of the histogram. Compare the function's generated random samples with the real ones. To assess the fit, we need to do statistical tests.

• Using Non-Parametric Density Estimation: In cases where the histogram's form deviates from a standard probability density function, but in our case we do not have to do this as the shape of our histogram and that of the probability density function is almost same.

Table 5: *Probability and recurrence period of the flood causing rainfall*

Year	Maximum Rainfall in Monsoon(mm)	Actual Frequency (%)
1990	279.43	0.029411765
1991	300.59	0.058823529
1992	258.49	0.088235294

1993	495.7	0.117647059
1994	406.05	0.147058824
1995	400.78	0.176470588
1996	379.69	0.205882353
1997	348.05	0.235294118
1998	263.67	0.264705882
1999	147.66	0.294117647
2000	342.77	0.323529412
2001	353.32	0.352941176
2002	210.94	0.382352941
2003	332.32	0.411764706
2004	379.63	0.441176471
2005	253.12	0.470588235
2006	326.94	0.5
2007	305.86	0.529411765
2008	421.88	0.558823529
2009	221.48	0.588235294
2010	495.78	0.617647059
2011	369.14	0.647058824
2012	284.77	0.676470588
2013	469.34	0.705882353
2014	332.23	0.735294118
2015	390.23	0.764705882

2016	279.49	0.794117647
2017	258.4	0.823529412
2018	379.7	0.852941176
2019	326.95	0.882352941
2020	321.68	0.911764706
2021	360.43	0.941176471
2022	465.89	0.970588235
2023	597.2	1

Histogram of rainfall data

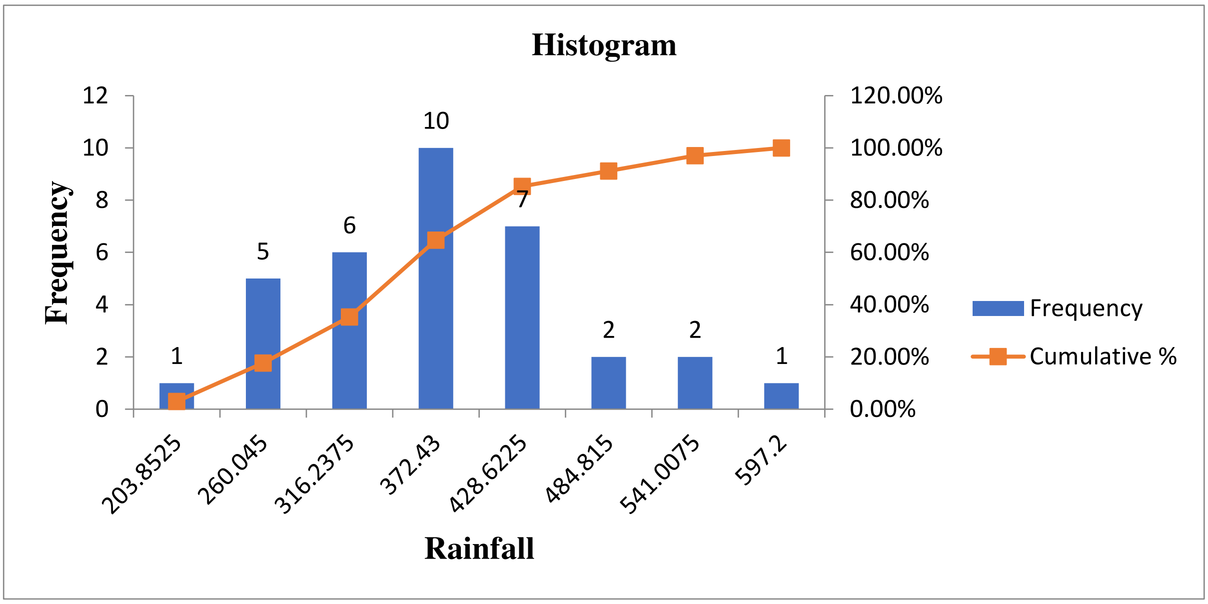

Fig 3.7: *Rainfall Histogram*

This graph shows that the average rainfall in the Barmana area near Koldam have a maximum probability of rainfall intensity to be around 372.43 mm . According to 34 years data the rainfall occurred almost 10 times in between this Rainfall intensity. Also, the maximum rainfall received in mm is equal to 597.2 mm which occurred only once in a span of 34 years. Rainfall of such intensity can cause a maximum flooding in the downstream areas and pose a major threat to Koldam.

Therefore, the water level at the day of this rainfall was around the FRL of the dam (137.2 m). Hence, this rainfall intensity is used to apply hydrostatic loading conditions on the dam in ABAQUS software.

Probability Density Function

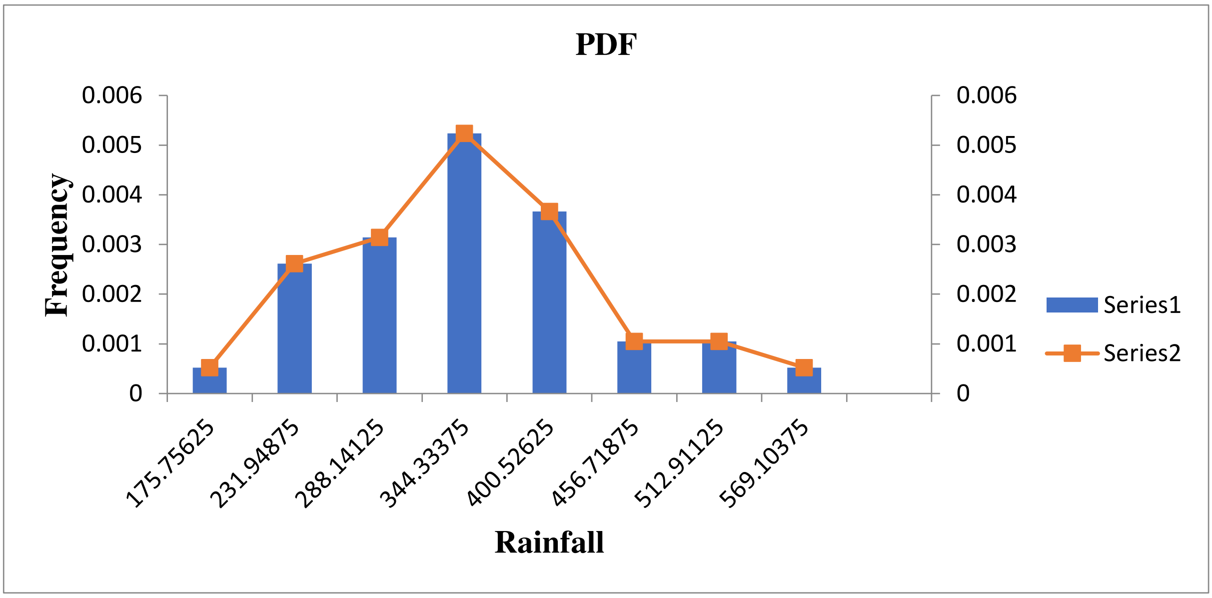

Fig 3.8: *Probability density function*

This plot shows that there is a maximum probability of occurrence of 344.3 mm rainfall in a 34 yrs. of data. Hence, the probability of rainfall above 400 cm that can cause flooding conditions in the area near Koldam is around 40%. Therefore, analysis of the dam is a must.

Cumulative Distribution Function

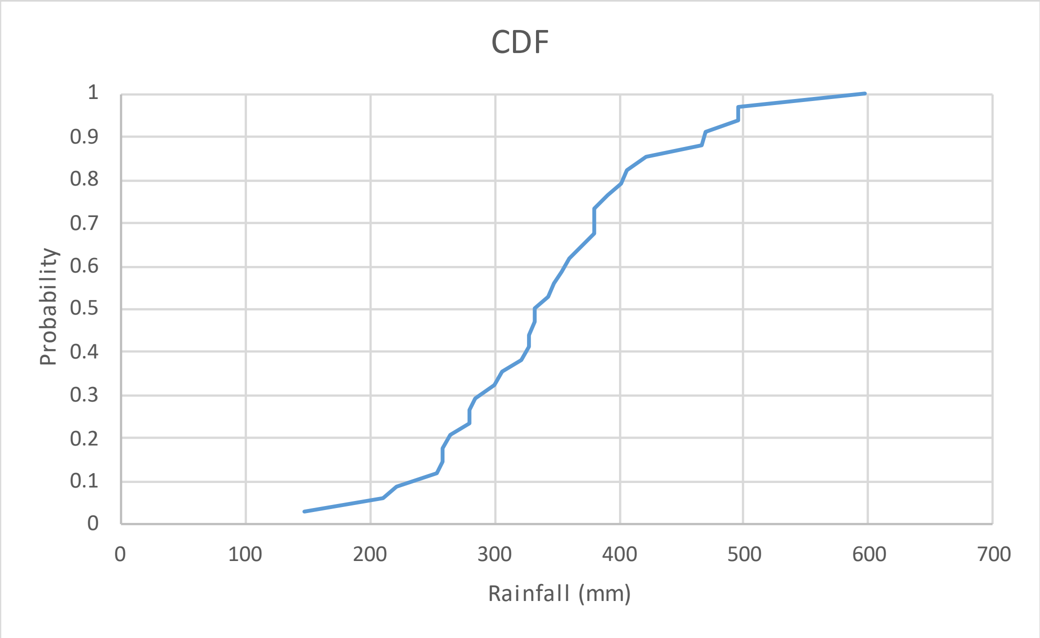

Fig 3.9: *Cumulative Distribution Function*

3.8 Vulnerability

Vulnerability refers to the extent of susceptibility to harm or adverse impacts, indicating weaknesses in individuals, communities, or systems that may be exposed to various challenges or hazards.

Major vulnerable things to floods:

Human Lives:

Floods pose a direct threat to human safety, leading to drowning, injuries, and loss of life.

Infrastructure Damage:

Homes, buildings, roads, bridges, and other infrastructure are susceptible to damage or destruction during floods.

Agricultural Land:

Crops and livestock are vulnerable to inundation, leading to economic losses for farmers.

Ecosystems:

Floods disrupt natural habitats, endangering wildlife and impacting biodiversity.

Economic Loss:

Floods can result in substantial economic losses due to damage to businesses, agriculture, and disruption of transportation.

Displacement of Communities:

Flooding can force people to evacuate their homes, leading to temporary or long-term displacement.

Infrastructure Disruption:

Utilities such as power, water supply, and sewage systems can be disrupted, impacting daily life.

Social Services:

Schools, healthcare facilities, and emergency services may be compromised, affecting societal well-being.

Chapter 4 – Seepage Analysis Based on ABAQUS

4.1.General

One of the primary applications of earth-rock dams is the prevention of seepage. The earth rock dam has water permeability and wide pores between the particles since it is a granular structure. Water will seep downstream through the dam's body, foundation, and shoulder once it has been obstructed by the dam due to the impact of the upper and lower water levels. This will result in leaks in the dam's body, foundation, and abutment. In addition to applying pressure or a floating force to a specific contact surface, seepage also has an impact on the individual soil particles.

Seepage analysis is a crucial component that must be accurate and reasonable because the buoyancy and drag force of the pore water flow, the pair of forces and reaction forces, have a certain destructive effect on the soil energy, influencing the stability of the dam. The secret to guaranteeing the safe operation of earth-rock dams is seepage analysis. There are two types of seepage fields in an earth-rock dam: saturated and unsaturated. The two are interdependent and mutually constrained, and the active zone of the saturated and unsaturated zones can be altered by a variety of influencing factors, including variations in water level and rainfall.

The steady seepage circumstances are simulated and the seepage of a clay core dam is analysed using ABAQUS finite element software. The design conditions' seepage flow, pore water pressure, and downstream escape point are computed.

4.2. Introduction

Seepage analysis in earth-rock dams is essential for delineating the seepage field, which encompasses both saturated and unsaturated regions. These regions interact with each other, contributing to the overall seepage dynamics. Unsaturated seepage is particularly complex due to the numerous influencing factors, making its behavior more intricate compared to saturated seepage.

The results from the simulations are deemed accurate and reliable, providing valuable insights for the construction and design of anti-seepage systems in earth-rock dams. By examining the wetting line, the analysis reveals how water infiltrates through the dam materials, transitioning from unsaturated to saturated conditions. The study also quantifies the seepage flow, offering a detailed picture of the water movement through the dam's body and foundation.

Furthermore, the stress and strain analysis provide a comprehensive understanding of how seepage pressures affect the dam's structural integrity. The interaction between water movement and the dam materials under varying saturation levels is crucial for assessing potential risks and ensuring the dam's stability and safety.

In essence, the finite element numerical simulation proves to be a powerful tool in understanding the complex behavior of seepage in earth-rock dams. The combination of engineering examples and advanced simulation techniques enables a thorough examination of both saturated and unsaturated seepage fields. This comprehensive analysis not only enhances our understanding of seepage dynamics but also informs the development of effective anti-seepage measures.

4.3. Model Establishment

4.3.1. Model Data

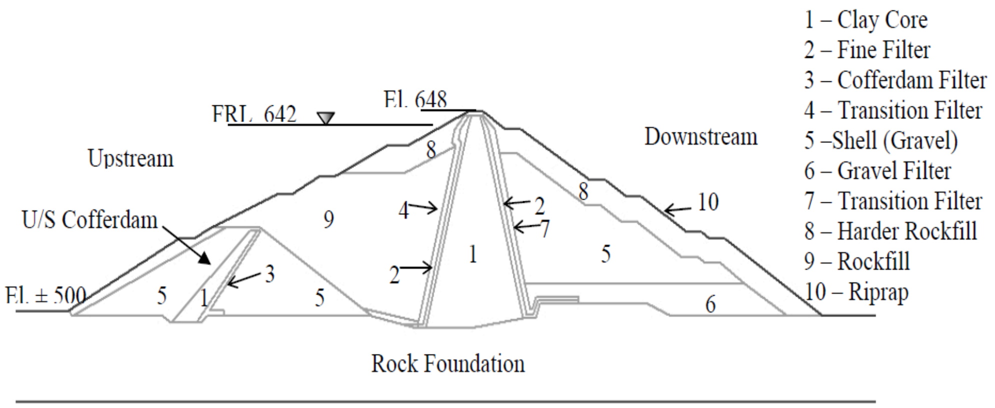

Fig 4.1: *Typical Section of Earth and Rockfill dam of Koldam HEPP*

The dam is a rockfill and clay core dam located in the centre. The dimensions of the dam are 14 m for the crest, 768.97 m for the bottom, and 167 m for the height. It features a drainage prism that is 4.5 meters high and has a top width of 1.5 meters. The average slope is 1.0 V to 2.25 H for upstream flow and 1.0 V to 2.0 H for downstream flow. The maximal hydraulic gradient across the core is slightly less than two due to its thickness.

Given the high level of seismic activity at the location, a wide crest width of 14 meters has been chosen. With a peak elevation of El 648 m, the freeboard is 6 m above the reservoir's full level.

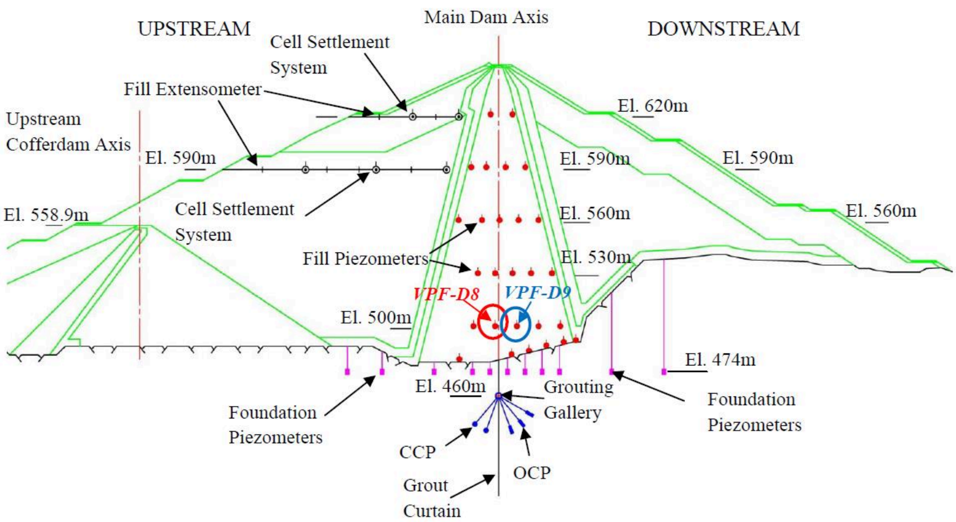

Fig 4.2: *Instrument Location*

4.3.2 Calculation Parameter

Construction criteria, such as layer thickness, ranges of placement moisture content (field moisture content), placement dry density (field dry density), etc., are chosen for different component materials during the design stage of an earth and rockfill dam. It is necessary to confirm these design parameters and make any necessary modifications in light of the material attributes and actual outcomes. The behaviour of the clay material that makes up an earth and rockfill dam's impermeable core is particularly sensitive to the moisture content and requires careful observation.

To ensure the integrity of the clay core against hydraulic fracture, it is essential that the B value remains below 1.0 during construction, with a target of keeping it under 0.8. The B value is influenced by construction parameters such as layer thickness, filling rate, and the clay's placement moisture content.

To monitor the development and dissipation of pore pressures in the clay core, instruments, particularly piezometers, are installed and closely observed throughout the construction process. These piezometers are crucial for making mid-course corrections if necessary, validating design assumptions, and determining the construction pace.

The impervious clay core of the Koldam HEPP earth and rockfill dam is placed in 35 cm thick layers and compacted to achieve 95% of the Proctor maximum dry density (Optimum Proctor Density). Figure 4.3 shows the evolution of pore pressures in piezometers VPF-D8 and VPF-D9 during construction. These piezometers are installed at an elevation of 500 meters in section D-D at the center of the clay core, with one positioned just upstream and the other just downstream of the dam axis. The center of the clay core is characterized by high pore pressure and the longest dissipation time.

The pore pressure evolution depicted in Figure 4.3 confirms the design criteria set for the Koldam HEPP rockfill dam, showing a gradual dissipation of pore pressures and a corresponding decrease in B values over time.

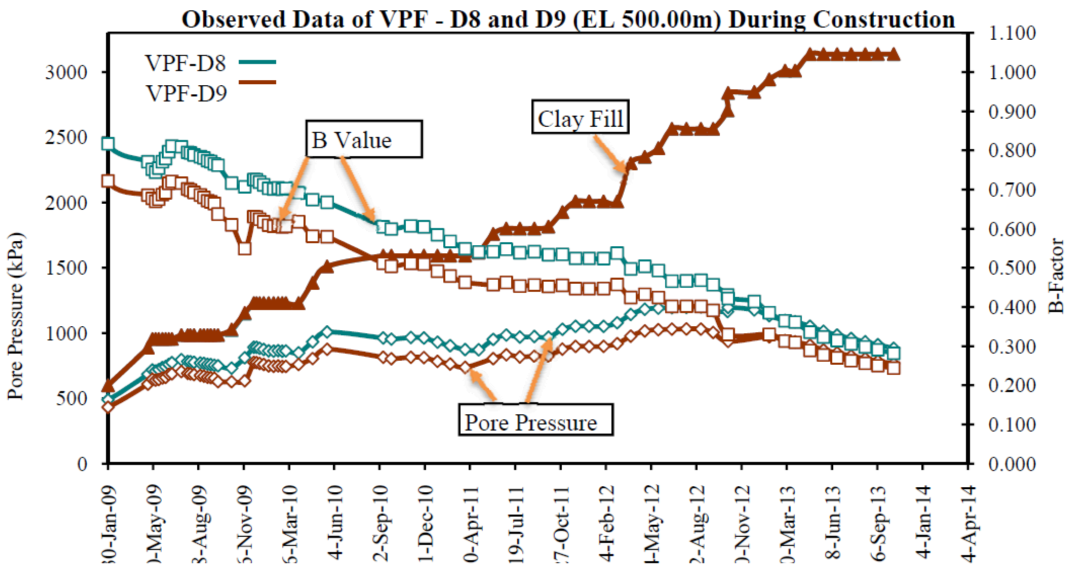

Fig 4.3: *Section D-D – Pore Pressure, B value and clay fill v/s Time*

Each part is treated as a homogeneous material, and the physical and mechanical properties of the specific materials are shown in Table no. 4.1

Table 4.1: Physical and mechanical indicators of dam body soil

Material	Wet Density ($t/m^3$0	Elastic		Permeability	
		Youngs's Modulus (Mpa)	Poisson's Ratio	k (m/s)	Void Ratio
Clay (Core)	1.96	32.5	0.3	$1.157x10^{-8}$	0.41
Gravel (Filter)	1.99	100	0.4	$3.5x10^{-5}$	0.8
Rockfill	2.02	100	0.3	0.75	0.538
Gravel (Shell)	2.32	55.6	0.25	$3.5x10^{-6}$	0.47

4.3.3. Boundary Conditions

The boundary conditions include a mechanical boundary and an infiltration boundary. The mechanical boundary consists of a stress boundary and a displacement boundary.

Stress boundary: The gravity field is taken as the initial stress field. The upstream and downstream water surface slopes are subjected to hydrostatic pressure, which is applied to the model as pore water pressure.

Displacement boundary: To simplify calculations, the bottom of the model is assumed to be a fixed boundary, restricting both horizontal and vertical displacements. The upstream and downstream surfaces are treated as free boundaries.

Infiltration boundary: For ease of calculation, the bottom of the model is assumed to be impermeable, while the slope's waterfront side and the rock mass are freely permeable. Using the CAE module in ABAQUS, a two-dimensional model of the earth-rock dam is established.

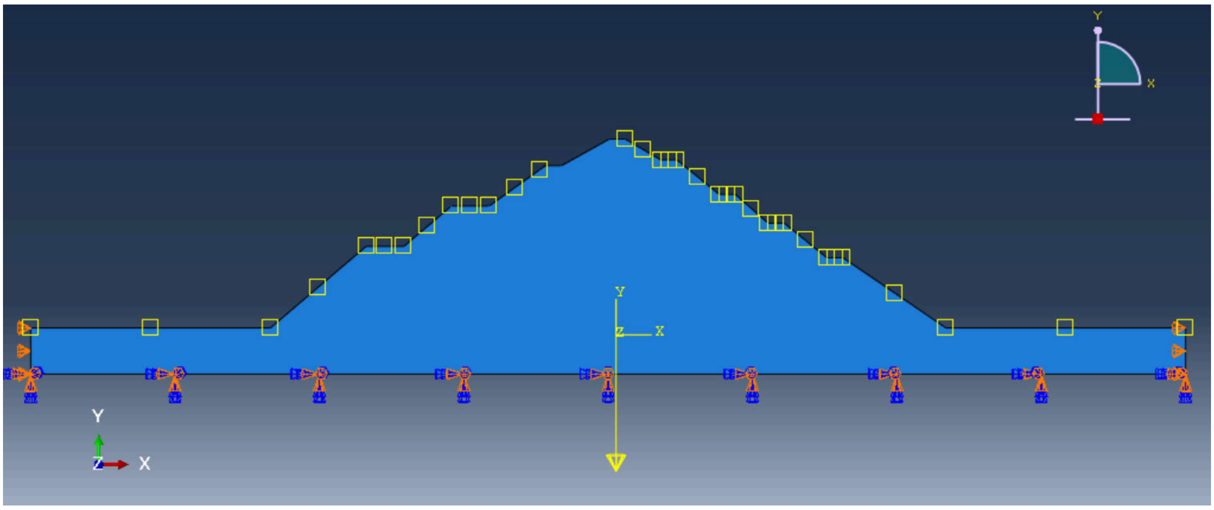

Fig 4.4: *Loading*

4.3.4 Calculation Conditions

The working condition chosen is to evaluate the water level condition, specifically the check flood level of 137.2 meters. As this represents the highest water level of the dam, it provides a more comprehensive and valuable reference for calculations. If the seepage, as well as the stress and strain at this water level, are found to be reasonable, it can be inferred that the seepage at the designed water level or dead water level is normal. This implies that the seepage risk for the reservoir is minimal, indicating the reservoir's safety.

4.4 Analysis of calculation results

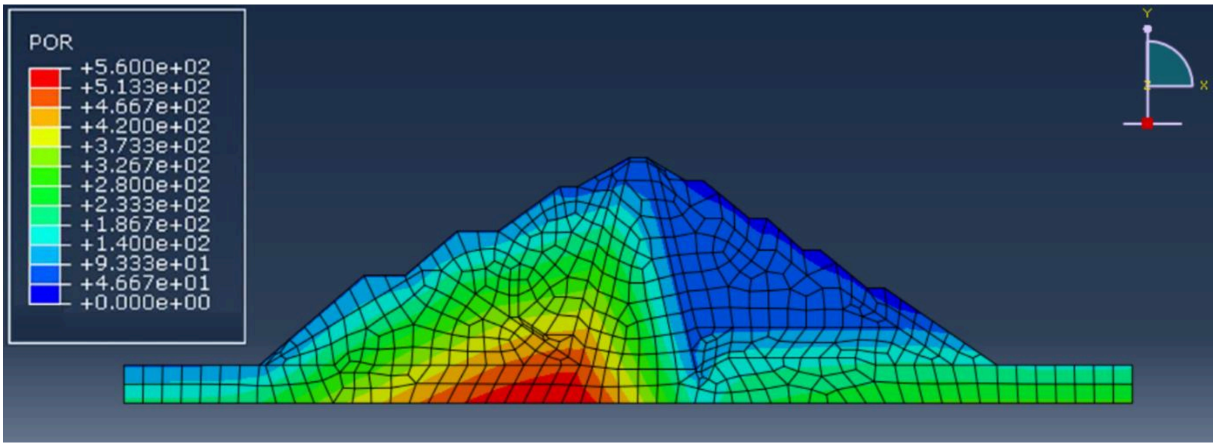

Fig 4.5: *Pore pressure distribution map*

Fig. 4.5 illustrates how the upward pore pressure gradually decreases and the maximum pore pressure is found at the bottom of the water-facing surface. There is a sharp drop process at the core wall at the interface where the pore pressure is zero, or the free water surface, and eventually the drainage layer is passed. The saturation profile and the graph are similar in general, but the pore pressure varies in the region where saturation 1 occurs and the two are positively associated in the negative pore pressure region.

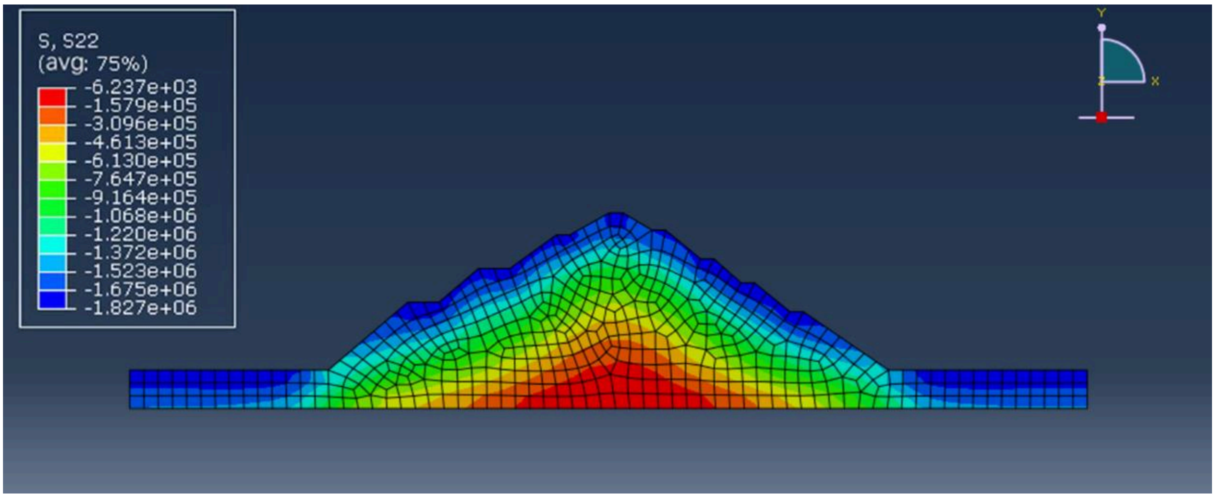

Fig 4.6: *Stress distribution diagram*

The stress distribution along the x- and y-axes is displayed in Fig. 4.6. Tensile force is the positive value, and pressure is the negative number. The graphic illustrates that the stress on the dam slope surface is highest in the x and y-axis directions in the upstream section. The ends of the core wall experience less stress the lower the stress.

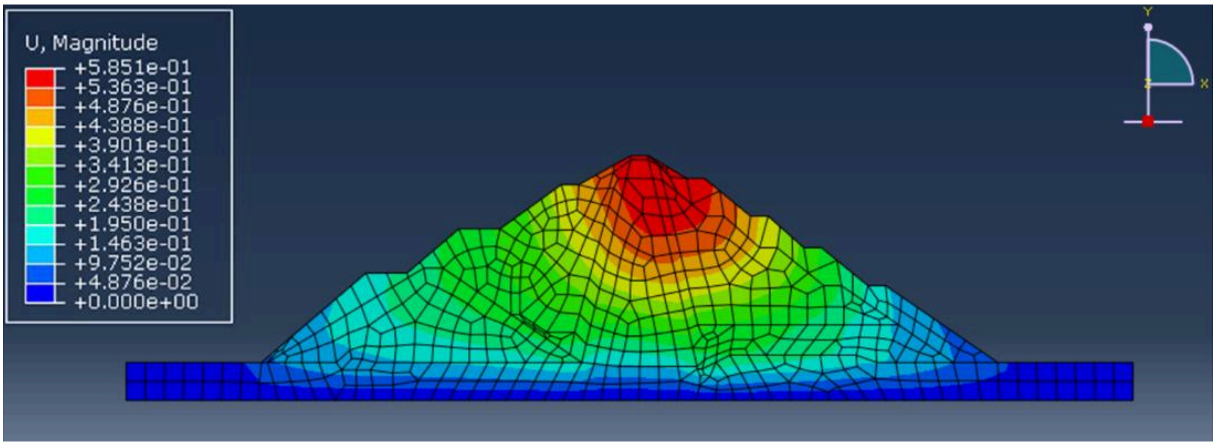

Fig 4.7: *Displacement map*

The displacement distribution map, as shown in Fig. 4.7, indicates that the top dam body displacement achieves its maximum of 0.5851 mm, and that the displacement decreases with decreasing displacement. The displacement at the dam's bottom is zero since we consider the foundation surface to be fixed. In actuality, there is some displacement of the dam base; however, this displacement has no bearing on our seepage estimate.

Chapter 5 – Conclusions

- The research showed that rainfall levels above 400 mm can cause flooding conditions in the Barmana area of Bilaspur District near Koldam. The maximum rainfall received on 1st September, 2023 is equal to 597.2 mm which occurred only once in a span of 34 years. Therefore, the water level at the Koldam was raised around the FRL of the dam (137.2 m). Hence, this rainfall intensity is used to apply hydrostatic loading conditions on the dam in ABAQUS software.

  There are four sections to the earth-rock dam. varied pieces have varied materials as well as different mechanical and physical characteristics. The analysis displays the earth-rock dam's pore pressure, displacement, and principal stresses.
- The displacement at the top of the dam achieves its maximum of 0.5851mm, according to the stress and displacement distribution of earth-rock dams; the lower the downward displacement, the zero displacement at the bottom of the dam. The stress on the surface facing the water is attained for the stress distribution. The more the value, the less the stress.
- The upward pore pressure gradually decreases, and the maximum pore pressure is found at the bottom of the water-facing surface. There is a sharp drop process at the core wall at the interface where the pore pressure is zero, or the free water surface, and eventually the drainage layer is passed. Max. pore pressure observed is equal to 560 Pa.
- The max. principal stresses generated due to hydrostatic loading in the dam when the water is at the FRL are equal to -6237 Pa in the bottom centre of the dam.

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