**The widest range of geophysical and seismic techniques services and technologies to address non-invasive investigation and the maintenance and monitoring of Dams, Embankments and Levees.**

# DAM SAFETY GROUP ©

The member companies of the Dam Safety Group offer proven solutions for the evaluation and monitoring of safety and subsurface ground characterization issues for new build or existing Dams and related hydrological projects.

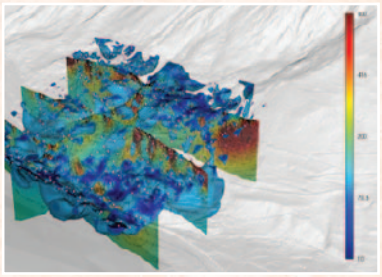
Together with market leading real time seismic Earthquake Early Warning Systems supported by a wide range of alerting technologies.

| Resistivity Imaging | Seismic Tomography | Ground Penetrating Radar (GPR) | Wireline Borehole Logging | Seismic Monitoring |
|---|---|---|---|---|
| IRIS INSTRUMENTS | GEOMETRICS Simplify your search | GSSI | ROBERTSON GEO Unlocking Your GeoData | KINEMETRICS Advancement through Innovation |

www.damsafetygroup.com

# Resistivity Imaging

- *Multi-channel electrical resistivity imaging (2D and 3D) to define the internal integrity of dams and locate potential points of failure*
- *Monitoring dam seepage, water saturation, piping and leakage paths*
- *3 dimensional characterization and monitoring of dam slopes*
- *2D and 3D imaging of lateral dam slopes to prevail potential landslide risk of over topped dams*



## Why use IRIS technology for Dam Safety?

**The successive evolution of IRIS resistivimeters over the last 30 years has developed equipment able to carry out measurements on long sections (higher than a kilometre) or in 3D. Time can also be recorded for monitoring purposes.**

These devices are very useful for imaging and monitoring the sides of dams and levees. The resulted images are called Electrical Resistivity Tomography (ERT) during use, induced polarization (chargeability property) is also recorded. The induced polarization (IP) method is an extension of the resistivity method providing, in addition to the electrical resistivity distribution, an additional property characterizing the ability of porous media to store electrical charges under. Both resistivity and induced polarization are active geoelectrical methods for which an electrical current is injected in the ground. The self-potential (SP) method is a passive geophysical technique for which we measure the electric field fluctuations generated by the flow of pore water in porous media. In other words, the source of current is inside the structure itself and its associated electrical field is measured remotely.

IRIS Instruments resistivimeters and electrical recorders are able to provide ERT, IP and SP information along boreholes, along 2D sections (even long) and in a 3D configuration.

The topography of dam areas and slopes also benefit from ERT, IP and SP imaging in three dimensions to predict potential landslides and related overtopping risks. IRIS Instruments equipment's provide dimensional imaging for technicians and service providers for dam issue predictability and longer-term monitoring for remedial work.

Among the infrastructure that need specific attention, one can consider the tailing dams. The failure rate of tailings dams is estimated to be 10 to 100 times higher than the failure rate of other earthen dams. The risk of tailings dams' failure is an issue as there is no standardised solution to avoid the disruptive impact on the environment, human activities, and human lives. The importance of tailings dam safety has been enhanced worldwide due to the recent failures that have occurred and the increased consciousness among society.

## IRIS instruments solutions through Dam Life Cycle

**The solutions provided by IRIS benefit at each stage of the life of a dam, from its design to monitoring its operation.**

**Feasibility:** In areas of altered rock or alluvial deposits, electrical prospecting is highly relevant, alone or in combination with seismic. In this technique, the variations of electrical resistivity of the ground are used to deduce those of the lithology, alteration and alteration and fracturing. The measurements can be made in the form of boreholes, of electrical drags, resistivity panels or in 3D.

**Design:** Geophysics, and electrical methods, is widely used for the dimensioning of structures such as dams. The objectives under consideration aim to characterize the soil, rock and groundwater at dam potential sites. The targeted properties are the lithology and patterns of fracturing and weathering, in addition to fracture orientation, depth to bedrock, and fault location. Electrical methods are more cost effective to other geotechnical methods in that they can still be used to observe formation of voids or sinkholes.

**Build:** During infrastructure construction projects, knowledge of the subsoil is essential for the success of the project but also for the safety of the workers. Here also, the presence of cavities, sink holes or ground movement (landslides) must be considered. Electrical methods offer a low-cost investigation.

**Working Life:** Owners and Dam managers need to understand the dam structures internal integrity to locate points of failure in real time or with time acquired monitoring. Geophysical techniques have the ability to non-intrusively probe dams and detect the occurrence of anomalous seepages within their structure. The ERT, IP and SP methods are valuable for imaging the foundations of dams and delineating their seeping zones. IP has recently been applied to detect seepages in Earth dams by monitoring the change in the water content over time. SP method which is easy to set up and cost-effective has a considerable potential for the detection of seepages in dams.

Electrical methods are particularly useful for surveying Earth dams. Earth dams play an indispensable role as they can be designed to store large volumes of water for domestic and industrial purposes such as supplying hydroelectric power stations. The most frequent causes of dam failure are related to the action of water resulting in overtopping, slope instability, seepage, and foundation failure.

The detection of seepage at the early stage of its development is essential for the safety of a water retaining structure as an embankment dam. ERT and SP monitoring has also been widely applied for solving environmental and engineering problems by studying the changes in the subsurface properties over time. SP changes are caused by water movements through the dam and resistivity changes reflect the changes in the electrical properties of the dam materials. Measuring SP is a powerful and easy way to detect leakage and time series resistivity measurements provide valuable information about the changes in condition of the dam.

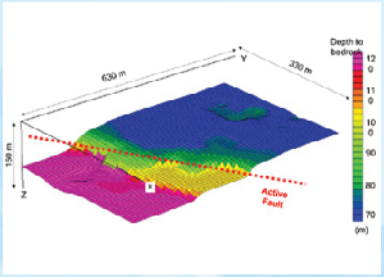
**Resistivity Imaging**

www.damsafetygroup.com

GEOMETRICS
Simplify your search

# Seismic Tomography

- *Characterize ground conditions in terms of shear wave velocity, rippability, bedrock mapping and soil condition*
- *Identify faults and related structures*
- *Soil type in levees*
- *Active and Passive Surface Wave Techniques*




## Using Geometrics Equipment in Dam Placement and Integrity

**Near-surface geophysical seismic investigation is a critical component for new dam construction and monitoring existing dam structures.**

In the earliest stages of planning and design, engineers rely on geophysical data to help assess the geotechnical conditions of a potential dam site. Seismic surveys provide important information on hazards such as faults, landslides, and Karst terrain They may provide information useful to dam construction, such as bedrock depth and topography, rippability, and soil classifications. Geophysical data is also useful in assessing the integrity of existing dams and levees. Earthen dams and levees in particular benefit from geophysical investigation, as zones of weakened soils can create a significant hazard to those living downstream. Seismic investigation provides insight into the geological suitability of a potential dam site as well as the integrity of existing earthen dams and levees.

Geometrics began manufacturing geophysical instruments in 1969 and have continued to do so for over 50 years. The equipment is an essential part of any geotechnical investigation, and designed for reliability, sensitivity, and ease of use. Geometrics products result from the work of a dedicated team of engineers, scientists and technicians for research, design, and manufacture of equipment. Licensed geologists and geophysicists who understand geotechnical field work and the necessary requirements for acquisition of the most accurate cost-effective data and with the most reliable instrumentation.

**Geometrics seismographs are highly versatile and can be used in many ways to investigate geotechnical and structural properties for characterising geologic hazards and engineering characteristics.**

- *Acquire data in multiple environments - Geometrics manufacture equipment for both marine and terrestrial applications so that you may perform refraction or reflection surveys anywhere necessary.*
- *May perform custom surveys without typical limitations - The expandable wireless system can be used in any geometry and with any sensor spacing. You are no longer constrained the pre-set spacing and geometries of your spread cable, or by site conditions such as high traffic areas, roadways, driveways or difficult to access terrain.*
- *Useful for evaluating seismic properties down to 1.5 km*
- *Software licenses don't expire and don't require renewal*

Geometrics instruments can be rented or purchased internationally through our network of representatives or by contacting us directly via **www.geometrics.com**

## Geometrics Seismographs and Dam Safety

**Dam safety begins with feasibility studies and continues throughout the life cycle of the dam, including post-construction monitoring and evaluation. A Geometrics seismograph will provide value in several key areas.**

**Hazard Assessment:** Feasibility studies include performing geophysical surveys to evaluate potential sites for hazards such as the presence and locations of and landslides. These surveys generally involve either or both seismic refraction and reflection surveys, both of which may be performed with the same Geometrics seismograph system. Acquiring quality data at this stage is essential for minimizing hazard and to ensure that geological conditions do not negatively impact the working life

**Design:** Engineers require specific information about ground conditions before making foundation and structural design decisions. This information includes information about depth to bedrock, bedrock topography, and soil properties, all of which are obtainable from seismic surveys. Surveys such as this can provide data for large areas. As the project evolves, this broad-scale investigation can be used to guide more detailed investigation.

**Construction:** Ground conditions can change abruptly, so having the tools available to perform an immediate evaluation can be crucial for keeping the project on schedule.

**Working Life:** An operational dam requires regular assessment to ensure that it remains functional and safe. Dam safety can be affected by something as simple as a strong storm, so having methods to non-destructively, quickly, and effectively evaluate the structural integrity of a dam can add much value to any safety program. Physical changes such as slumping, leaking, piping, cracking, scouring, or even rodent activity can severely impact a dam. Stability failures within the dam my not be visible to inspectors and may only be determined using a geophysical method. For earthen levees, active and passive seismic methods allow engineers to identify low-density zones within the dam. Having this information early, before a failure occurs, could mean the difference between making a simple repair and having a catastrophic failure.

**Upgrade/Replacement:** The earlier an engineer recognizes a change in a dam's integrity, the easier, safer, and less expensive it will be to fix the problem. Geophysical techniques can be used in a variety of ways to provide information useful for repairing, upgrading, or replacing a dam before failure occurs.

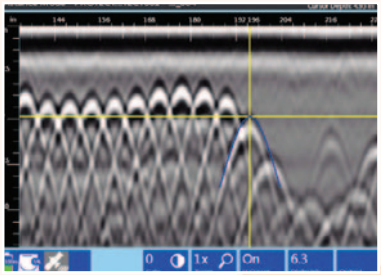
**Seismic Tomography**

GEOMETRICS
Simplify your search

www.damsafetygroup.com

# Ground Penetrating Radar (GPR)

- *Non-destructive imaging of the subsurface and manmade materials*
- *Characterizing Internal Structures*
- *Detection of cavities*
- *Concrete inspection and geotechnical investigation of dams, earthen levees and embankments*
- *Reservoir and stilling basin examination*



## Why use GSSI technology for Dam Safety?

**In the never-ending struggle to maintain the world's critical infrastructure, many professionals are seeking out non-destructive testing (NDT) methods that can assist in accurately determining the soundness of structures and assessing their remaining functional lifetime.**

Ground Penetrating Radar (GPR) is one of the many effective geophysical tools for investigating voids, fissures, and fractures in dam infrastructure. GPR offers non-destructive testing and investigation of defects in concrete or earthen dam structures like spillways, rip rap, buttresses, etc. These defects or deformations can occur because of water saturation, erosion, water load, or any number of engineering faults which can put human life in danger.

A technological pioneer for over 50 years, GSSI is the world leader of GPR systems that are trusted daily by professionals around the world. Each system sold is backed by a two-year warranty and includes complimentary training from our dedicated professional trainers during the warranty period. With every purchase, users enjoy unmatched technical support for the lifetime of their system.

GPR uses RADAR (Radio Detection and Ranging) to transmit and receive high frequency electromagnetic waves to image the subsurface. A tiny pulse of radio-frequency energy is sent into a material using an antenna. This wave reaches a target and is reflected to the receiver antenna showing anomalies that can affect the structure of the dam. GPR features extremely low power emission rates – less than 1 percent of the radio waves used by a cell phone – so there is no need for extra safety equipment or safety training to use these antennas.

GSSI customers have been using GPR systems for decades to conduct non-destructive dam investigations that provide information on sediment buildup and leak or void detection. Low frequency GPR systems can offer a number of non-destructive testing options for dam monitoring. High frequency antennas are ideal concrete condition assessment and repair, detecting voids in real-time, and accurately locating rebar position and depth.

## GSSI Technologies and Assessing Dam Health

**GSSI's systems aid in identifying and correcting potential structural problems throughout the lifecycle of a dam. Our systems can collect a large amount of very deep data quickly, allowing for easy monitoring of large structures.**

**Feasibility:** GPR works best in resistive conditions like sand, concrete, and fresh water. Where you have highly conductive environments, GPR signals tend to attenuate. Depending on the frequency of the antenna used, you can get 12 inches of data with very high resolution or up to 70 feet with lower resolution. Choosing the correct antenna frequency depends on the scope of your project and site assessment needs.

**Design:** Before construction on a dam may begin, it is essential to understand the surrounding environment to ensure long-term structural stability. Using low frequency antennas can quickly collect large amounts of very deep data. Users can perform water bed and bathymetric mapping, identify sub-bottom structures, visualize lithological discontinuities and identify remediation and repair locations. High frequency systems can help determine where any drilling or core may need to take place in a safe environment.

**Hazard Assessment:** Engineers require specific information about ground conditions before making foundation and structural design decisions. High frequency antennas provide sharp vertical resolution for imaging rebar, small voids and fissures as well as enabling useful slab analysis. This information will be useful to pinpoint questionable locations within the concrete slab or other shallow areas to prevent catastrophic failures. Low frequency antennas can help to identify stratigraphic changes, lithological discontinuities, and sub bottom structures in the dam and reservoir.

**Working Life:** Safe operation requires that dams are regularly monitored for structural stability. GPR systems are ideal for locating problem areas which may develop over the lifetime of a dam. GSSI's low frequency antennas can show the interior of large and/or very deep structures to locate large voids, fractures, or leaks. The ability to collect large amounts of data that can be difficult to obtain using invasive methods makes low frequency GPR the go-to for a quick geophysical analysis. Identifying these remediation and repair locations early on means issues can be addressed before they develop into serious problems which could jeopardize the entire structure.

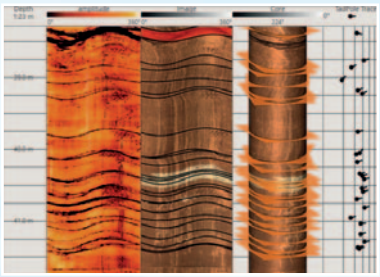
**Upgrade/Replacement:** GPR is one of the most cost effective and quickest geophysical surveying that can be done on a site. Significant upgrades or even complete replacement of an existing dam may be required as the dam ages and requirements change. GPR can provide a wealth of information to inform the decision-making process in real time.

**Ground Penetrating Radar (GPR)**

www.damsafetygroup.com

# Wireline Borehole Logging

- *Characterize ground conditions in terms of condition, stiffness, fractures and lithology*
- *Gain an understanding of the groundwater conditions*
- *Investigate the condition of existing structures associated with dams*



## Why use Robertson Geo technology for Dam Safety?

**The use of geophysical logging techniques for dam inspection and monitoring has long been recognised as critical for structural assessment over the life of a dam.**

Subsurface investigation provides detailed insight into the fabric and condition of dam walls, buttresses, foundations, and adjacent infrastructure such as spillways and bypass waterways.

Robertson Geo logging technology, developed over 40 years, provides consistent, fully calibrated data that is essential for the planning, construction, monitoring and remediation of dam structures. The technology is supported by a highly experienced personnel team, specialising in reliable tool production, quality control, accurate calibration, and data acquisition with innovative engineering solutions.

A range of proprietary logging tools can be used to investigate geotechnical, hydrogeological, and structural properties to characterize geological conditions, groundwater scenarios and any impairment of the existing hard structures. These include the use of:

- *Acoustic/optical televiewers and borehole cameras for imaging, fracture detection and lithological bed modelling*
- *Borehole calipers for hole condition quality control*
- *Probes for determining electrical resistivity characteristics, flow gradients, formation porosities, temperature, and conductivity indicators. These are essential tools for groundwater assessment and examination of near-borehole lithological characteristics*
- *PS Logger® and Formation Density probes for analysis of velocities, small strain moduli and density (FD)*

Robertson Geo borehole logging tools can be accessed internationally through onsite service, full system sales and equipment rental.

## Robertson Geo Technologies and the Dam Life Cycle

**The vital role of geophysical logging, as provided by Robertson Geo technologies, can be summarized by examining at the various stages in the life cycle of a dam.**

**Concept:** At the feasibility stage a programme of geophysical investigation will invariably be conducted. In addition to areal surveys by surface methods a suite of boreholes will be specified to collect samples and gather geophysical information pertaining to lithology, fractures, stiffness, and hydrogeology across relevant areas of the prospect. More and better data at this stage has the greatest potential for producing cost savings throughout the dam's life cycle.

**Design:** As the dam design crystallizes, additional data will be required especially in those areas where significant structures will be built. This will generally involve higher density data from further targeted drilling and geophysical data collection to confirm the ground conditions are suitable. This feedback loop is essential for optimising the design of the dam.

**Build:** For any civil engineering project, not least in dam construction, ground conditions remain the greatest unknown. Where unexpected ground conditions are encountered in the build phase, for example issues with artesian water, further targeted drilling and geophysical investigation may be required in order to solve local problems.

**Working Life:** Once the dam is commissioned and operational further geophysical investigation may be required as part of a programmed system of checking and maintenance. This will often be in response to feedback from permanent monitoring systems put in place to ensure the ongoing safety of the dam structure. Additionally, as the dam structures age, pilot holes may be drilled into parts of the structure to confirm its integrity. Here televiewers can provide a visual record which is a permanent and legally binding assessment of condition. For older dams there may be paucity of original information regarding the detailed design of the dam and its associated structures. This lack of information can often be easily remedied by an invasive programme of geophysical investigation into the structures themselves via pilot boreholes.

**Events:** Could be described as "when things go wrong". The most common events involving dams are:

- *Overtopping - caused by water spilling over the top of a dam*
- *Foundation defects – which includes settlement and slope instability*
- *Cracking - caused by movements such as natural settlement of a dam*
- *Poor maintenance – equipment failures, blockages etc.*
- *Piping – poor control of seepage which can undermine dam structure*

**If any of the above events threaten the safety of the dam, then a rapid programme of geophysical investigation may be required to provide additional information to inform the evaluation of potential solutions.**

**Upgrade/Replacement:** Significant upgrades or even complete replacement of the existing dam may be required as the dam ages and requirements change. Geophysical borehole logging can provide a wealth of information to inform the decision-making process.

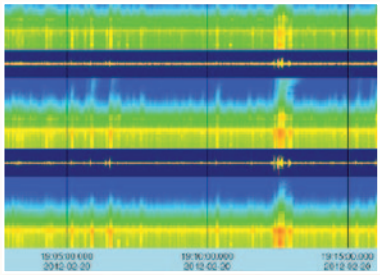
**Wireline Borehole Logging**

www.damsafetygroup.com

KINEMETRICS
Advancement through Innovation

# Seismic Monitoring

- *Monitor earthquakes and structural response with business continuity decision making*
- *Provide installation, training, maintenance, operational support for very high system availability*
- *Deliver services from seismic hazard and risk assessment to performance-based earthquake engineering*



## Why Kinemetrics Products and Solutions for Dam Safety?

**Since 1969, Kinemetrics and its subsidiaries have been the global market leaders in designing technologies, products, and solutions for monitoring earthquakes and their effects on people and structures.**

A dam's strength and serviceability can be considerable - even terminally - reduced by natural or human-made events, such as earthquakes, extreme levels of operation, uncontrolled structural changes, and various other effects. Deploying seismic instrumentation and structural monitoring systems provides timely and actionable information about potential problems.

Kinemetrics offers a variety of products to monitor your dam(s) effectively, from classic to innovative:

- *Smart, IP-ready, communication-link agnostic sensors maximizing flexibility and scalability*
- *Standalone free field stations or networked in (common) trigger or real-time streaming mode*
- *Real-time FFT & PSD with alarm notifications*
- *Automatic generation of engineering reports*
- *High-availability data acquisition, processing, and information/alarm dissemination platform*
- *Kinemetrics' Management Infrastructure platform provides APIs to digital twin technology*

Our comprehensive solution **KMI**Dam (**K**inemetrics **M**anagement **I**nfrastructure system for Dams), is an end-to-end product consisting of intelligent, IP-based accelerographs, high-availability data acquisition and processing framework with APIs to effectively disseminate information and feed digital twins. The high-performance and compact accelerographs leverage the latest technology to maximize flexibility and scalability. Besides command & control of the monitoring sites, **KMI**Dam can inform operator(s) and emergency personnel on the real-time status of many dams by feeding data into modern infrastructure management systems, for example, the generation of digital twins.

## Importance of seismic instrumentation of Dams

**The use of seismic instrumentation and monitoring, especially in the last decade, is a result of the increasing need for the monitoring of hazards and associated risks as well as better management of the safety issues concerning dams.**

Such development is further enhanced by the ongoing development and sophistication of sensors, data acquisition systems, communication, and other advances in technology.

**Reservoir Induced Seismicity (RIS):** In the past, we have seen significant structural failures in dams due to earthquakes, such as at the Kremasta Dam, Greece, in 1965, where once the impoundment of the dam began, two magnitude 6 events occurred within 120km of the dam. The largest induced earthquake (M6.5) occurred at the Koyna Dam, India, in 1967, killing roughly 200 people and injuring over 2,000. This happened in a region of low natural seismicity.

**Dynamic Monitoring:** Despite progress in the dynamic analysis of dams, it is still not possible to reliably predict the behavior of dams during very strong ground shaking due to the difficulty in modeling the inelastic behavior of dams, the insufficient information on the spatial variation of ground motion and other factors. The factors that eventually lead to failure and their severity and effect on the structure can be measured and monitored with seismic instrumentation in real-time, providing a current state of the dam. Therefore, timely notifications about potential problems can be generated, and the dam's behavior can be visualized with **KMI**Dam leveraging the emergence of digital twin technology.

**Actionable Information:** A comprehensive infrastructure management system like **KMI**Dam satisfies the needs of many stakeholders within the Dam monitoring community:

- *Policymakers - Improve safety mandates*
- *Dam Owners - Save money by reducing downtime*
- *Facility Managers - Better manage decisions and save life/property*
- *Nearby Residents - Increase confidence in safety*
- *Operators - Receive immediate status on dam safety and functionality*
- *Engineers - Receive immediate status on network conditions*

Providing actionable information tailored for users with different requirements in terms of content and timeframe is critical for any monitoring system for Dams. Kinemetrics is addressing this demand with its product line.

**Seismic Monitoring**

KINEMETRICS
Advancement through Innovation

www.damsafetygroup.com

**The Dam Safety Group brings together a group of member companies, both instrument OEMs and service contractors, ideally positioned to use proven geophysical technologies, services and products for Dam site investigation and monitoring together with seismic monitoring via earthquake early warning and evaluation systems.**

DAM SAFETY GROUP ©

**The cost effective and flexible deployment of these technologies provides the characterization of on-site ground conditions by the use of data acquisition both real time and for analysis of the subsurface properties for the important evaluation of hydrological, geological and construction issues.**

Geophysics technology can provide effective rapid deployment to provide subsurface information, continuous evaluation and monitoring throughout the structures life. It is reliably non-invasive and can be integrated with other forms of ground surveys to build a visual understanding of the overall subsurface of the site.

There are significant risks for dam structures in earthquake-prone locations. Facility Managers/Operators will be required to decide to stop operation and implement lifesaving evacuation or to minimise loss by continuing operation. Earthquake monitoring systems assist such decision making by predictive data and evaluating structural damages immediately after earthquake events.

**Non-invasive or destructive techniques**

**Regular monitoring of Dams**

**Early warning detection of geotechnical problems**

**Assists the design and build of remedial projects**

**Assists to assess remedial work after completion**

**Identifies damaged areas within the body of the Dam**

**Locates fractures, voids and zones of seepage**

The Dam Safety Group is a co-operative family of Companies from within the OYO Corporation of Japan; a corporate voice of the environmental, international resources and energy, natural disaster prevention and mitigation and infrastructure maintenance, management and renovation industries.

OYO is a 2200 employee and 460 million US Dollar Global Corporation.

| Resistivity Imaging | Seismic Tomography | Ground Penetrating Radar (GPR) | Wireline Borehole Logging | Seismic Monitoring |
|---|---|---|---|---|
| IRIS INSTRUMENTS | GEOMETRICS Simplify your search | GSSI | ROBERTSON GEO Unlocking Your GeoData | KINEMETRICS Advancement through Innovation |

www.damsafetygroup.com

DAM SAFETY GROUP ©