Combine UAV and 2D ERT Approach for Identification of Water Leakage Zones in Gul Dheri Dam, Akora Khattak, Nowshera

By

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Military College of Engineering, Risalpur
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(2024)

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A thesis submitted to the National University of Sciences and Technology, Islamabad,

in partial fulfillment of the requirements for the degree of

Bachelors in Civil Engineering

Supervisor: Dr. Muhammad Junaid

Military College of Engineering, Risalpur
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(2024)

THESIS ACCEPTANCE CERTIFICATE

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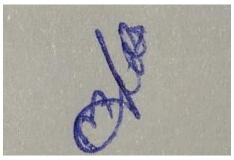
Signature: 

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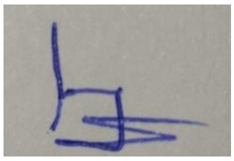
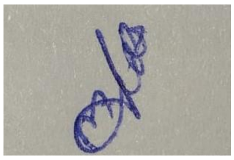
Date: 15/05/2024

CERTIFICATE OF APPROVAL

This is to certify that the research work presented in this thesis, entitled "Combine UAV and 2D ERT Approach for Identification of Water Leakage Zones in Gul Dheri Dam, Akora Khattak, Nowshera" was conducted by Mr. Irfan Haider Khan under the supervision of Dr Muhammad Junaid. No part of this thesis has been submitted anywhere else for any other degree. This thesis is submitted to the Military College of Engineering, NUST, Risalpur in partial fulfillment of the requirements for the degree of Bachelors of Civil Engineering.

Student Name: Irfan Haider Khan Signature: 

Supervisor Name: Dr Muhammad Junaid Signature: 

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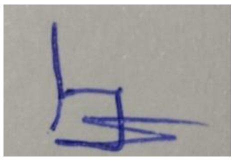
Student Name: Irfan Haider Khan Signature: 

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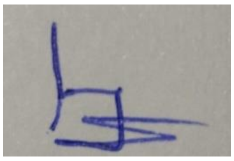
` Signature: 

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LIST OF ACRONYMS

ERT	-	Electrical Resistivity Tomography
NDT	-	Non-Destructive Testing
UAV	-	Unarmed Aerial Vehicle
GIS	-	Geographic Information System
GCP	-	Ground Control Point

ABSTRACT

This research explores the fusion of 2D Electrical Resistivity Tomography (ERT) and advanced Drone Survey techniques to identify and map potential leakage zones within dam structures. Addressing the critical need for comprehensive and non-invasive methodologies in dam safety assessment, this study aims to revolutionize the identification and characterization of subsurface anomalies indicative of potential leaks.

The integration of 2D ERT, a geophysical method measuring subsurface resistivity variations, and Drone Survey technology, offering high-resolution aerial imaging capabilities, provides a synergistic approach. The ERT technique enables the characterization of subsurface resistivity distribution, while drone-based surveys provide detailed visual data of surface features, facilitating a holistic understanding of the dam's condition.

Through a series of field experiments conducted at Gul Dheri Dam, multi-electrode ERT surveys were conducted to acquire resistivity data, capturing the subsurface variations. Simultaneously, drone-mounted cameras captured high-resolution imagery of the dam surface and surrounding areas, allowing for detailed visual inspections.

Data integration and analysis involved use of Zone Resz 2D software for creating 2D cross sectional subsurface profiles and ArcGIS for calculation of areas of zones. Interpretation of the integrated data facilitated the identification of anomalous zones that may indicate potential seepage or leakage paths within the dam structure.

This research not only contributes to the advancement of geophysical and remote sensing methodologies but also holds significant implications for dam safety management practices. The outcomes offer insights into the development of efficient monitoring strategies to mitigate risks associated with potential leaks in dams, thereby safeguarding communities and infrastructure.

Keywords: Data interpretation, Electrical Resistivity Tomograpghy, Drone Survey, leakage zones, mapping, ArcGIS, subsurface evaluation, area calculation, dam health assessment.

CHAPTER 1

INTRODUCTION

1.1 Background Study

Electrical Resistivity Tomography (ERT) is an advanced geophysics method used to determine sub surface's resistivity distribution by making measurements on ground surface. ERT data is rapidly collected with an automated multi-electrode resistivity meter. Electro tomography is a non-invasive geophysical method used to image the subsurface of earth structures, like dams.

1.1.1 Importance of Resistivity Testing in Dam Safety

1.1.1.1 Early Detection of Leaks. Resistivity testing helps in detecting leaks and seepage in the dam structure. ERT can be a valuable tool for dam safety assessments, particularly in the early detection of leaks. By providing detailed subsurface information and detecting changes in resistivity associated with water infiltration, ERT helps identify and address potential issues before they escalate into major problems

1.1.1.2 Identifying Weak Zones. It assists in identifying areas of low resistivity, indicating potential weak zones in the dam.

1.1.1.3 Monitoring Structural Stability. Regular testing ensures ongoing monitoring of the dam's structural stability and integrity.

1.1.1.4 Preventing Catastrophic Failure. Early identification of potential issues helps in preventing catastrophic dam failures and ensures public safety. By leveraging the capabilities of ERT for subsurface imaging and monitoring, dam operators and engineers can enhance their ability to detect early warning signs of potential failures, implement timely interventions, and ultimately reduce the risk of catastrophic dam collapses or structural failures.

1.1.1.5 Evaluation of Embankment Integrity. For earth-filled dams, resistivity testing can be used to assess the integrity of the embankment materials. Variations in resistivity within the embankment can indicate areas of potential weakness or saturation, which may require remedial actions such as compaction or drainage improvements.

1.1.2 Background Study of 2D-Electrical Resistivity Tomography (ERT)

1.1.2.1 Historical Development. ERT has its roots in electrical prospecting methods developed in early 20th century. The application of resistivity measurements to map subsurface structures gained prominence in the mid-20th century with development of more sophisticated instrumentation and computational techniques. Transition from manual resistivity profiling to tomographic imaging occurred in late 20th century, driven by advancements in computer technology and mathematical algorithms.

1.1.2.2 Principle. ERT has its roots in electrical prospecting methods developed in the early 20th century. The application of resistivity measurements to map subsurface structures gained prominence in the mid-20th century with the development of more sophisticated instrumentation and computational techniques. The transition from manual resistivity profiling to tomographic imaging occurred in the late 20th century, driven by advancements in computer technology and mathematical algorithms.

1.1.2.3 Instrumentation. Modern ERT systems consist of a control unit, electrodes, cables, and a computer for data acquisition and processing. Electrical current is introduced into the ground through a pair of electrodes, while potential differences are measured using another pair of electrodes. Multiple configurations, such as Wenner, dipole-dipole, or pole-dipole, can be used depending on the desired depth of investigation and resolution.

1.1.2.4 Applications. ERT has diverse applications in geophysics, environmental studies, archaeology, civil engineering, and hydrogeology. In civil engineering, ERT is used for site characterization, subsurface imaging for infrastructure projects, and monitoring of geotechnical structures such as dams and levees. In environmental studies, ERT helps in delineating contaminant plumes, mapping groundwater resources, and assessing the integrity of waste containment facilities. Archaeologists use ERT to identify buried artifacts, archaeological features, and ancient structures without disturbing the site.

1.1.2.5 Challenges and Limitations. Interpretation of ERT data can be complex due to factors such as electrode spacing, subsurface heterogeneity, and noise interference. Resolution decreases with depth, limiting the applicability of ERT to shallow subsurface investigations in some cases. Environmental conditions, such as soil moisture and temperature, can affect resistivity measurements, requiring careful calibration and quality control.

1.1.3 Methodology of Electro Tomography for Resistivity Testing

1.1.3.1 Electrodes Placement. Electrodes are strategically placed around the dam to measure resistivity at various depths.

1.1.3.2 Data Collection. Electric currents are injected into the dam, and the resulting voltage measurements are recorded.

1.1.3.3 Imaging Analysis. Advanced algorithms create 2D or 3D images depicting the distribution of resistivity within the dam.

1.1.3 Using 2D Electrical Resistivity Tomography (ERT) offers several benefits across various fields of application

1.1.4.1 Non-invasive Imaging. 2D ERT allows for the visualization of subsurface structures without the need for invasive drilling or excavation. This non-destructive nature is particularly advantageous in archaeological studies, environmental assessments, and civil engineering projects where preserving the integrity of the site is crucial.

1.1.4.2 High Resolution. While 2D ERT may not provide the same level of detail as 3D methods, it still offers relatively high resolution for shallow subsurface investigations. It can delineate features with fine spatial resolution, making it suitable for mapping near-surface geological layers, detecting buried objects, and characterizing shallow hydrogeological conditions.

1.1.4.3 Cost-effective. Compared to more complex and expensive geophysical techniques like 3D ERT or seismic imaging, 2D ERT is often more cost-effective. Its simplicity in terms of data acquisition and processing makes it accessible to a wider range of researchers & engineers.

1.1.4.4 Rapid Data Collection. With modern instrumentation and software, data acquisition for 2D ERT surveys can be conducted relatively quickly, allowing for rapid field assessments and timely decision-making. This efficiency is valuable for time-sensitive applications such as site investigations for construction projects or emergency response efforts.

1.1.4.5 Versatility. 2D ERT can be applied across various environments and geologic settings. It is used in diverse fields including geotechnical engineering, groundwater exploration, environmental monitoring, archaeology, and mineral exploration. Its versatility makes it a valuable tool for addressing a wide range of subsurface imaging needs.

1.1.4.6 Quantitative Analysis. ERT data can be processed to provide quantitative information about subsurface properties such as electrical resistivity, which can be correlated with material properties like lithology, porosity, and moisture content. This quantitative analysis enhances the interpretation of subsurface structures and facilitates informed decision-making in engineering and environmental applications.

1.1.4.7 Integration with Other Techniques. 2D ERT can be integrated with other geophysical methods, such as ground-penetrating radar (GPR), seismic surveys, and borehole logging, to provide complementary information and improve subsurface characterization. By combining multiple techniques, researchers and practitioners can achieve a more comprehensive understanding of subsurface conditions.

1.1.4.8 Risk Mitigation. By identifying potential hazards such as buried utilities, unexploded ordnance, or geotechnical anomalies, 2D ERT surveys contribute to risk mitigation efforts in construction, infrastructure development, and environmental remediation projects. Early detection of subsurface features minimizes the likelihood of costly delays, accidents, or environmental damage during project implementation.

Overall, the benefits of using 2D ERT include its non-invasiveness, high resolution, cost-effectiveness, versatility, quantitative analysis capabilities, compatibility with other techniques, and contribution to risk mitigation in various applications requiring subsurface imaging.

1.2 Problem Statement

Current methods for assessing the health and integrity of dam infrastructure rely on drilling, are invasive in nature and provide access to smaller depth. This study aims to address this gap by investigating the utilization of Non Destructive Geophysical techniques. Electrical Resistivity Tomography (ERT) in conjunction with drone surveys will be used to enhance the efficiency and depth of dam health evaluations. The primary concern revolves around the need for a more advanced and integrated approach to monitor and assess dam structures, identifying potential weaknesses and environmental impacts to ensure proactive maintenance and risk mitigation strategies.

1.3 Objectives

1.3.1 Objective 1

To identify leakage zones in Gul Dheri Dam using ERT Survey and Drone Survey

1.3.2 Objective 2

To map the leakage zones in the study area by using ArcGIS for calculating areas of saturated, partially saturated and unsaturated zones

1.3.4 Objective 4

To recommend remedial measures for enhancing the life of a dam

1.4 Organization of the Report

The thesis begins with Chapter 1 discussing the major concept of Geophysical Survey (Electric Resistivity Tomography) in non-destructive Health assessment of Dam. Chapter 2 builds upon the general outline of the thesis, giving a deeper insight into the literature review conducted to support the thesis. Moving to Chapter 3, the thesis explains the methodology used in the research and interpretation of data obtained through ERT Survey followed by Drone Survey of Gul Dheri Dam. Chapter 4 gives the details about the remedial measures required to address leakge issues in dams.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The safe operation and proper maintenance of dam infrastructure is critical taking into account social and economic impacts in case of a failure. Currently, the assessment of dam structures is based on geodetic and geotechnical monitoring instrumentation. However, the majority of these instruments do not provide repeatable and reliable information about the mechanisms occurring inside the body of dams that could compromise the integrity of the structure. Geophysical methods can provide important information to define the safety level of dam infrastructure. Continuous dam monitoring would also enable early remedial maintenance and repair actions to be carried out improving public safety and reducing costs for dam owners, insurers and maintainers. The maintenance and inspection of dams are therefore of increasing importance. Systematic monitoring of dam infrastructure can deliver key information providing early warning signs of an impending failure and a better understanding of the on-going performance of the structure.

2.2 Dam Health Assessment

Health and structural assessment of dams is imperative due to the critical role these structures play in managing water resources, providing hydroelectric power, and safeguarding downstream communities. Dams are complex engineering marvels that are subjected to various environmental forces, such as water pressure, seismic activity, and erosion, which can impact their structural integrity over time. Regular health assessments help identify potential vulnerabilities, enabling proactive maintenance and repairs to prevent catastrophic failures. A comprehensive evaluation of a dam's health involves monitoring factors like seepage, deformation, and concrete degradation. Additionally, technological advancements, such as remote sensing and sensor networks, contribute to more accurate and timely assessments, ensuring the safety and reliability of dams in the face of evolving environmental conditions.

Moreover, with the increasing impact of climate change, understanding how dams respond to extreme weather events is crucial for designing resilient structures that can withstand the challenges posed by a changing environment. Overall, health and structural assessments of dams are indispensable for mitigating risks, ensuring public safety, and optimizing the long-term performance of these critical infrastructure assets.

In many occasions internal erosion and seepage mechanisms within the body of dams are very difficult to be detected by conventional methods. The current practice to assess these mechanisms is based on geotechnical instrumentation. However, major issues exist with geotechnical instruments as they do not provide distributed, repeatable and reliable information in the long-term due to lack of 3rd Joint International Symposium on Deformation Monitoring Vienna, 30th March - 1st April 2016 maintenance as they are located inside the body of the dam. Geodetic measurements are also used to assess the deformations of the structure but they do not provide a direct insight of the internal mechanisms that influence the dam behavior. The assessment and safety of dam infrastructure would be significantly improved with non-destructive techniques that would allow internal erosion and seepage characteristics to be detected. [1]

2.3 Teton Dam Disaster 1976

One notable example of a dam disaster attributed to seepage is the failure of the Teton Dam in Idaho, USA, in 1976. The Teton Dam was an earthen dam constructed on the Teton River for irrigation and flood control. The disaster occurred on June 5, 1976, just a few months after the dam's completion. The primary cause of the failure was identified as seepage through the dam's foundation and abutments.

During the initial filling of the reservoir, seepage was observed at the base of the dam. Despite efforts to address the seepage, it intensified, leading to the disintegration of the dam structure. Ultimately, the dam breached, releasing an immense volume of water downstream. The catastrophic failure resulted in the loss of 11 lives, the destruction of numerous homes, and significant damage to agricultural land and infrastructure.

The Teton Dam failure highlighted the critical importance of thorough geotechnical investigations, proper foundation preparation, and vigilant monitoring for signs of seepage in dam construction. Subsequent dam engineering practices have incorporated lessons learned from such disasters to enhance the safety and reliability of dams worldwide.

Figure 1:Teton Dam Failure

2.4 Various Techniques of Dam Health Assessment

Assessing the health of dams involves employing various techniques to monitor and evaluate structural integrity, seepage, and other critical parameters. Some common techniques include

2.4.1 Geotechnical Investigations.

Detailed analysis of soil and rock properties at the dam site helps engineers understand the foundation's stability and potential risks.

2.4.2 Instrumentation and Monitoring.

Installation of sensors and monitoring equipment, such as piezometers, tiltmeters, and strain gauges, to continuously track factors like water pressure, movement, and stress within the dam structure.

2.4.3 Seismic Analysis.

Evaluating the dam's resilience to seismic activity by conducting seismic hazard assessments and implementing measures to enhance seismic resistance.

2.4.4 Non-Destructive Testing (NDT).

Employing methods like ultrasonic testing, ground-penetrating radar, and infrared thermography to assess the condition of dam materials without causing damage.

2.5 Electric Resistivity Tomography

Electrical Resistivity Tomography (ERT) stands as a powerful geophysical method employed in assessing the health of dams and other civil structures. By mapping the subsurface resistivity distribution, ERT provides valuable insights into the integrity of dam foundations, detecting potential seepage paths, voids, and structural weaknesses. This non-invasive technique plays a pivotal role in ensuring the safety and reliability of dams.

2.5.1 Procedure

The ERT procedure involves a systematic approach to gather resistivity data across the dam and its surroundings

2.5.1.1 Array Setup. Electrodes are strategically placed in an array along the dam and its vicinity. Arrays can vary, with common configurations being Wenner, Schlumberger, or dipole-dipole, depending on the specific goals of the assessment.

2.5.1.2 Current Injection. A known electrical current is injected into the ground through two electrodes, while potential differences are measured using other electrodes. The resulting voltage distribution allows the determination of subsurface resistivity.

2.5.1.3 Data Acquisition. Resistivity measurements are taken at multiple electrode positions to create a resistivity profile. These profiles are then combined to generate a 2D or 3D image of the subsurface, depicting variations in resistivity.

2.5.1.4 Data Interpretation. Interpretation involves identifying anomalies in the resistivity distribution, such as areas of higher or lower resistivity, which may indicate the presence of geological features or structural issues.

2.5.2 Benefits.

ERT offers several advantages in dam health assessments. These include

2.5.2.1 Subsurface Imaging. ERT provides detailed images of the subsurface, allowing engineers to identify potential issues, such as seepage paths, voids, or variations in material properties.

2.5.2.2 Non-Destructive. As a non-invasive method, ERT minimizes the impact on the dam structure, making it a preferred choice for routine health assessments without compromising dam integrity.

2.5.2.3 Cost-Effective. Compared to traditional drilling methods, ERT can be a cost-effective solution, especially when dealing with large dam structures or challenging terrains.

2.5.2.4 Real-Time Monitoring. ERT allows for real-time monitoring, enabling continuous assessments and timely detection of changes in subsurface conditions (Karaoulis, 2018)

2.6 Surveying and Geographic information System (GIS): Exploring the capabilities of Unmanned Aerial Vehicle (UAV/Drones)

2.6.1 General

Drone surveys can be used for various purposes, including; dams and bridges inspections [2] land surveying [3]; construction monitoring [4], slope monitoring [5] and urban traffic monitoring [6]

A desktop application for GIS drone mapping such as ArcGIS Drone2Map software has been used to capture drone data using site scan flight or any third party drone data collection app (ESRI, 2022). After the flight, the user creates a project to download the drone imagery. Ground control points are added and 2D and 3D outputs are processed and created. With the 2D or 3D outputs, measurements can be made, changes tracked, and other analysis can be made. Advanced analysis can also be done in ArcGIS Pro, utilizing a range of tools such as advanced spatial, temporal and spectral analysis, as well as data management (ESRI, 2022).

2.6.2 Benefits of Drone Survey

2.6.2.1 Improved Quality and Accuracy. Drones are essential due to their ability to capture reality, that is, images with coordinates and elevation, thereby ensuring quality through capturing many images and the use of sensors such LIDAR, infrared cameras and multi-spectral sensors (MRICS, 2019). Software such as Pix4D allows users to add ground control points (GCPs) to help improve data accuracy.

2.6.2.2 Saving Time. Given that drones make it easier to convey data in real-time, while automation of data processing and export is also made easier (ESRI, 2022) by software such as DroneDeploy, Pix4D, and thereby allowing users to save time and costs.

2.6.2.3 Improved Work Safety and Coverage. Given that drones are controlled remotely, they are safer to use, and have the ability to reach inaccessible areas, including areas dangerous to human life.

2.6.2.4 Integration with other GIS Software. Image processing software is part of GIS system, which provides access to tools for geospatial analysis. As such, end products from drone software can be exported and opened easily in ArcGIS desktop or ArcGIS Pro for integrated management. ArcGIS Online or ArcGIS Enterprise can also be utilized to publish or share the imagery data products and their elevation datasets (Seo et al. 2018).

2.6.3 Methodology

The study consists of five stages (Figure 1) which are: pre-survey, drone preparation, data acquisition, image processing and further processing with ArcGIS.

2.6.4 Integration with GIS

The DSM model generated by Pix4D was exported into ArcGIS desktop 10.8, creating contour lines map, providing the user with better understanding of the surface of the area captured by the drone. By exporting the DSM into ArcGIS, contours with elevation of 10m and resolution 100cm were generated.

2.7 Summary

Ensuring the safety and maintenance of dams is vital, considering their profound social and economic consequences in the event of failure. While current monitoring techniques lack reliability in detecting internal structural risks, integrating geophysical methods can offer early warnings, facilitate prompt remedial actions, and reduce costs, underlining the importance of systematic monitoring and inspection protocols for dam infrastructure.

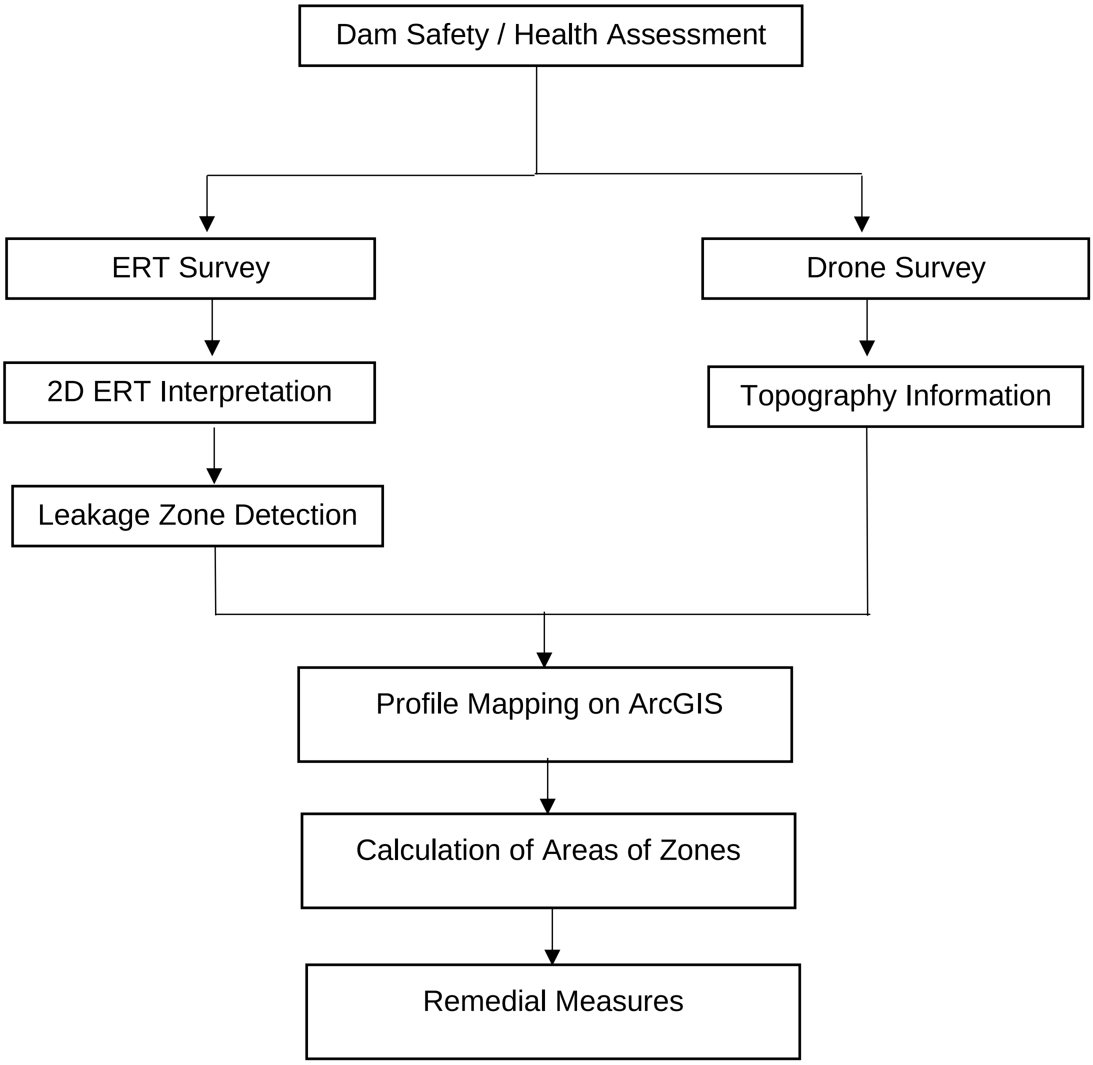
The failure of the Teton Dam in 1976, attributed to seepage through its foundation and abutments during initial reservoir filling, resulted in catastrophic consequences including loss of life and extensive damage. This disaster underscored the necessity of rigorous geotechnical investigations, adequate foundation preparation, and vigilant monitoring to detect and address seepage in dam construction, influencing subsequent engineering practices globally.

Electrical Resistivity Tomography (ERT) is a powerful geophysical method used to assess the health of dams and civil structures by mapping subsurface resistivity, providing insights into dam foundation integrity, identifying seepage paths, voids, and structural weaknesses, thus playing a crucial role in ensuring dam safety and reliability. Drone surveys, offer versatile applications such as inspections of dams and bridges, land surveying, construction monitoring, slope monitoring, and urban traffic monitoring, enabling efficient data collection, analysis, and visualization for various infrastructure projects.

CHAPTER 3

METHODOLOGY AND FIELD TESTS / RESULTS

Flow Chart



3.1 ERT Survey

3.1.1 General

Leakage or fluid-filled fractures' response to electrical current is a very remarkable signature and provides relatively lower electrical resistivity values as compared to the surrounding host rocks. Therefore, this makes electrical resistivity tomography an excellent technique in exploration. Additionally, it is also one of the challenging tasks to provide probable location and direction of seepage flow or trends in the study area. In this project, electrical resistivity tomography profiling, topographic and surface geological map data acquired through drone survey will be integrated to get meaningful results to mark probable location and direction of dam leakage in the studied area. The electrical resistivity method is used in the study of horizontal and vertical discontinuities and uses the electrical properties of the ground. It utilizes direct currents or low-frequency alternating currents to investigate the electrical properties (resistivity) of the subsurface.

The age of the rock is an important factor of resistivity as a young volcanic rock (Quaternary Rocks) shows lower resistivity compared with old volcanic rock (Precambrian Rocks). Electrical resistivity is commonly applied to groundwater exploration, mineral exploration, detection of cavities and Oil exploration.

3.1.2 Resisitivity Imaging Equipment

The Geomative GD-10 (Resistivity Meter /IP) was utilized to acquire electrical resistivity data in the research area. This equipment is commonly used for groundwater exploration, environmental and engineering and geological investigations, etc. it is light in weight, convenient in operation, having a transmitter and receiver combined in the same case.

The nine configurations of electrodes are displayed by large LCD. Other main accessories of the equipment are a 300 m long multi-electrode intelligent cable with 5 m takeout spacing, four rechargeable batteries, 60 stainless steel electrodes, hammers, and measuring tapes. The Geomative GD-10 resistivity / IP meter is designed for optimum versatility in infrastructure projects and environmental studies. Additionally, the tool has built-in quality control and feedback to the operator. It can acquire 1D, 2D and 3D, and 4D geoelectrical resistivity surveys.

3.1.3 Fieldwork / Results

An ERT survey was applied on Gul Dheri Dam in Nowshera for delineating potential seepage paths contributing to the reservoir storage loss. By Interpreting the acquired geophysical results by different interpretative techniques, such as the 2D inversion of ERT, practiced on 6 executed profiles (ERT-P1, ERT-P2, ERT-P3, ERT-P4, ERT-P5 and ERT-P6).

This work aimed to identify probable dam leakage pathways in the dam site. The GPS-based topography was used for electrode location along with the ERT profiles and each profile having a length of 300 meters and starting (1st) electrode & ending (60th) electrode and Midpoint (30th) electrode.

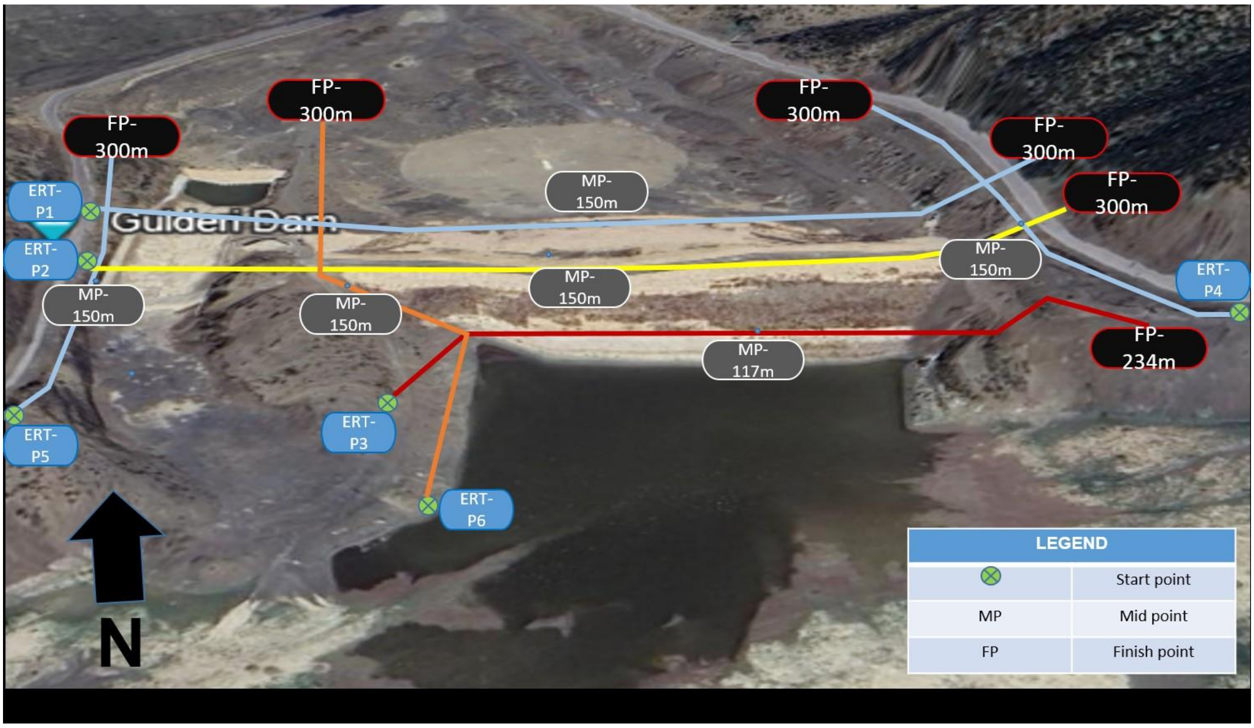


Figure 2: ERT Profiles

3.1.3.1 ERT P-1

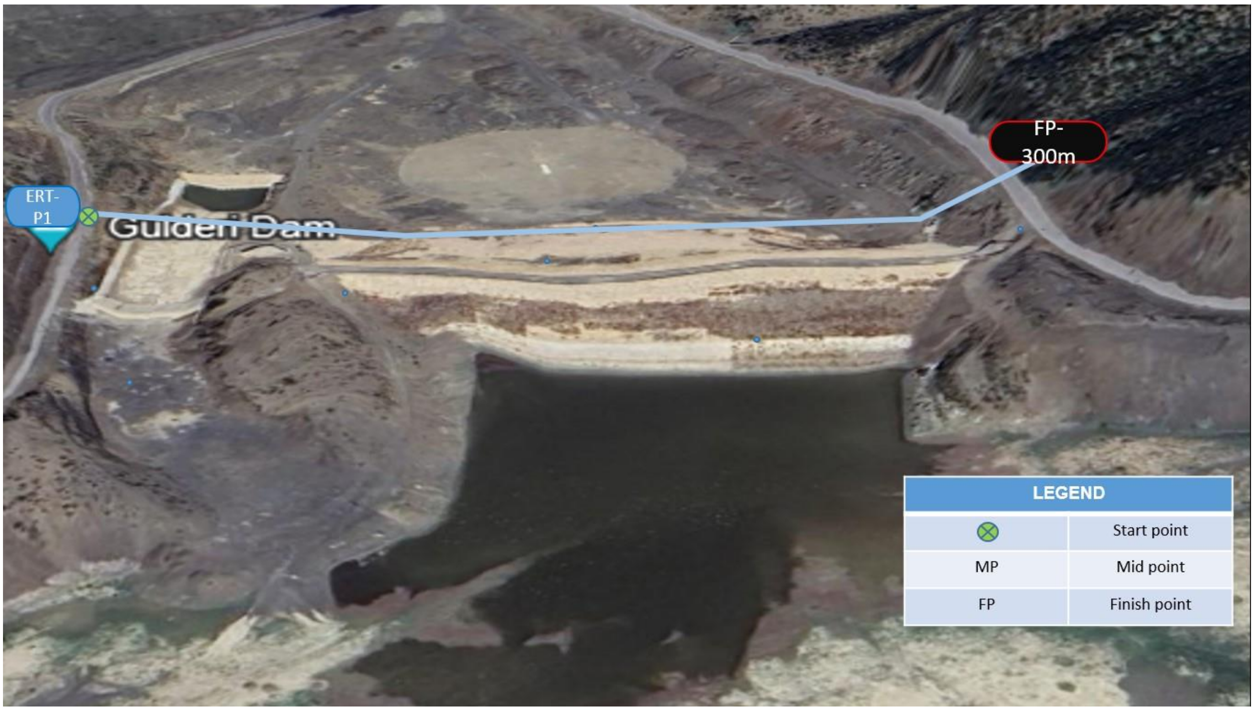
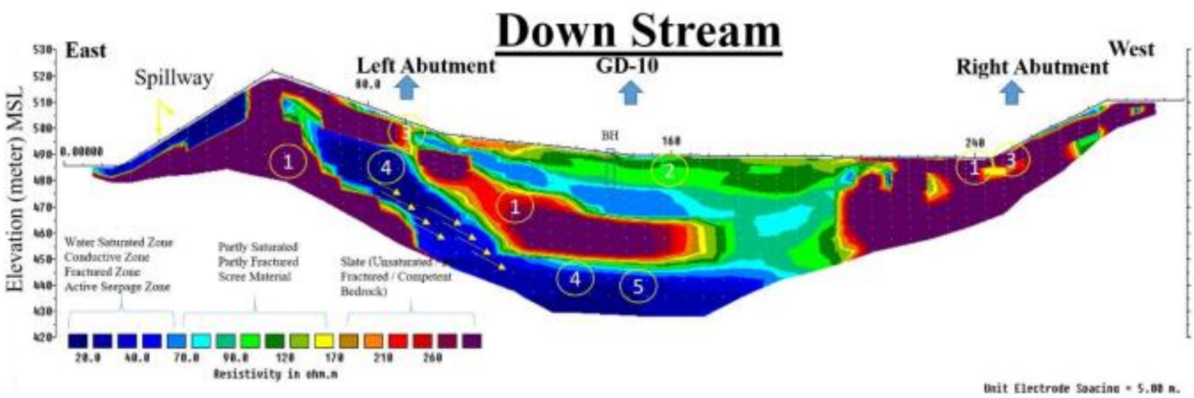


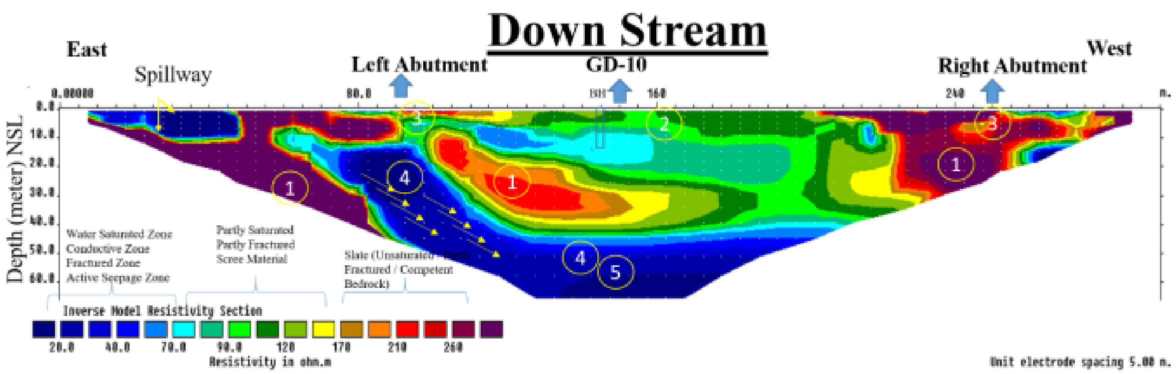
Figure 3:ERT P-1

ERT-P1 was acquired in the Down Stream area (as shown in Figure 5). The profile was orientated in the East-West direction, the midpoint of the ERT-P1 profile was lined up as per the geotechnical diagram especially the installed piezometer borehole. The maximum profile length was 300 meters with a 5-meter takeout interval. The starting point (1st electrode) was placed in the eastern part and extended toward the western part. All electrodes were installed in the natural subsurface ground and planted electrodes were wetted with salty water to ensure good contact with the underlying soil and to reduce the noise. Figure 4 shows the inverted ERT-P1 geo-electrical cross-section (COVERING EAST-WEST NALA SECTION & SEGMENT OF SPILLWAY), which can be divided into three principal distinguished blocks horizontally.



Legends:
1. Slate (Unsaturated / Partly Fractured / Competent Bedrock)
2. Stream Deposit (Partly Saturated)
3. Spillway & Abutments
4. Fully Saturated Condition beneath Spillway, Left Abutment & Front of Dam Body
5. Active Seepage zones

Figure 4: ERT P-1 (2D-ERT)



Legends:
1. Slate (Unsaturated / Partly Fractured / Competent Bedrock)
2. Stream Deposit (Partly Saturated)
3. Spillway & Abutments
4. Fully Saturated Condition beneath Spillway, Left Abutment & Front of Dam Body
5. Active Seepage zones

Figure 5: ERT P-1 (2D-ERT)

Figures illustrate the ERT-P1 (downstream) electrical resistivity cross-section, all major features were incorporated in the figure such as left and right abutment, spillway, unsaturated, partly saturated, saturated zone, and active seepage zone.

The 1st zone is directly related to the HIGHLY SATURATED ZONE, marked clearly by blue color as shown in Fiure. The electrical resistivity of this HIGHLY SATURATED ZONE is between 20 to 60 ohm-m and which is started at 500 m (MSL) and extended up to 420 m (MSL), contrary meaning is that the depth of this HIGHLY SATURATED ZONE is started below 20 m depth (below the left abutment). This conductive zone is subsurface water flow channels. Left abutment comprise of rocks that are highly fragile in nature and provide passage to reservoir water which ultimately decreases the overall electrical resistivity of this zone.

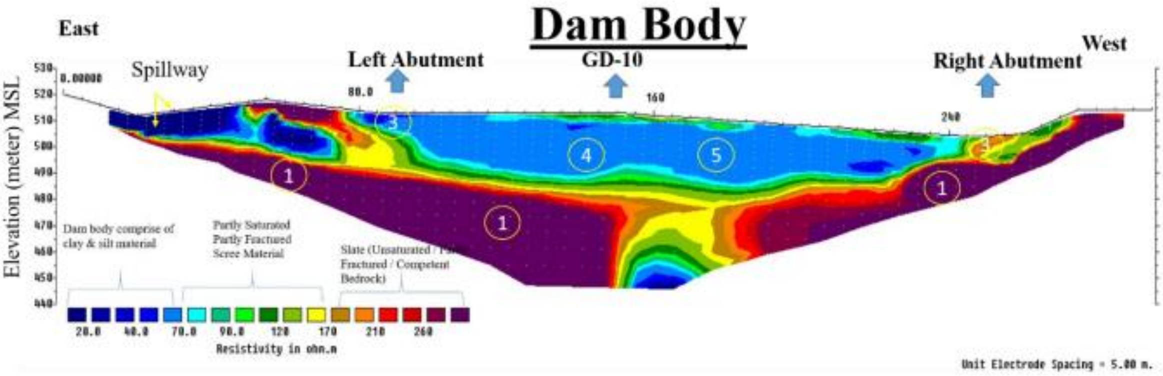
The 2nd zone is MODERATE RESISTIVE ZONE, which is clearly shown by green color as shown in Figure. The electrical resistivity of this MODERATE RESISTIVE ZONE is between 60 to 170 ohm-m and starts from 490 m (MSL) below and extended up to 460 m (MSL) as shown in Figure. Field condition shows that downstream side comprises rounded to sub rounded gravels, pebbles, cobbles, sand,. The stream water is gradually infiltrated in friable sand & sandstone formation. The electrical resistivity cross-section shows overall resistivity of the formation is reduced due to the percolation of surface water into the friable sandstone formation. The cumulative resistivity of the sandstone formation is up to 170 Ohm-m.

The 3rd zone is a HIGH RESISTIVE ZONE, which is clearly shown by red color as shown in Figure. The electrical resistivity of this HIGH RESISTIVE ZONE is greater than 180 ohm-m and starts from 490 m (MSL) and extended up to 440 m (MSL) toward right abutment. High resistivity values are interpreted as unsaturated / slightly fractured formation as justified by field condition. The right abutment comprises of moderate thickness of slate rock, however, the left abutment slate formation is very fractured, thin bedded and weaker which probably help in infiltration of reservoir water.

3.1.3.2 ERT P-2

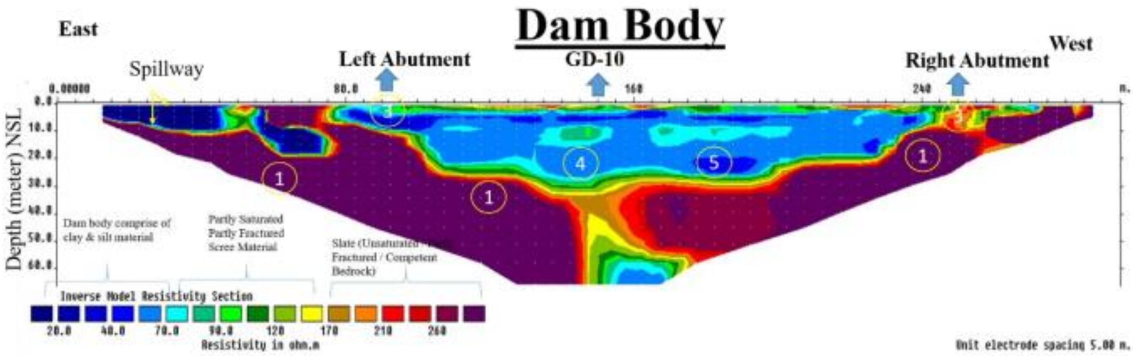
Figure 6: ERT P-2

ERT-P2 was acquired on the Dam Axis (as shown in Figure). The profile was orientated in the East-West direction. The maximum profile length was 300 meters with a 5-meter takeout interval. The starting point (1st electrode) was placed in the eastern part (Left) and extended toward the Western part (Right Abutment); this profile provides the East-West cross-sectional area of the dam axis and small portion of spillway and right abutment. All electrodes were installed in the natural subsurface ground and planted electrodes were wetted with salty water to ensure good contact with the underlying soil and to reduce the noise.



Legends:
1. Slate (Unsaturated / Partly Fractured / Competent Bedrock)
2.
3. Spillway & Abutments
4. Dam body
5. Clay & Silt Materials

Figure 7: ERT P-2 (2D-ERT)



Legends:
1. Slate (Unsaturated / Partly Fractured / Competent Bedrock)
2.
3. Spillway & Abutments
4. Dam body
5. Clay & Silt Materials

Figure 8: ERT P-2 (2D-ERT)

Figures Illustrate the ERT-P2 (DAM AXIS) electrical resistivity cross-section, all major features were incorporated.

The 1st zone is HIGHLY SATURATED ZONE directly related to the clayey core of the dam body, marked clearly by blue color as shown in Figure. The junction of green yellow (below blue color) represents the lower boundaries of the clay core. The electrical resistivity of the clayey core zone is 20 to 60 ohm-m. The clayey core of the dam seems to be intact and structurally homogenous and lower boundaries are clearly distinct especially at the contact with the underlying bedrock. It is important to note that abnormal conductive zone is detected at deeper depth in the central part of the dam body. It is suggested to mark more analysis to identify the problem. Furthermore, spillway was constructed on highly fractured, thin bedded and incompetent slate rock portion of formation, the ERT P2 result indicates very conductive zone below the spillway which is interpreted as active seepage zone beneath the spillway and left abutment.

The 2nd zone is MODERATE RESISTIVE ZONE, which is clearly shown by green color as shown in Figure. The electrical resistivity of this MODERATE RESISTIVE ZONE is between 50 to 150 ohm-m and starts from 500 m (MSL) below and extended up to 490 m (MSL) as shown in Figure.

The 3rd zone is a HIGH RESISTIVE ZONE. The electrical resistivity of this HIGH RESISTIVE ZONE is greater than 170 ohm-m and starts from 490 m (MSL) and extended up to 440 m (MSL) toward the both abutments and top portion of the High resistivity values are interpreted as unsaturated slate rock formation as justified by field condition.

3.1.3.4 ERT P-3

Figure 9: ERT P-3

ERT-P3 was acquired which covers the Upstream Toe. The profile was orientated in the East-West direction. The maximum profile length was 300 meters with a 5-meter takeout interval. The starting point (1st electrode) was placed in the eastern part and extended toward the western part (Right Abutment). All electrodes were installed in the natural subsurface ground and planted electrodes were wetted with salty water to ensure good contact with the underlying soil and to reduce the noise.

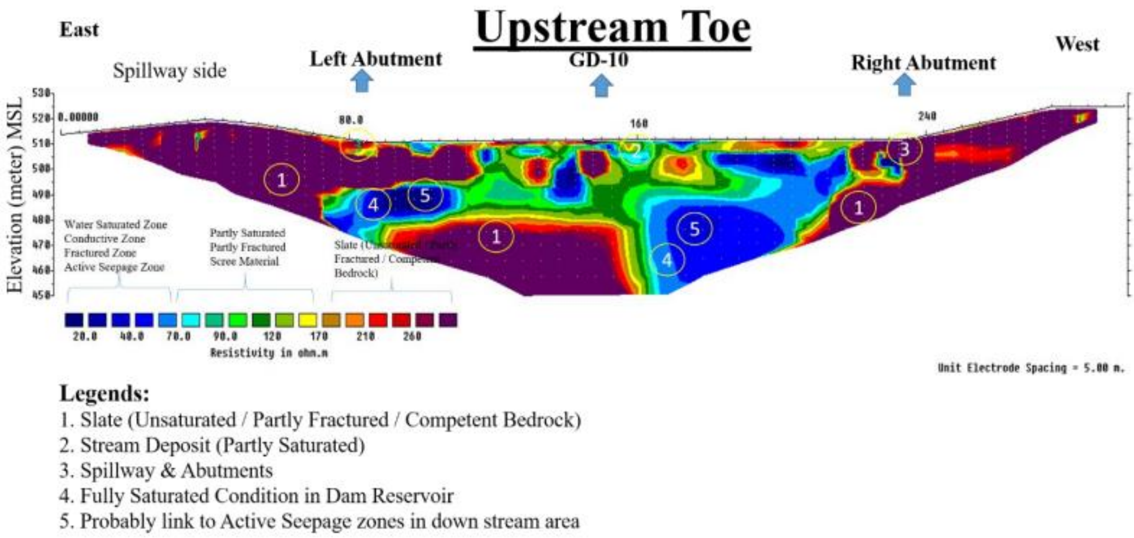


Figure 10: ERT P-3 (2D-ERT)

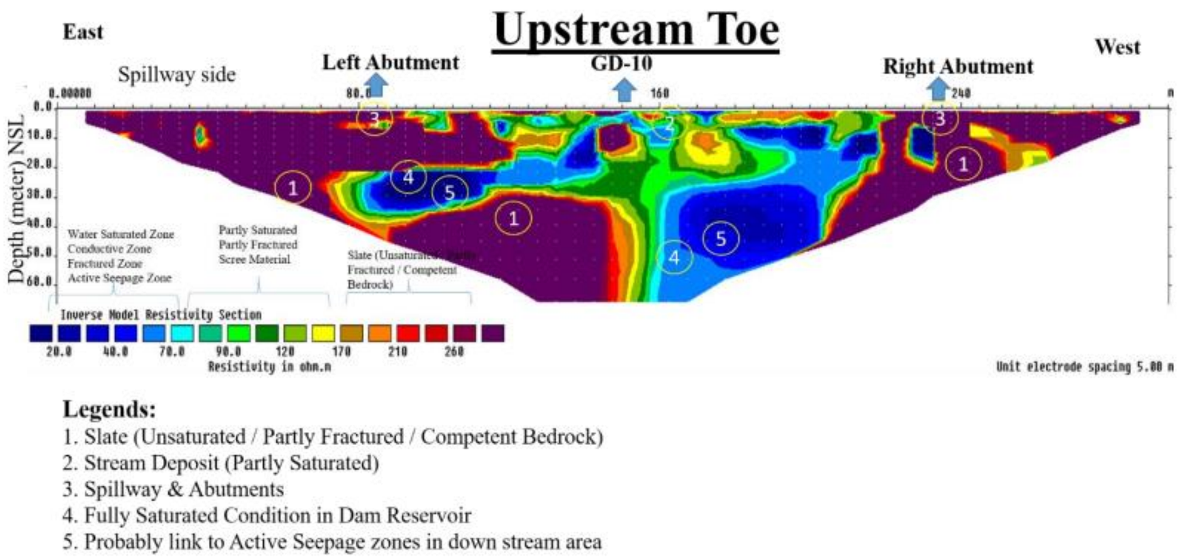


Figure 11: ERT P-3 (2D-ERT)

Figures Illustrate the ERT-P3 (UPSTREAM TOE) electrical resistivity crosssection, all major features were incorporated.

The 1st zone is directly related to the HIGHLY SATURATED ZONE, marked clearly by blue color. The electrical resistivity of this HIGHLY SATURATED ZONE is between 20 to 60 ohm-m and which is located elevation ranges 490~450 m (MSL), in other words, it means that the depth of this HIGHLY SATURATED ZONE is between 10~40 m depth. The surface geological condition indicates that the right abutment is comprised of moderate thickness of slate rock, however, the left abutment slate rock is highly fractured and thin bedded. By incorporating the geological information, electrical resistivity tomography results revealed that highly fractured and thin bedded slate rock are mainly responsible for percolating and infiltrating the surface stream's water into the subsurface groundwater system. This formation possess high porosity and permeability which allow to saturate clay stone / mudstone and ultimately produced low electrical resistivity in this zone.

The 2nd zone is MODERATE RESISTIVE ZONE, which is clearly shown by green color. The electrical resistivity of this MODERATE RESISTIVE ZONE is between 60 to 170 ohm-m and which starts from 510 m (MSL) and extended up to 480 m (MSL), contrary meaning is that the depth of this MODERATE RESISTIVE ZONE occupies almost half portion in the cross-section. As the surface geological condition depicts that alluvial deposit responsible for reducing the electrical resistivity of the formation by allowing surface water to infiltrate. Hence, reduced the overall resistivity of the formation up to 170 Ohm-m. The surface geological condition indicates that the right abutment is comprised of moderate bedded slate rock formation.

The 3rd zone is a HIGH RESISTIVE ZONE, which is clearly shown by red color. The electrical resistivity of this HIGH RESISTIVE ZONE is greater than 170 ohm-m and starts from 520 m (MSL) and extended up to 480 m (MSL) toward the both abutments. High resistivity values are interpreted as unsaturated slate rock as justified by field condition.

3.1.3.4 ERT P-4

Figure 12: ERT P-4

ERT-P4 was acquired in RIGHT ABUTMENT. The profile was orientated in the North-South direction. The maximum profile length was 300 meters with a 5-meter takeout interval. The starting point (1st electrode) was placed upstream and extended toward downstream area (this profile was acquired along the road side). All electrodes were installed in the natural subsurface ground and planted electrodes were wetted with salty water to ensure good contact with the underlying soil and to reduce the noise.

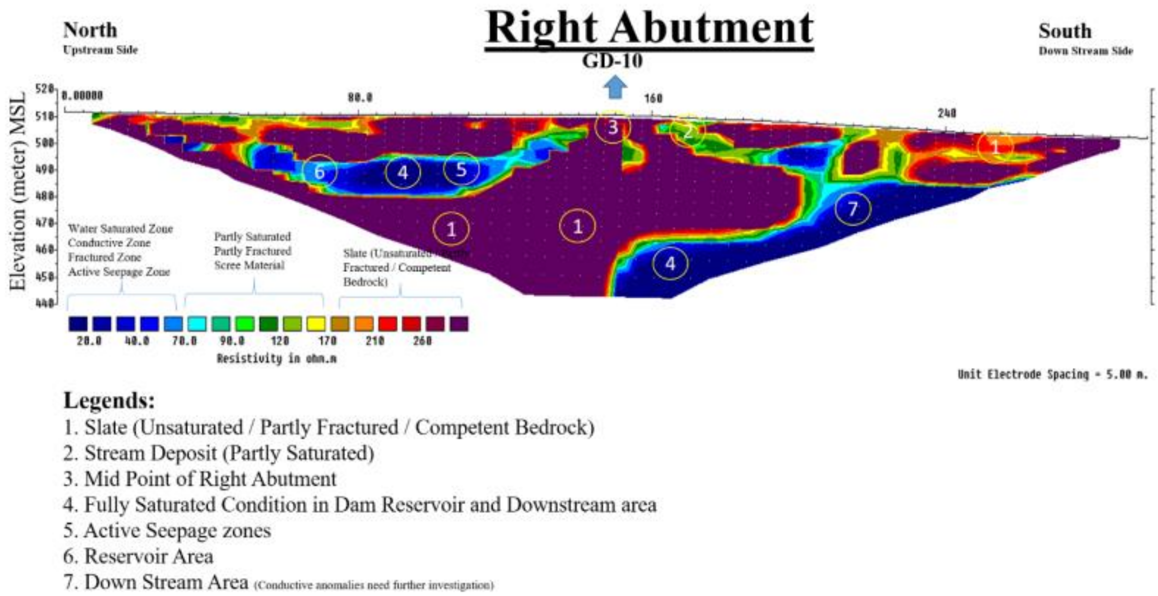


Figure 13: ERT P-4 (2D ERT)

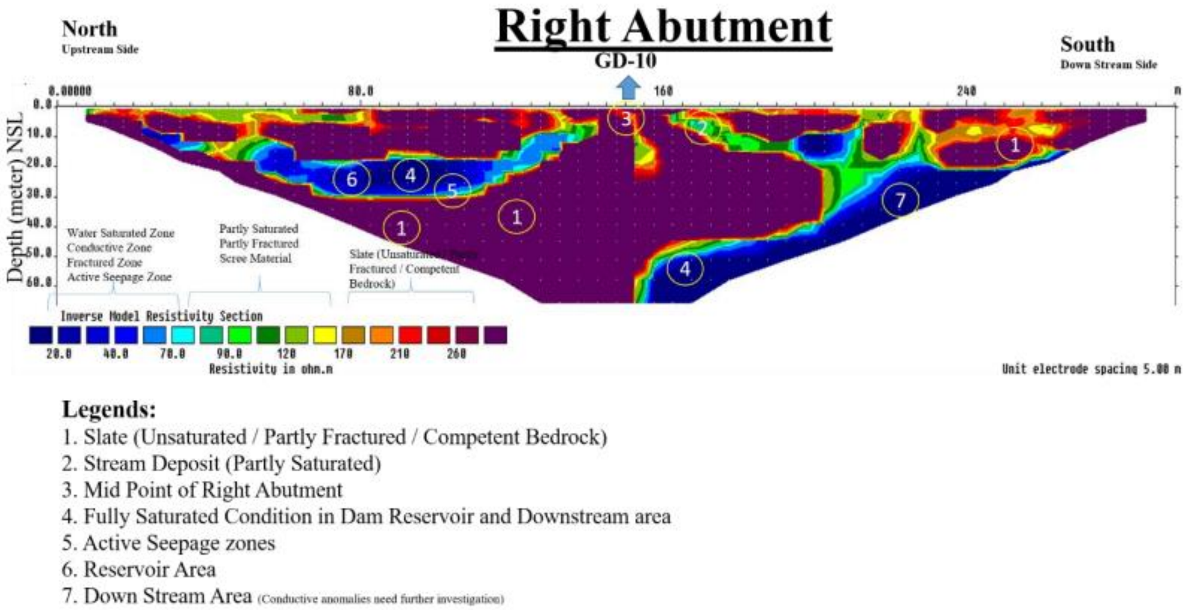


Figure 14: ERT P-4 (2D ERT)

Figures Illustrate the ERT-P4 (RIGHT ABUTMENT) electrical resistivity crosssection), all major features were incorporated.

The 1st zone is directly related to the HIGHLY SATURATED ZONE, marked clearly by blue color. The electrical resistivity of this HIGHLY SATURATED ZONE is between 20 to 60 ohm-m. The conductive anomalous zones in ERT-P4 profile can be further divided into two zone. There are two conductive anomalies present in the subsurface, one is located in upstream area and other is in downstream area, the downstream conductive anomaly is widely distributed along the road side.

(GREEN COLOR) The 2nd zone of the ERT-P4 section shows partly saturated slate formation with moderate electrical resistivity values. Surface geological observation that that the right abutment is also composed of slate formation. The 2nd zone is MODERATE RESISTIVE ZONE, which is clearly shown by green color as shown in Figure 7. The electrical resistivity of this MODERATE RESISTIVE ZONE is between 60 to 170 ohm-m. The 3rd zone is a HIGH RESISTIVE ZONE, which is clearly shown by red color as shown in Figure 7. The electrical resistivity of this HIGH RESISTIVE ZONE is greater than 170 ohm-m.

3.1.3.5 ERT P-5

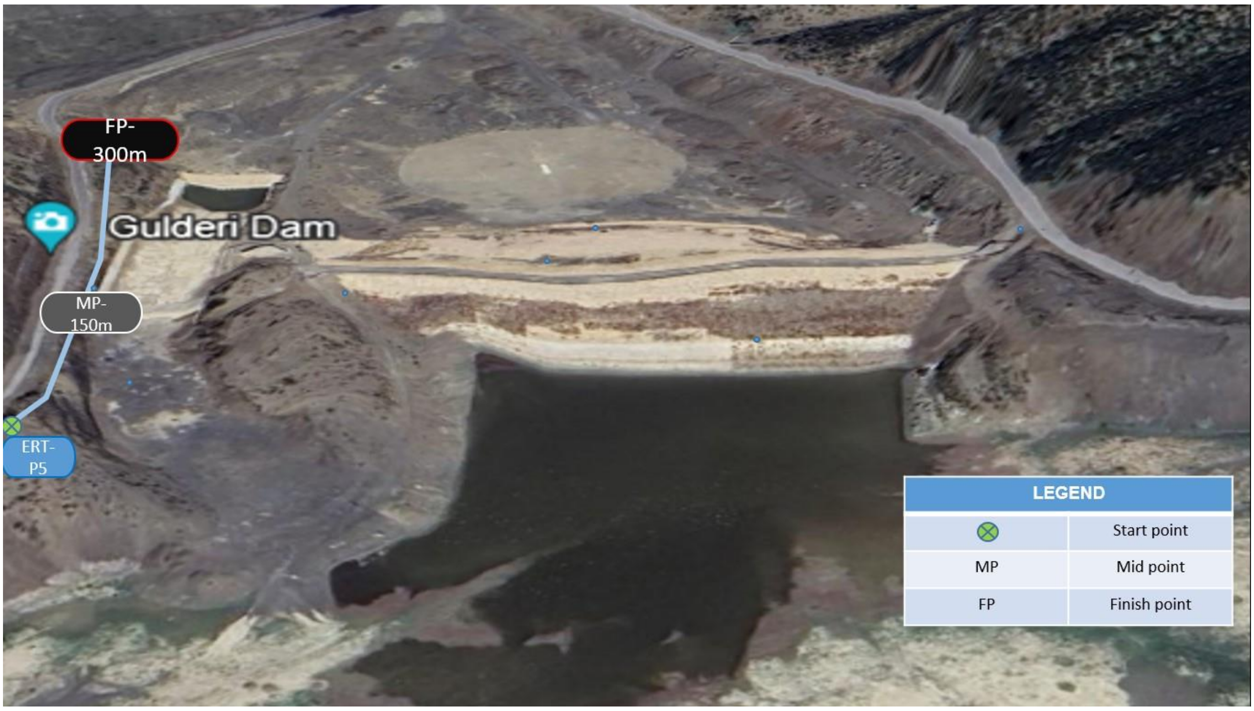
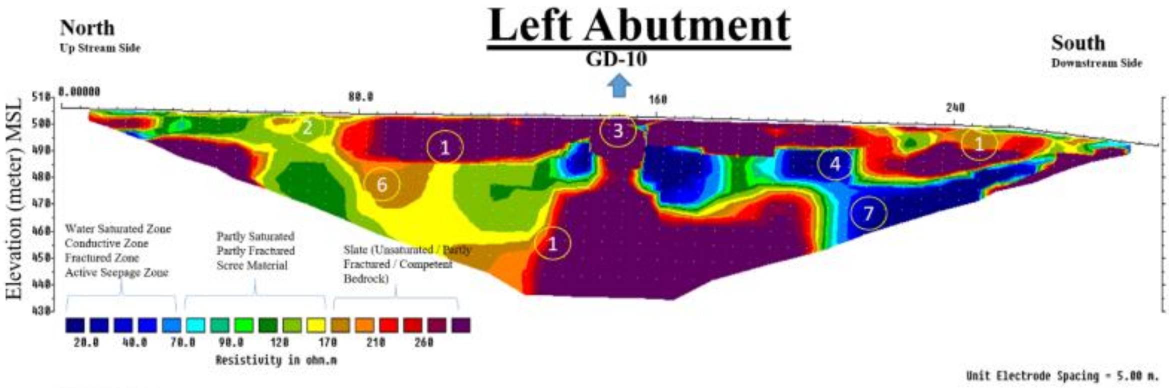


Figure 15: ERT P-5

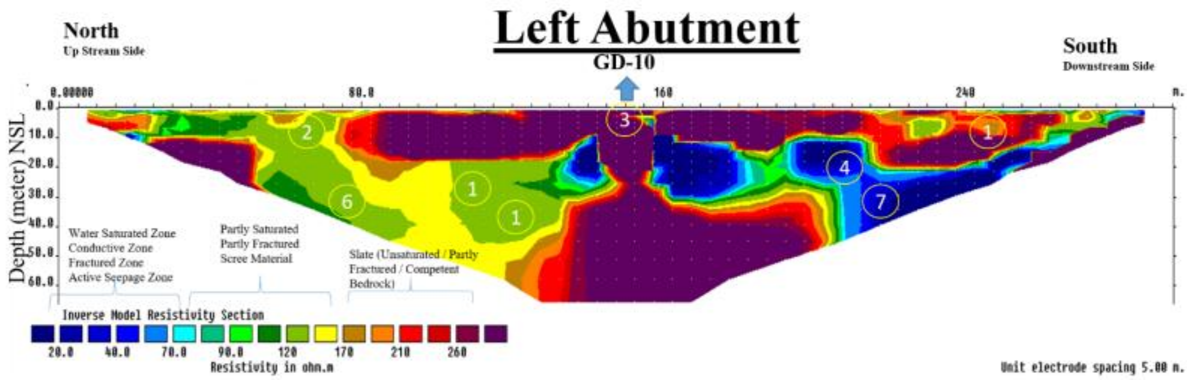
ERT-P5 was acquired in LEFT ABUTMENT. The profile was orientated in the North-South direction, the midpoint of the ERT-P5 profile was lined up as per the geotechnical diagram (midpoint of ERT-P5 was perpendicular to dam crosssection). The maximum profile length was 300 meters with a 5-meter takeout interval. The starting point (1st electrode) was placed upstream and extended toward downstream area (this profile was acquired along the road side). All electrodes were installed in the natural subsurface ground and planted electrodes were wetted with salty water to ensure good contact with the underlying soil and to reduce the noise.



Legends:

1. Thin bedded Slate (Unsaturated / Partly Fractured / Competent Bedrock)
2. Stream Deposit (Partly Saturated)
3. Mid Point of Right Abutments
4. Fully Saturated Condition in Dam Reservoir
5. Active Seepage zones
6. Reservoir Area
7. Down Stream Area

Figure 16: ERT P-5 (2D ERT)



Legends:

1. Thin bedded Slate (Unsaturated / Partly Fractured / Competent Bedrock)
2. Stream Deposit (Partly Saturated)
3. Mid Point of Right Abutments
4. Fully Saturated Condition in Dam Reservoir
5. Active Seepage zones
6. Reservoir Area
7. Down Stream Area

Figure 17: ERT P-5 (2D ERT)

Figures illustrate the ERT-P5 (LEFT ABUTMENT) electrical resistivity cross-section, all major features were incorporated in the figure.

The 1st zone is directly related to the HIGHLY SATURATED ZONE, marked clearly by blue color. The electrical resistivity of this HIGHLY SATURATED ZONE is between 20 to 60 ohm-m. There is one conductive anomaly has been observed in downstream area, which justifies the leakage from the reservoir body.

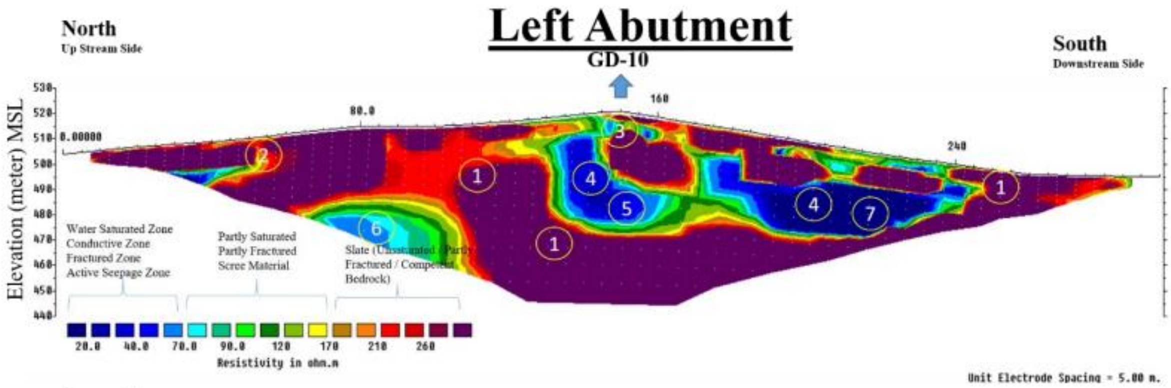
(GREEN COLOR) The 2nd zone of the ERT-P5 section shows partly saturated deposit and slate formation with moderate electrical resistivity values. Surface geological observation reveal the right abutment is also composed of slate formation. The 2nd zone is MODERATE RESISTIVE ZONE, which is clearly shown by green color. The electrical resistivity of this MODERATE RESISTIVE ZONE is between 60 to 170 ohm-m.

The 3rd zone is a HIGH RESISTIVE ZONE, which is clearly shown by red color as. The electrical resistivity of this HIGH RESISTIVE ZONE is greater than 170 ohm-m.

3.1.3.6 ERT P-6

Figure 18: ERT P-6

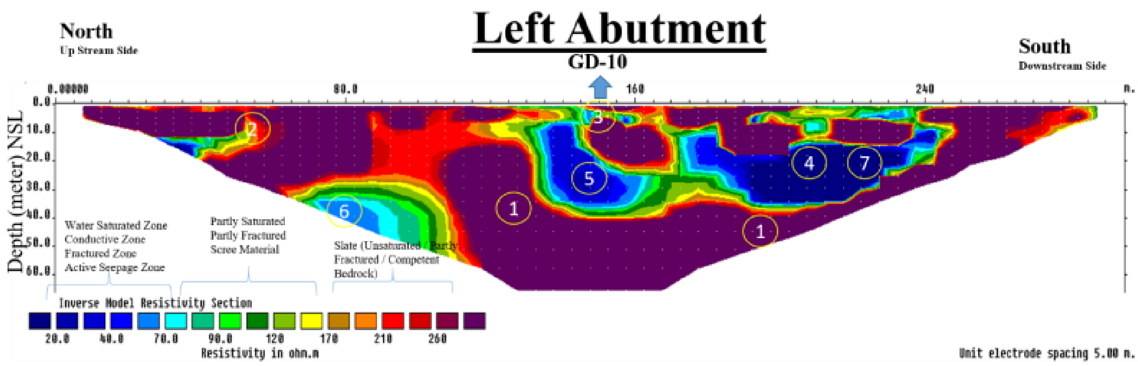
ERT-P6 was acquired in LEFT ABUTMENT. The profile was orientated in the North-South direction. The maximum profile length was 300 meters with a 5-meter takeout interval. The starting point (1st electrode) was placed upstream and extended toward downstream area (this profile was acquired on the left abutment. All electrodes were installed in the natural subsurface ground and planted electrodes were wetted with salty water to ensure good contact with the underlying soil and to reduce the noise.



Legends:

1. Thin bedded Slate (Unsaturated / Partly Fractured / Competent Bedrock)
2. Stream Deposit (Partly Saturated)
3. Mid Point of Left Abutment / GD 10
4. Fully Saturated Condition in Dam Reservoir
5. Active Seepage zones (*tie point on left abutment*)
6. Reservoir Area
7. Down Stream Area

Figure 19: ERT P-6 (2D ERT)



Legends:

1. Thin bedded Slate (Unsaturated / Partly Fractured / Competent Bedrock)
2. Stream Deposit (Partly Saturated)
3. Mid Point on Left Abutment
4. Fully Saturated Condition in Dam Reservoir
5. Active Seepage zones (*left abutment tie point*)
6. Reservoir Area
7. Down Stream Area

Figure 20: ERT P-6 (2D ERT)

Figures Illustrate the ERT-P6 (LEFT ABUTMENT) electrical resistivity crosssection, all major features were incorporated in the figure.

The 1st zone is directly related to the HIGHLY SATURATED ZONE, marked clearly by blue color. The electrical resistivity of this HIGHLY SATURATED ZONE is between 20 to 60 ohm-m. The first 30-meter depth in upstream area at 125-meter horizontal distance comprise of unsaturated condition in the upstream area, additionally, a conductive zone can be seen just below 80-meter horizontal distance at depth of 40 meter from NSL. In term of, elevation (m) from MSL, the conductive at horizontal distance 80-meter at the elevation level below 480 m MSL. The upper part of this anomaly can be interpreted as clay core, however, the lower part at 480~490 m MSL are considered as the active seepage zones.

(GREEN COLOR) The 2nd zone of the ERT-P6 section shows partly saturated slate formation with moderate electrical resistivity values. Surface geological observation and geotechnical drilling reveal that the left abutment is also composed of slate formation.

The 2nd zone is MODERATE RESISTIVE ZONE, which is clearly shown by green color. The electrical resistivity of this MODERATE RESISTIVE ZONE is between 60 to 170 ohm-m. When the geological materials are partly saturated then these materials show moderate electrical resistivity values, when fractures are fully saturated then same materials show low electrical resistivity values.

The 3rd zone is a HIGH RESISTIVE ZONE, which is clearly shown by red color. The electrical resistivity of this HIGH RESISTIVE ZONE is greater than 170 ohm-m.

3.1.4 Areas of zones in ERT Profile using ArcGIS

Only the procedure for ERT P-2 (Dam Axis) is shown below

Figure 21: Georeferencing 1

Figure 22: Georeferencing 2

Then supervised classification was done by using Support Vector Machine Classifier.

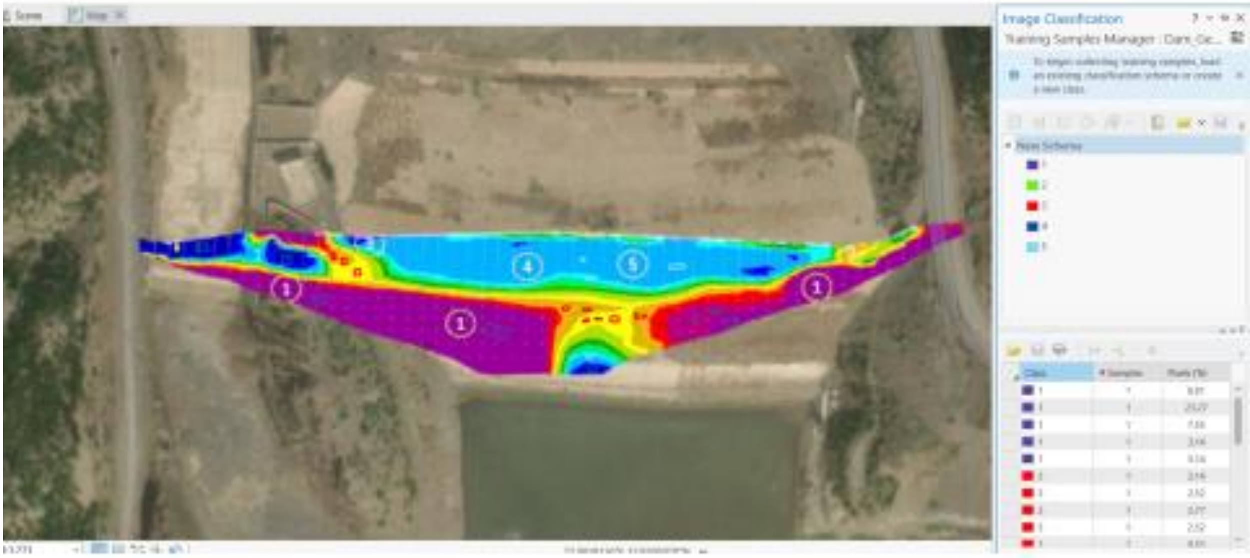


Figure 23: Classification 1

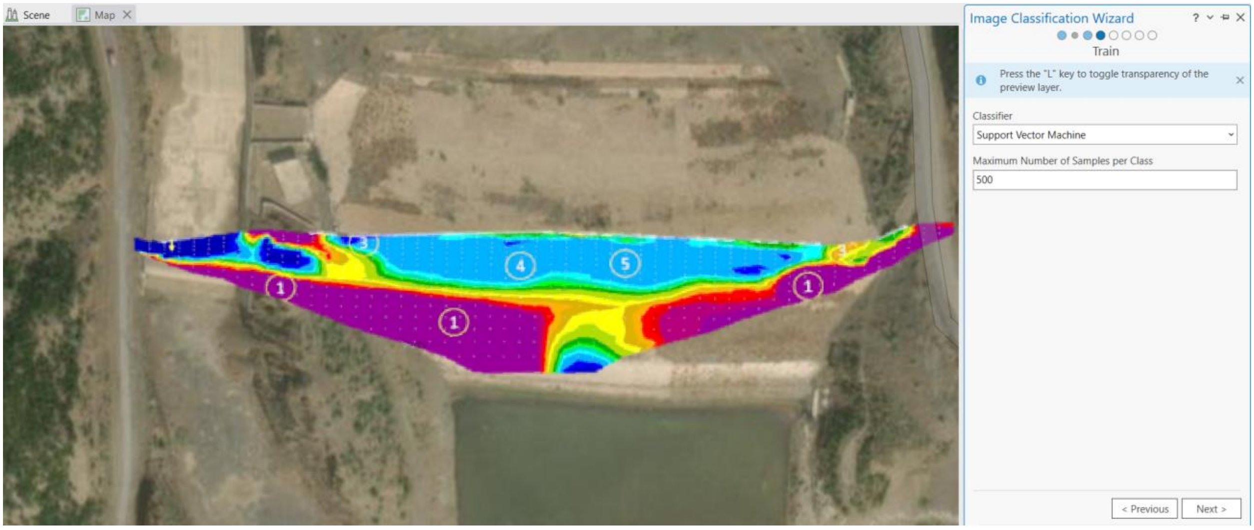


Figure 24: Classification 2

Areas were calculated by dividing each profile into 3 zones i.e. Saturated Zone, Partially Saturated Zone and Unsaturated Zone. The results are as shown below.

3.1.4.1 ERT P-1 (Downstream)

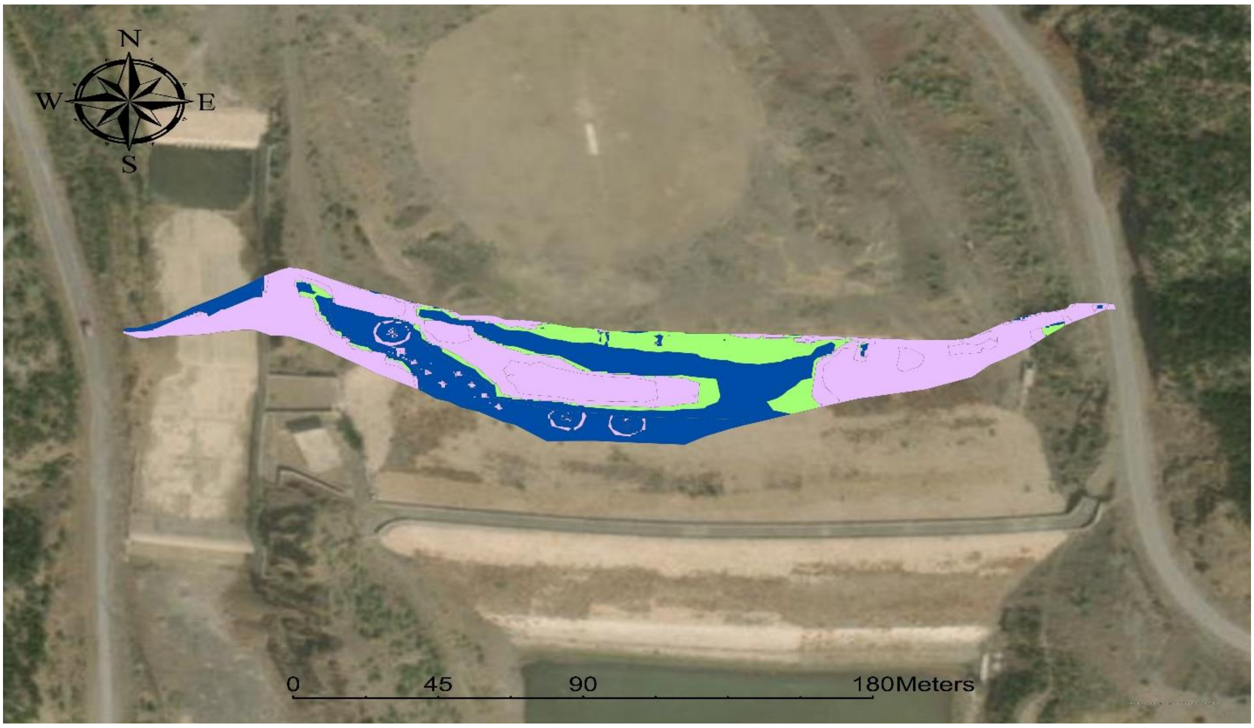


Figure 25: ERT P-1 (Classified)

Ser No	Zone	Color	Area(sqm)
1.	Saturated		1183.232854
2.	Partially Saturated		802.4545011
3.	Unsaturated		2837.343082
4.	Total		5857.706387

Table 1: AREAS (ERT P-1)

3.1.4.2 ERT P-2 (Dam Axis)

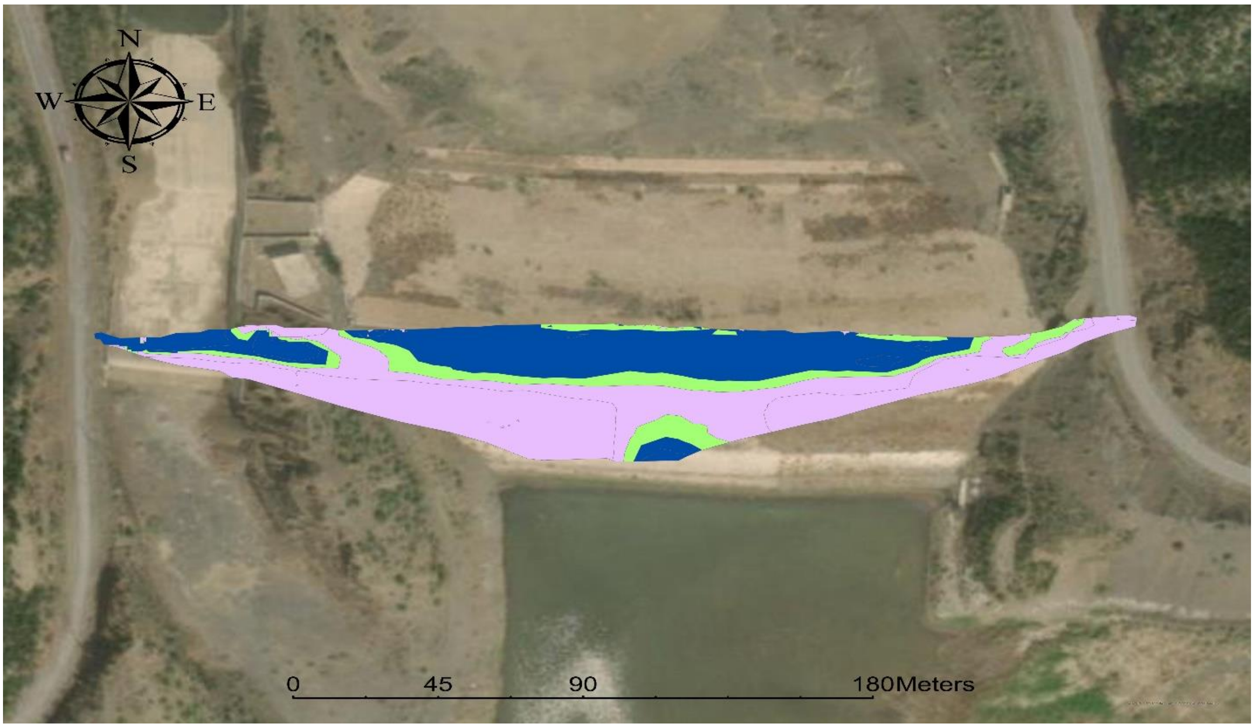


Figure 26: ERT P-2 (Classified)

Ser No	Zone	Color	Area(sqm)
1.	Saturated		2127.914916
2.	Partially Saturated		971.0396796
3.	Unsaturated		3474.659957
4.	Total		6902.277892

Table 2: AREAS (ERT P-2)

3.1.4.3 ERT P-3 (Upstream Toe)

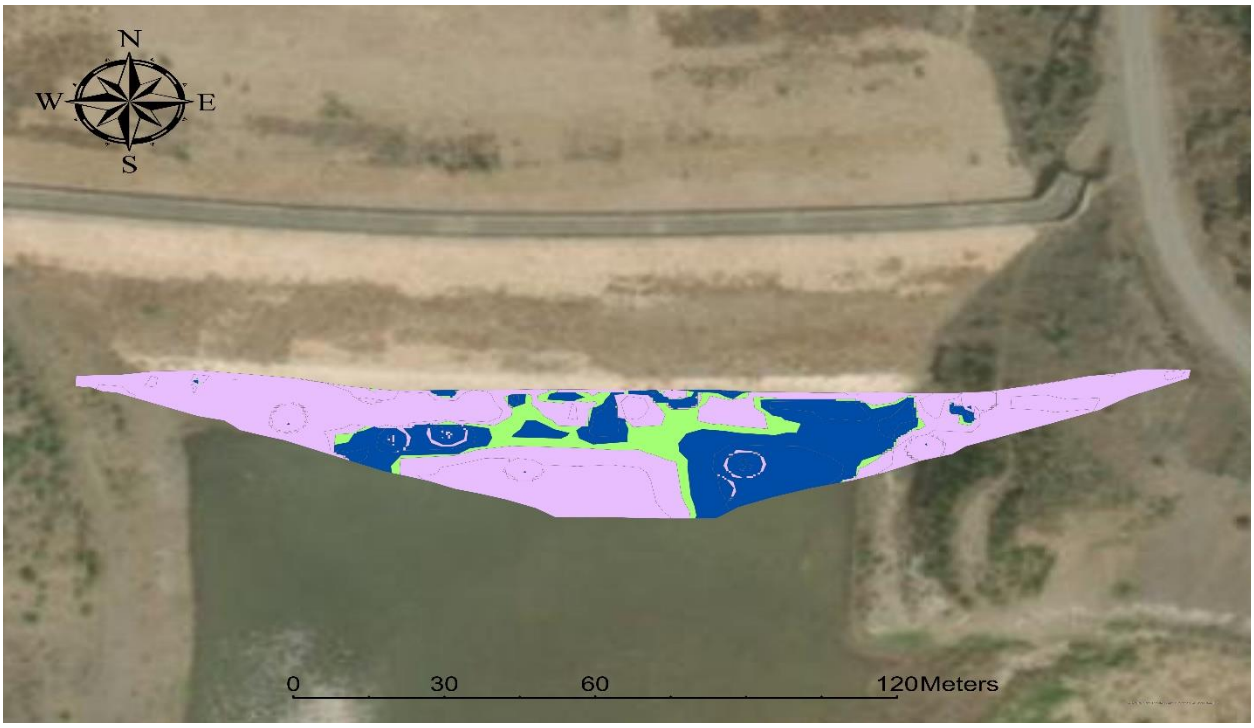


Figure 27: ERT P-3 (Classified)

Ser No	Zone	Color	Area(sqm)
1.	Saturated		491.8345312
2.	Partially Saturated		294.284142
3.	Unsaturated		1802.85506
4	Total		2948.171789

Table 3: AREAS (ERT P-3)

3.1.4.4 ERT P-4 (Right Abutment)

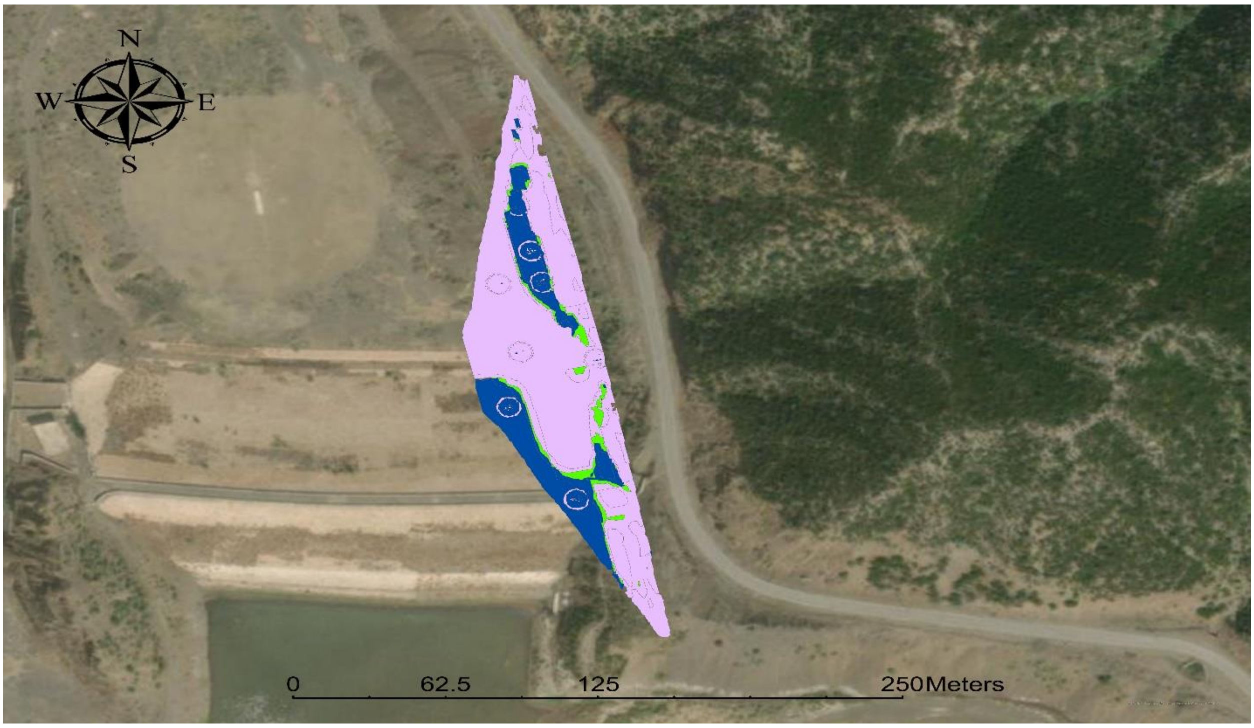


Figure 28: ERT P-4 (Classified)

Ser No	Zone	Color	Area(sqm)
1.	Saturated		387.3952797
2.	Partially Saturated		284.3349064
3.	Unsaturated		5029.136916
4.	Total		6783.87297

Table 4: AREAS (ERT P-4)

3.1.4.5 ERT P-5 (Left Abutment 1 - Outer)

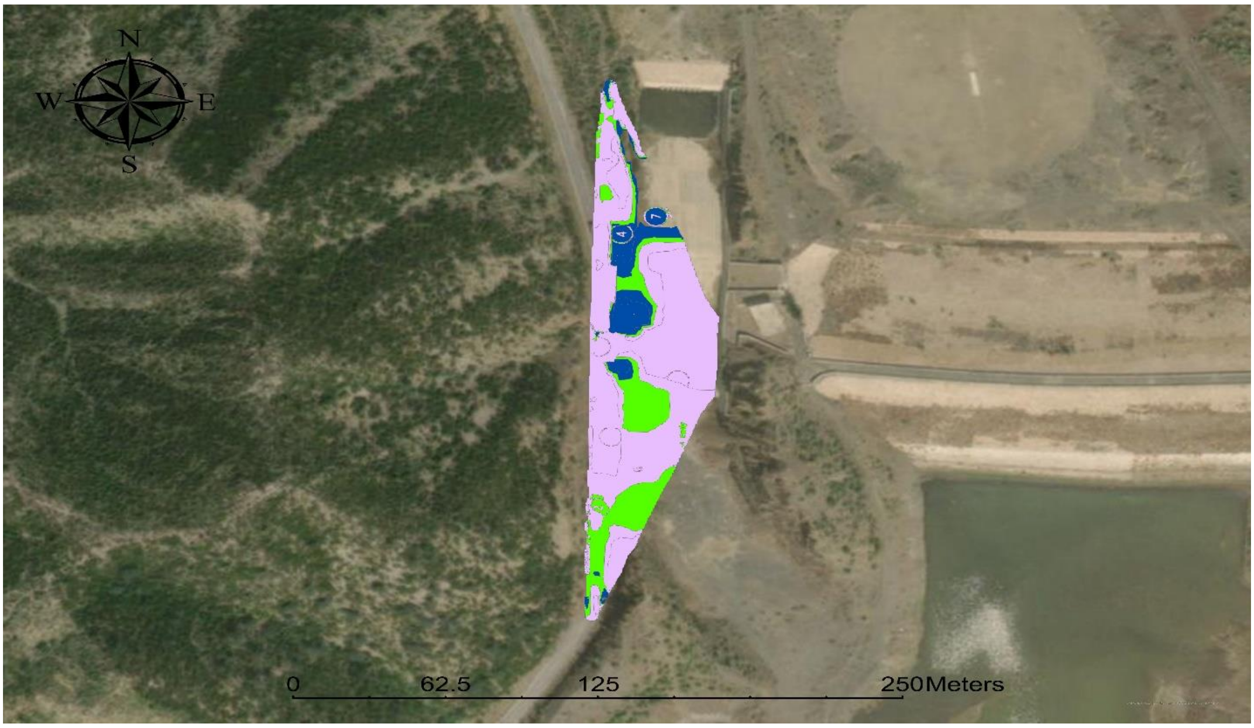


Figure 29: ERT P-5 (Classified)

Ser No	Zone	Color	Area(sqm)
1.	Saturated		333.4748811
2.	Partially Saturated		1154.041824
3.	Unsaturated		4200.499355
4.	Total		6021.881188

Table 5: AREAS (ERT P-5)

3.1.4.6 ERT P-6 (Left Abutment 2 - Inner)

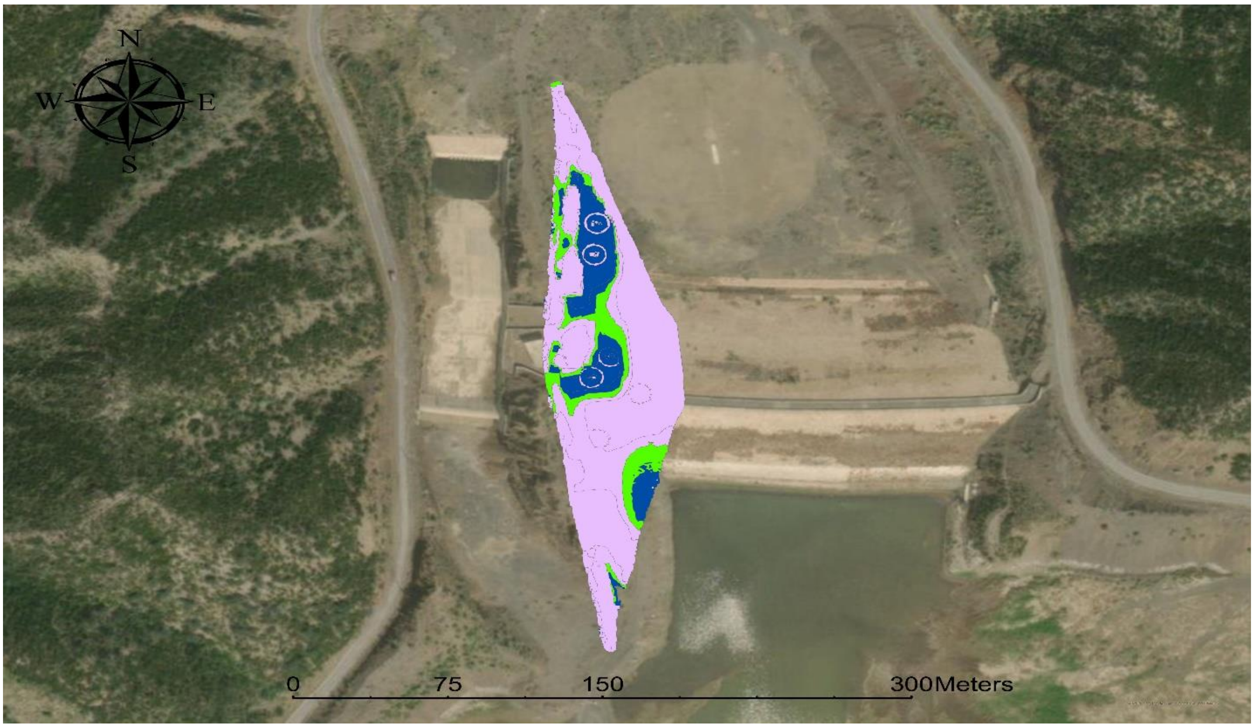


Figure 30: ERT P-6 (Classified)

Ser No	Zone	Color	Area(sqm)
1.	Saturated		673.47064
2.	Partially Saturated		1068.313103
3.	Unsaturated		6563.9973
4.	Total		9139.178173

Table 6: AREAS (ERT P-6)

3.1.5 Dam Site View with zones of all profiles

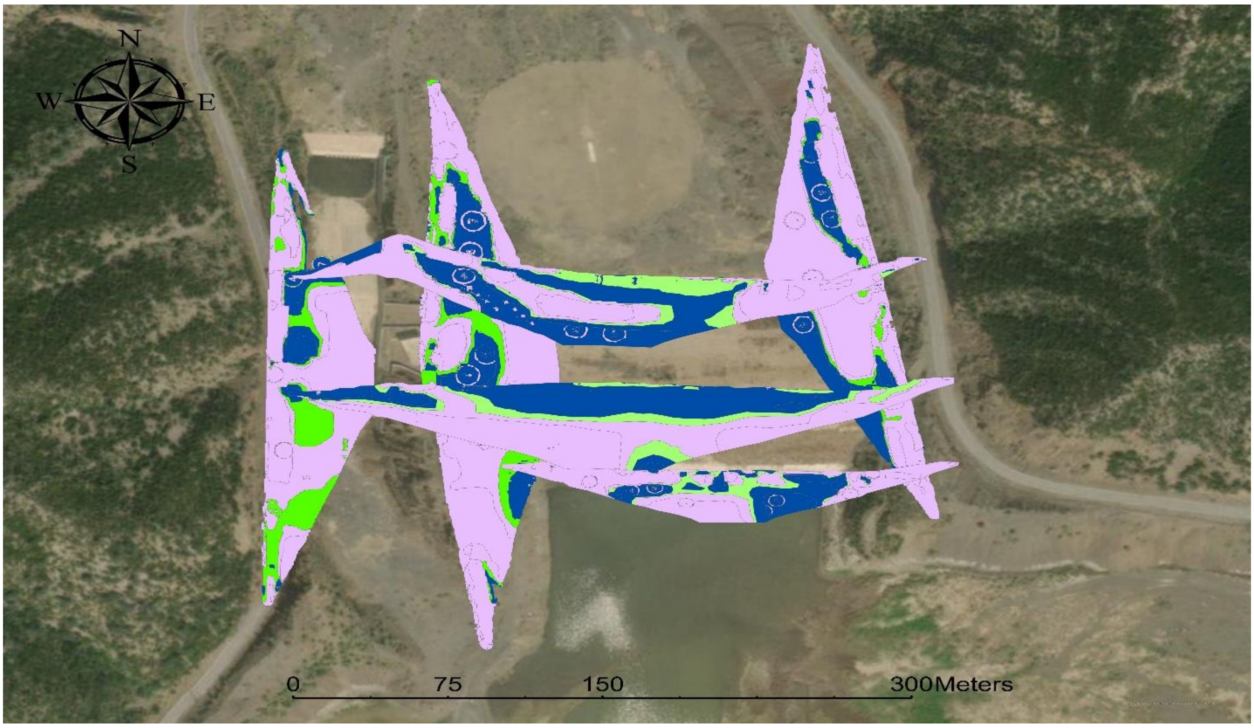


Figure 31: Dam view with all profiles

3.2 Drone Survey

For better understanding of the terrain and its relationship with the seepage of water, a drone survey was carried out on Oct 31st, 2023.

Figure 32: Drone Survey

3.2.1 Benefits of Drone Survey

Following are some benefits for carrying out a drone survey.

3.2.1.1 Precision Monitoring. Drone surveys offer accurate, detailed data for monitoring earth fill dam conditions, detecting issues like erosion or structural deformities early on.

3.2.1.2 Time and Cost Efficiency. Drones swiftly cover large areas, reducing survey time and costs compared to traditional methods, making monitoring more accessible and affordable.

3.2.1.3 Enhanced Safety. By eliminating the need for personnel in hazardous terrains, drones improve safety during dam inspections, minimizing the risk of accidents or injuries.

3.2.1.4 Data Accessibility. Drone survey data is quickly processed, providing real-time insights. This accessibility allows for prompt decision-making and proactive maintenance to ensure dam stability.

3.2.2 Results of Drone Survey

Figure 33: Aerial View of Dam Site

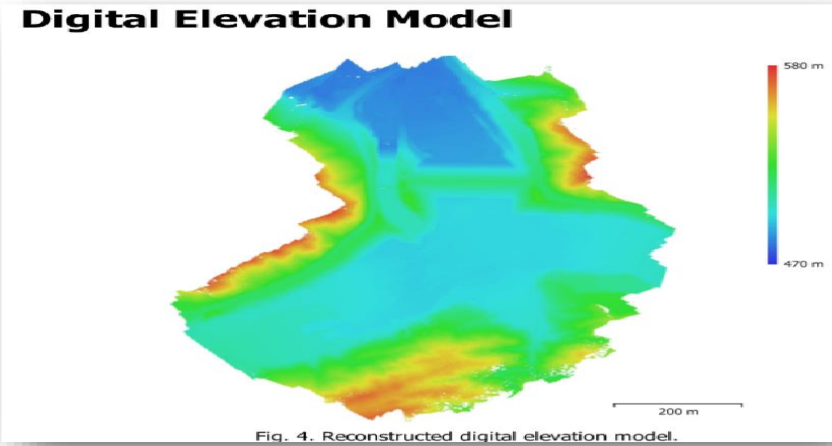


Figure 34: Digital Elevation Model

The above model shows the elevation of the selected terrain on a heat map, with red being the highest and blue being the lowest / deepest areas.

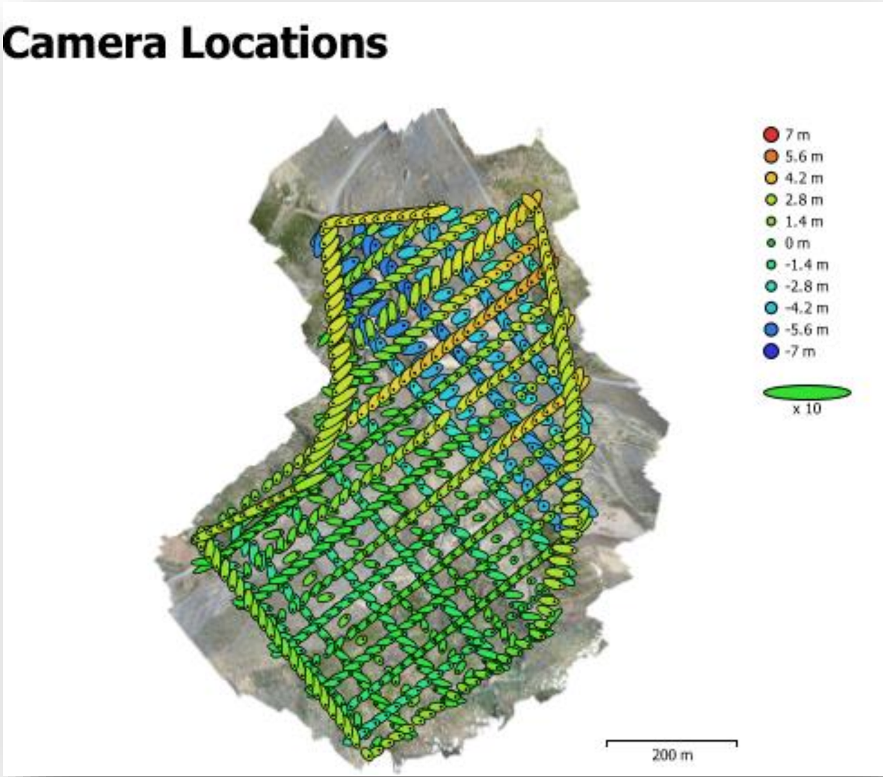


Figure 35: Camera Locations

Above is a pictorial representation of the camera locations and the path it took while conducting the survey

Fol are some specifications of the svy.

Ser No	Heading	Remarks
1.	Number of images	840
2.	Flying altitude	133 m
3.	Ground resolution	2.92 cm/pix
4.	Coverage area	0.495 km²
5.	Camera stations	838
6.	Tie points	2,229,832
7.	Projections	7,748,657
8.	Reprojection error	1.49 pix
9.	Elevation of area	470 – 580m above MSL

Table 7: Drone Survey Specifications

CHAPTER 4

REMEDIAL MEASURES

SER NO	HEADING	DESCRIPTION
1.	**Grouting**	Grouting involves injecting grout (a mixture of cement, water, and sometimes additives) into the cracks and fissures in the slate formation to seal them and reduce permeability. This can be done using various techniques such as permeation grouting or pressure grouting.
2.	**Cutoff walls**	Constructing cutoff walls along the leakage zones can help prevent water from seeping through the slate formation. These walls are typically made of impermeable materials such as concrete or steel sheet piles and are driven into the ground to depths below the water table. These barriers can be designed to extend to depths where the slate formation transitions to less permeable strata.
3.	**Geomembranes**	Installing geomembranes on the upstream face of the dam can act as a barrier to prevent water from penetrating through the slate formation. Geomembranes are impermeable liners made of synthetic materials such as high-density polyethylene (HDPE) or polyvinyl chloride (PVC).
4.	**Drainage systems**	Implementing drainage systems within the dam structure can help collect and redirect water that seeps through the slate formation away from the dam. This can involve installing horizontal and vertical drains along with sumps and pumps to manage water flow.
5.	**Reinforcement**	Strengthening the dam structure through techniques such as soil stabilization or adding additional layers of fill material can help reduce the potential for seepage through the slate formation.

6.	**Monitoring and maintenance**	Regular monitoring of the dam and its foundation, including instrumentation to measure water seepage and ground movement, can help identify potential issues early on. Routine maintenance activities such as inspecting grout curtains and repairing any damage promptly can help ensure the effectiveness of remedial measures over time.
7.	**Compaction grouting**	Compaction grouting involves injecting a low-slump, low-mobility grout into the soil or rock formation to densify and strengthen it. This technique can help reduce permeability by filling voids and stabilizing the surrounding ground.
8.	**Pressure grouting with chemical additives**	In addition to traditional cement-based grouting, chemical additives can be used to enhance the effectiveness of pressure grouting. These additives can improve the penetration of grout into small fissures and provide better long-term sealing.
9.	**Vegetative Covers**	Implementing vegetative covers on the downstream slope of the dam can help manage water infiltration by promoting evapotranspiration and reducing surface runoff. This natural approach can complement other remedial measures and provide additional stability to the dam embankment.
10.	**Electrokinetic Stabilization**	Electrokinetic stabilization involves the application of an electric field to the ground to induce chemical reactions that alter the properties of the soil or rock. This method can help strengthen the slate formation and reduce permeability by promoting precipitation of minerals or by enhancing soil compaction.
11.	**Soil nailing**	Soil nailing involves drilling steel bars or rods into the slope or embankment and grouting them in place to reinforce the soil mass. This technique can stabilize the slope and reduce the potential for water infiltration through the slate formation.
12.	**Soil-Bentonite Cutoff Walls**	Soil-bentonite cutoff walls utilize a mixture of soil and bentonite clay to create an impermeable barrier within the

		dam foundation. This technique can adapt to irregularities in the slate formation and provide a flexible yet effective solution for reducing leakage.

Table 8: Remedial Measures

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