



Monitor
with
Confidence



Dam Safety- Instrumentation & Monitoring

Date: 22 November 2019

Hanoi, Vietnam

INTERNATIONAL SYMPOSIUM ON ROCK MECHANICS
AND ENGINEERING- THE 35TH VSRM ANNIVERSARY

Why is dam instrumentation and monitoring important?

- Basic question to answer: *“How is the dam performing?”*
- Dams change with age, and may develop defects over time
- Visualization surveillance is the backbone of all performance monitoring
- But- instrumentation can supply measurements of performance indicators that evade visual surveillance
- There are no two dams alike

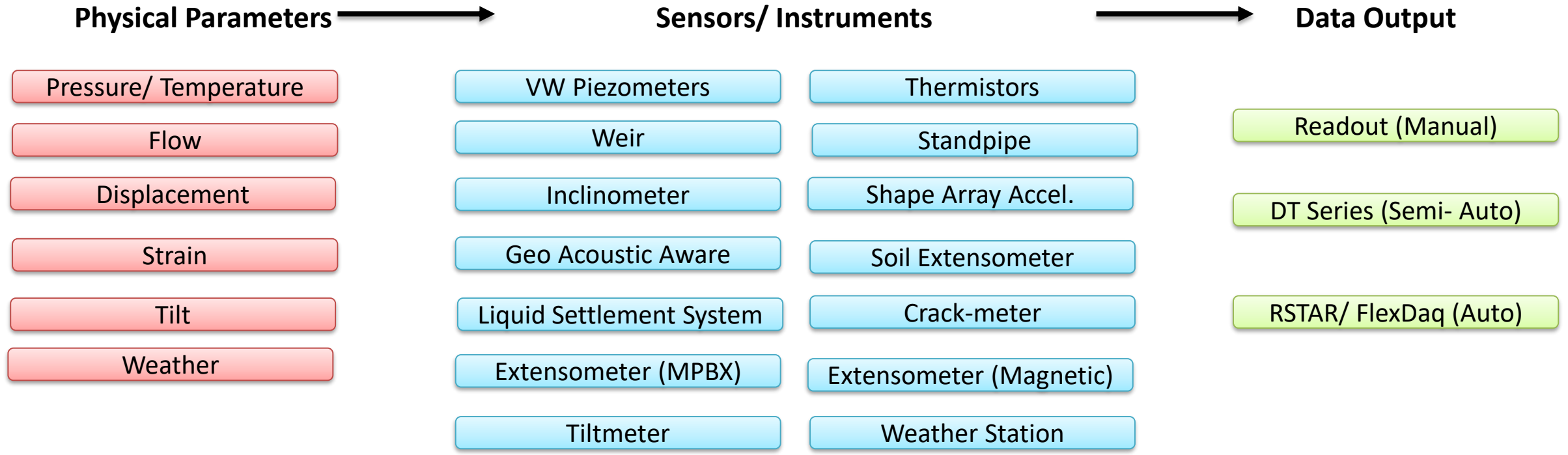
Understand what
could cause
failure

Which
performance
indicators needed

**Plan &
Implement
the Program**

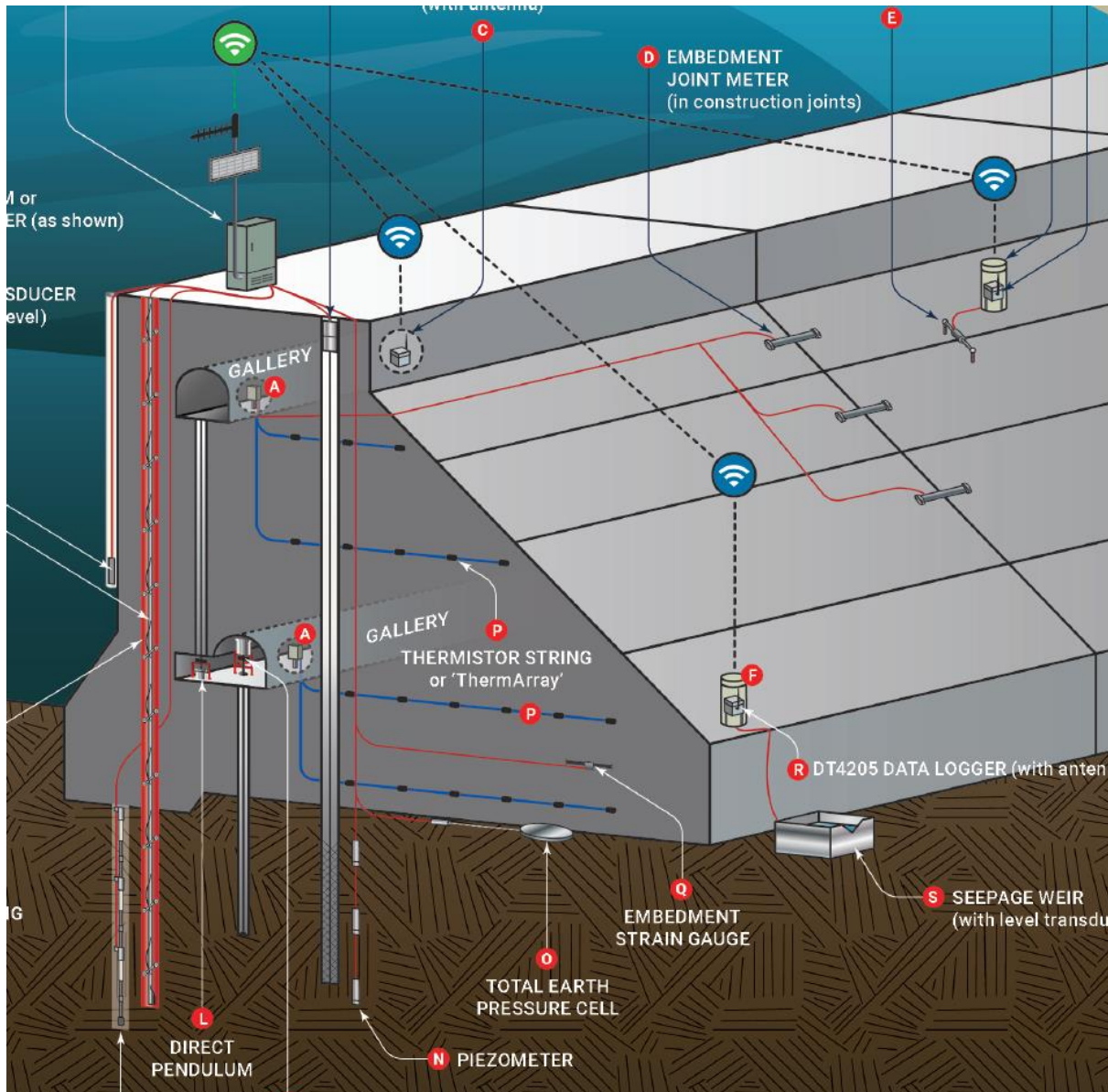
Gather, manage,
and present the
data

Evaluate the data
&
Make decision



- Instruments used for measuring different dam performance parameters
- Select the appropriate instrumentation for a monitoring program to answer performance questions
- Instrumentation monitoring is a valuable tool for dam safety

Concrete Dam Application



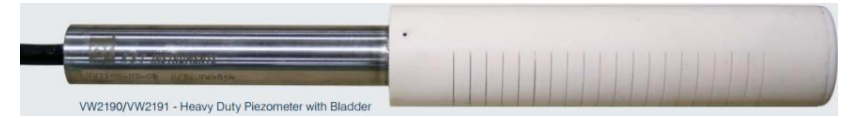
Typical Parameters Monitored:

- Pore Pressure (piezometers)
- Deformation (inclinometers, in-place inclinometers, crack meters, joint meters, strain gauges)
- Seepage (thermistors, weirs/transducers)
- Tilt (pendulums)

WATER PORE PRESSURE- PIEZOMETERS/ STANDPIPE

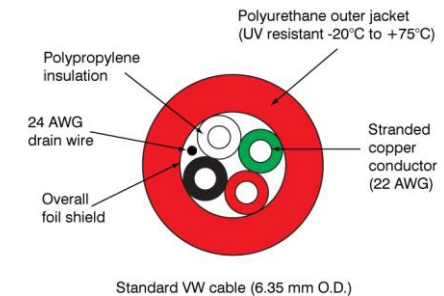
VW Piezometer

- Accuracy = 0.1% F.S., Resolution = 0.025% F.S.
- Hermetically sealed stainless steel housing
- Option for seawater → piezometer with bladder
- VW2106- durable, compact design for excellent portability and field use, stores location and data points



RST Cable (EL380004)

- 4 (2 twisted pairs), 22 AWG (0.33mm²), OD 6.35mm
- waterproof, abrasion- resistant polyurethane jacket
- available heavy-duty cable, OD 9.52mm, 12.7mm



Standpipe, Casagrande

- Specification 25mm ID with 3mm wall, OD = 31mm
- RST's Casagrande 1 inch, OD = 33.5mm, PP0312 (30.48cm)



LATERAL GROUND DISPLACEMENT- MEMS INCLINOMETER SYSTEM (manual)

- Micro Electro Mechanical Systems (MEMS)- stable, sensitive, and accurate
- Used to measure horizontal displacement
- Applications: dams, landslides, rock cuts, diaphragm walls
- Installation: boreholes via inclinometer casing
- Used for manual readings, 0.5m, various cable lengths, FieldPC readout where you can see the data at the borehole

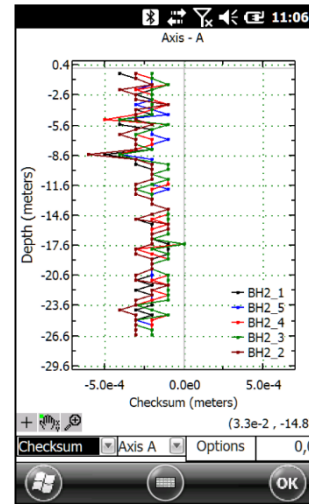
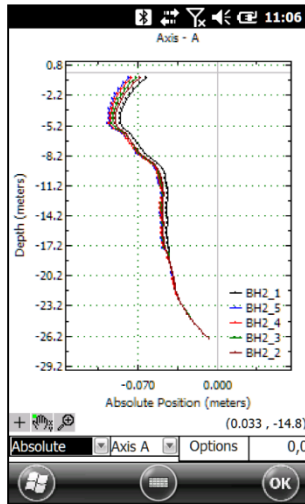
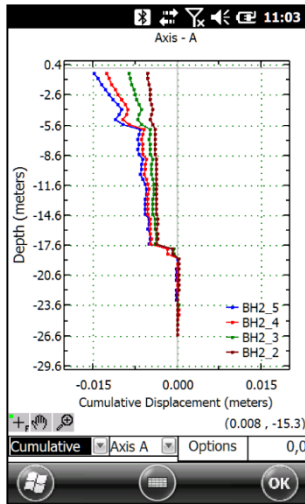
System includes:

- 0.5m inclinometer probe
- Thin, lightweight Kevlar cable
- Reel- Bluetooth enabled
- Rugged Field PC2
- Casing cable grip
- Carrying case for system and reel
- Cable and chargers



LATERAL GROUND DISPLACEMENT- INCLINOMETER SYSTEM (manual)

- Wireless communication between readout and probe using Bluetooth
- Flash memory providing space for more than 1,000,000 readings
- Data analysis and comparison to previous data sets 'at the borehole'



File Name	Base	Select
S BH2_5.csv		
S BH2_4.csv		
S BH2_3.csv		
S BH2_2.csv		
B BH2_1.csv		
spiral.csv		

Date Descending

File Information:

Site : 01
 Borehole : BH_2
 Depth\Interval : 26.5\0.5\0.5 meters
 Reading Units : meters
 Reading Date : 19-Sep-07 09:52
 File Type : Standard RST

Graph Files View Files Save As

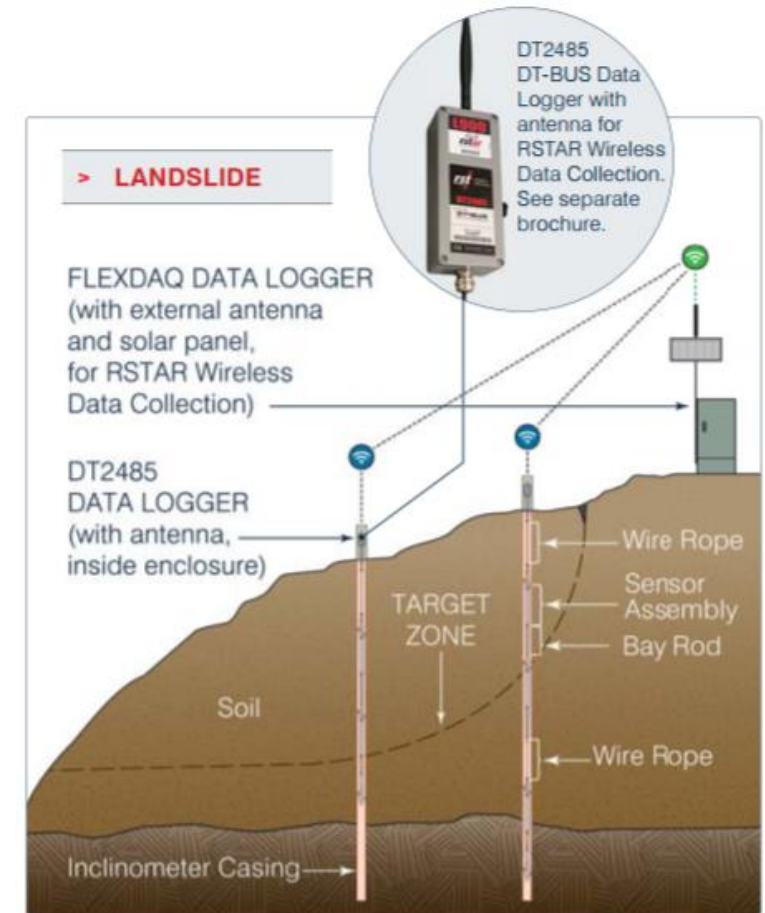
Depth-m	Face A+	Face A-
-0.5	0.0050	-0.0054
-1.0	0.0050	-0.0053
-1.5	0.0039	-0.0041
-2.0	0.0029	-0.0031
-2.5	0.0020	-0.0023
-3.0	0.0022	-0.0024
-3.5	0.0007	-0.0008
-4.0	0.0004	-0.0007
-4.5	-0.0001	-0.0001
-5.0	-0.0036	0.0032
-5.5	-0.0060	0.0056
-6.0	-0.0032	0.0030
-6.5	-0.0036	0.0033
-7.0	-0.0031	0.0028
-7.5	-0.0035	0.0032
-8.0	-0.0055	0.0053
-8.5	-0.0065	0.0060
-9.0	-0.0039	0.0036
-9.5	-0.0022	0.0019
-10.0	-0.0009	0.0007
-10.5	0.0009	0.0007

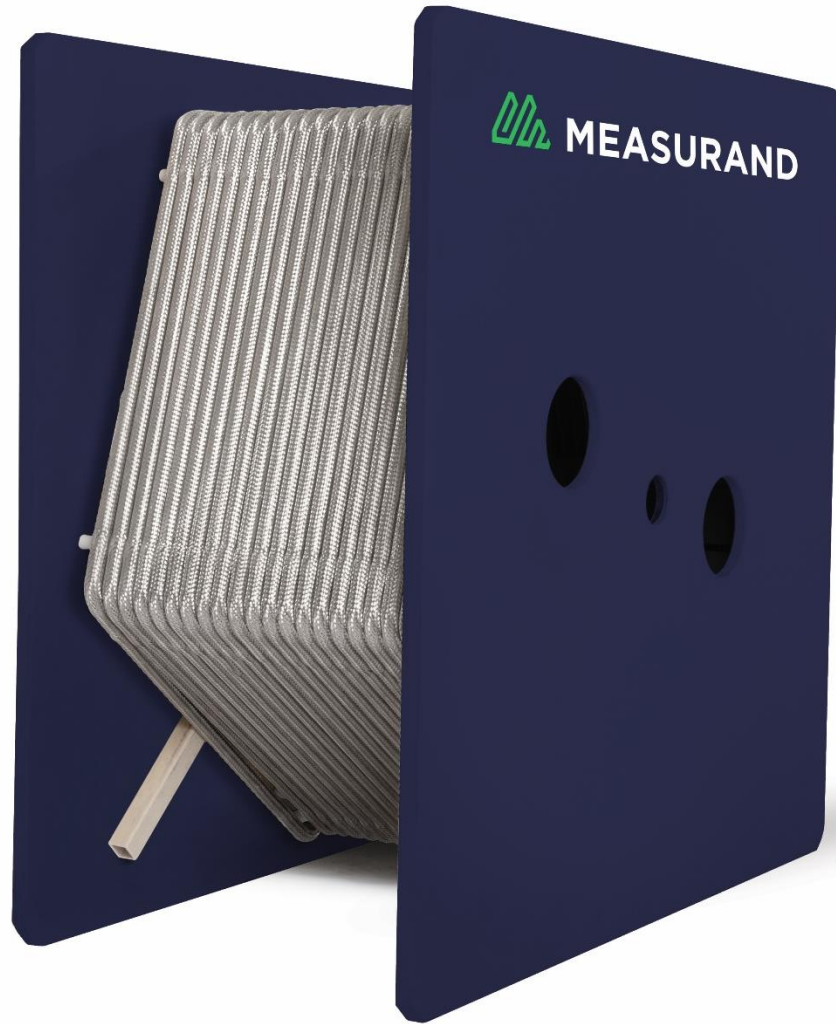
Decima 4 Graph



LATERAL GROUND DISPLACEMENT- IN-PLACE INCLINOMETER SYSTEM (auto)

- Are installed in standard inclinometer casing
- Custom configuration- bay rods, wire rope (spacers); bay rods available: 0.5m, 1.0m, 1.5m, 2.0m, 3.0m
- Can be connected to Automatic Data Acquisition Systems (ADAS) including RSTAR and DT Link.
- Only require 1 cable downhole as digital bussed sensors are used to create DT-Bus
- Long term accuracy $\pm 0.002^\circ$ or 0.03 mm/m.





 MEASURAND

SHAPEARRAY

An automated shape-measuring tool, designed to offer maximum versatility and control :

- Arrives assembled and calibrated on a reel
- Fast and simple installation
- Can be installed in any orientation*
- Resilience to deformation
- Sub-millimeter data accuracy
- Open data export
- Real-time monitoring
- Three models available: SAAV, SAAX and SAAScan

SAAV: Patented cyclical installation

CASING CAP

- A spring box assembly that holds the instrument in compression

EXTENSION TUBES

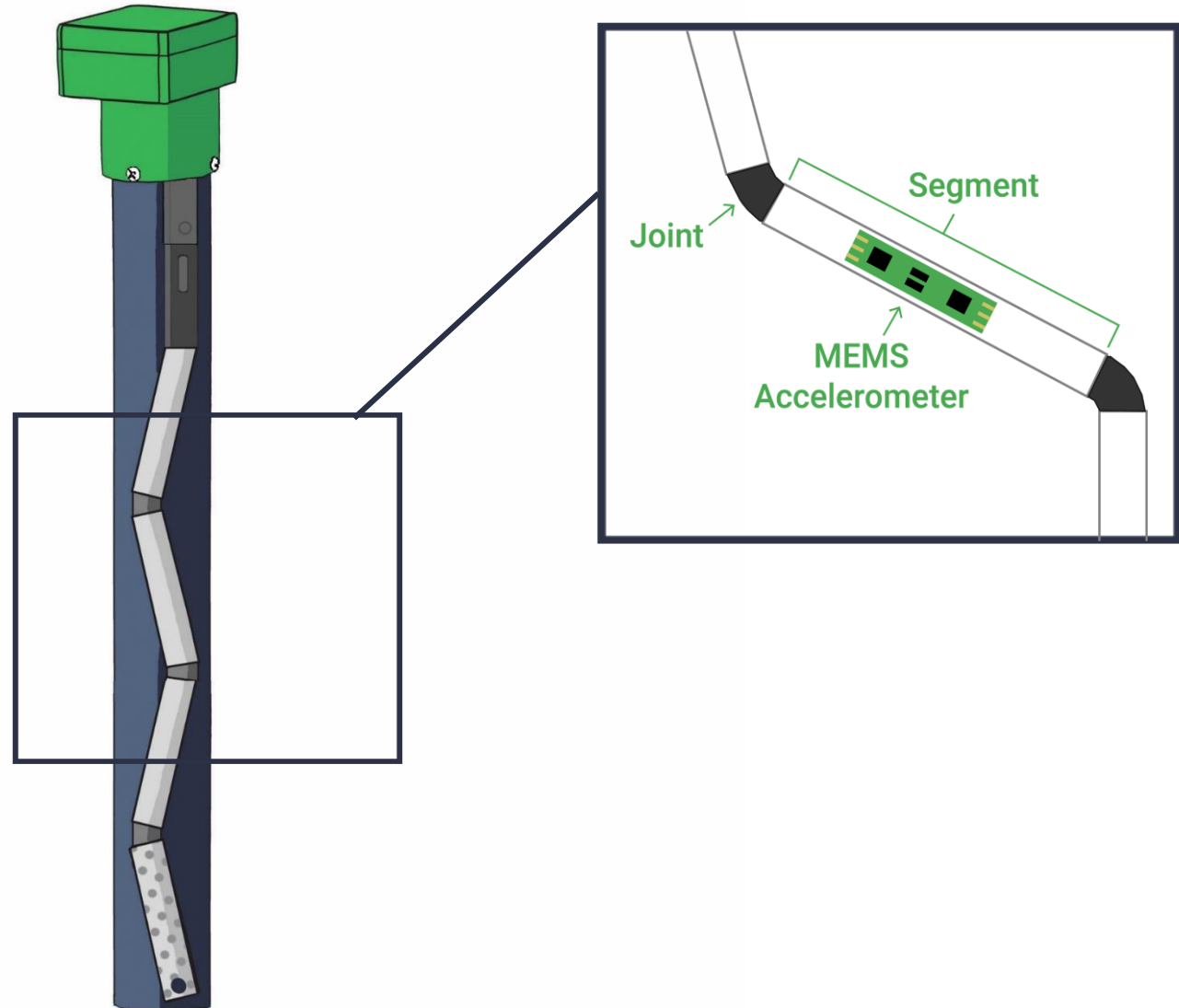
- Lower the zone of measurement
- Available in 1 and 2 m lengths
- Installed in the field

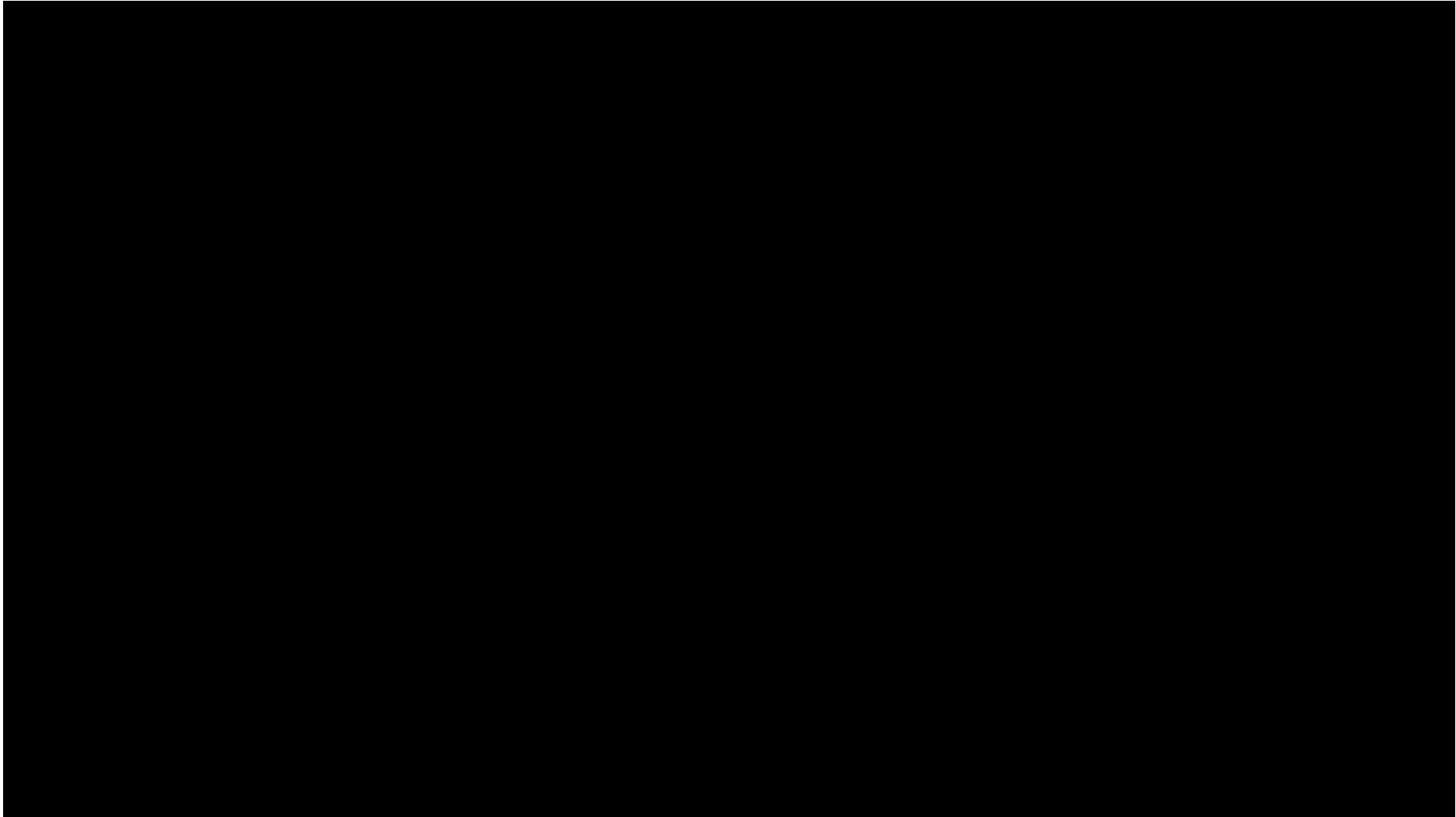
SENSORIZED SEGMENTS

- Rigid stainless steel 0.5 m segments connected by flexible joints
- Each segment contains three MEMS tilt sensors, microprocessor and digital temperature sensor

SILENT SEGMENTS

- Raise the zone of measurement
- Installed in the field or during production



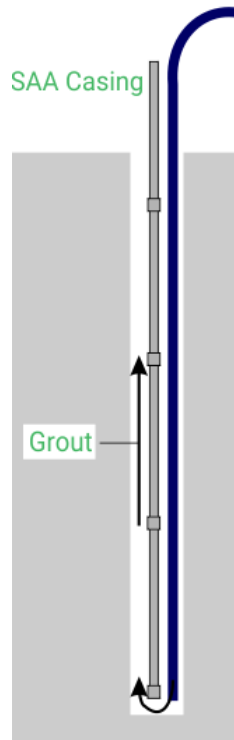


<https://goo.gl/dAeJjD>

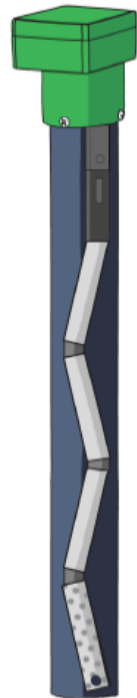




INSTALLATION ADAPTABILITY



VERTICAL



CYCLICAL



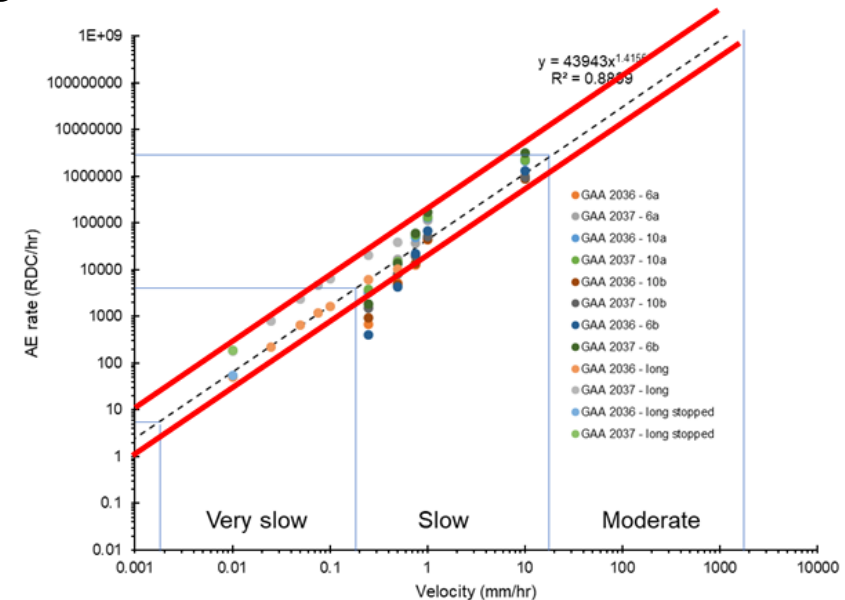
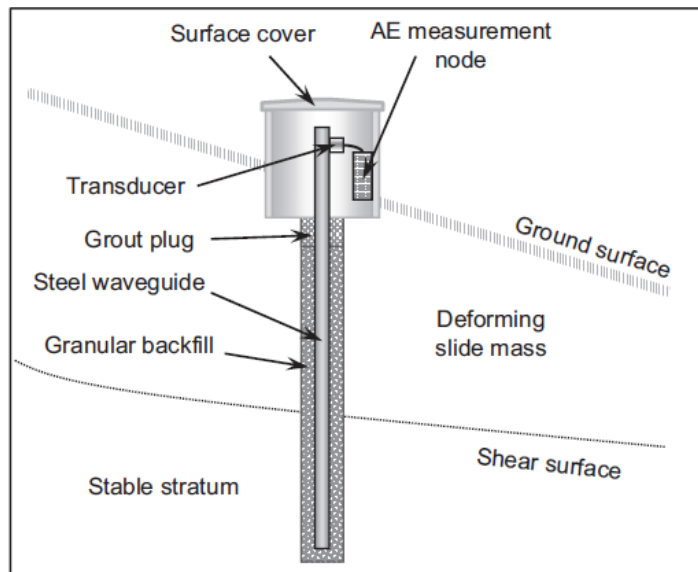
HORIZONTAL



CONVERGENCE

LATERAL GROUND DISPLACEMENT- GEO-ACCOUSTIC AWARE

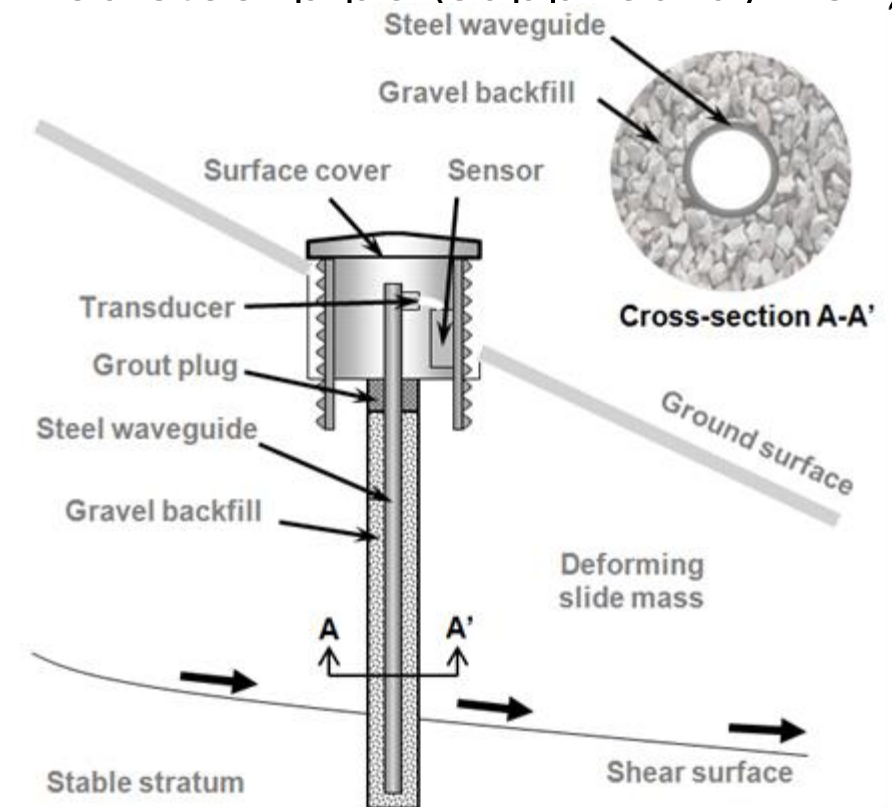
- Monitors slope movements by picking up acoustic emission stress waves, generated by inter-particle friction in the granular borehole backfill
- Waves are transmitted up a pipe (waveguide) installed in the borehole
- Sensors mounted near the top of waveguide counts the waves, which correlate to a range of movement rates



LATERAL GROUND DISPLACEMENT- GEO-ACCOUSTIC AWARE

Installation in the ground

- Waveguide is installed in borehole (5" minimum diameter)
- Studied for use on shallow installations
- 1.5" schedule 40, flush threaded custom 480, galvanized steel pipe (supplied by RST)
- Borehole backfilled with 5-10mm angular gravel
- Low cost for installed materials downhole



SETTLEMENT/ DISPLACEMENT- MAGNETIC EXTENSOMETER (manual)

- Magnetic targets are anchored to the ground around a PVC pipes, inclinometer casing or corrugated pipe, anchors coupled to the pipes and free to move



- **Datum Magnets** are installed at the bottom of the pipe and grouted in place to server as a reference



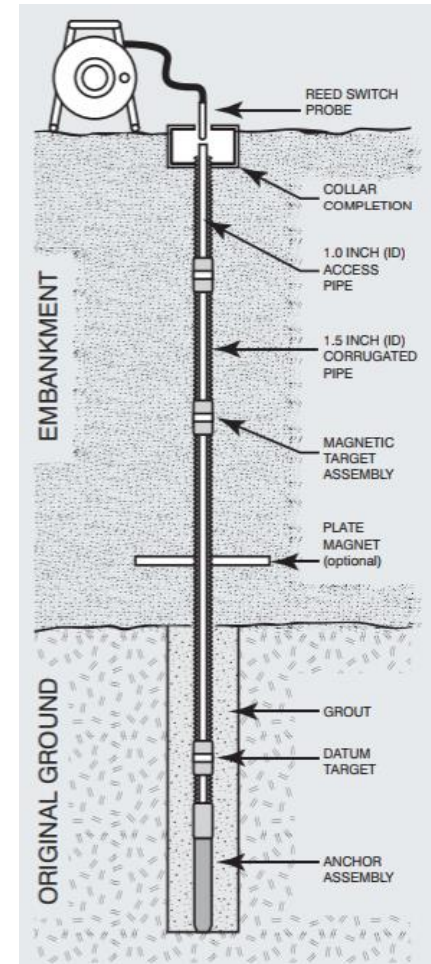
- **Plate Magnets** are use in fill, large surface area for fill



- **3- legged, 6-legged spider** anchors, deployed down the hole

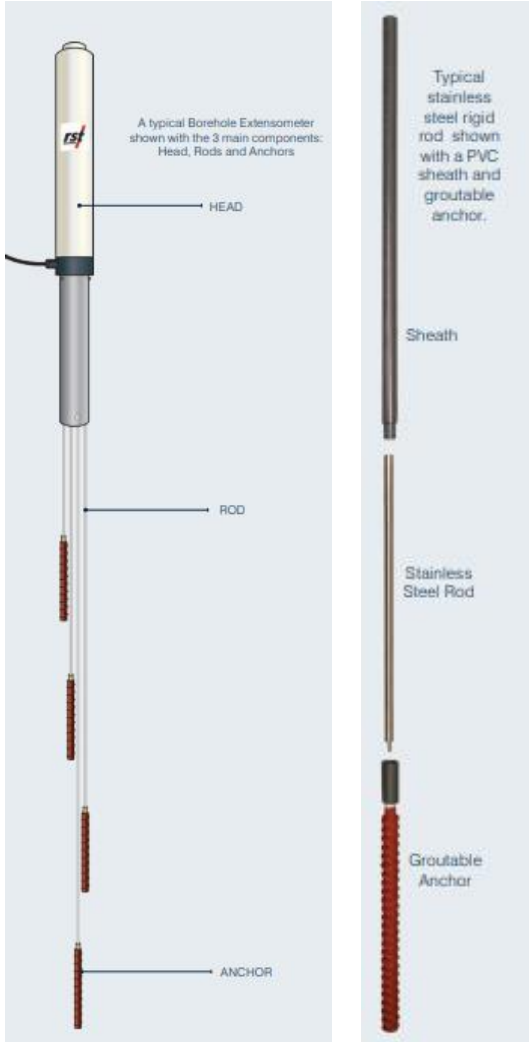


- **Reed Switch Probe**, 1mm resolution

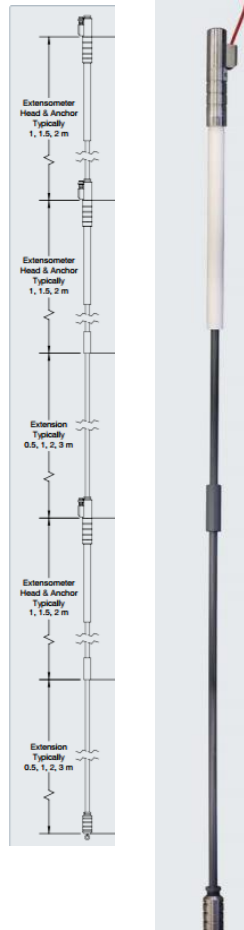


SETTLEMENT/ DISPLACEMENT- EXTENSOMETER (auto)

Multi-Point Extensometer



In-Line Extensometer

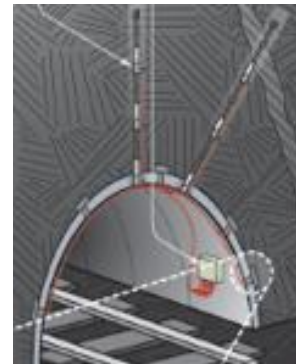


Extensometer

- consist of reference head, rods, and anchors
- Customize configuration: number of points/ type of anchors/ range of sensors/ type of rods/ length of rods
- Rigid rod types vs. flexible rod types

Vibrating Wire In-Line Extensometer

- Low profile, small diameter (3" borehole)
- Large range, sum of all sensor range
- Easy assembly



DISPLACEMENT

Crack Meter

- Designed to measure movement across surface cracks and joints
- Installed by grouting, bolting, etc.
- Available in 1D, 2D, or 3D (custom)



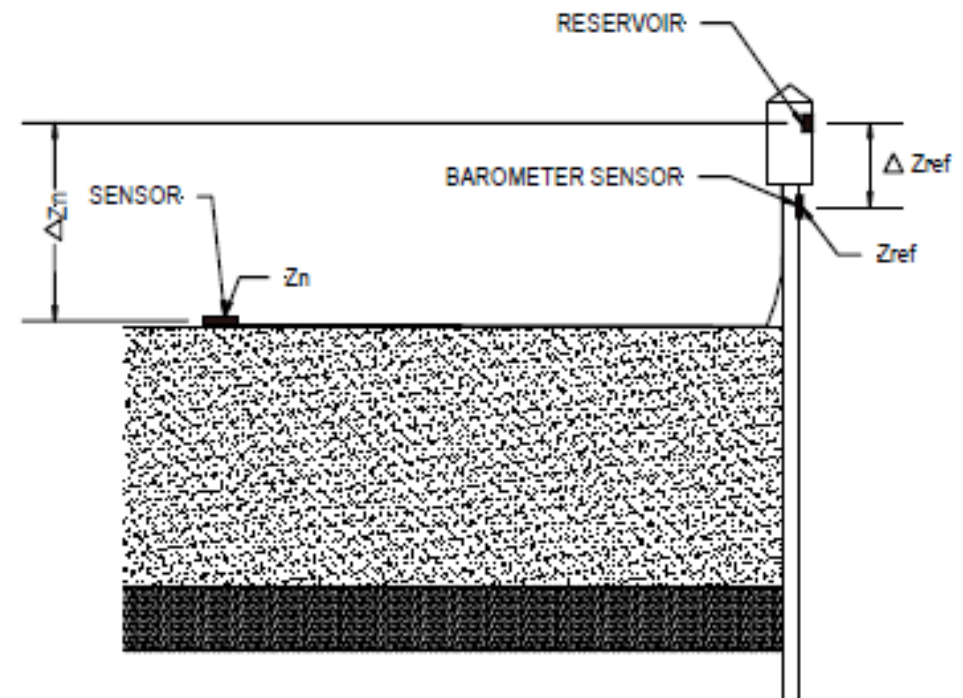
Soil Extensometer

- Measure lateral and longitudinal deformation on soil
- Consist of two flanges and telescopic section
- Be able to installed in a chained



SETTLEMENT/ DISPLACEMENT- LIQUID SETTLEMENT SYSTEM

- Monitors settlement or heave in soils and different types of man-made structures as embankments, and earth and rockfill dams. Measurement take relative to initial reading
- Consist of fluid body, reservoir, flexible tubing, and sensor and readout, sensors connected to fluid-filled tubes branching from the manifold
- Additional sensor at the manifold to compensate for change in evaporation
- Tubes to be protected, covered (from heating)
- Range: 2, 7, 17m (resolution 0.1% F.S.)



4. SETTLEMENT/ DISPLACEMENT- SUBMERSIBLE TILT METER

- Remote monitoring of tilt of submerged structures- inclination of concrete-face rockfill dams slabs and concrete dam
- MEMS inclinometer sensor and electronics mounted inside a rugged waterproof enclosure
- Solid construction for extreme endurance over long-term, high pressure underwater situations



AUTOMATION- DT SERIES DATA LOGGER



RST Instruments has been very successful with its line of **small battery-powered** data loggers since 2005.

Vibrating Wire

- DT2011B Single Channel VW Logger
- DT2055B 10 Channel VW Logger
- DT2040 40 Channel VW Logger

MEMS Tilt/ Logger

- DTL201B Uniaxial Tilt Logger
- DTL202B Biaxial Tilt Logger

4-20mA: DT4205 10 Channel 4-20mA Logger

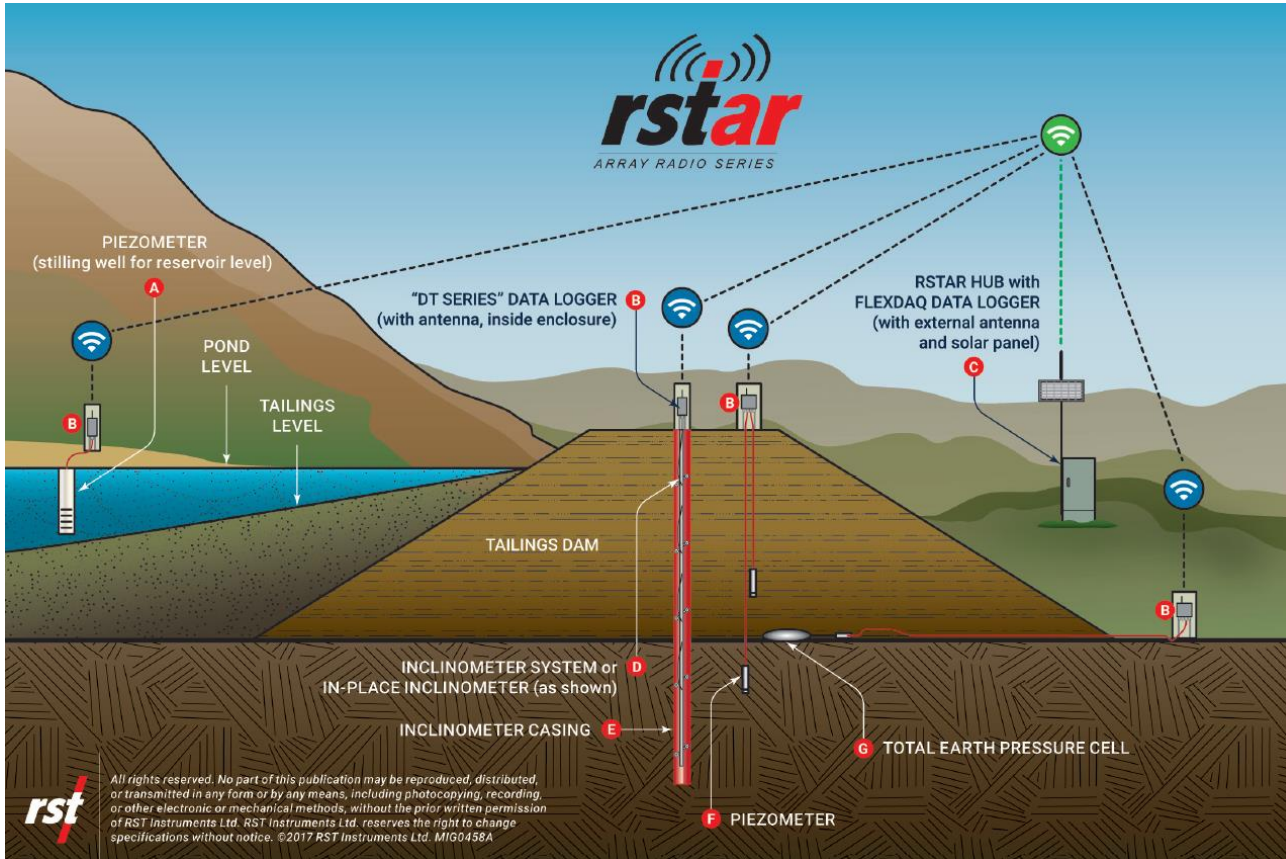
DT-BUS: DT2485 DT-Bus Logger

DT2306 **Potentiometer:** monitors up to 3-6 potentiometer sensor

DT2350 2 Channel Load Cell Data Logger: 2 channel **resistance** strain gauges load cells, and other strain gauge sensors, pressure, transducer, etc.

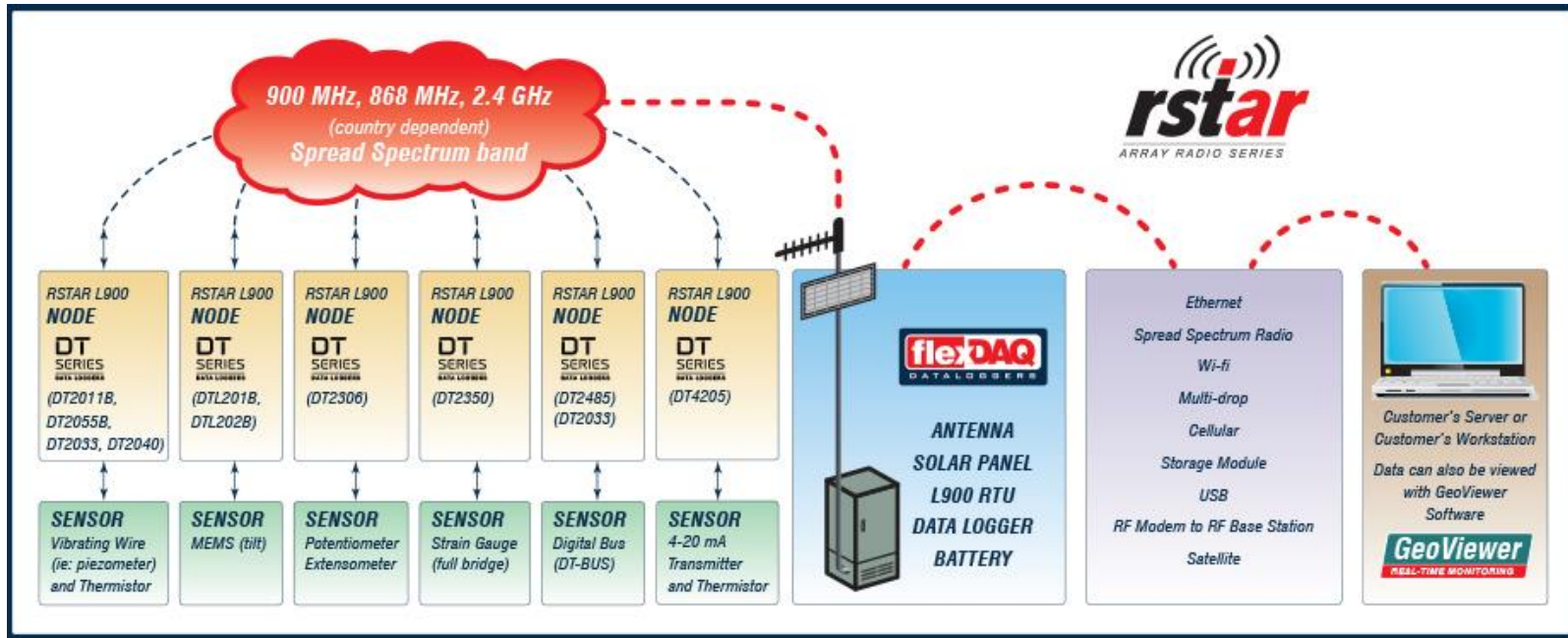


AUTOMATION- WIRELESS COLLECTION, RSTAR



- Wireless real-time automated data collection
- Simple network system
- 14 km open country hub-to- node range (900 MHz)
- Up to 255 Nodes (dataloggers per hub)
- Multiple telemetry options- cellular modem, wifi, radio, satellites, etc.

AUTOMATION- WIRELESS COLLECTION, RSTAR



Advantage

- Savings on cable cost
- Less cable to manage; low risk of cable damage
- Data collected saved on data logger and the hub as well (data backed up)
- Low power consumption (data logger, sleep schedule after transmitting), 1 x D Cell battery
- Able to re-modify and re-configured network during life of project



AUTOMATION- WIRELESS COLLECTION, RSTAR

Infrastructure → Roadways, Pipelines, Buildings, Bridges, Excavation Monitoring

Ontario (Canada), Saskatchewan (Canada), Spain, California (USA), Manitoba (Canada), Quebec (Canada), Turkey, UK, Alberta (Canada), Colorado (USA), Australia, Malaysia, Taiwan

Mining → Open Pit Mine, Tailings Ponds

Australia, Peru, BC (Canada), Ontario (Canada), Dominican Republic, Chile, Serbia, Saskatchewan (Canada), Arizona (USA), Brazil, Chile, Colorado (USA), Alberta Oil Sands (Canada)


Utilities → Hydro Electric Dams, Concrete Gravity, CFRD, Dam Safety Monitoring

(20+ irrigation dams) Thailand, BC-Hydro (Canada), California (USA), Ontario (Canada), Slovenia, Malaysia

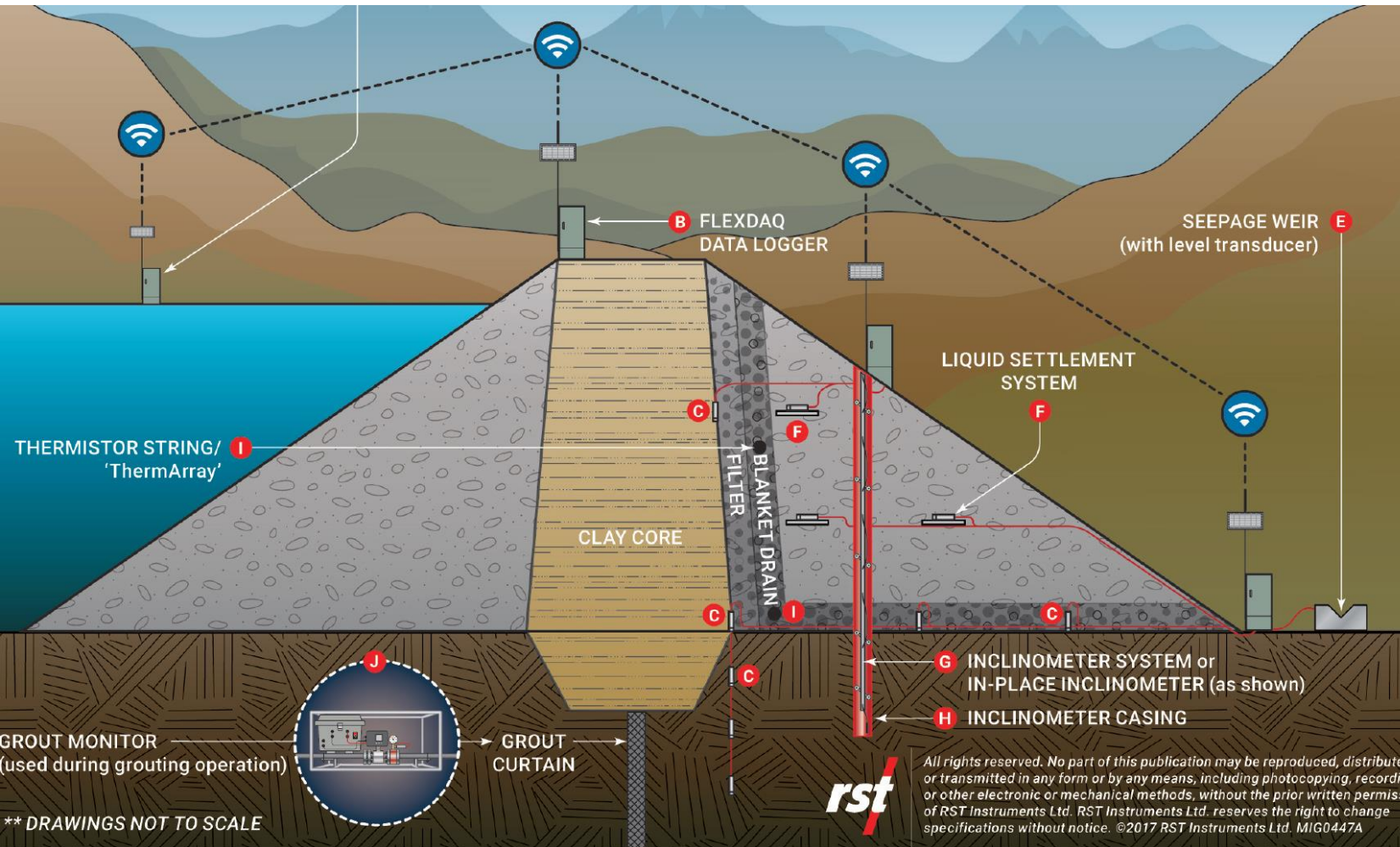


DT Datalogger and RSTAR Telemetry

RST Dam Projects- South East Asia

Date	Project/ Location	Instrument Supplied	
2016- Present	Indonesia- Tapin, Kureto, Karolloe 4+ upcoming dams in 2020 	VW Piezometers Soil Extensometer Weather Station VW Settlement System VW Crack Meter	DT Series Datalogger Standpipe Piezometers VW Soil Extensometer
2006- Present	Cua Dat Dam, Vietnam 	VW Piezometer/ VW Readout Submersible ELS Tiltmeters VW Strain Gauges VW Settlement System w/ Multi-Position Reservoir VW Joint Meters	3D VW Joint Meters/ Crack Meters RSTAR System VW Soil Extensometer Stand Pipe Piezometers Water Level Meters In-Place Inclinometer
2004- Present	EGAT and RID Dams Upgrade, Thailand Over 20 dams instrumented 	VW Piezometers Terminal Stations Digital Inclinometer System	Inclinometer Casing VW Readout- VW2106
2004- Present	Song Ba Ha Hydropower Project, Vietnam 	VW Peizometers VW Jointmeters VW Crackmeters VW Strain Gauges VW Temperature Sensor	VW Readout- VW2106 Thermistors flexDAQ 10 Dataloggers Geoviewer Software
2004- Present	Pleikrong Hydropower Project, Vietnam 	VW Piezometers VW Crack Meters VW Joint Meter VW Embedment Strain Gauge	Thermistors VW Readout- VW2106 Field Services
2003- Present	Gampo Dam, Korea 	VW Piezometers Inclinometer Casing Digital Inclinometer	VW Soil Extensometer Reed Switch Settlement System VW Total Earth Pressure Cells
2003- Present	Yixing Pump Scheme, China 	VW Piezometer Inclinometer Casing VW Soil Extensometer Vertical & Horizontal IPIs	Digital Inclinometer System VW Liquid Settlement System Portable Readouts

Earthfill Dam - Application



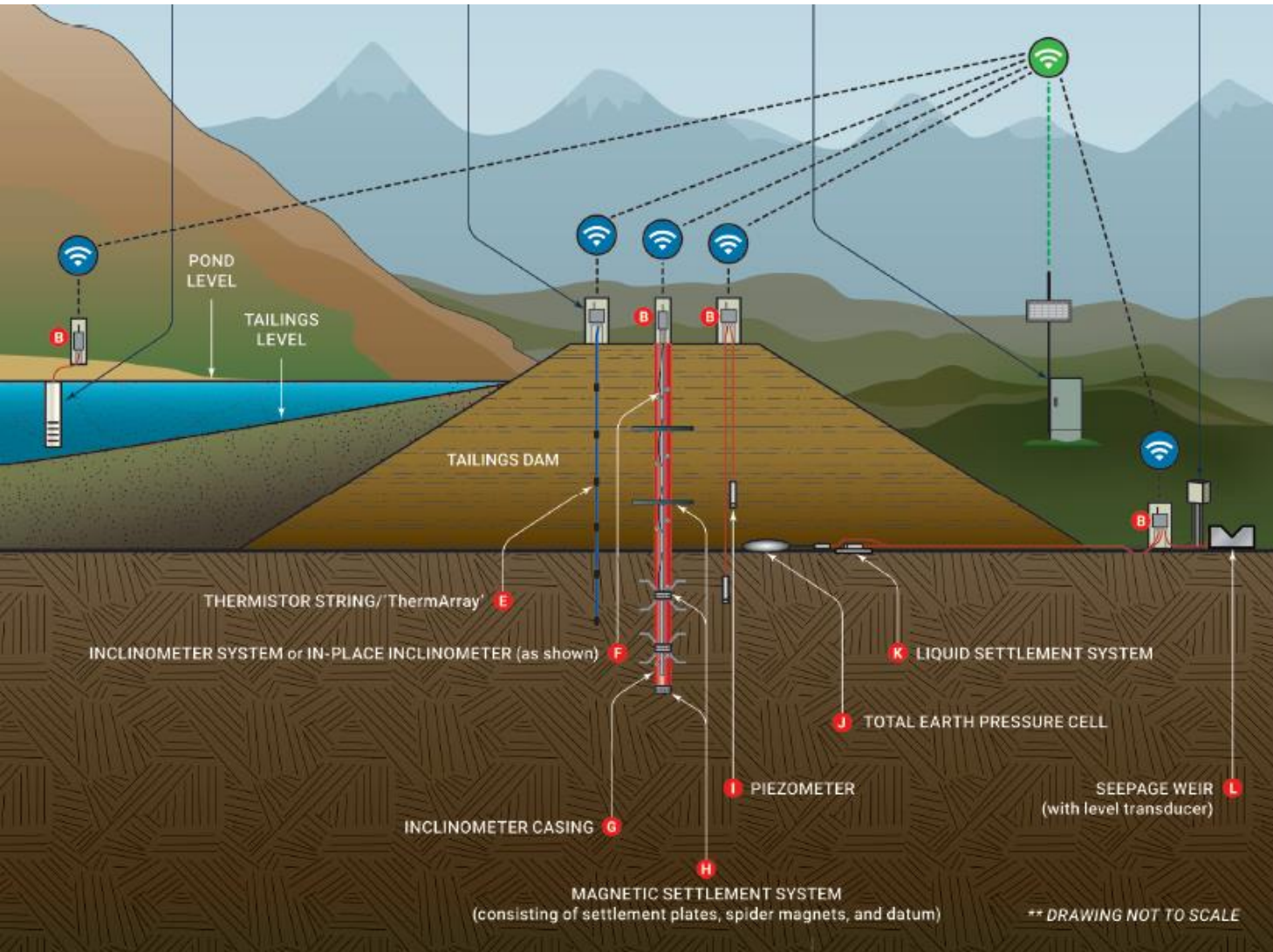
Typical Parameters Monitored:

- Pore Pressure (piezometers)
- Deformation (inclinometers, in-place inclinometers)
- Settlement (liquid settlement system)
- Seepage (weirs/transducers, grout monitor)

La Yesca Dam - Mexico



Tailings Dam Application



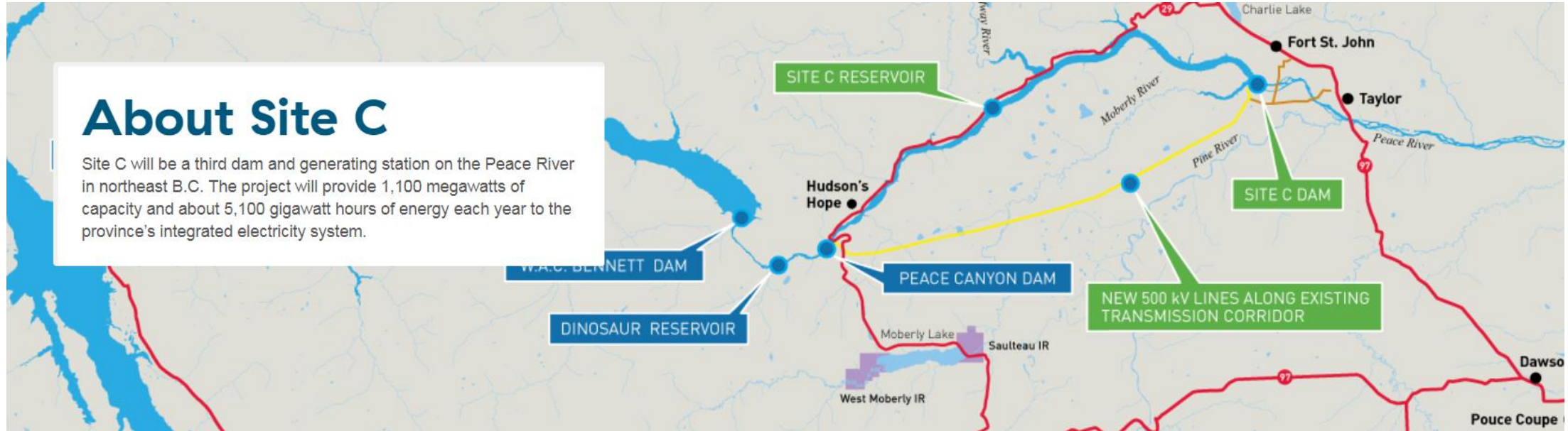
Typical Parameters Monitored:

- Pore Pressure (piezometers)
- Deformation (inclinometers, in-place inclinometers, ShapeArray – SAA, soil extensometers, Geo-Acoustic Aware - GAA)
- Settlement (settlement cells, magnetic settlement)
- Pond level (piezometer)
- Seepage (weir & transducer, thermistors)

Site C Dam - Canada



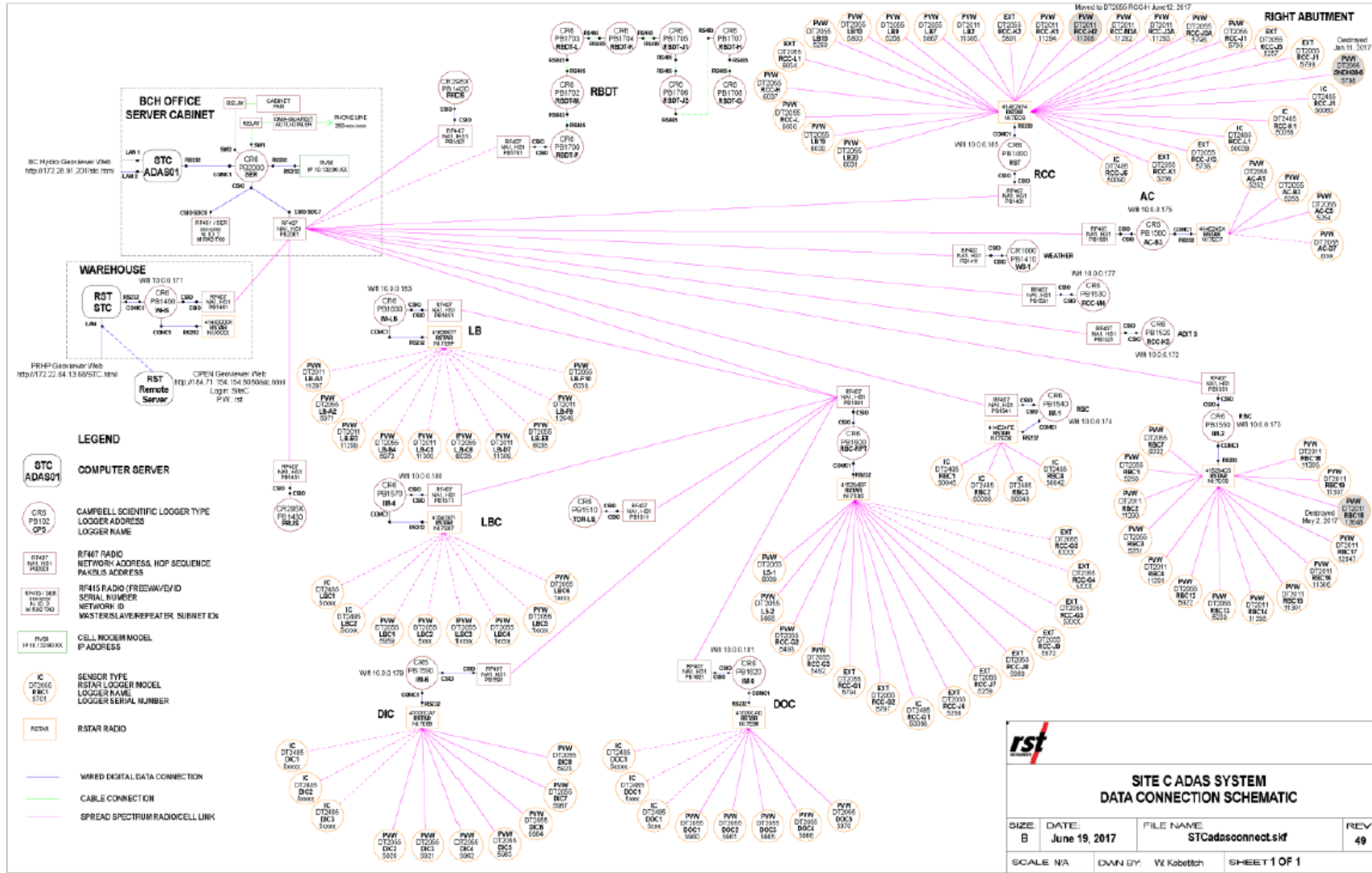
PROJECT EXPERIENCE- DAMS



- 1,100 megawatt capacity
- RST Supplied Instrument/ Services
- Provided sensors, instrumentation
- Provided Data Acquisition System for the Dam
- Started Construction 2015, Completion in 2024



PROJECT EXPERIENCE- DAMS



SITE C ADAS SYSTEM DATA CONNECTION SCHEMATIC			
SIZE	DATE:	FILE NAME	REV
B	June 19, 2017	STCAdasconnect.skf	49
SCALE: N/A	DWN BY: W. Kobelich	SHEET 1 OF 1	