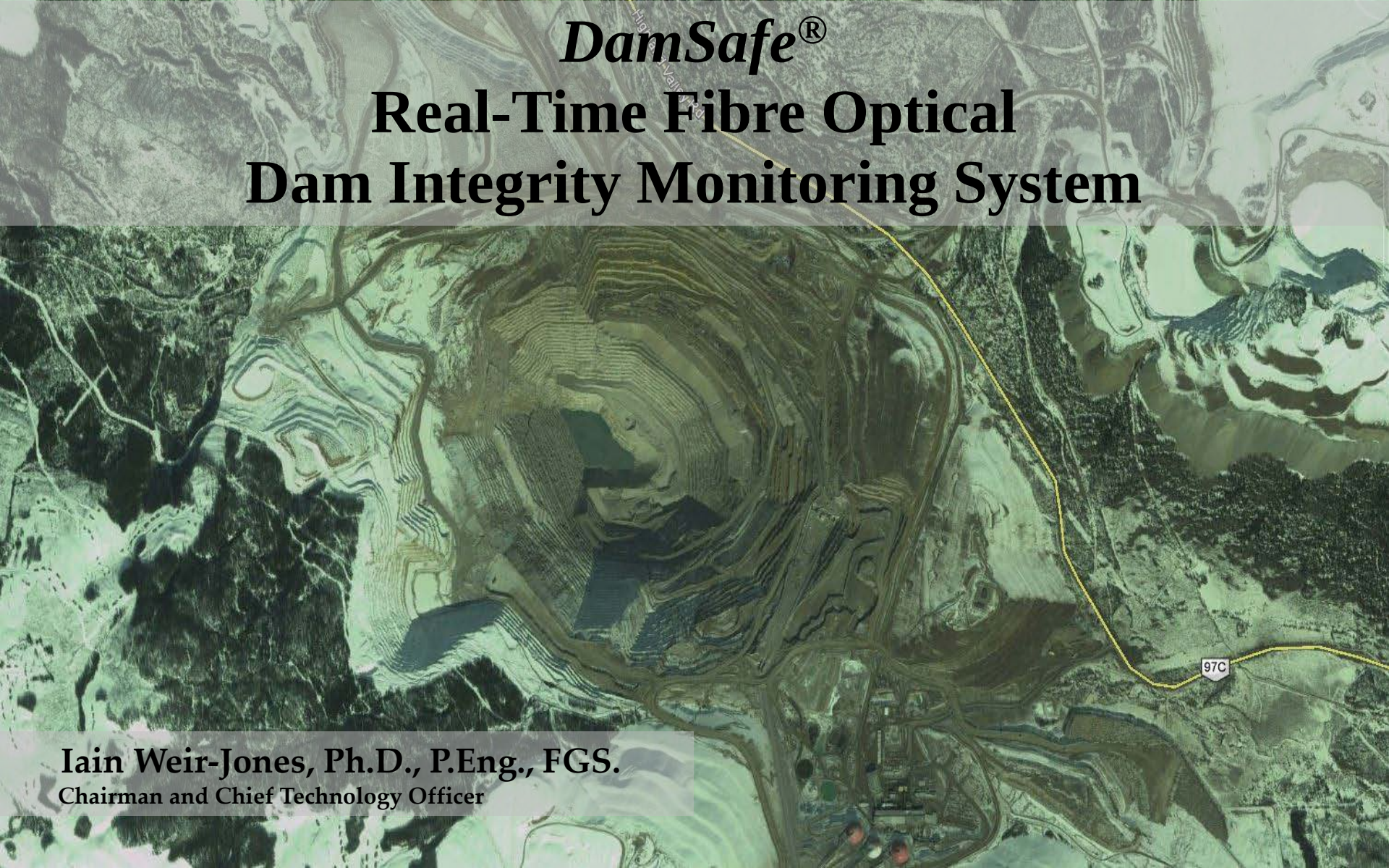
DamSafe®
Real-Time Fibre Optical Dam Integrity Monitoring System



Iain Weir-Jones, Ph.D., P.Eng., FGS.
Chairman and Chief Technology Officer

WEIR-JONES ENGINEERING LTD.

Integrity Monitoring Systems for the Transportation and Resource Industries

Private companies established in 1971 with a specialized team of engineering professionals.

Over 47 years of experience providing specialized monitoring and analytical systems for clients in the resource, oil & gas, heavy industrial and defence sectors in over 55 countries around the world.

Systems typically incorporate proprietary hardware, firmware, and custom software to provide turn-key solutions developed for the client's specific needs.

Weir-Jones Engineering Consultants Ltd.	• Specialized Investigative and Forensic Engineering Services • Contract R & D • Vibration & Stress Analysis
Weir-Jones Engineering Ltd.	• Turnkey Integrity Monitoring Systems for the resource, transportation, heavy industrial and defense sectors
Terrascience Systems Ltd.	• Sensors and acquisition equipment for public safety and infrastructure integrity monitoring projects • Autonomous Seismic Monitoring Systems
Weir-Jones Offshore Ltd.	• Offshore Structural Monitoring Integrity Systems

In 47+ years and 55+ countries, our clients have included:

Experience – Over 47 Years. More Than 55 Countries


Passive Microseismic Monitoring (Saudi Arabia)


Integrated Monitoring Systems for Dams


Central U.S.A. Induced Seismiticy Monitoring


Earthquake Early Warning System - GMT


Remote Pipeline Integrity Monitoring Systems (N. Canada)


Structural Monitoring System for Offshore Platforms


Seismic Hazard Monitoring at NPP


Integrity Monitoring for the Skytrain in Vancouver


Qualification and Testing of Accelerometers


Production of Precision Accelerometers for the F-117


Pipeline Vibration Monitoring in NE B.C.


One of 100 Microseismic Monitoring Systems (Cold Lake, AB)

From Individual Sensors to Turnkey Solutions

Examples of Dam Failure

Samarco Dam Failure in Brazil

Mt. Polley Tailings Dam Failure in BC

The Problem & Solution

Tailings dam failures are typically caused by:

1. Steepening downstream dam face.
2. Overtopping of the dam.
3. Water flow through the dam.
4. Excessive water flow under the dam.
5. Earthquakes can induce failure.
6. Reservoir induced seismicity is common in places like Brazil. Magnitudes 4.2 have been recorded.

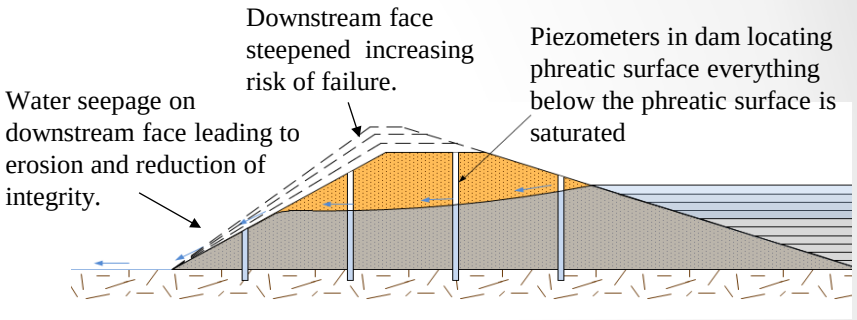
To monitor these events effectively, we offer three integrated systems:

→ ***DamSafe®*** monitors the ongoing structural integrity of the dam.

→ ***ShakeAlarm®*** provides a warning of an actual earthquake.

→ ***QuakeMonitor®*** detects low level induced or natural seismic activity for analysis and prediction.

Poorly Designed Tailings Dam:



OBJECTIVE

MONITOR THESE PROGRESSIVE EVENTS IN REAL-TIME TO REDUCE THE LOSS OF LIFE AND PROPERTY

Comprehensive Integrity Monitoring System

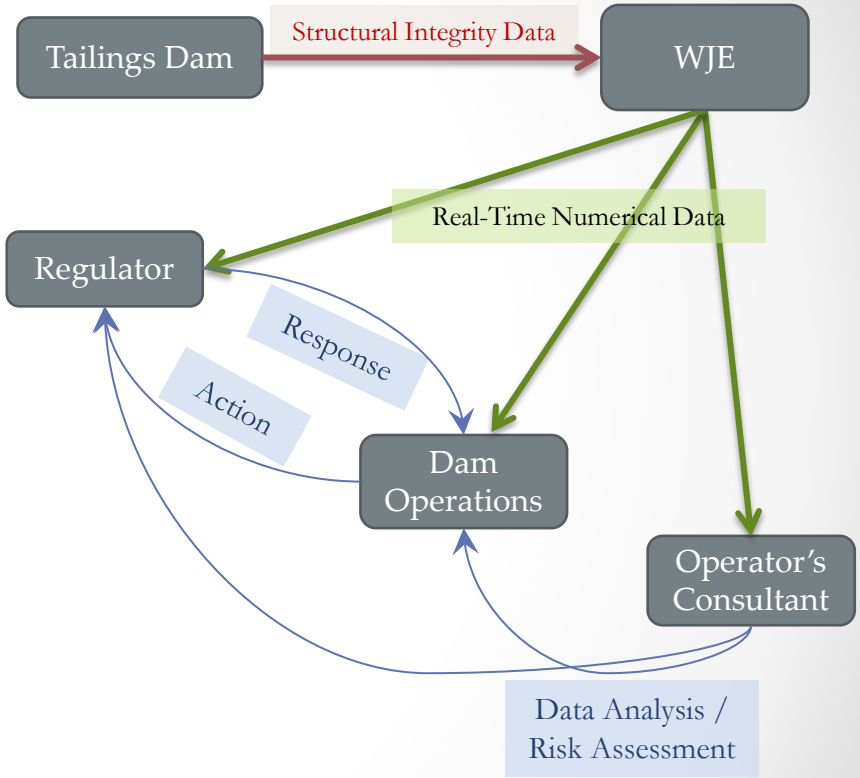
- *DamSafe®* utilizes fibre optical sensing techniques to continuously monitor displacement and temperature changes on or in the dam to evaluate the structural integrity in real-time.
- Reading frequency is a function of potential risk, the system architecture delivers verified engineering data to stakeholders in real-time.
- Provides a cost effective, real-time structural integrity monitoring service using proven optical technologies for mine operators, their consultants, and the Regulator.
- Where natural or induced seismicity may present a risk to a dam, *QuakeMonitor®* is a cost effective system to monitor natural and induced seismicity and reports by cellular or satellite links.
- *ShakeAlarm®* autonomously monitors seismic activity in the vicinity and then gives warning of actual earthquakes allowing for critical operations to be shut down.

DamSafe®

Real-time fibre optical structural integrity monitoring system that provides operators with information on dam deformation, strain, deflection and temperature. Operators know the condition of their dams in real-time and can respond to any structural or safety concerns prior to a failure.

Functional Description of *DamSafe®* System

1. A mine operates one or more tailings dams.
2. WJE has staff & geotechnical consultants, who analyze numerical data & advise stakeholders.
3. Stakeholders wish to ensure dam safety.
4. WJE informs regulator of current condition.
5. Regulator sees result of action in real-time.
6. Regulator and independent geotechnical consultants review data in context of dam design and operation
7. WJE designs, commissions, and maintains the system, analyzes data flow and carries out daily system health checks to validate data.

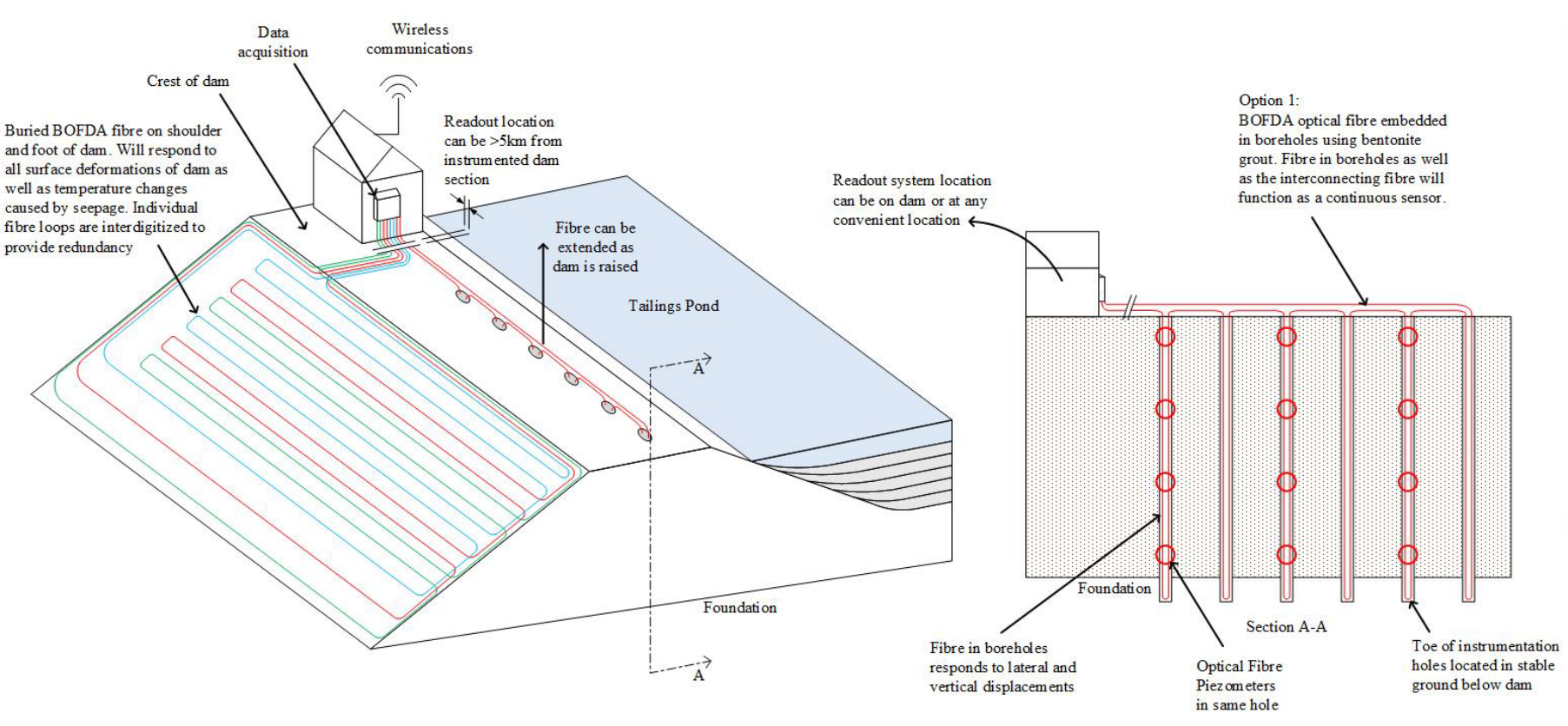


Cost Effective – Reliable - Transparent

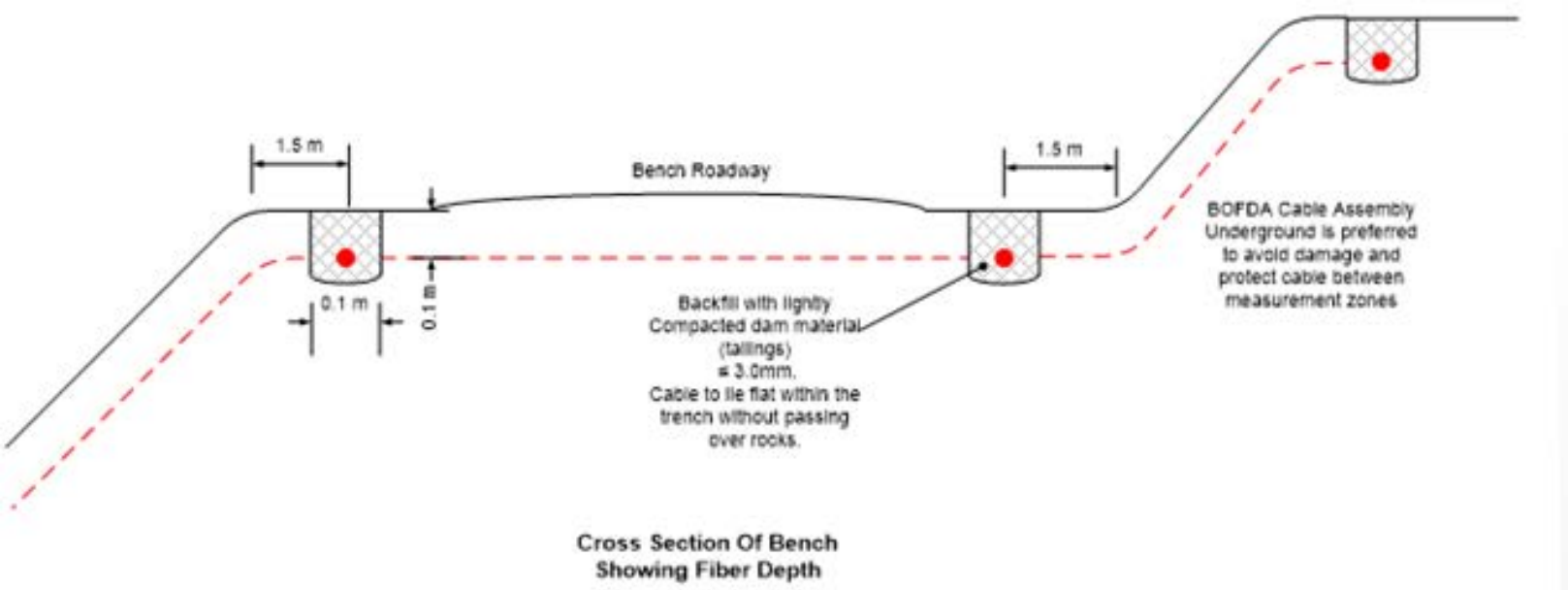
DamSafe®: Fundamentals

- ***DamSafe®:*** Optical fibre based slope and dam integrity monitoring system measures changes in parameters related to dam integrity.
- The most cost effective monitoring system is Brillouin Optical Frequency Domain Analysis, BOFDA, this can be augmented with remotely read piezometers.
- Using BOFDA, ***DamSafe®*** can make real-time strain and temperature measurements along >25 kms of optical fibre at intervals as small as ~± 0.5 m with a precision of ~± 2με and ~± 0.1°C respectively.
- For piezometric measurements, other optical technologies can be used.
- Installation of the distributed sensing cable is quick and cost effective, it can be laid in long runs without any splices to attach sensors.
- The optical fibre is the sensor and is inexpensive, reliable and has a long life.

DamSafe®: System Details



DamSafe®: System Details

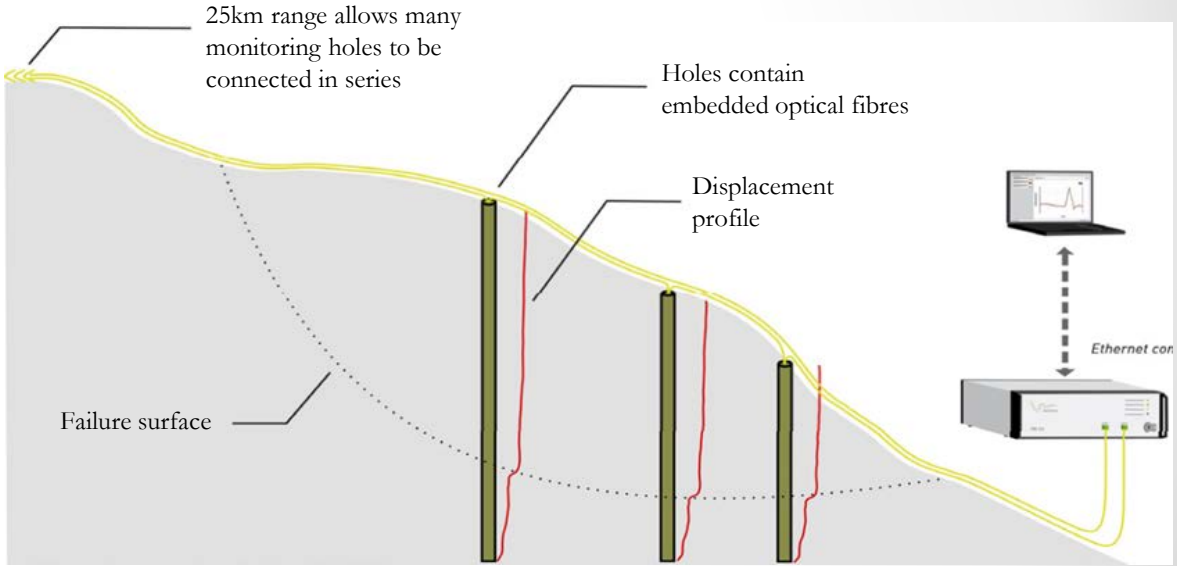


Cross Section Of Bench Showing Fiber Depth

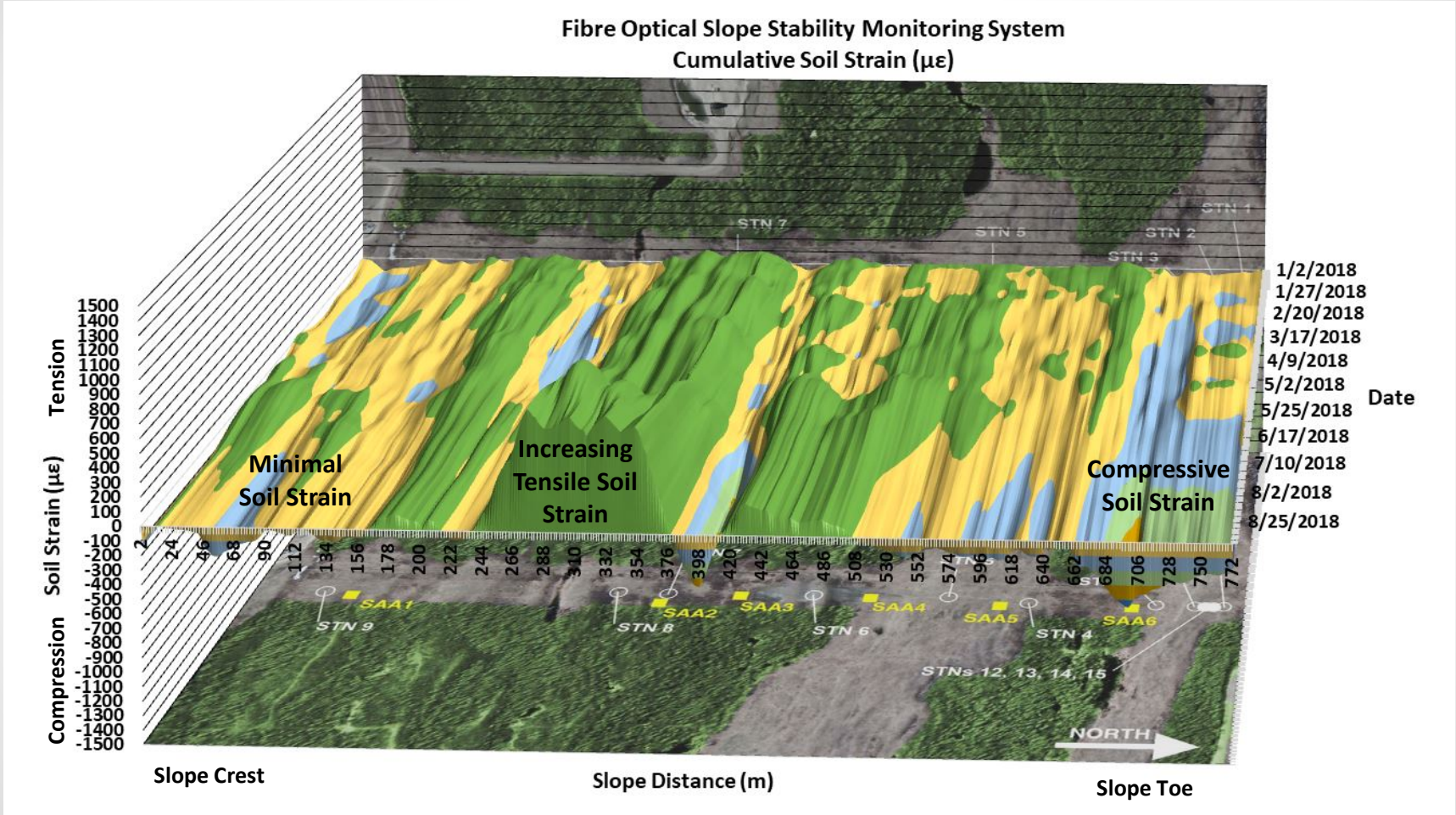
Deep Seated Slope Displacement Monitoring

By fitting fibre optic cables into vertical boreholes, the vertical and horizontal strain profile of the boreholes is continuously measured.

This strain data is converted into a 3-D image of dam displacement. Depending on the spacing and depth of the vertical boreholes, thousands of monitoring locations can be connected to one optical interrogator. This provides cost effective continuous and autonomous monitoring.



Slope Displacement Monitoring

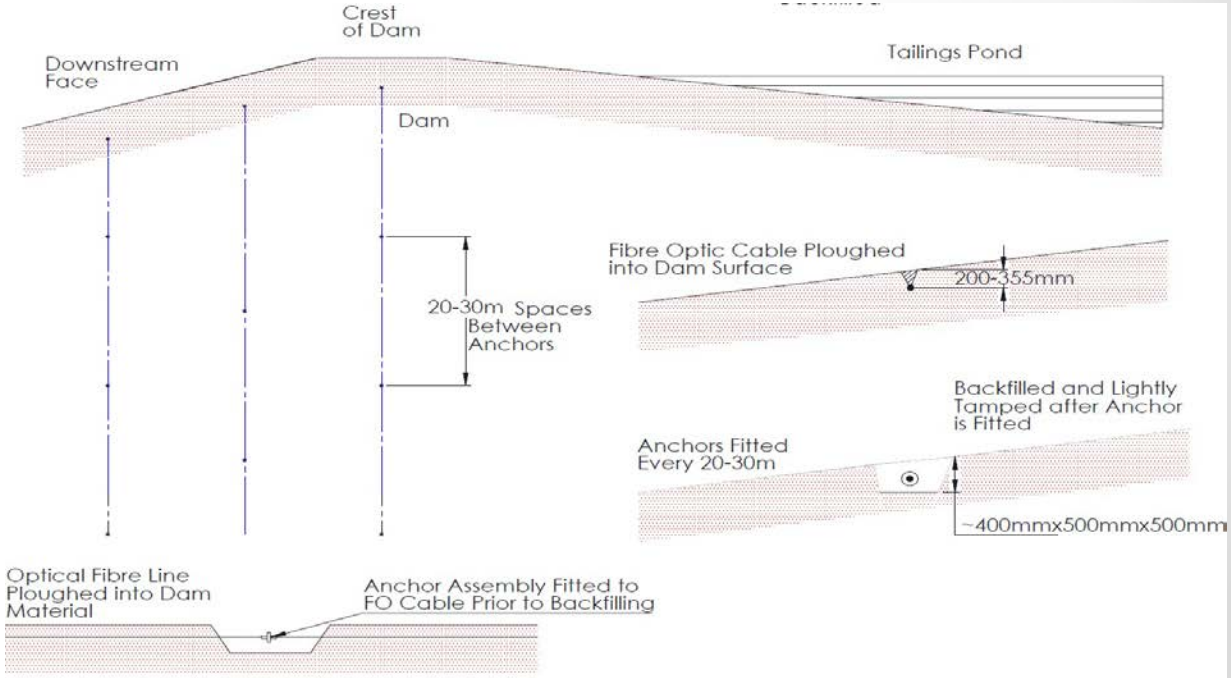


Distributed FO Cable Installation

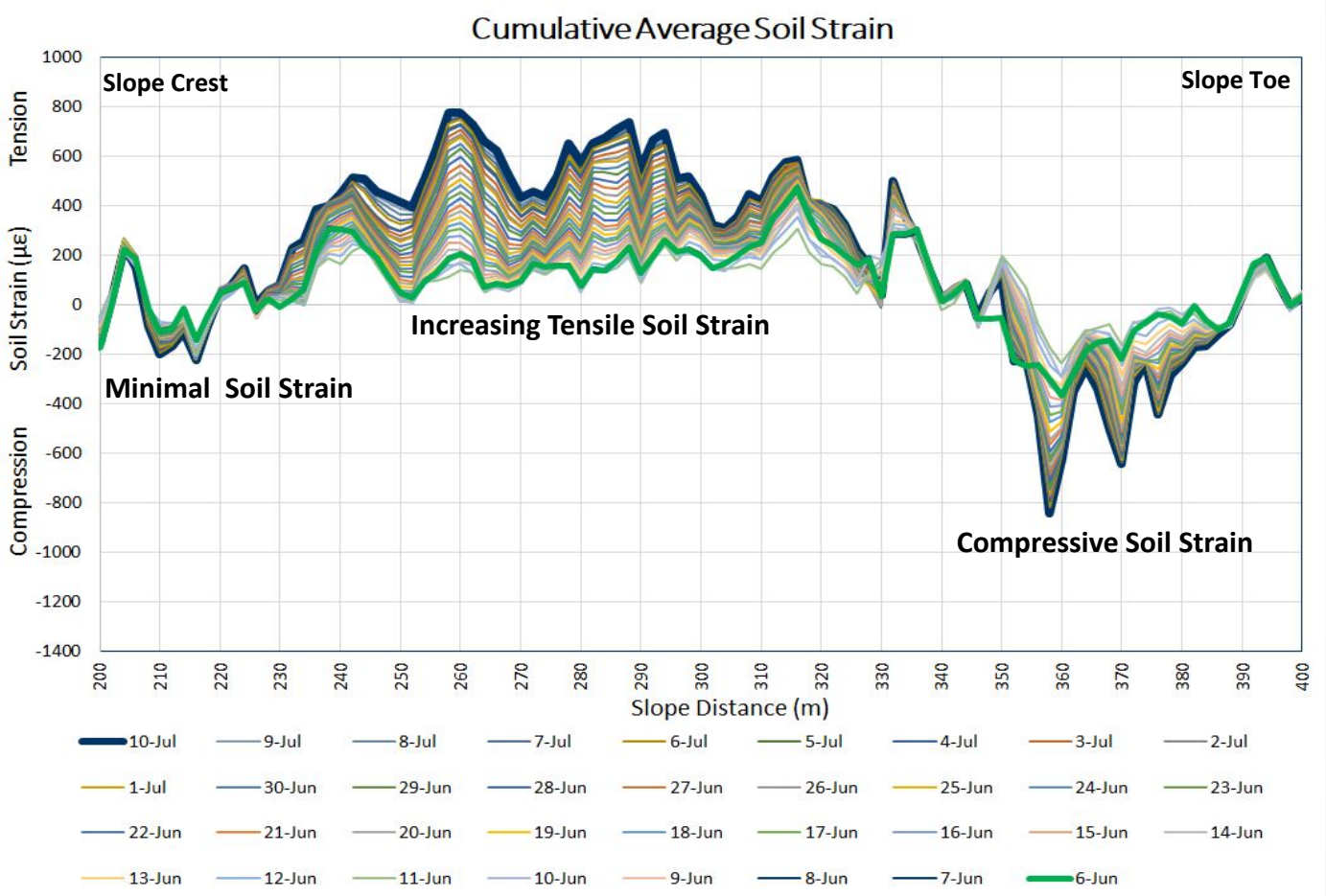
Individual optical cables, ploughed or embedded in the slope or dam surface are used to monitor surface deformation. Deformation of the surface strains the optical fibres and this is measured by the optical interrogator.

If necessary, the robust optical fibres are fitted with soil anchors.

Anchor are placed at intervals along the fibre optic line. FO cables are ploughed into tailings, and soil anchors fitted, or are placed in sand filled trenches.



Slope Displacement Monitoring



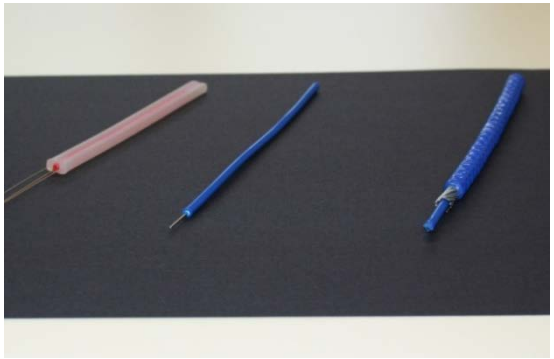
Distributed Fibre Optical Cables

DamSafe®: Equipment and Installation

1: By placing fibre optic cables in vertical boreholes, the vertical and horizontal deformation and temperature profiles of the boreholes can be continuously measured.

2: Individual optical cables, either ploughed into the dam surface or placed in shallow trenches can be used to monitor surface deformation.

Optical Interrogator unit performing structural integrity monitoring in Northern Canada.



Some examples of distributed FO strain and temperature sensing cable.

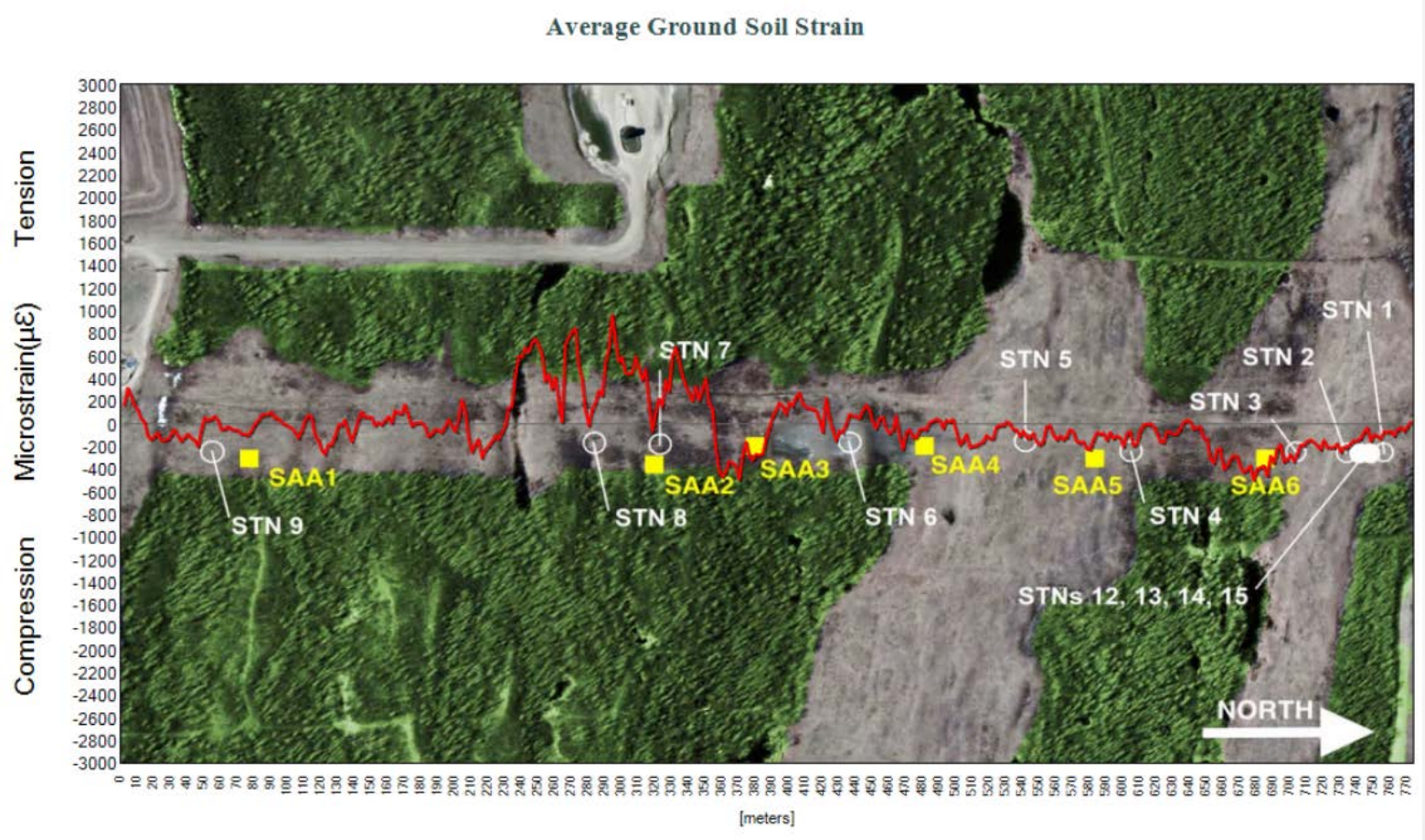
Ploughing optical fibre and warning tape into the soil. Installation rates of between 400m and 1000m/hour.

DamSafe®: Real Time Data Acquisition

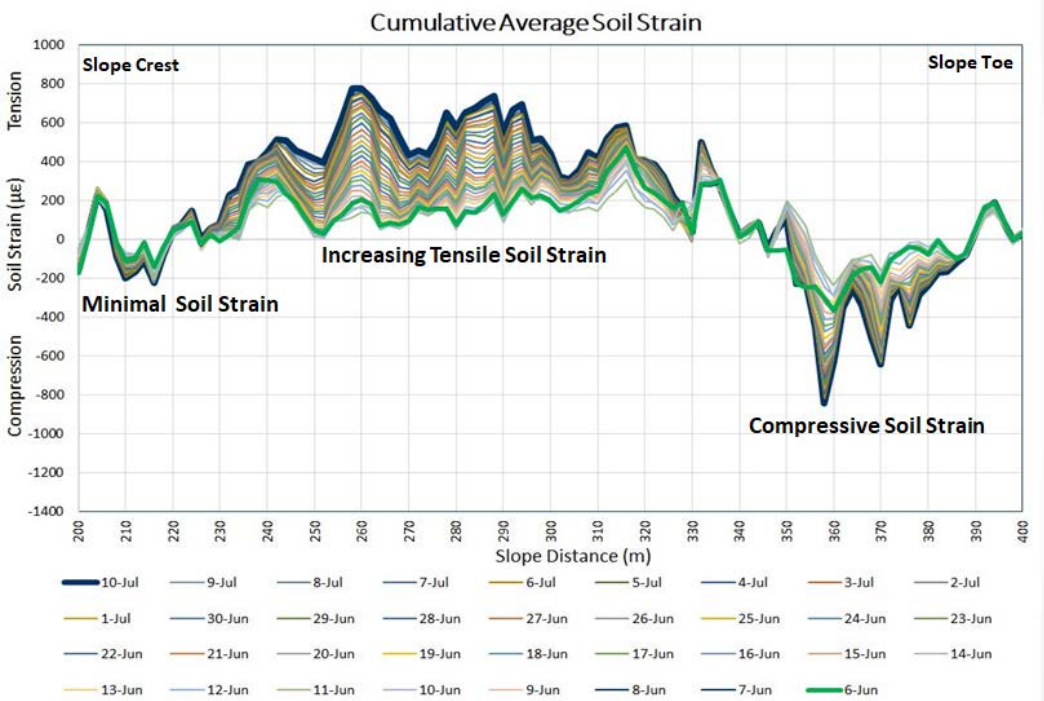
- Data from the electrical or fibre optical strain based SIMS are processed in the WJE Vancouver office and results sent to stakeholders with minimal latency. They can also be sent directly to the operator's control room and SCADA system along with an integrated alarm protocol.




Real Time Slope Movement Monitoring



Real Time Slope Movement Monitoring

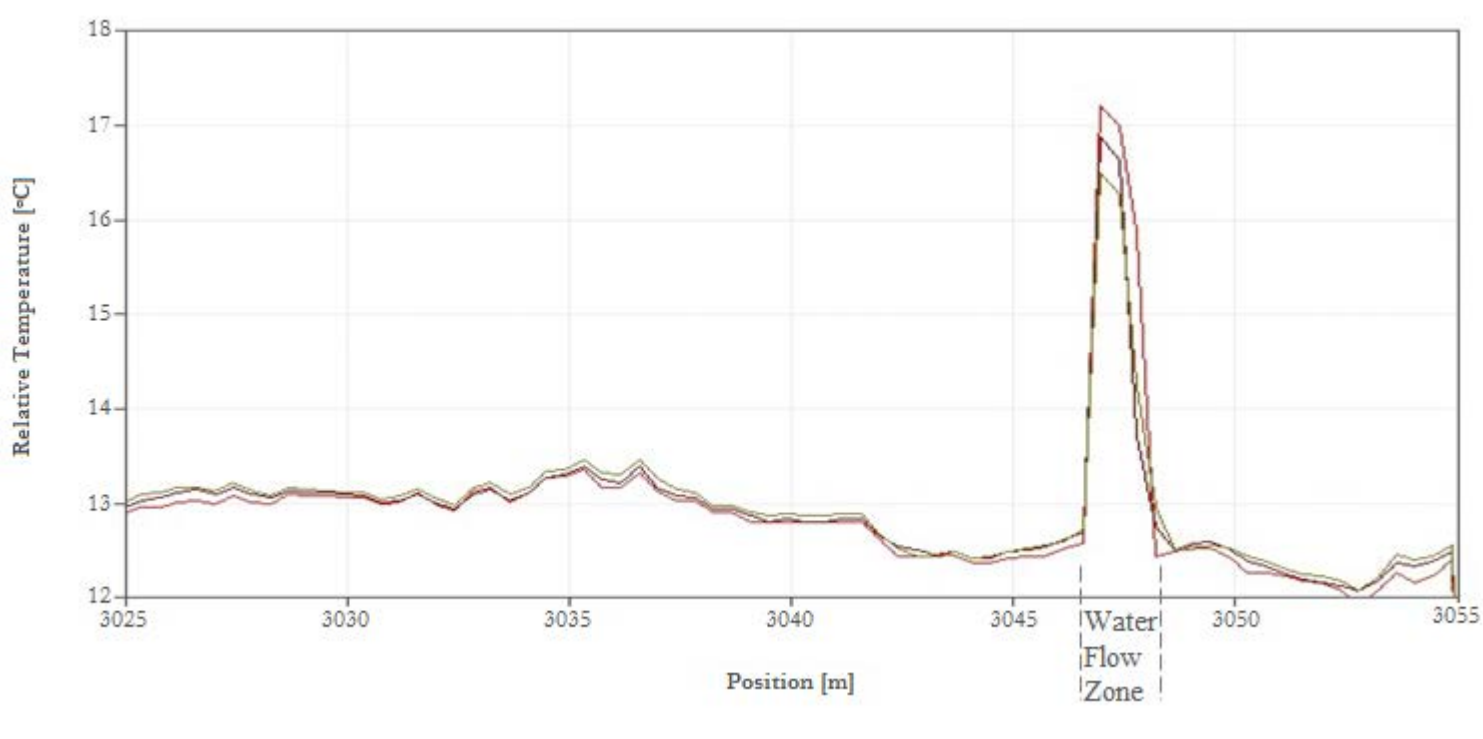


WJE alerted the operator to increasing tensile soil strains at the mid-slope. Field staff visited the site and discovered tensile ground cracks at the mid-slope.

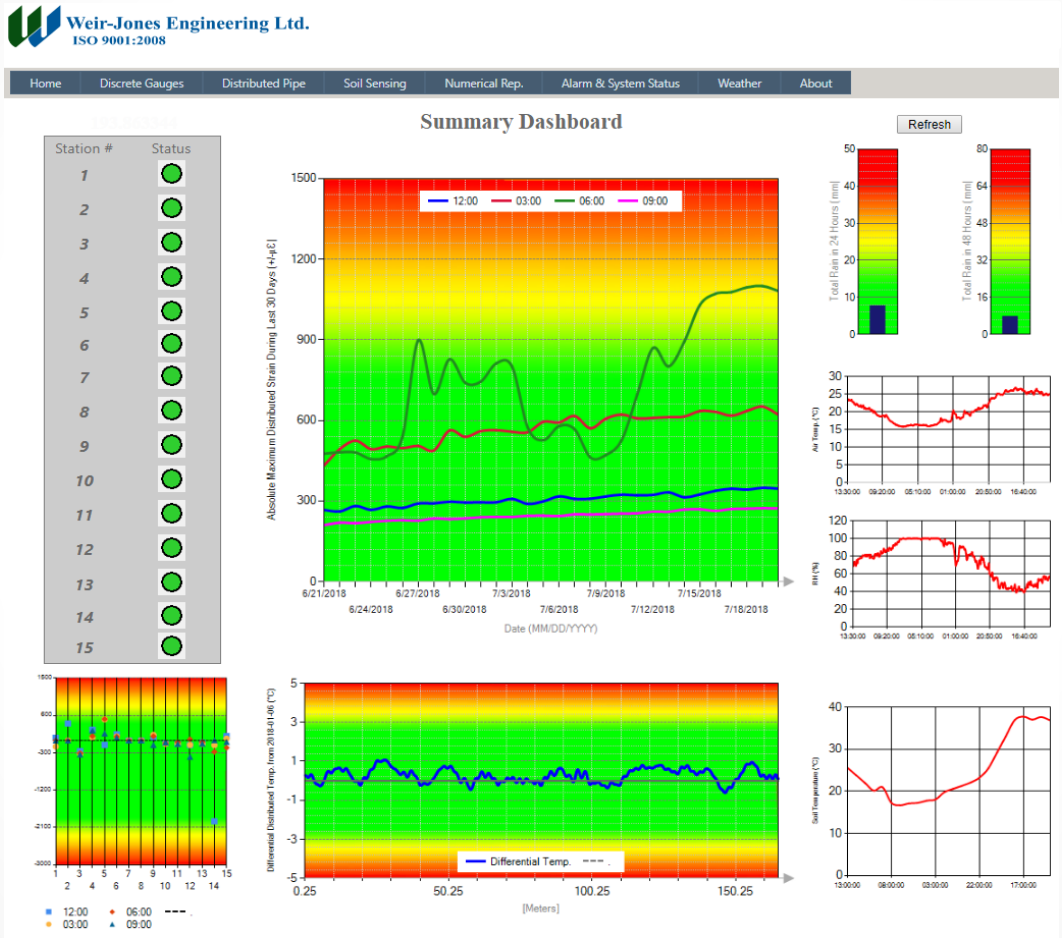
- Real-time slope movement measured by WJE fibre optic cables buried in the overburden over a 200m section of a landslide zone, following a large rainfall event. This resulted in excessive surficial erosion and tensile ground cracks which required field remediation to be implemented by the operator.

In Situ Temperature Monitoring

Variations in internal soil temperature due to changes in water flow can be measured in real time along the fibers allowing for an appropriate response.



Real Time Data Visualization – Dashboard

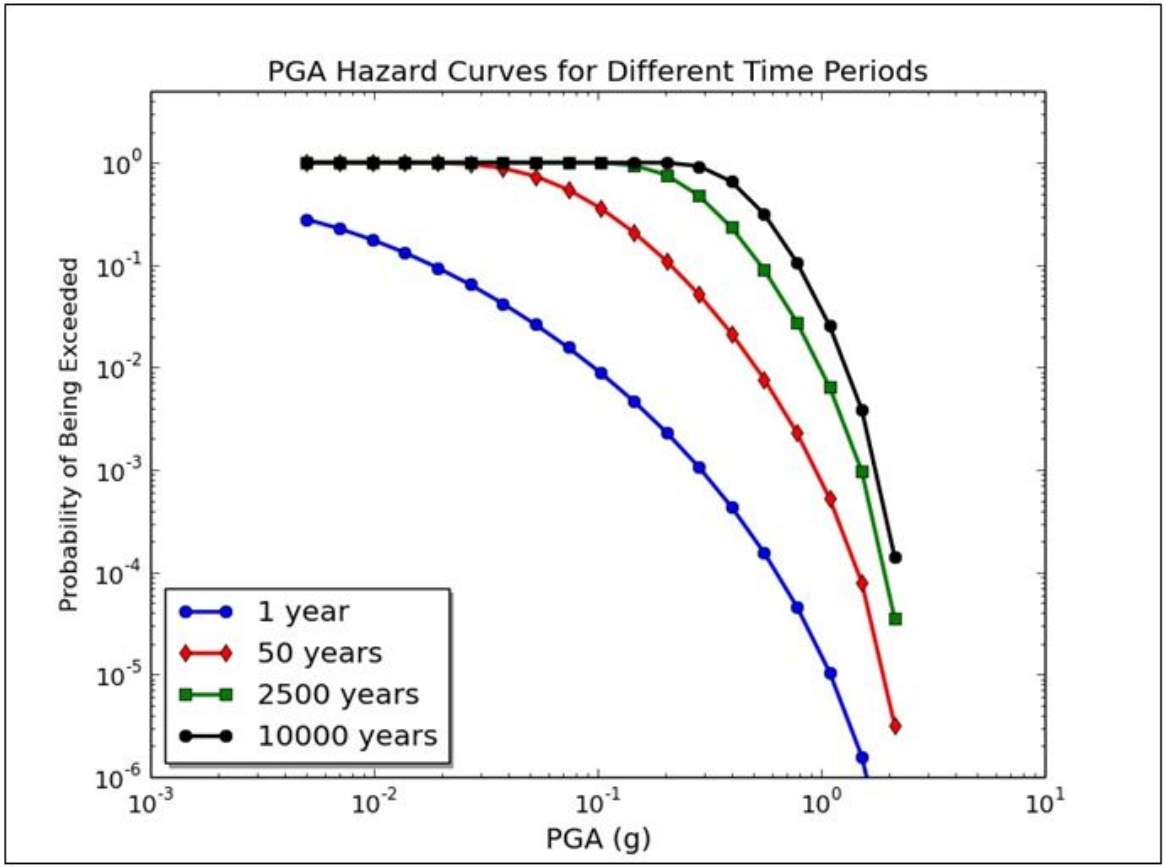


ShakeAlarm®

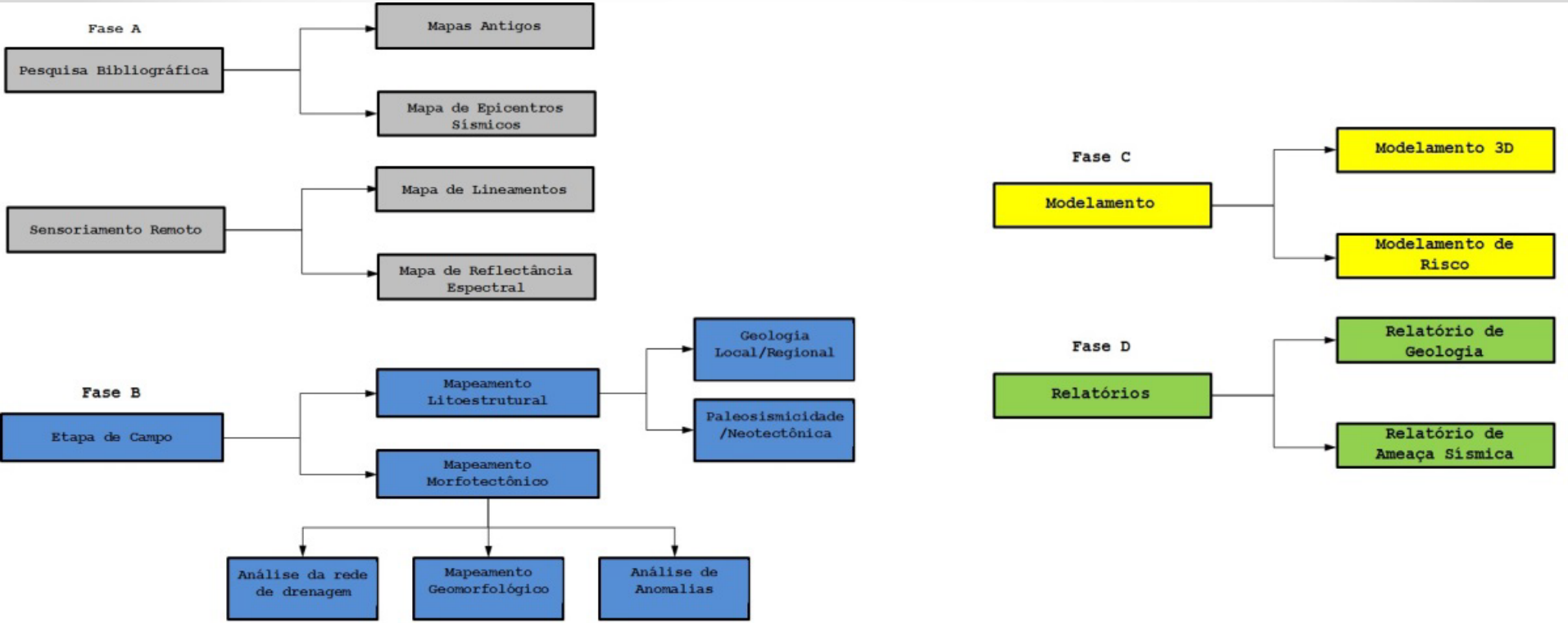
- *Produces early warning of earthquakes.*
- *Detects the faster, less destructive P waves in advance of the more damaging S waves.*
- *The further away from the epicentre the longer the warning.*
- *Many tailings dams have safety factors of ≃1.0.*
- *Small earthquakes can trigger tailings dam failures.*

ShakeAlarm® : Earthquake Early Warning System

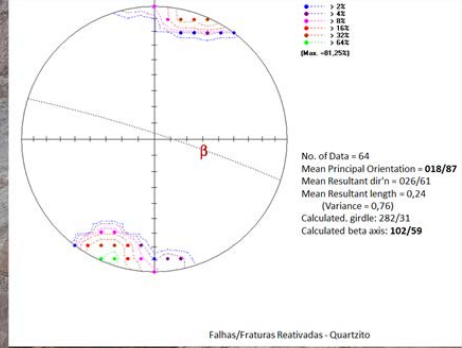
Samarco Dam Failure in Brazil



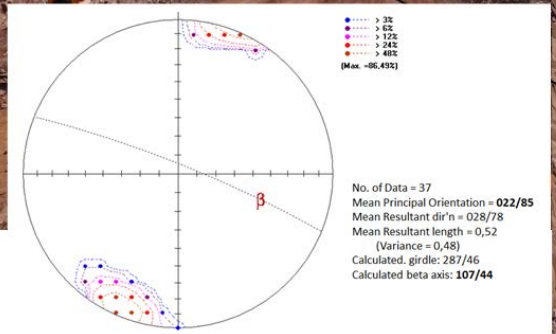
Samarco PGA hazard curves for four time periods: 1, 50, 2,500 and 10,000 years.



Solo Arenoso preenchendo fratura/falha

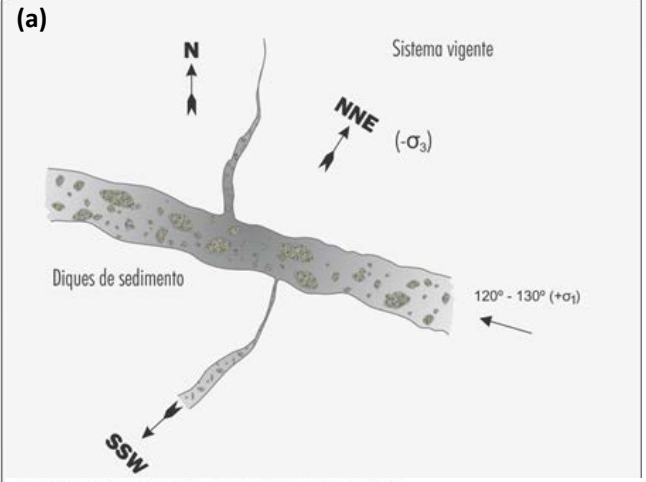


Falhas/Fraturas Reativadas - Quartzito



Falhas/Fraturas Reativadas - Xistos

(a)



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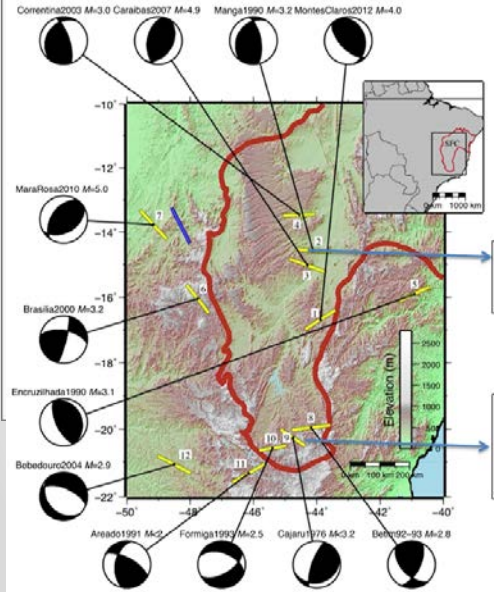
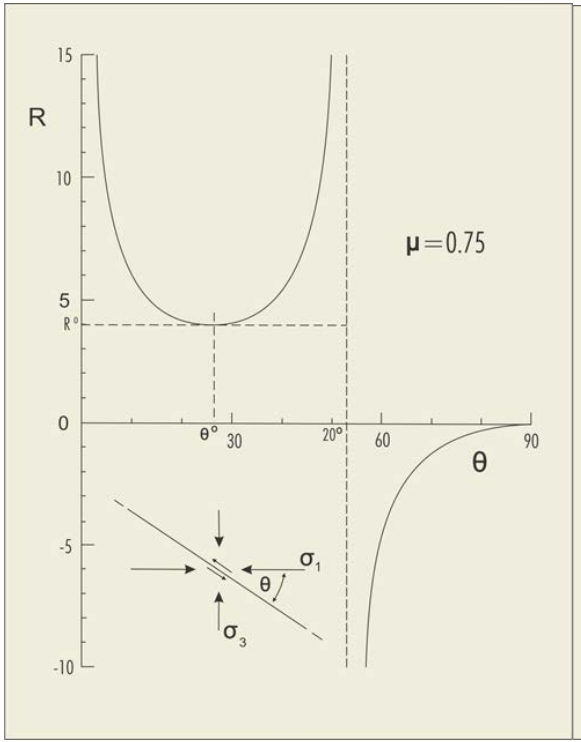
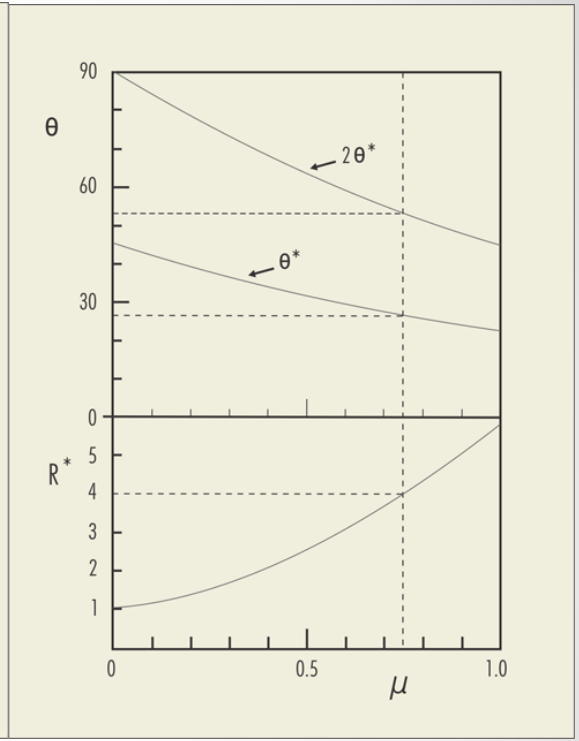


Mecanismos focais e direção estimada de SHmax (barras amarelas)

Regime compressivo: Compressão E-W

Regime transcorrente: Compressão E-W Tração N-S





BETA NUMBER	SAMPLE	MATERIAL	PRE T	d13C	CONV.AGE	d14C
437485	SAM065	WOOD	acid/alkali/acid	-28.4 o/oo	117.4 ±O.3 Pmc	174.2±2.9 o/oo

YEAR	MO	DA	HR	MI	SE	LATITUDE	LONG	DEPTH	ERR	MAC	MT	Q	Is	Area	M_TYPE	MW_SCOR	MW_BRProx	s_MW_BRProx	ST	Locality	(Reference) Comments
1840		0				-21,03	-44,75	0	0	3	4	C	4		M(lo)	3,6	3,0	0,6	MG	BOM SUCESSO	VARIOS EVENTOS
1901	4	4	16			-21,03	-44,75	0	0	3	4	C	4		M(lo)	3,6	3,0	0,6	MG	BOM SUCESSO	varios eventos
1901	4	5	8			-21,03	-44,75	0	0	3	4	C	4		M(lo)	3,6	3,0	0,6	MG	BOM SUCESSO	
1901	6	2	2			-21,03	-44,75	0	0	3	4	C	4		M(lo)	3,6	3,0	0,6	MG	BOM SUCESSO	
1901	9	4	21			-21,03	-44,75	0	0	3	4	C	4		M(lo)	3,6	3,0	0,6	MG	BOM SUCESSO	
1919	6	5	4	20		-21,03	-44,75	0	0	3,2	4	C	4-5		M(lo)	3,8	3,2	0,6	MG	BOM SUCESSO	OUTROS EVENTOS
1920	1	31	11	10		-21,03	-44,75	0	10	4	3	B	6	9,5	M(Af)	4,4	3,8	0,4	MG	BOM SUCESSO	
1920	2	1	4	35		-21,03	-44,75	0	0	3,2	4	C	4-5		M(lo)	3,8	3,2	0,6	MG	BOM SUCESSO	VARIOS EVENTOS
1920	2	9	16	20		-21,03	-44,75	0	0	3	4	C	4		M(lo)	3,6	3,0	0,6	MG	BOM SUCESSO	
1920	3	11	22	15		-21,03	-44,75	0	0	3	4	C	4		M(lo)	3,6	3,0	0,6	MG	BOM SUCESSO	
1935	10	21	10	40		-21,03	-44,75	0	10	3,7	3	C	5-6	2,8	M(Af)	4,2	3,4	0,4	MG	BOM SUCESSO	OUTROS EVENTOS
1977	1	15	9	38	40	-21,2	-44,8	0	30	2,1	1	I	-		MR	2,8	1,6	0,3	MG	BOM SUCESSO	(VELOSO-MENDIGUREN 1980)
1977	1	15	9	43	15	-21,2	-44,8	0	30	2,6	1	I	-		MR	3,2	2,2	0,3	MG	BOM SUCESSO	(VELOSO-MENDIGUREN 1980)
1996	12	20	3	20	2	-21,03	-44,76	0	20	2	5	I	3		Ind	2,7	2,0	0,6	MG	Bom Sucesso	(UnB, IAG)

ShakeAlarm® : Earthquake Early Warning System

ShakeAlarm® : System Details

- Assesses response of new and old dams and structures.
- Reduces the cost of periodic structural inspection.
- Works autonomously in remote areas.
- Redundant system consists of:
  - At least two instrumented boreholes with multiple sensors
  - Data Acquisition
  - Communication and power supply

Borehole Sensor Location

ShakeAlarm® Data Acquisition, Communications and Power Supply Unit

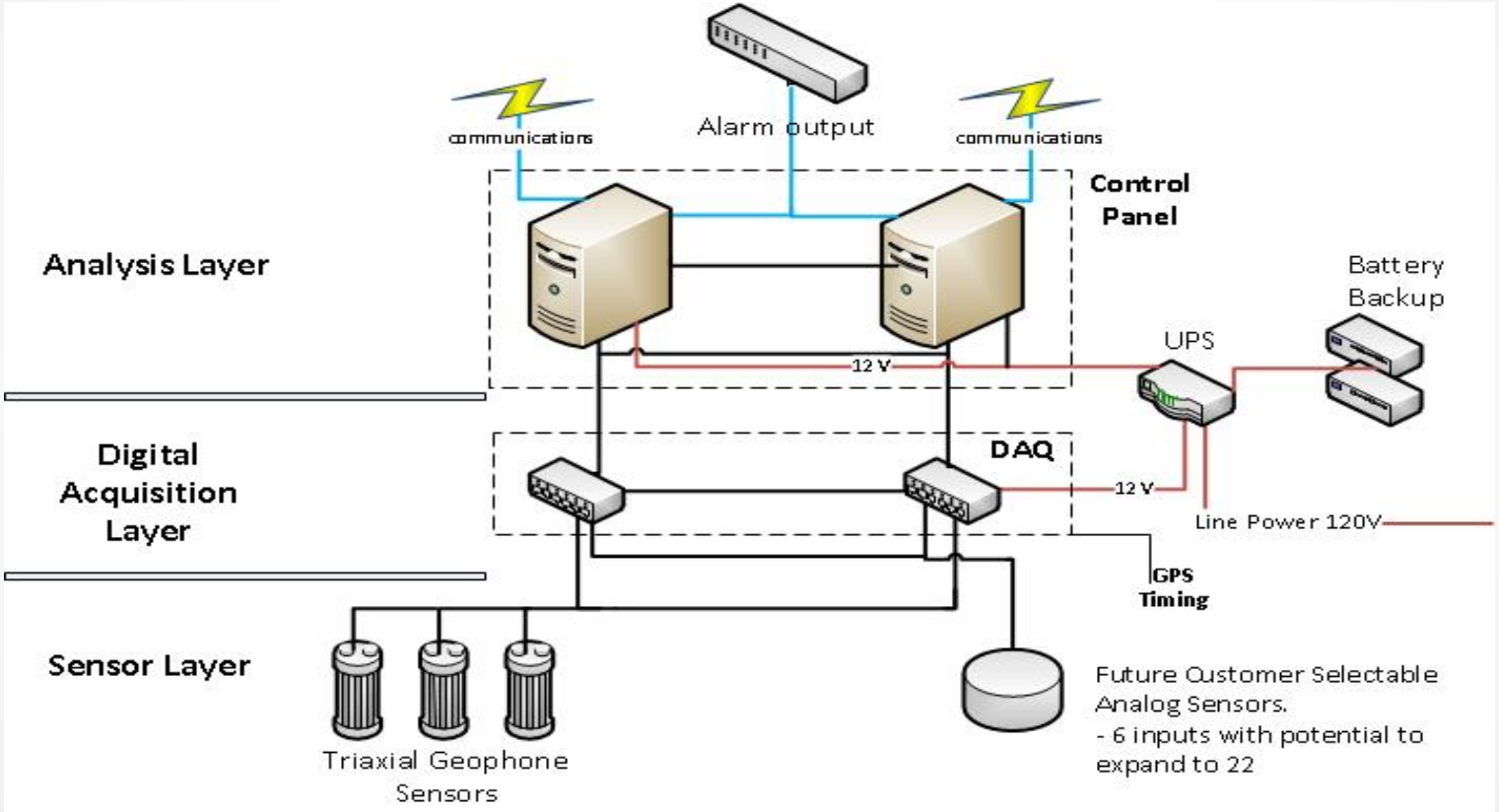
ShakeAlarm® *and* *ShakeAlert®*: Earthquake Early Warning System

Applications of EEWS to facilitate protection of infrastructure and the public:

- Controlled shut down of dams, mines, pipelines and plant operations
- Evacuation of buildings,
- Safe Shutdown/Operating Basis Earthquake for NPPs & HPP
- Roads, Tunnels, Bridges Closure
- Facilitate post event analysis

- **Safety measures for critical facilities, *ShakeAlarm®*, distributed public alerting, *ShakeAlert®*, post event analysis, *ShakeMonitor®***

ShakeAlarm® : Earthquake Early Warning System



ShakeAlarm® : Earthquake Early Warning System

- *ShakeAlarm®* offers reliability and availability which approaches 100% of total deployment time, > 99.9990%
- *ShakeAlarm®* operates autonomously
- *ShakeAlarm®* is fully redundant
- *ShakeAlarm®* has demonstrated a system functional life in excess of 100,000 hours
- *ShakeAlarm®* performance is verified by simple annual calibration
- *ShakeAlarm®* incorporates COTS components

ShakeAlarm® : Earthquake Early Warning System

- Robust multi-parametric algorithms
- Efficient sensor platforms
- Approved by nuclear regulatory agencies in North America and Europe

BC Legislature EEWS installed in 2016.

- ***ShakeAlarm®*** deployment parameters include:
  - Site specific geological information/ Local seismicity
  - Sources of uncertainty/ Anthropogenic analysis
  - Hardware design, redundancy, and accuracy
  - P-Wave detection algorithm, processing time, and warning time
  - Precise calibration
- George Massey Tunnel installation has demonstrated 100% reliability since 2009.

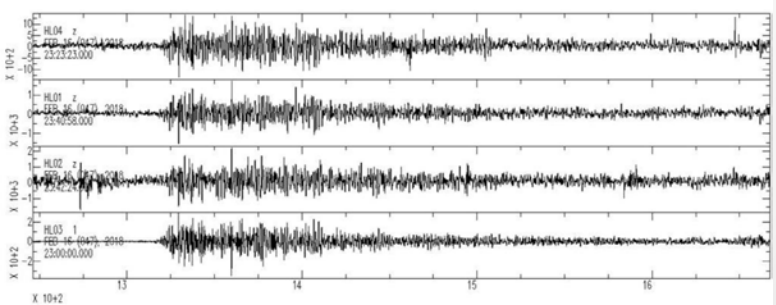
QuakeMonitor®

Provides stakeholders with real-time monitoring information about natural and induced seismicity and vibration, and the effect on critical infrastructure such as Slopes, Dams, Bridges, Refineries and Mines.

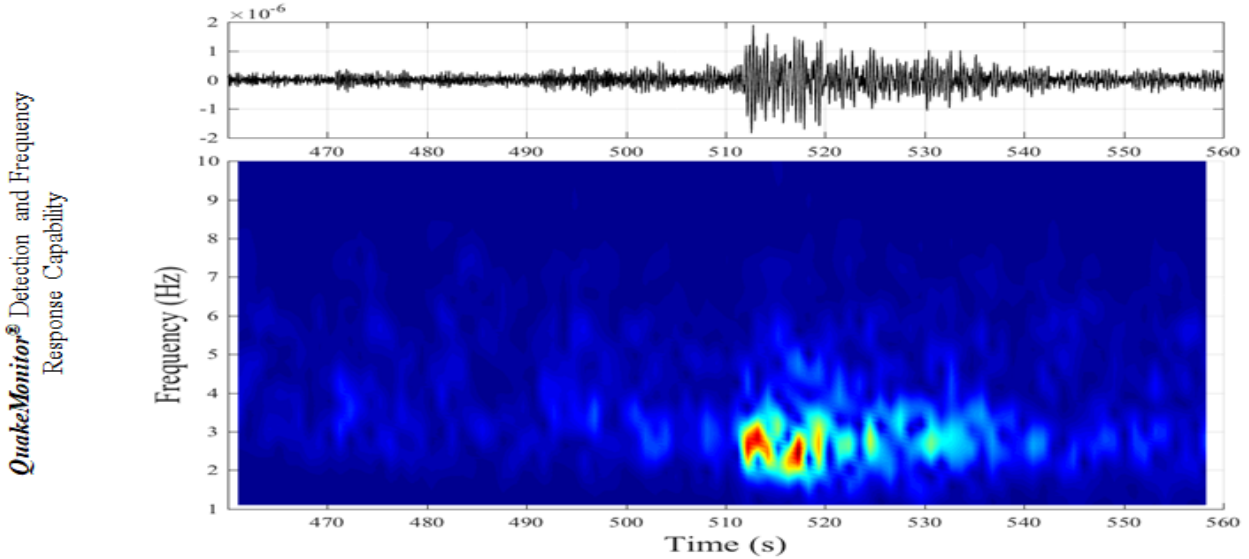
QuakeMonitor® : Induced Seismicity and Vibration Monitoring System

QuakeMonitor® : Induced Seismicity and Vibration Monitoring System

The Oaxaca, Mexico earthquake was detected by a *QuakeMonitor®* induced seismicity monitoring (ISM) system over 2,900km away in Central USA.



QuakeMonitor® : Induced Seismicity and Vibration Monitoring System



- A *QuakeMonitor®* network located 480 km away from 3.7M induced seismic event detected it even though the system had been deployed to monitor a local site. The detection capabilities of the *QuakeMonitor®* allows stakeholders to detect, locate, and share regional and local seismicity data over a large distance.

QuakeMonitor® and *ShakeAlarm® for Pipelines*

In situations where threats to the structural integrity of pipelines due to natural or induced seismicity exist, ***QuakeMonitor™*** and ***ShakeAlarm®*** can be integrated into our **Pipeline Structural Integrity Monitoring Systems (SIMS)** to form a comprehensive pipeline integrity monitoring system with the following features:

- Designed to help operators enhance safety and comply with regulations.
- Cost effective with multiple levels of redundancy.
- Operates autonomously and is customized for specific technical requirements.
- Offer reliability approaching 100% of total deployment time > 99.9999%.
- Has demonstrated a system functional MTBF in excess of 100,000 hours.
- Communication options include fibre, cellular modem, and Iridium® satellite.
- Operational verification by simple annual calibration and automated daily health monitoring.
- Manufactured to ISO 9001:2015 standards.
- Ideal for remote, unmanned sites.

An integrated *Pipeline Structural Integrity Monitoring System (SIMS)* reduces the risk to life and property and improves public acceptance.

Thank-you, are there any questions?

For more information regarding our Structural Integrity Monitoring Systems, please contact us by phone at 604-732-8821, or by email at:
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abdulm@weir-jones.com

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