Projetos e Sistemas de Gestão de Barragens de Rejeitos: uma perspectiva mundial.

Dr. Richard Dawson, P.Eng.
Executive Vice President

April 25, 2017

NORWEST
CORPORATION

"the dam safety system applied to the oil sands industry is the best in the world" (Morgenstern, 2011)

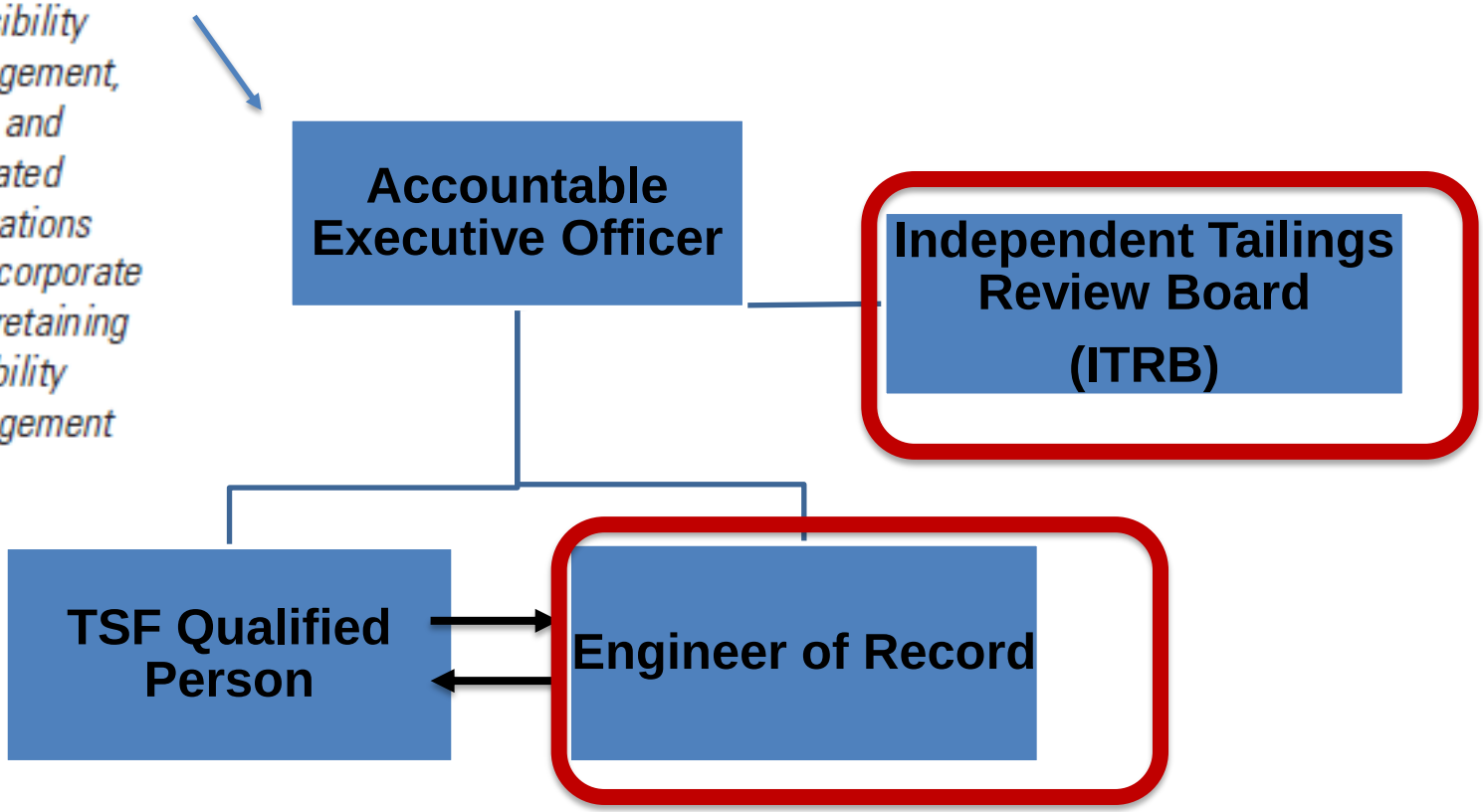
Outline

- Roles and Responsibilities
- Design Standards
- Technology Development
- Risk Management
- Dam Safety Reviews

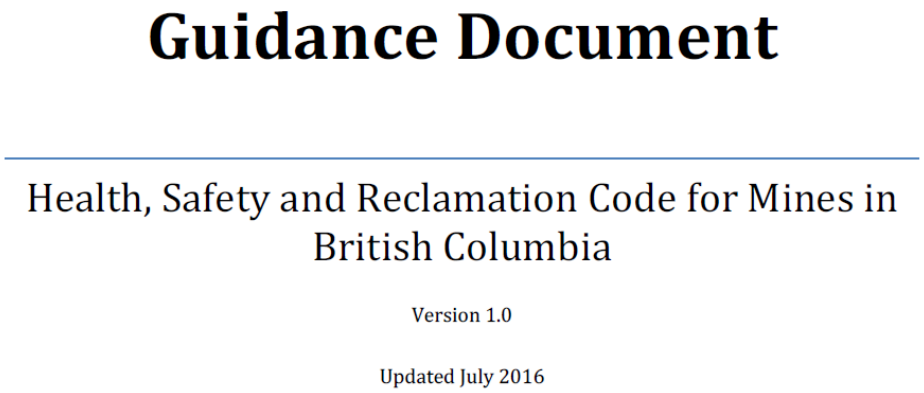
Roles and Responsibilities

MAC, 2011:

- *It is expected that the executive officer will delegate responsibility for tailings management, budgetary issues and other tailings-related functions to operations and other senior corporate personnel while retaining overall accountability for tailings management performance.*



Engineer of Record (EOR)


Guidance Document

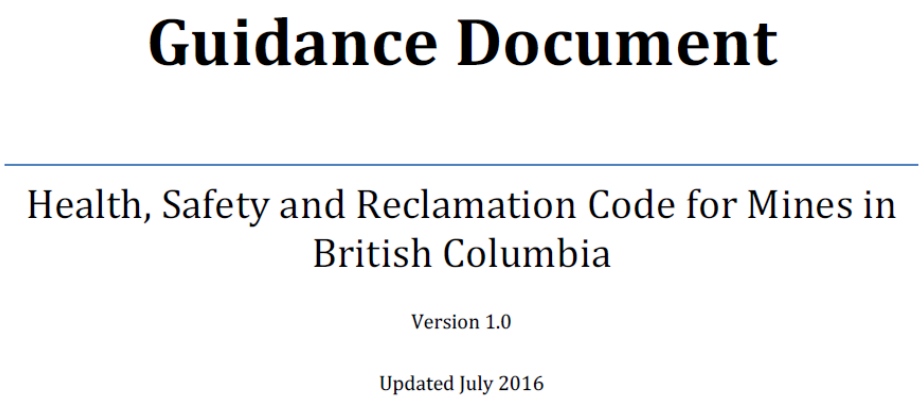
Health, Safety and Reclamation Code for Mines in British Columbia

Version 1.0

Updated July 2016

- **"Is a qualified and competent engineer with experience commensurate with the consequence classification and complexity "**
- **"Holds the professional responsibility for the facility design and is responsible for evaluating the adequacy of the as-built facility relative to the design as well as applicable standards, criteria, and guidelines"**

Independent Tailings Review Board (ITRB)



- **“Made up of independent subject matters experts not currently involved in or responsible for the design, operation or construction of the facility”**
- **“Provides non-binding advice and guidance, but does not direct the work or perform the role of the Engineer of Record”**

Design Standards – Factor of Safety Criteria Comparison

Phase	Condition	Brazil (ABNT) 2006	Canada (CDA)	Australia (ANCOLD)
Short Term (EOC)	Potential Loss of Containment	**1.5**	➢ **1.3**	**1.5**
	No Potential Loss of Containment			**1.3**
Long Term (Steady State)			**1.5**	**1.5**
Rapid Drawdown		**1.1**	**1.2 - 1.3**	
Critical Phreatic Level		**1.3**		
Seismic	Pseudo-Static	**?**	**1.0**	
	Post Earthquake	**?**	**1.2**	**1.0 – 1.2**

Samarco Stability Design Criteria

Phase	Condition	Brazil (ABNT) 2006	Comment
Short Term (EOC)	Potential Loss of Containment	**1.5**	**Existing Brazil regulatory standard**
	No Potential Loss of Containment		
Long Term (Steady State)		**1.5**	
Rapid Drawdown		**1.1**	
Critical Phreatic Level		**1.3**	
Seismic	Pseudo-Static	**1.0**	**Adopt CDA guideline**
	Post Earthquake/**Post liquefaction***	**1.2***	

***** **Include static liquefaction**

Best Practices

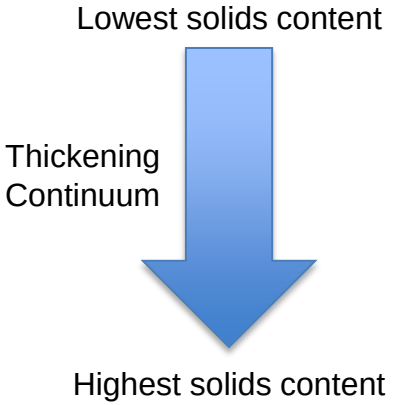
- **Best Applicable Technology Economically Achievable – BATEA** - combination of technologies and techniques that most effectively reduce the economic, physical, geochemical, ecological and social risks associated with tailings during all stages of operation and closure.
- **Best Available/Applicable Practice – BAP** - management systems and operational procedures to ensure that tailings storage facilities are designed, constructed, operated, maintained, monitored and closed to support sustainable mining practices.

EXAMPLES:

- Filter Tailings
- Remote Monitoring
- Cone Penetration Testing

BATEA – Filter Tailings

- Conventional Slurry Tailings
- Thickened Tailings
- Paste Tailings
- Filtered Tailings / “Dry” Stack



Filter Press

BATEA – Tailings Technology Alternatives Evaluation

AREA:	TECHNICAL		ENVIRONMENTAL/SOCIAL							ECONOMIC		PROJECT RISK	
Tailings Disposal Method [2]	Dewatering of Tailings [3]	Tailings Deposition [4]	Process Make-Up Water (m^3/hour)	Disturbed Surface Area (ha) Total	Disturbed Surface Area (ha) Tailings Surface Area	Risk of Breach Failure [5]	Dust Potential	Seepage	Visual Impact [6, 9]	Reclamation	CAPEX	OPEX	Proven Technology at 65,000 tonnes/day	Regulatory Concern
Conventional Un-thickened (32% solids) Un-buttressed Facility	Most Favorable	Most Favorable	1.087	700	589 (326 beach, 263 pond)	Least Favorable	Less Favorable	Least Favorable	More Favorable (1,060m)	Less Favorable	$223 M	$123 M	Most Favorable	Less Favorable
Conventional Un-thickened (32% solids) Buttressed Facility [7]	Most Favorable	Most Favorable	1.087	700	589 (326 beach, 263 pond)	Less Favorable	Less Favorable	Least Favorable	More Favorable (1,060m)	Less Favorable	$223 M	$123 M	Most Favorable	Less Favorable
Thickened (60% solids) Buttressed Facility [7]	More Favorable	More Favorable	764	690	550 (450 beach, 100 pond)	More Favorable	More Favorable	Less Favorable	Most Favorable (1,056m)	More Favorable	$226 M [8]	$132 M [8]	Most Favorable	More Favorable
Paste (75% solids) Buttressed Facility [7]	Less Favorable	Less Favorable	730	603	461 (411 beach, 50 pond)	More Favorable	Most Favorable	More Favorable	Least Favorable (1,095m)	Least Favorable	Expected to be higher than thickened	Expected to be higher than thickened	Least Favorable	Least Favorable
Dry Stack (85% solids) Buttressed Facility [7]	Least Favorable	Least Favorable	400	429	362	Most Favorable	Least Favorable	Most Favorable	Least Favorable (1,055)	Most Favorable	$442 M	$430 M	Least Favorable	Most Favorable

Notes:

1. Qualitative ranking in order of preferred option is: Most Favorable -> More Favorable -> Less Favorable -> Least Favorable

Trade off study to determine BATEA at a site in British Columbia, Canada

Operational Filtered Tailings Stack

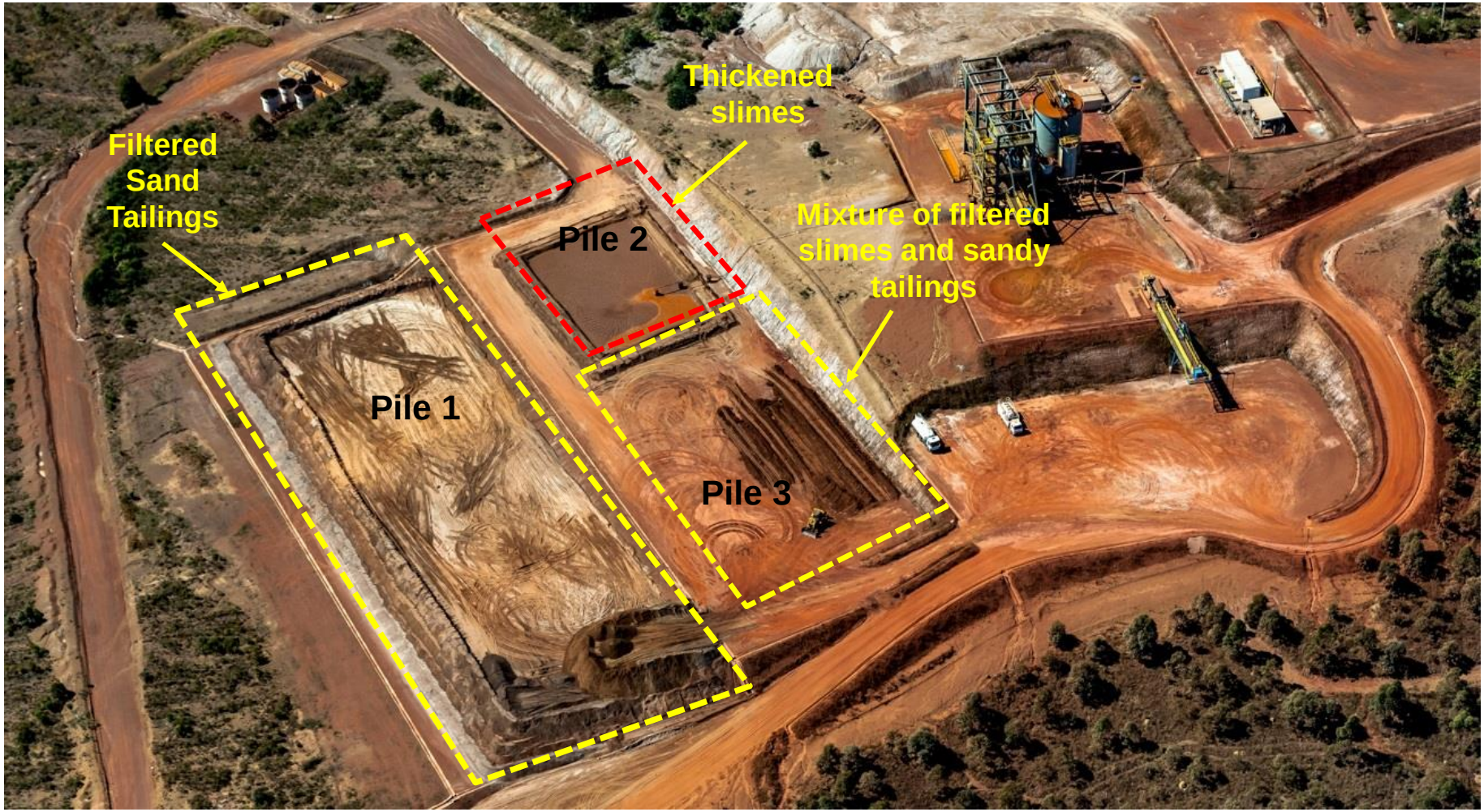
Eldorado Gold Efemcukuru Mine, Turkey

Controlled Material Placement		
Transportation	Spreading	Compaction

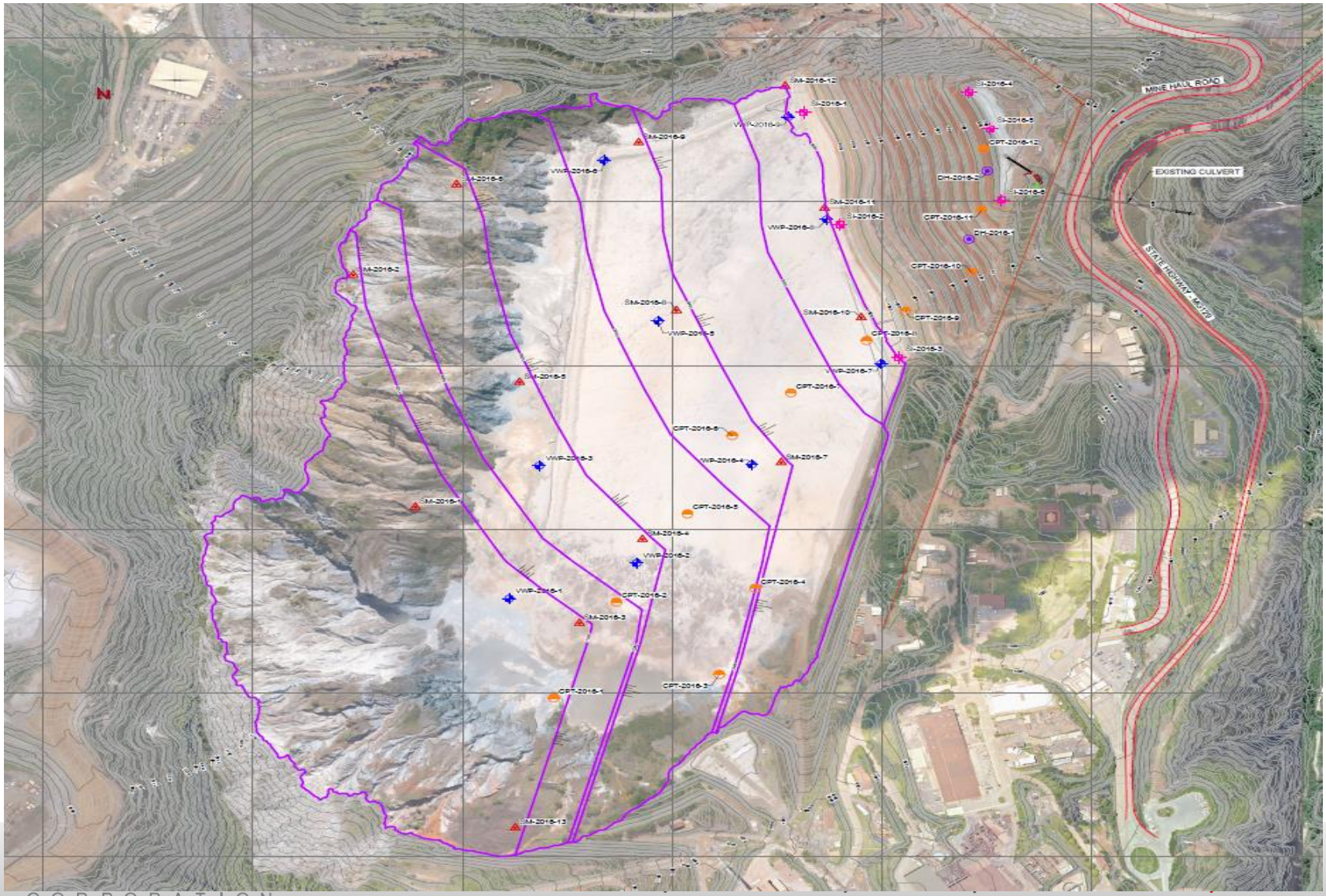




Brasil Filter Tailings Pilot Plant and Test Plots



Samarco Germano Pit Filter Tailings Design



BAP - Cone Penetration Test (CPT)

ADVANTAGES:

- Fast and continuous profiling
- Repeatable and reliable data
- Economical and productive
- Strong theoretical basis for interpretation
- Additional sensors

LIMITATIONS:

- High capital investment
- Skilled operators
- No soil sample
- Penetration restricted in gravels/cemented layers

CONVENTIONAL DRILLING & SAMPLING

DIRECT-PUSH TECHNOLOGY

Lab

Cased Boreholes

CHT: V_s, V_p

FIRM SAND

SPT: N_{60}

SOFT CLAY

VST: s_u, S_t

PMT: E'

Packer: k_{vh}

SCPTù

q_t

f_s

u_2

t_{50}

V_s

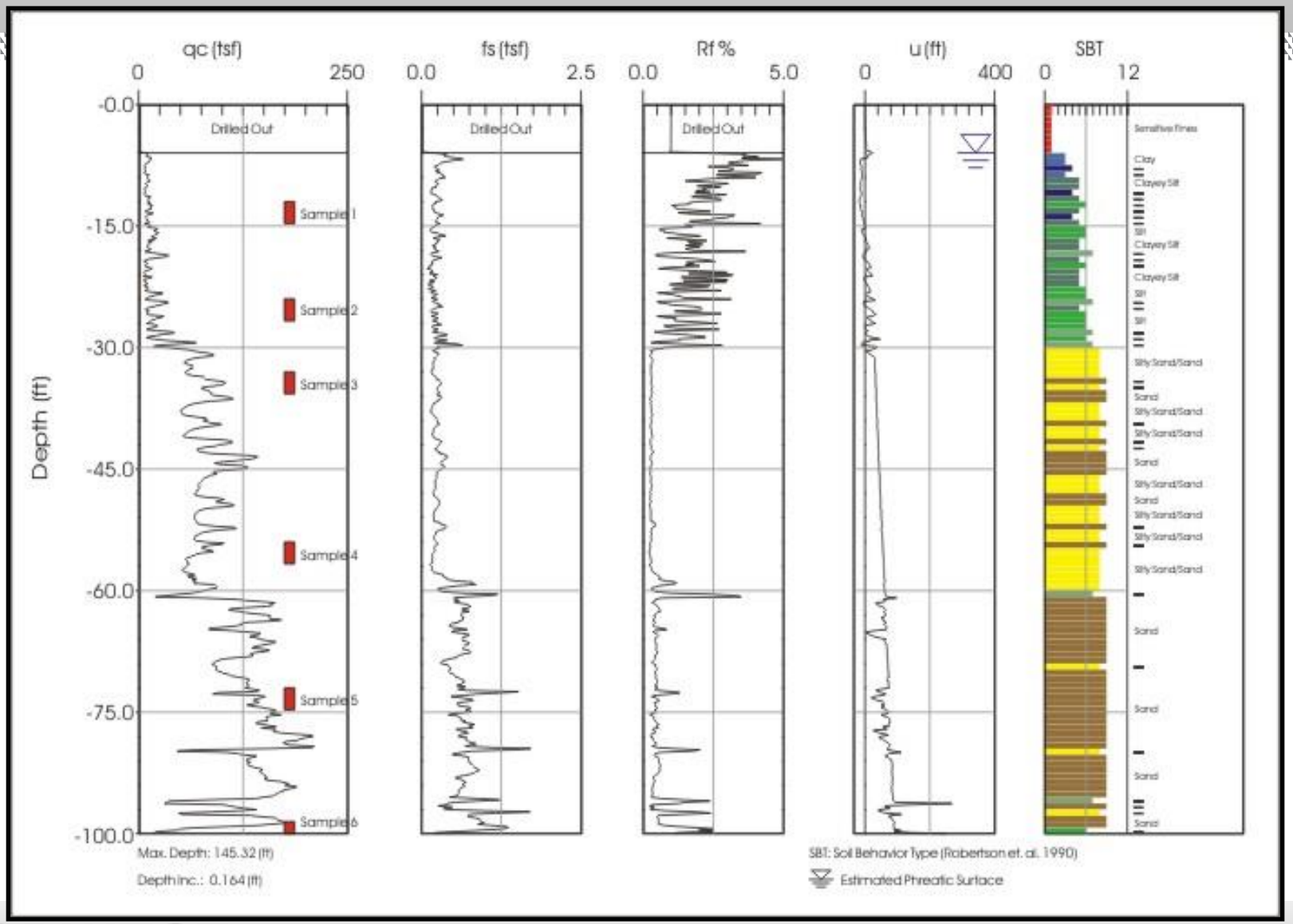
Fast 2cm/s
Continuous
Repeatable
Cost effective

old new

After Mayne, 2010

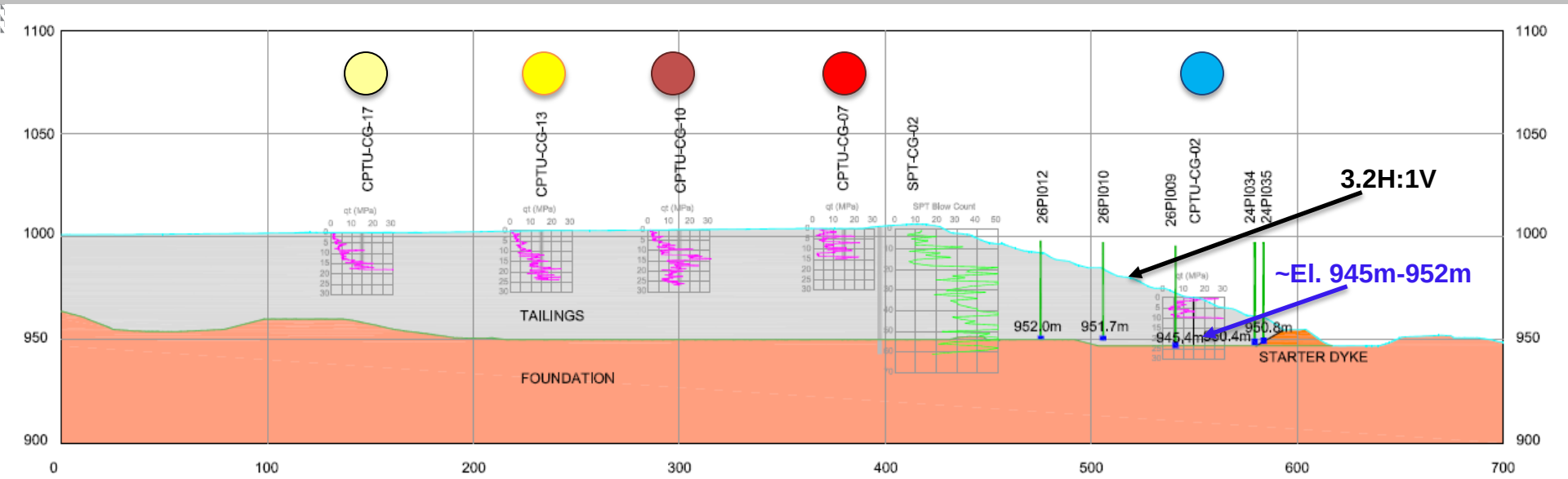
NORWEST CORPORATION EXPLORE the Depths of our Experience www.norwestcorp.com

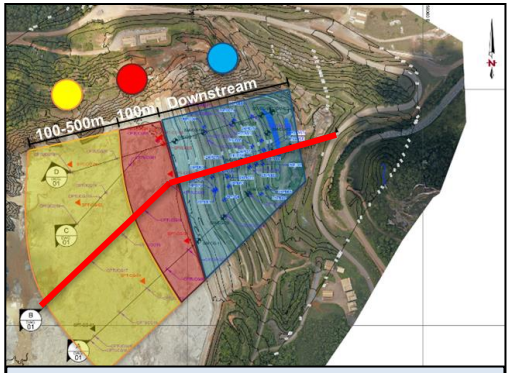
CPT Data Presentation



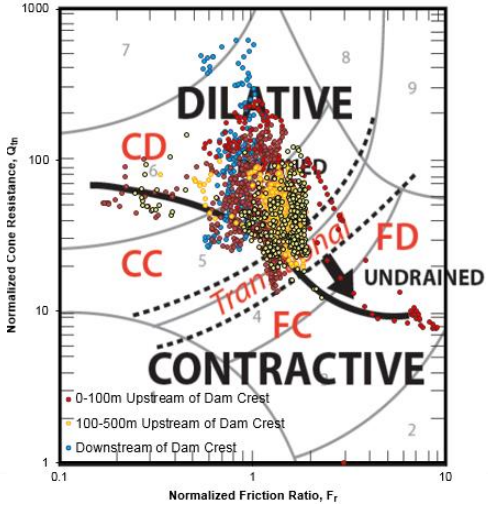
Standard CPTu Plot

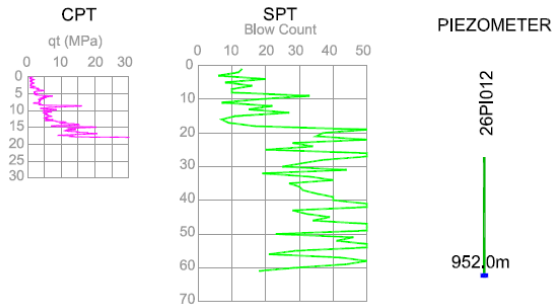
CPTU for Liquefaction Evaluations





Key Plan





BAP - Automated Instrumentation Systems

Sensors
(Vibrating Wire Piezometer, Shape Accelerometer Array (SAA), In-Place Inclinometer (IPI), Transducer, Tiltmeter, Strain Gauge, GPS, Radar, inSAR)

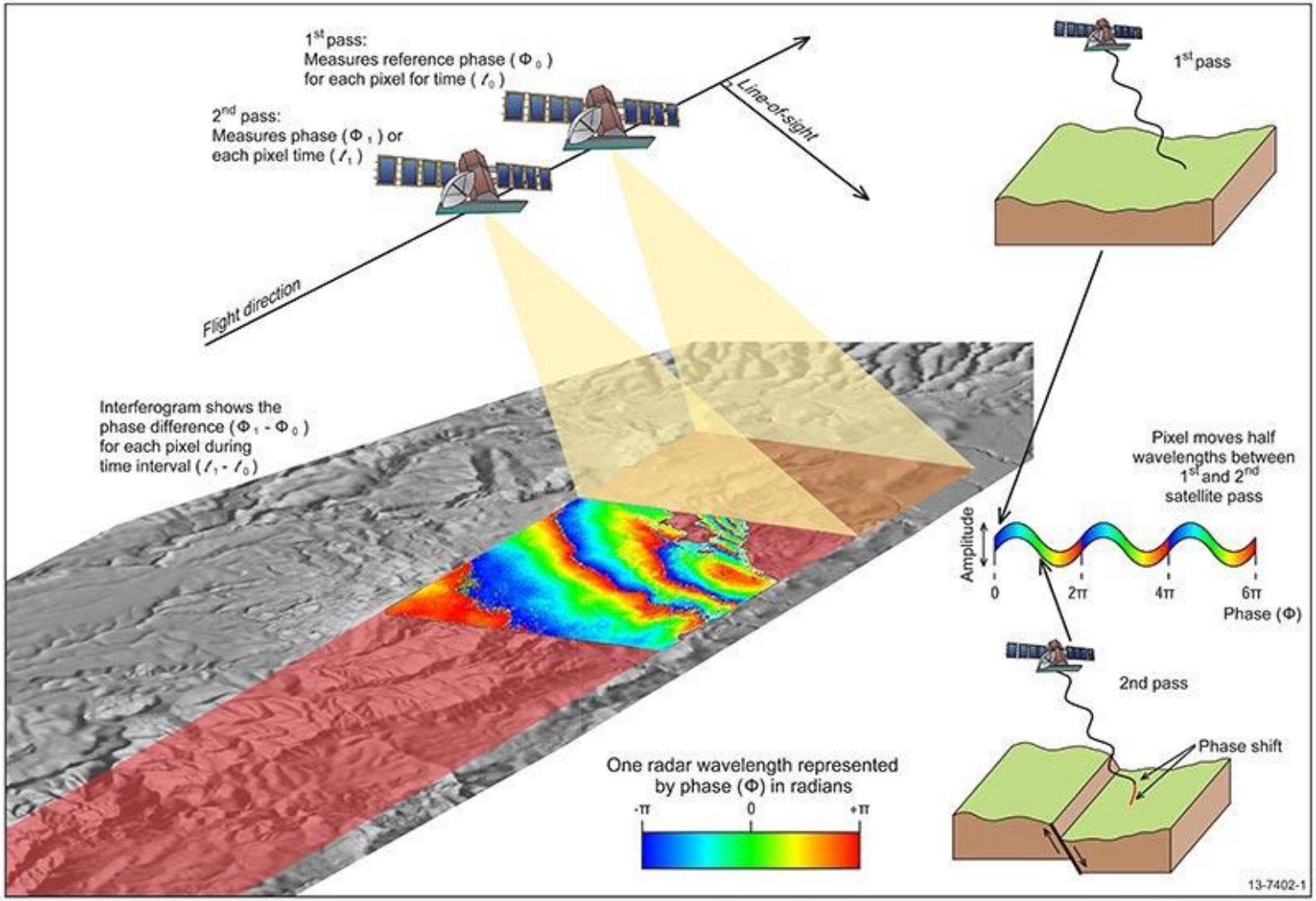
Datalogging and Telemetry
(Storage and transmission of data via networked radios, cellular or satellite communication)

Acquisition and Analysis
(Web/Server based monitoring software, near real-time readings, alarm criteria and alert systems, Factor of Safety (FOS) analysis)

Design and Operational Decisions
(Performance based decisions, construction sequencing)

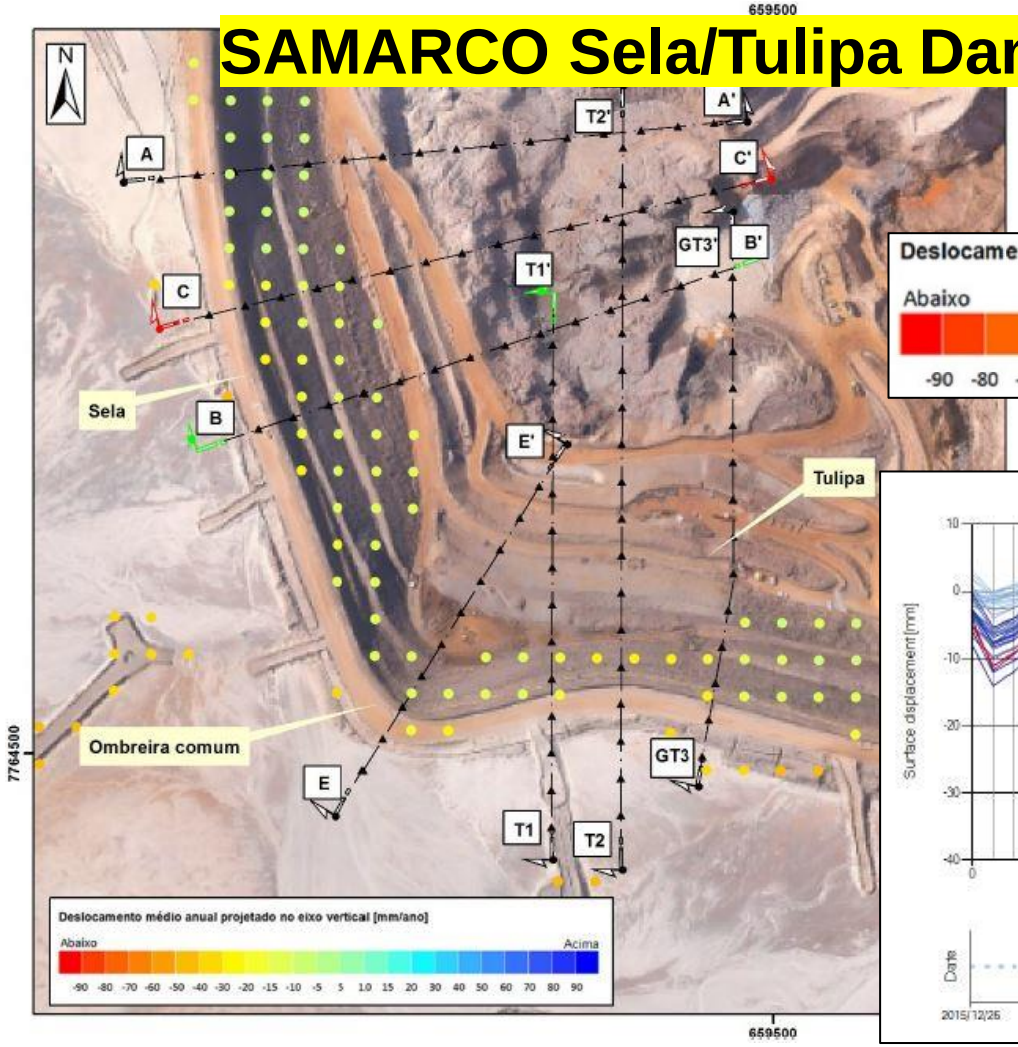
Samarco Monitoring System

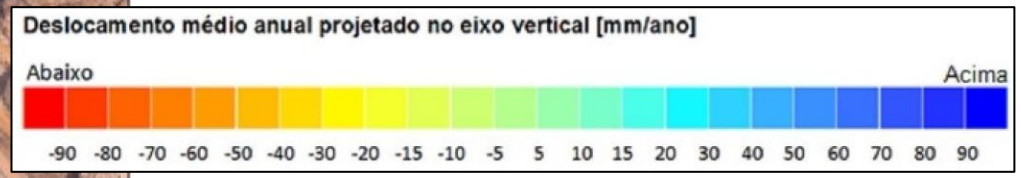
BAP- Interferometric Synthetic Aperture Radar (InSAR)

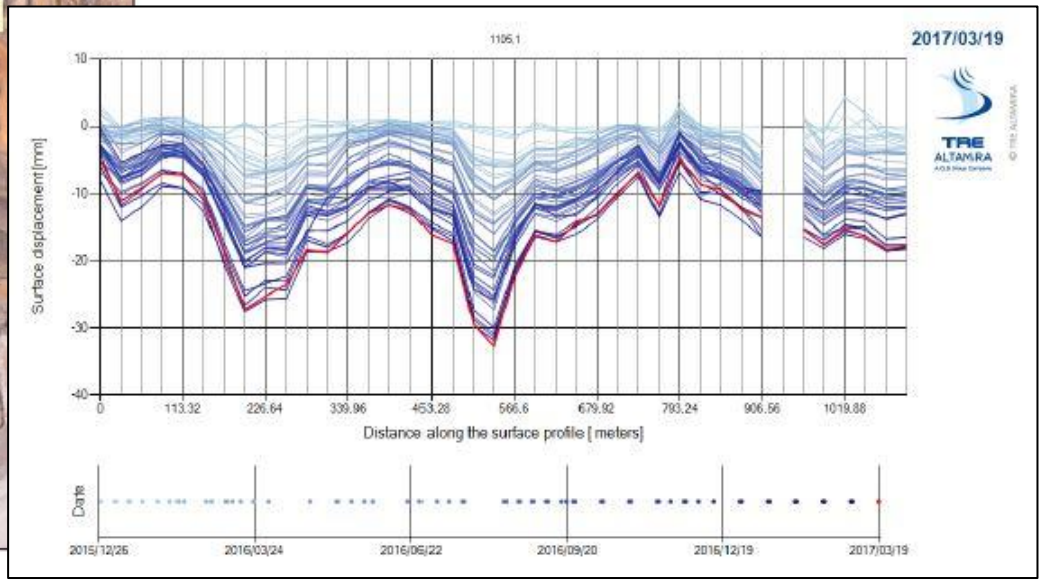


Interferometric Synthetic Aperture Radar (InSAR)

SAMARCO Sela/Tulipa Dams





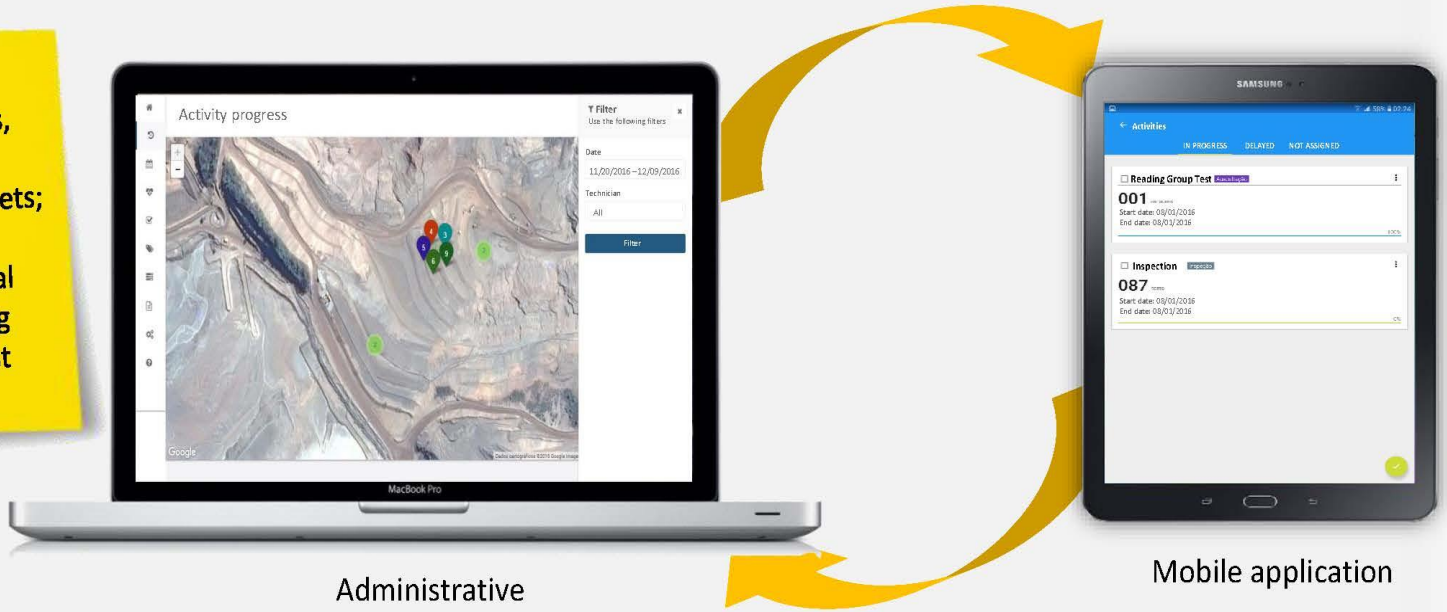


BAP – Mobile Data Collection

GEO INSPECTOR

Geo Inspector is a mobile solution with an administrative interface that allows real-time and safe management of monitoring and inspection activities.

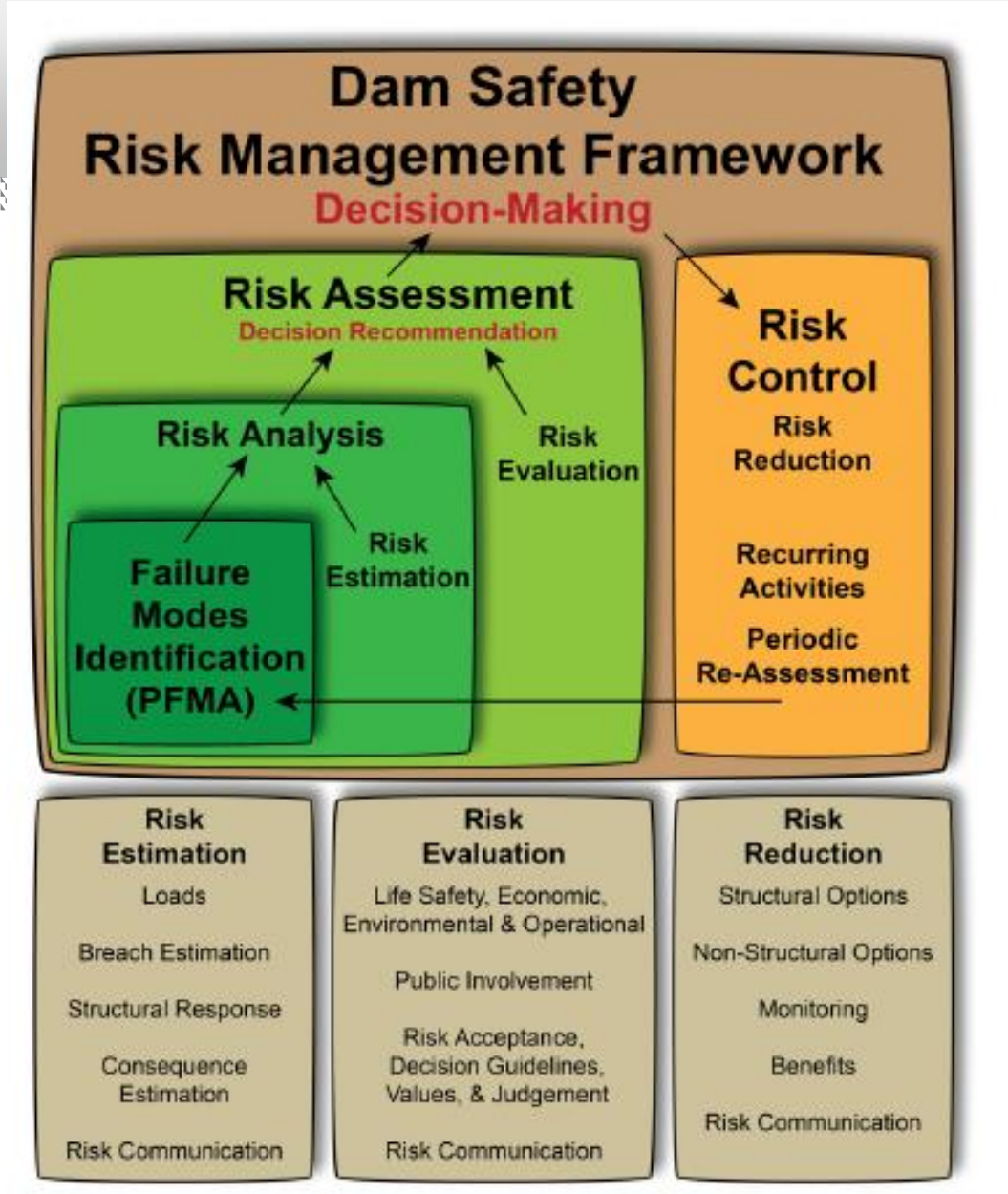
Allows integrated management of activities, shifts and scales of technicians; anomalies; assets; and the generation of managerial and statistical reports aimed at making decisions in the shortest possible time.

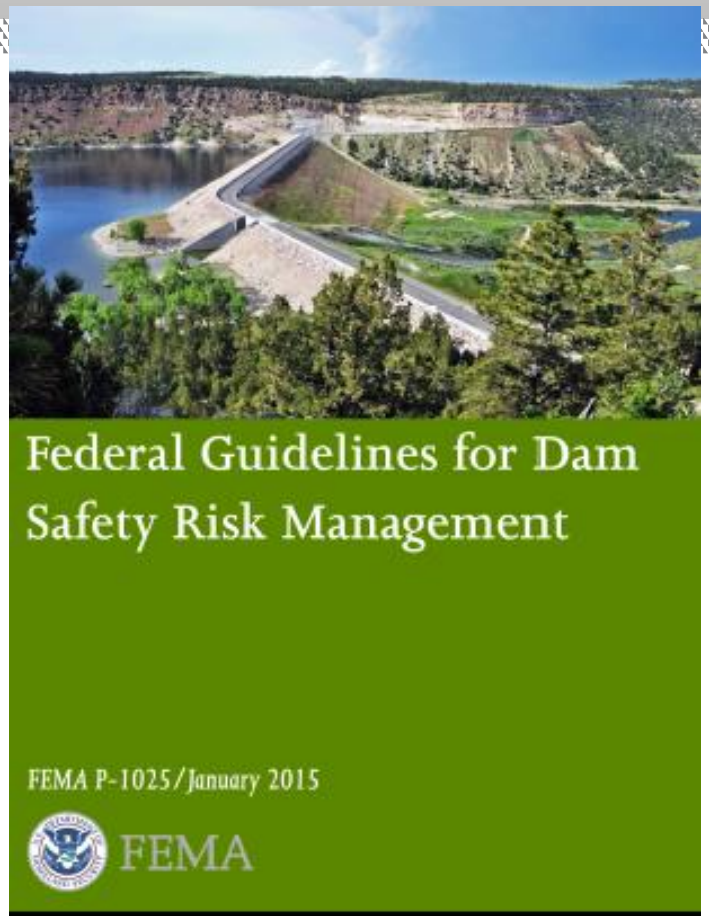


Administrative interface

Mobile application

Intelltech is a Brazilian technology company


Dam Safety
Risk Management Framework
Decision-Making
Risk Assessment
Decision Recommendation
Risk Analysis
Risk Evaluation
Failure Modes Identification (PFMA)
Risk Estimation
Risk Control
Risk Reduction
Recurring Activities
Periodic Re-Assessment
Risk Estimation
Loads
Breach Estimation
Structural Response
Consequence Estimation
Risk Communication
Risk Evaluation
Life Safety, Economic, Environmental & Operational
Public Involvement
Risk Acceptance, Decision Guidelines, Values, & Judgement
Risk Communication
Risk Reduction
Structural Options
Non-Structural Options
Monitoring
Benefits
Risk Communication

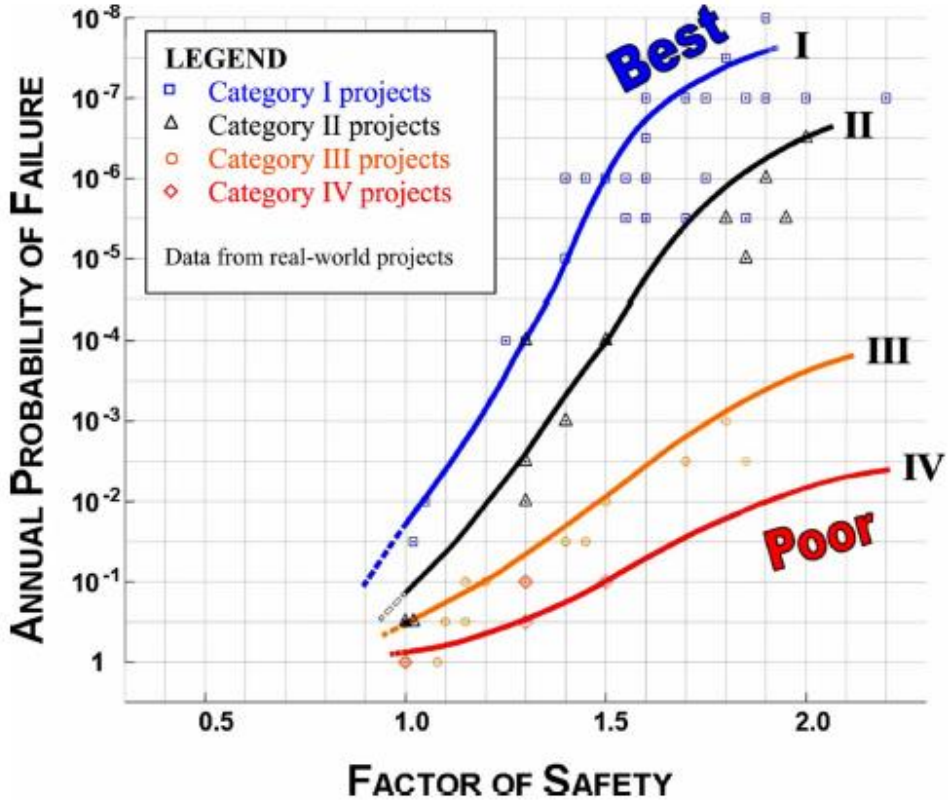

Federal Guidelines for Dam Safety Risk Management
FEMA P-1025/January 2015
FEMA

Potential Failure Modes Analysis

Failure Category	Potential Failure Mode Description	Controlling Areas	Positive Factors	Adverse Factor	Warning Time (hours, days, weeks)	Barriers/Controls	Hazard Category	Recommendations and Comments
Dyke Fails by Overtopping (Reservoir Goes Up)	Large storm exasperated by a pumping failure leading to a rising pond level and a subsequent breach of the dyke. Unplanned operational rise in the pond water leading to a rising pond level and a subsequent breach of the dyke.	All areas.	• Freeboard exceeds the incident PMP by a factor of 5. • Recycle water barges are in place. • Very slow increase with sufficient time to implement mitigations. • Control of the fresh water intake.	• Closed water management system. • Ultimate containment for all site water.	Weeks	• Containment structure with generous freeboard. • Specific procedures are in place to manage a rising pond condition (OMS).	IV	• There are no recommendations or comments at this time.
	Failure of the TT containment dykes leading to a wave or flow event which subsequently overtops the perimeter dyke.	EETA	• TT containment is hundreds of meters away from the perimeter dyke. • The EETA is planned as a "dry" facility. • Deposit characteristics limit the mobility. • Beaching from the perimeter dykes means that any TT released from the TT containment dykes will have to overcome a positive beach slope for some distance, as well as the perimeter dyke freeboard.	• TT dykes will be higher than the surrounding perimeter structure for a period of time. • Characteristics are not well known. • Tailings plans are subject to change.	Hours	• Continuous monitoring.	IV	• Per the CP16 plan CST beach is built in advance of the TSRU deposit, and therefore, this scenario is unlikely given the current plan. • Evaluate critical failure mechanisms.
	Failure of the BBW leading to a wave or flow event which subsequently overtops the perimeter dyke.	WETA	• BBW has slumped without consequence. • TSRU is strong (30 degrees) and compressible. • Freeboard of 3 m. • TSRU feed goes in-pit when storage space is available. • Current beach above water widths are greater than the minimum. 50 m of beach above water is added to the structural zone by Operations as a form of contingency.	• Steep (30 degrees)TSRU BBW slopes. • Removal of FFT supporting the TSRU BBW from the pond for use in TT.	Hours	• Continuous monitoring.	IV	• Operational risks (non-breach) for TSRU BBW need to be assessed. • Although this failure mode could develop quickly, the potential risk for an overtopping event is considered negligible.
			• CPT programs demonstrate BAW is dilative for the rate of	• Liquefaction occurs very rapidly and cannot be managed		• Beach surveillance program is in place		• Liquefaction potential of the BAW relies on the

- Identify “credible” failure modes
- Provide complete descriptions of each failure mode including the initiating event and sequence of steps leading to an uncontrolled release from the impoundment
- Describe the magnitude of the breach

Risk Analysis Techniques



Probability and Risk of Slope Failure

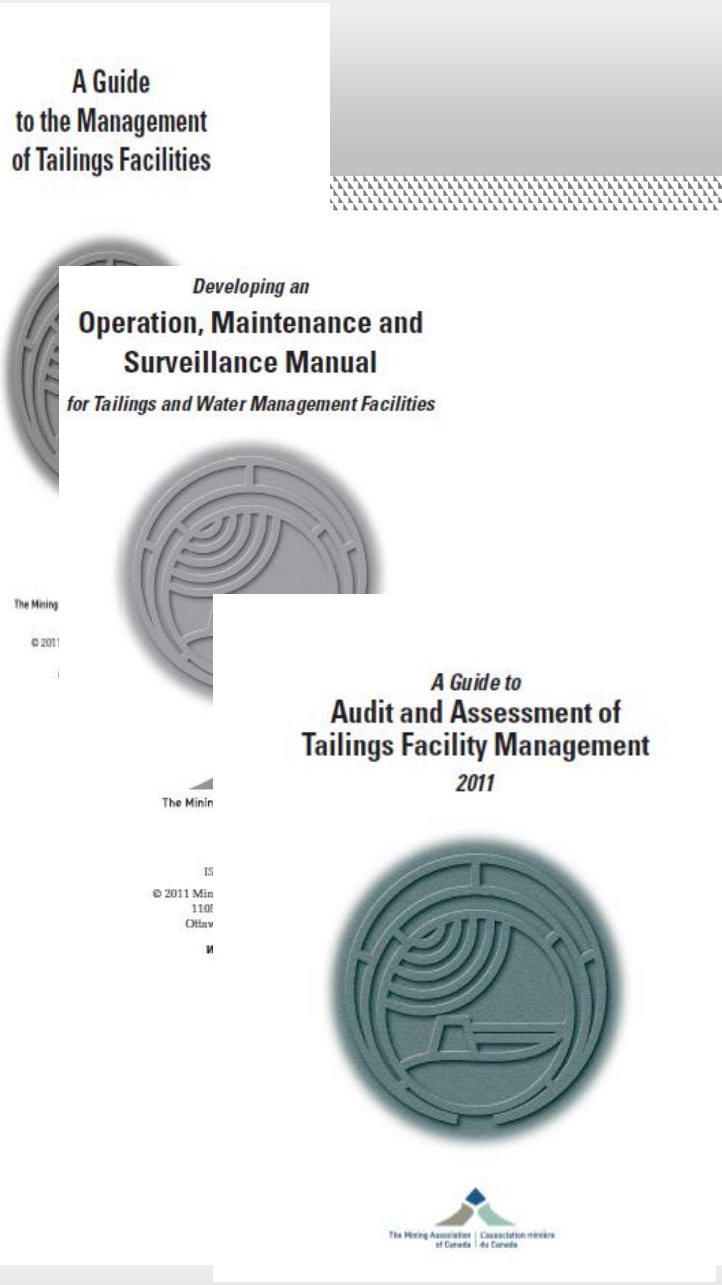
Francisco Silva, M.ASCE[1]; T. William Lambe, Hon.M.ASCE[2]; and W. Allen Marr, F.ASCE[3]

1692 / JOURNAL OF GEOTECHNICAL AND GEOENVIRONMENTAL ENGINEERING © ASCE / DECEMBER 2008

Some examples:

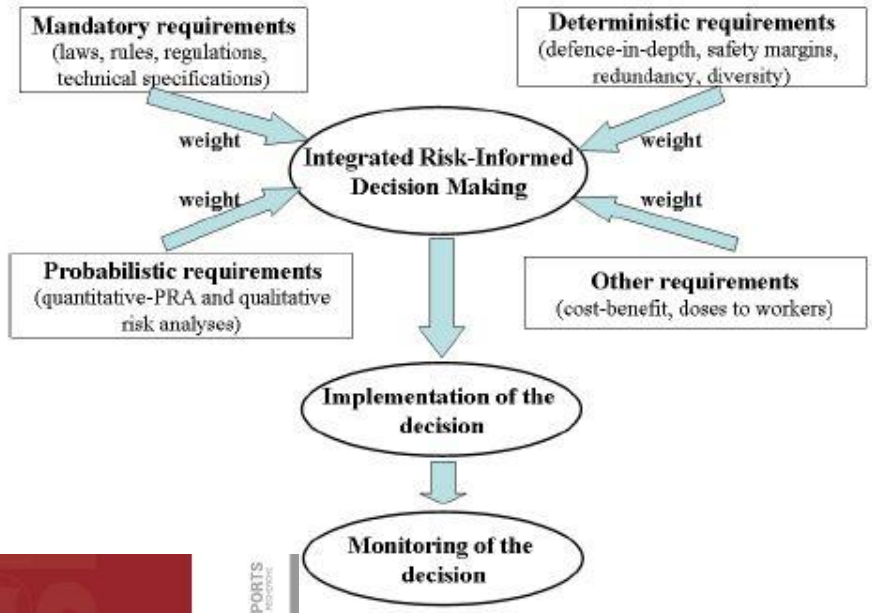
- Failure Modes and Effects Analysis (FMEA)
- Bow Tie Analysis
- Event Trees
- Fault Trees
- Reliability Analysis
- Consequential Risk Analysis
- Subjective methods
- Vulnerability Index

Dam Safety Risk Controls



- Dam Safety Management System (MAC Guidelines)
- Operating Plans and Procedures
- Maintenance and Testing of Critical Equipment
- Surveillance Plans
- Performance Evaluation/Observational Method
- Mitigation/Repair
- Emergency Management

Risk Informed vs Risk Based Dam Safety Decisions

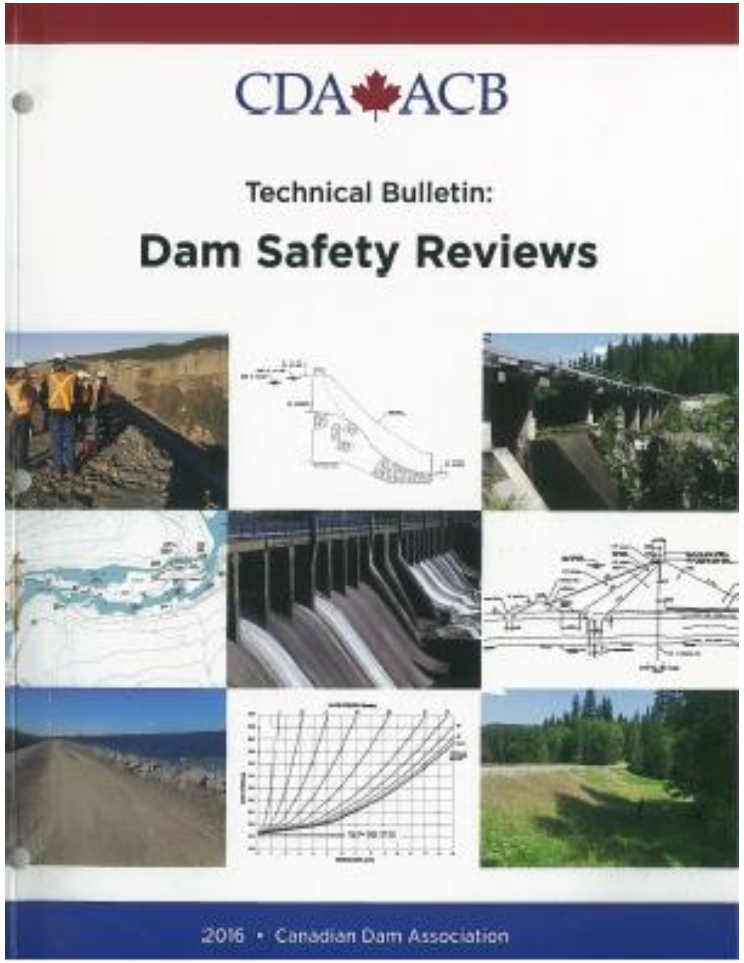


FEMA, 2015:

- **"Risk informed dam safety decision making implies that decisions are made considering risk estimates and many other contributing factors that might include confidence in the risk estimates, risk uncertainty, deterministic analyses, and the overall dam safety case in addition to other local or regional considerations"**

- **"Risk based dam safety decision making implies that a comparison of a risk estimate to risk criteria is the basis for decision making"**

Dam Safety Reviews

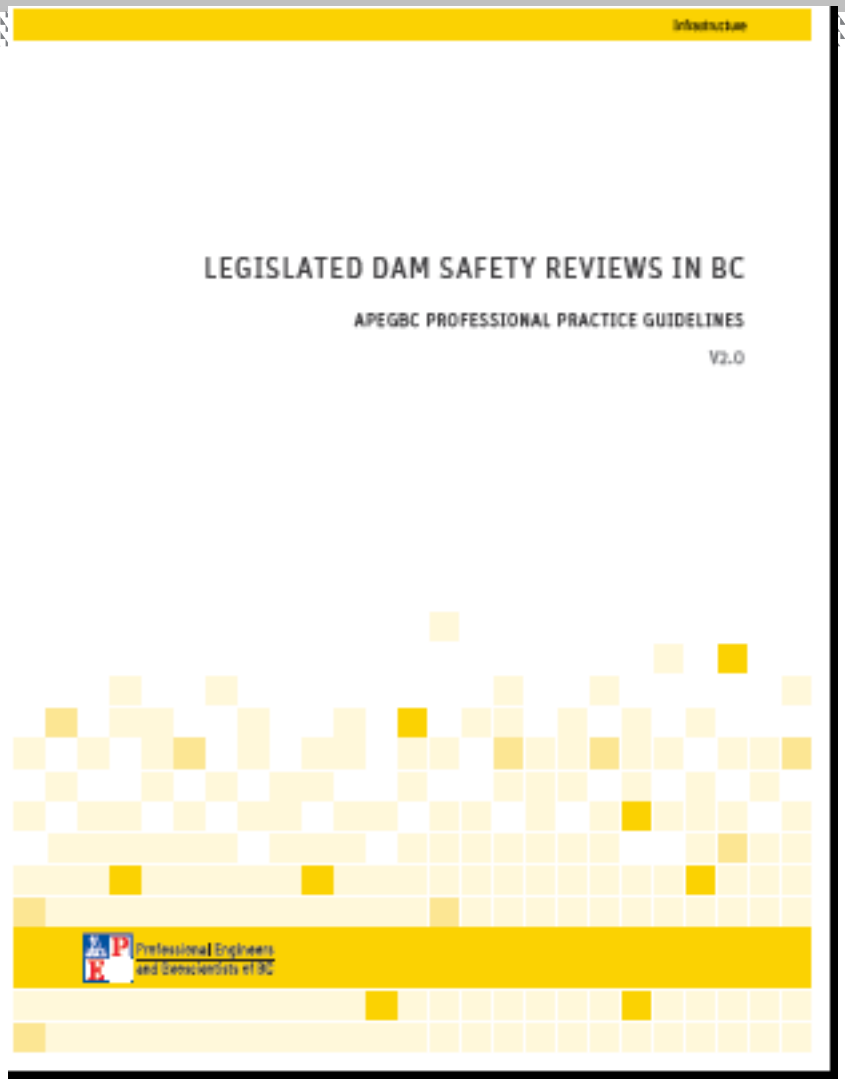


"A dam safety review is part of the dam safety management system that has the overall goal to protect people, property and the environment from harmful effects of misoperation or failure of dams and reservoirs."

Companion CDA references:

- CDA (2007, 2013); Dam Safety Guidelines
- CDA (2014) Technical Bulletin – Guidelines to Mining Dams

Types of Dam Safety Reviews



- Audit type
- Comprehensive
- Detailed Design-based Multi-disciplinary
- Comprehensive and Detailed Design and Performance Review

Deficiencies and Non-conformances (CDA, 2016)

- A dam safety “deficiency” is an inadequacy or uncertainty in the inadequacy of the dam system to meet its performance goals in accordance with good dam safety practices
- A dam safety “non-conformance” is an inadequacy in the non-physical controls (procedures, processes and management systems) necessary to maintain the safety of the dam

APEGBC Dam Safety Assurance Statement – Mining Dams

Check one

☐ The *dam* is reasonably safe in that the *dam safety review* did not reveal any unsafe or unacceptable conditions in relation to the design, construction, maintenance and operation of the *dam* as set out in the attached *dam safety review report*.

☐ The *dam* is reasonably safe but the *dam safety review* did reveal non-conformances with the regulatory requirements as set out in section(s) ____ of the attached *dam safety review report*.

☐ The *dam* is reasonably safe but the *dam safety review* did reveal deficiencies and non-conformances as set out in section(s) ____ of the attached *dam safety review report*.

☐ The *dam* is not safe in that the *dam safety review* did reveal deficiencies and/or non-conformances which require urgent action as set out in section(s) ____ of the attached *dam safety review report*.

The *Dam Safety Review Assurance Statement* introduces the term "reasonably safe" which, in terms of these guidelines is intended to mean that the *dam owner* has implemented all *dam* safety management measures which conform to those norms that are considered by the *regulatory authority* and the *qualified professional engineer* to reasonably reflect established engineering and *dam* safety management practices.

Key Messages – Governance

- ✓ Well defined roles, responsibilities and accountabilies for key positions (ex. Engineer of Record)
- ✓ Formal independent review requirements with Independent Tailings Review Boards (ITRB) reporting to senior management.

Key Messages – Best Practices

BATEA

- ✓ Rapid development of tailings dewatering processes. Technology sharing occurs at international conferences and workshop (ex. Paste conference, Tailings and Mine Waste conference) and with expert review. Each site is unique and alternative assessments are required.

BAP

- ✓ Performance management and the observational method
- ✓ CPTU is the "standard" for evaluating tailings deposits
- ✓ Remote monitoring technologies and systems
- ✓ Mining Association of Canada (MAC) tailings guides

Key Messages – Process

- ✓ Systems based approach ….. Mining Association of Canada (MAC) Guidelines
- ✓ Dam Safety Reviews
- ✓ Risk Management:
  - Failure Modes Identification and Risk Control are critical to the process. Need to get it right….experience required
  - Quantitative Risk Assessment is not exact…..serves to calibrate judgement
  - Very High and Catastrophic failure modes dominated by the consequence of failure …..unless the mechanism can be virtually eliminated as non-credible