Fiber Optic Applications for Deformation Monitoring

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ROCTEST SMARTEC NOVA METRIX

Outline – Fiber Optic Applications

- **Sensor Types**
  - Traditional
  - Fiber Optic
- **Fiber Optic Sensor Technologies**
  - Point Sensors
  - Quasi Distributed
  - Long Gage
  - Distributed
- **Readout Units**
- **Software**
  - SDB – SOFO/MuST
  - DiView - Distributed
- **Case Studies**
  - I-35 - Minneapolis
  - Rio Puerco – New Mexico
  - Turcot Interchange - Montreal
  - High Speed Train Tunnel – Spain
  - Sinkhole Monitoring – Kansas
  - I-40 Slope Stability – Tennessee
  - Dangeruous Slope Monitoring - Korea

Sensor Types

Traditional Instrumentation

Fiber Optic Instrumentation Advantages

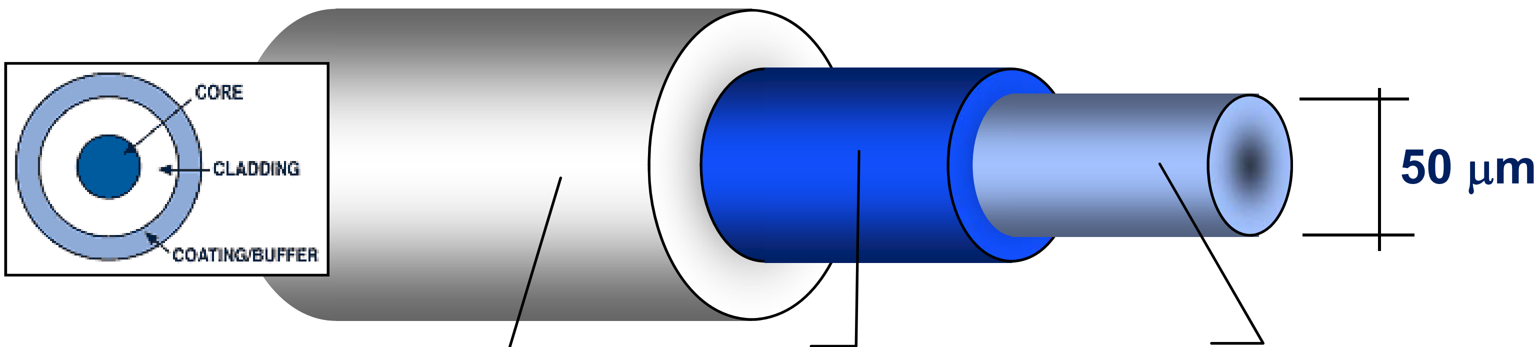
- ✓ Extended measurement base length
- ✓ Small dimension
- ✓ Simplified wiring
- ✓ Static or very fast dynamic measurements
- ✓ Insensitive to electromagnetic and radio frequency interferences (EMI - RFI)
- ✓ Not affected by lightning and statics
- ✓ Safe in hazardous environments (presence of volatile chemicals)
- ✓ Intrinsically safe

Fiber Optic Instrumentation Challenges

- Specialist knowledge necessary
- Wide scope of capabilities
- Combine with conventional sensing when possible (hybrid solutions)
- Post processing: display, post processing and analysis of multi-parameters / technologies
- Specialty equipment for instrumentation: optical time domain reflectometer, fiber optic fusion splicer
- Costs of reading units (rental or periodic readings possible)

Fiber Optic Instrumentation Sensor Elements

An optical fiber consists of three principal elements, arranged concentrically:



Coating / Buffer:

Typically consists of polymer layers that protect the silica structure against physical or environmental damage.

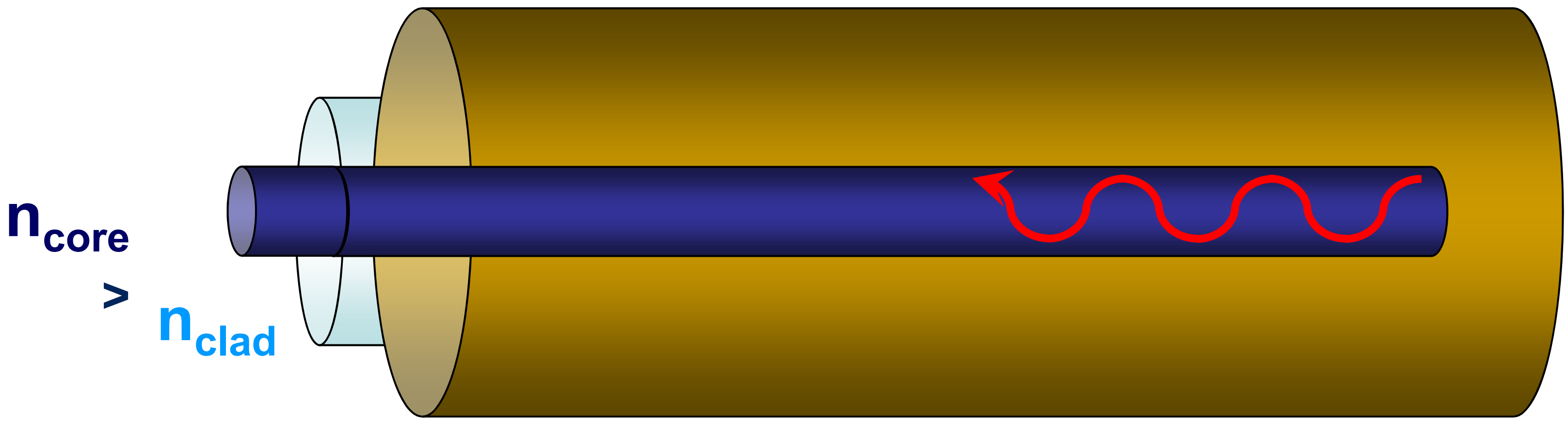
Cladding:

The first optical layer around the core, the cladding creates an optical waveguide that confines the light. It is usually made of silica

Core:

Central section made of silica, it is the high-transmitting region of the fiber.

Fiber Optic Instrumentation
How does fiber transmit light?



- Refractive indexes: $n_{core} > n_{cladding}$
- Incident light is reflected at the boundary between core and cladding
- Light is guided by total internal reflection

Fiber Optic Instrumentation Sensor Types

Strain

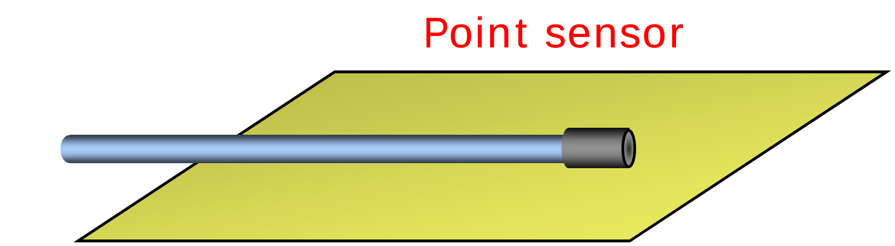
Temperature

Pressure

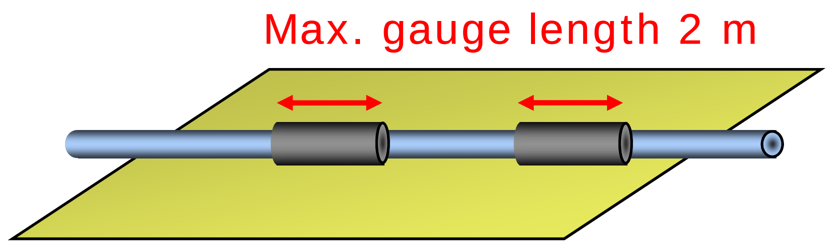
Displacement

Fiber Optic Sensor Technologies

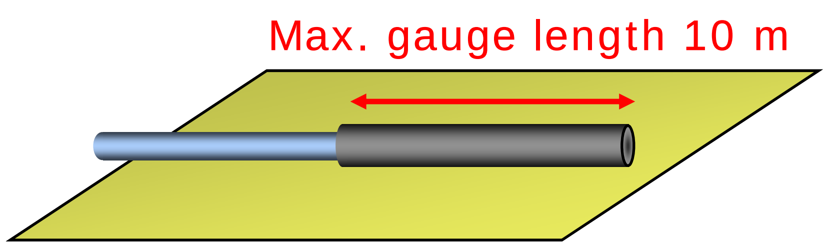
Types of Sensors by Gauge Length



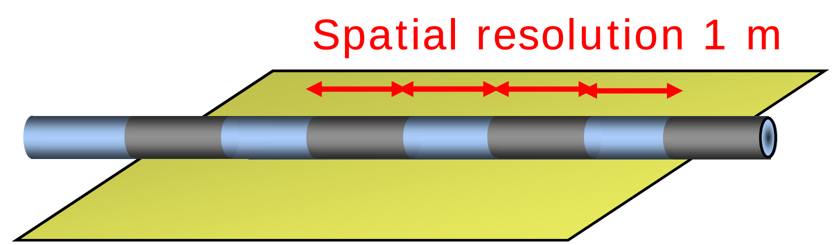
Point Sensor:
FISO Fabry-Pérot



Quasi distributed (multiplexed):
MuST Fiber Bragg Sensor (FBG)

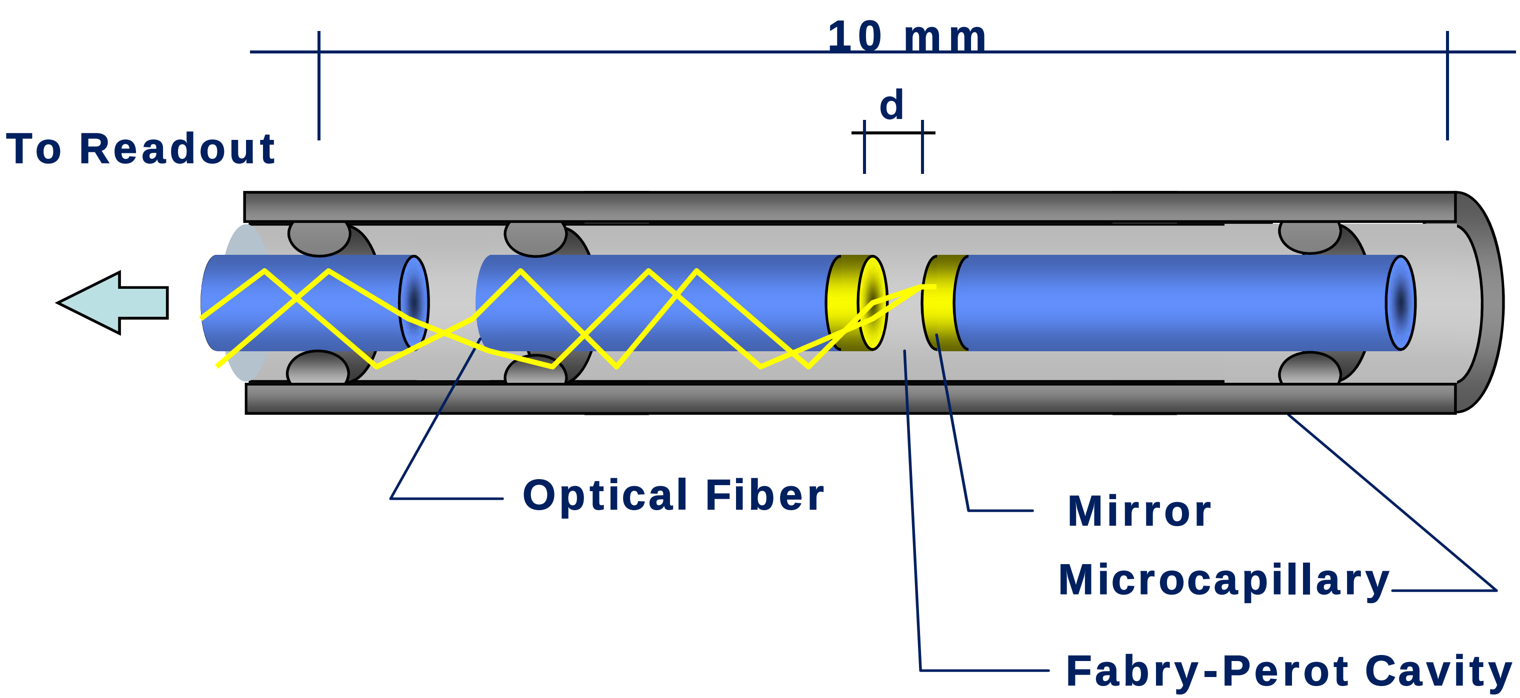


Long guage Sensor:
SOFO sensor



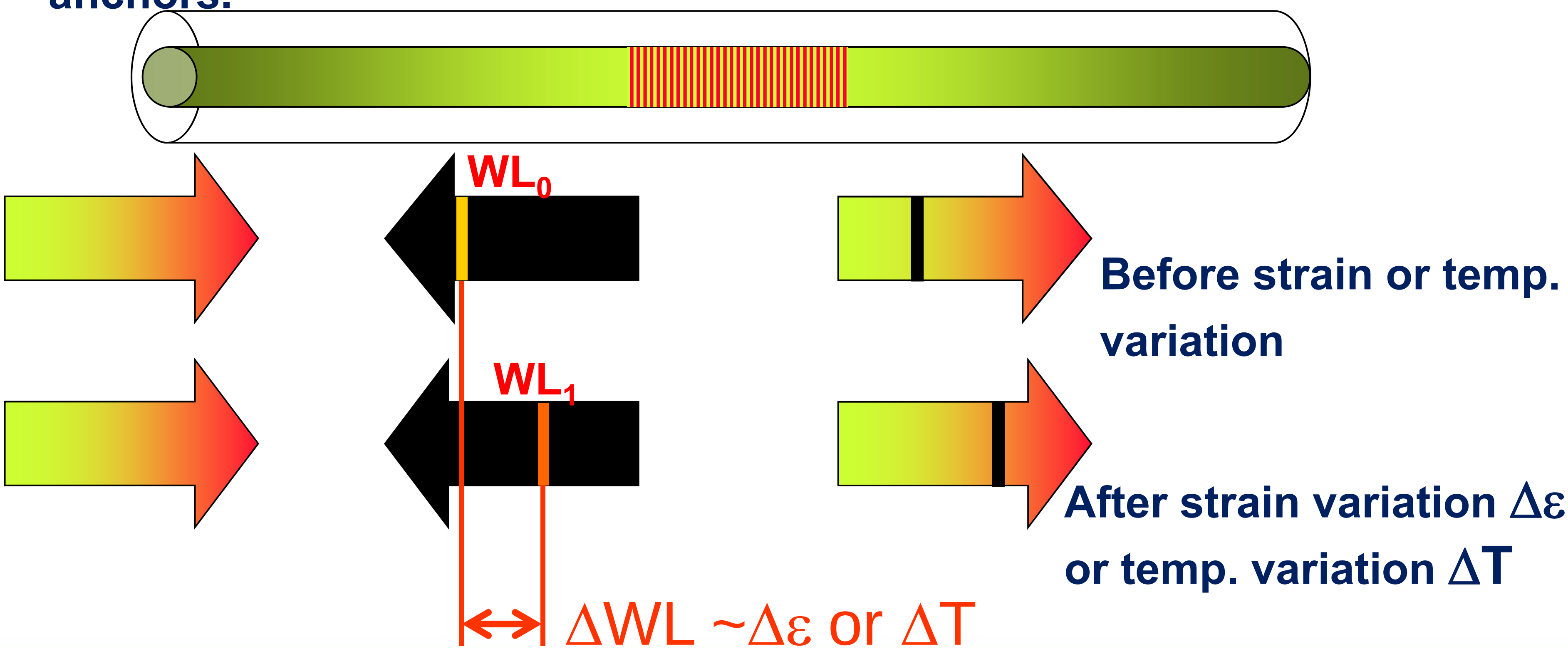
Distributed: DiTeSt / DiTemp
Brillouin and Raman scattering
Max range 45 km

Fabry Perot Point Sensors

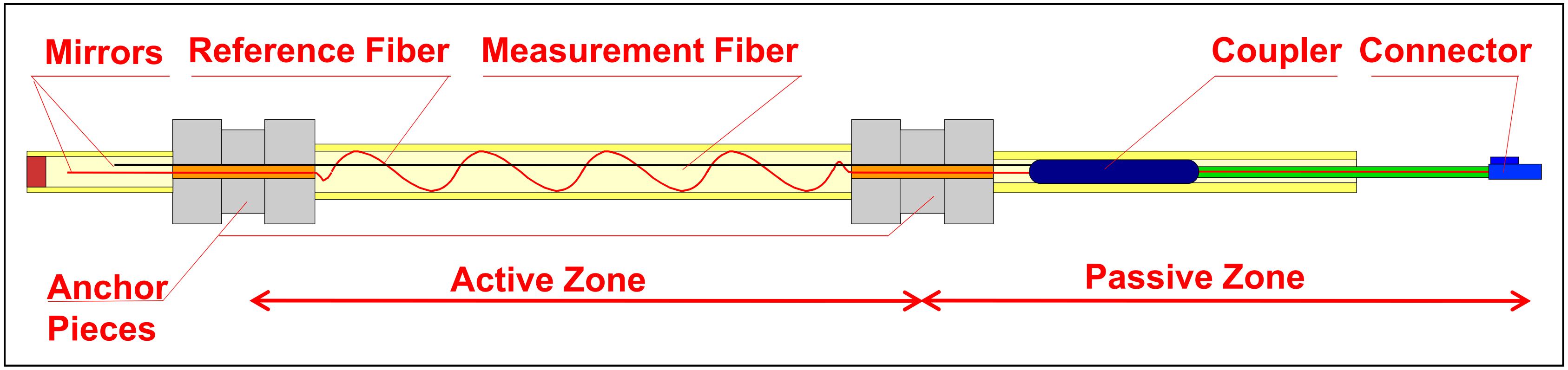


MuST Quasi Distributed
(Fiber Bragg Grating) 1 to 6 feet length

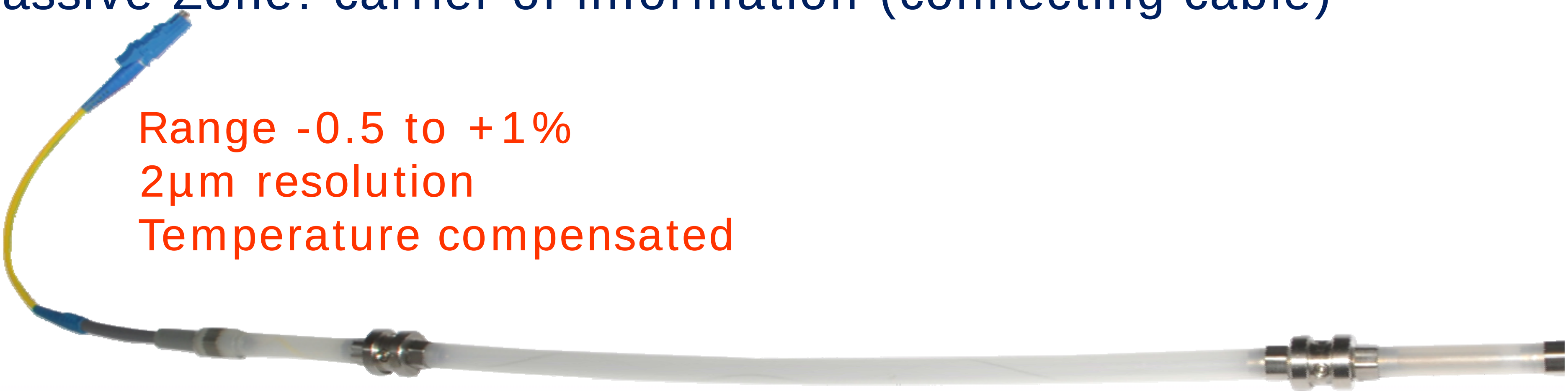
- The variation of strain or temperature will induce change in distance between the gratings and the wavelength reflected by the grating changes in proportion. Allows discreet measurements between anchors.



SOFO ® Long Gauge (Interferometry) 1 to 30 feet

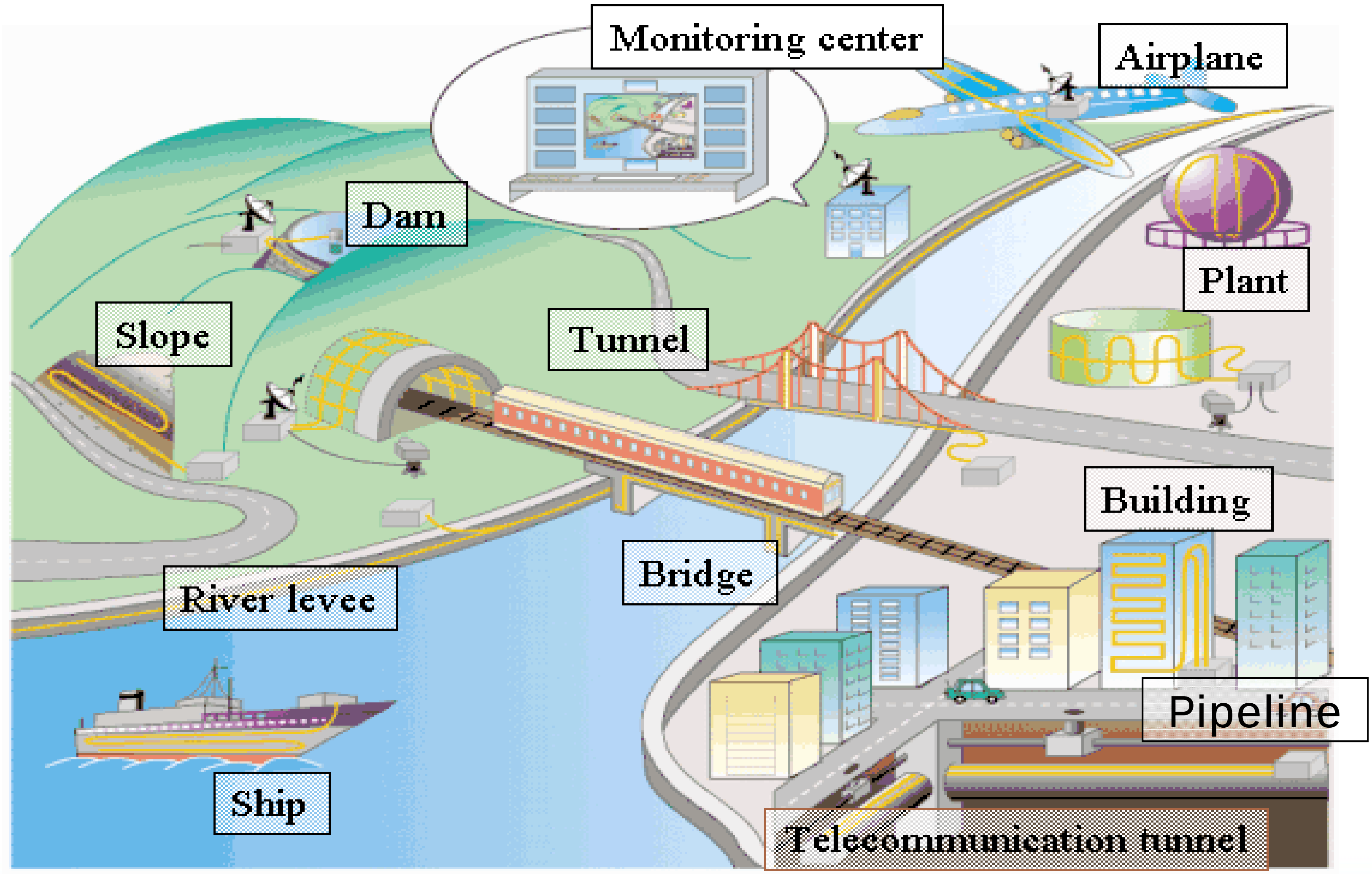


Active Zone: measurement basis or gage length
Passive Zone: carrier of information (connecting cable)



Range -0.5 to +1%
2µm resolution
Temperature compensated

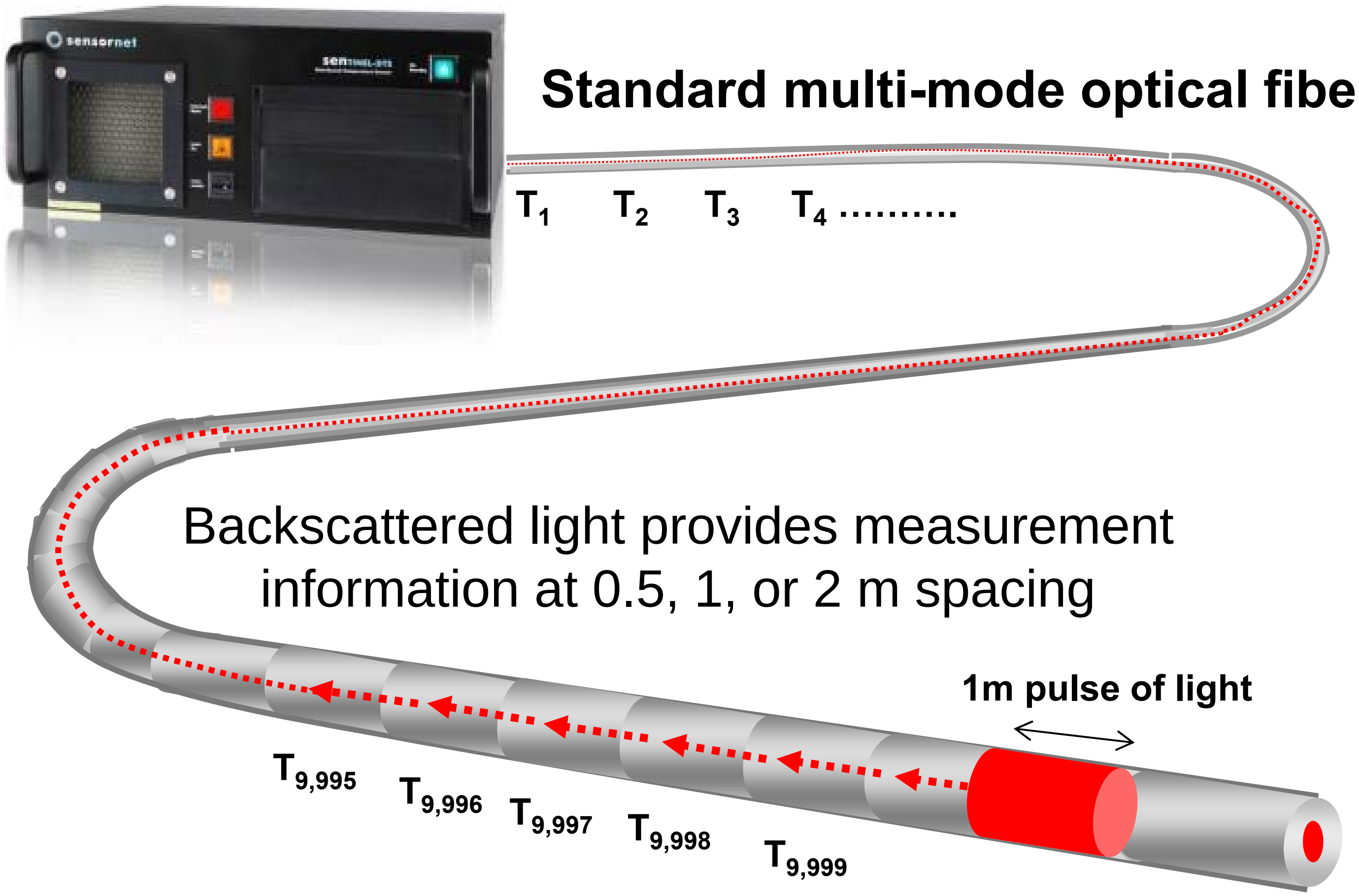
Distributed Sensing
Distributed Sensing Applications



Distributed Sensing
DiTeSt / DiTemp Systems

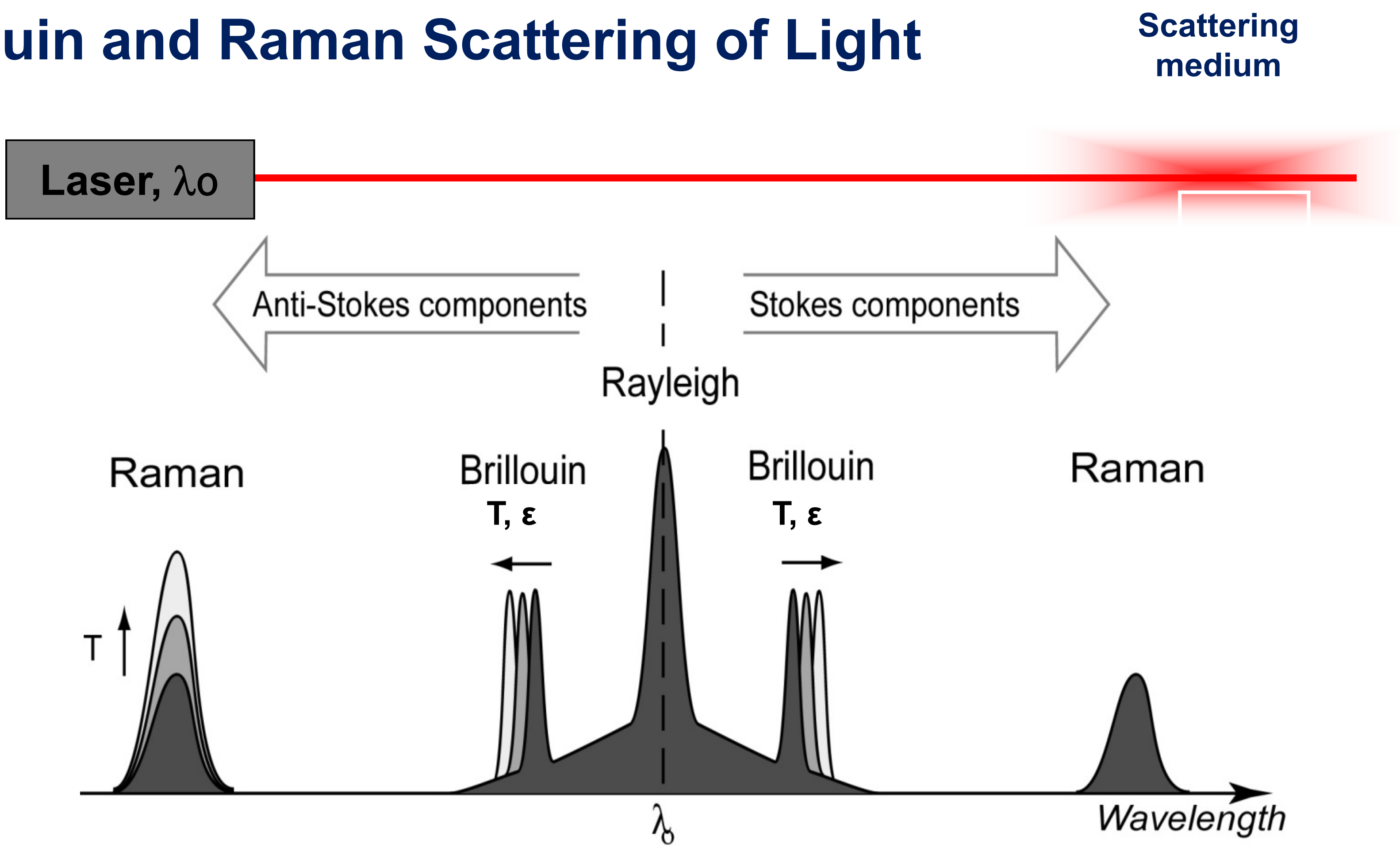
- Benefits :
- Distributed measurement of strain and/or temperature along a single FO cable
- Specialized cables for distributed sensing
- High spatial resolution: 2, 3, or 6 ft
- Long range: up to 40 miles
- Long-term stability
- Dedicated software for data analysis and visualization
- Cost-effective solution for large number of points
- Immune to electromagnetic interference and lightning

Distributed Sensing
The Fiber is the Sensor



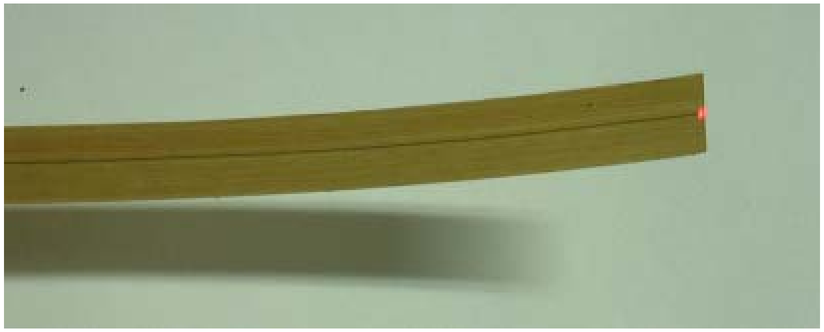
Distributed Sensing
Light Scattering Effect

Brillouin and Raman Scattering of Light

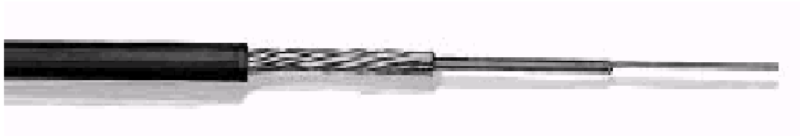


Distributed Sensing Cable Design

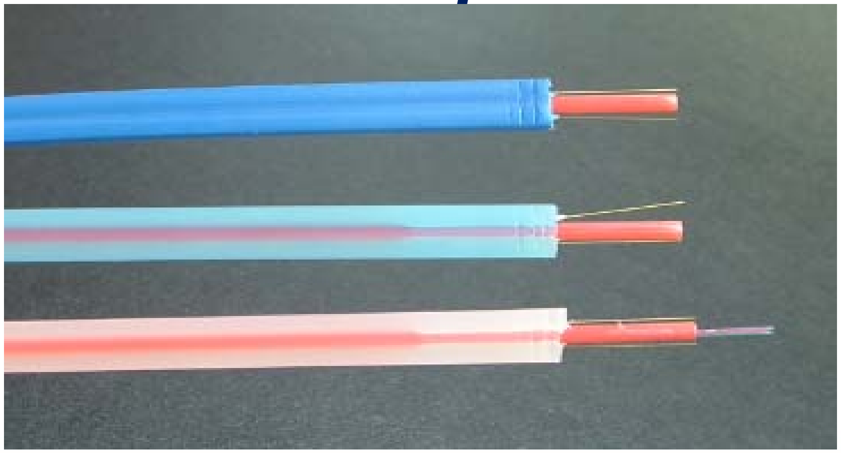
SMARTape: *Strain sensing*



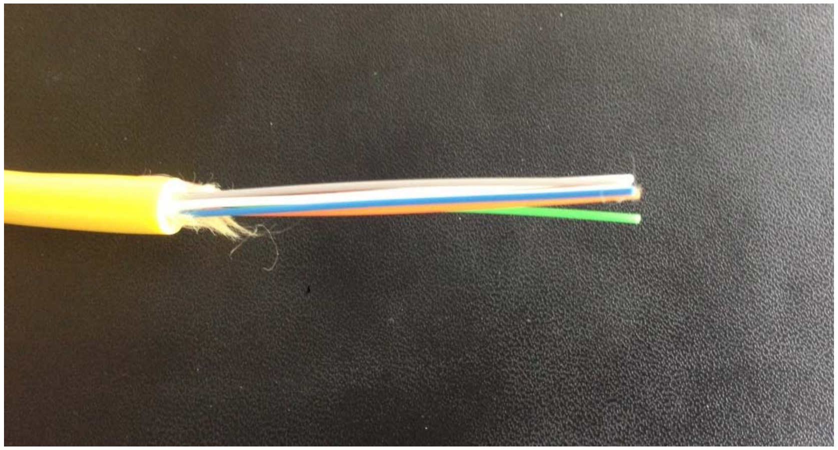
Temperature Cable



SMARTProfile: *Strain &Temperature*



Hydro & Geo: *Strain &Temperature*



Fiber Optic Readout Units

FO Readouts and Loggers

- **Point Sensors**

Single Ch

16 or 32 Ch

- **Long Gauge Sensors**

Portable Readout
SOFO and/or MuST

SOFO Lite
SOFO

SOFO and/or
MuSt

- **Distributed Sensors**

DiTemp Logger

DiTemp HARSH

DiTeSt Logger

Software

SDB Software
SOFO® Long Gauge / MuST Quasi Distributed

Sensor list.

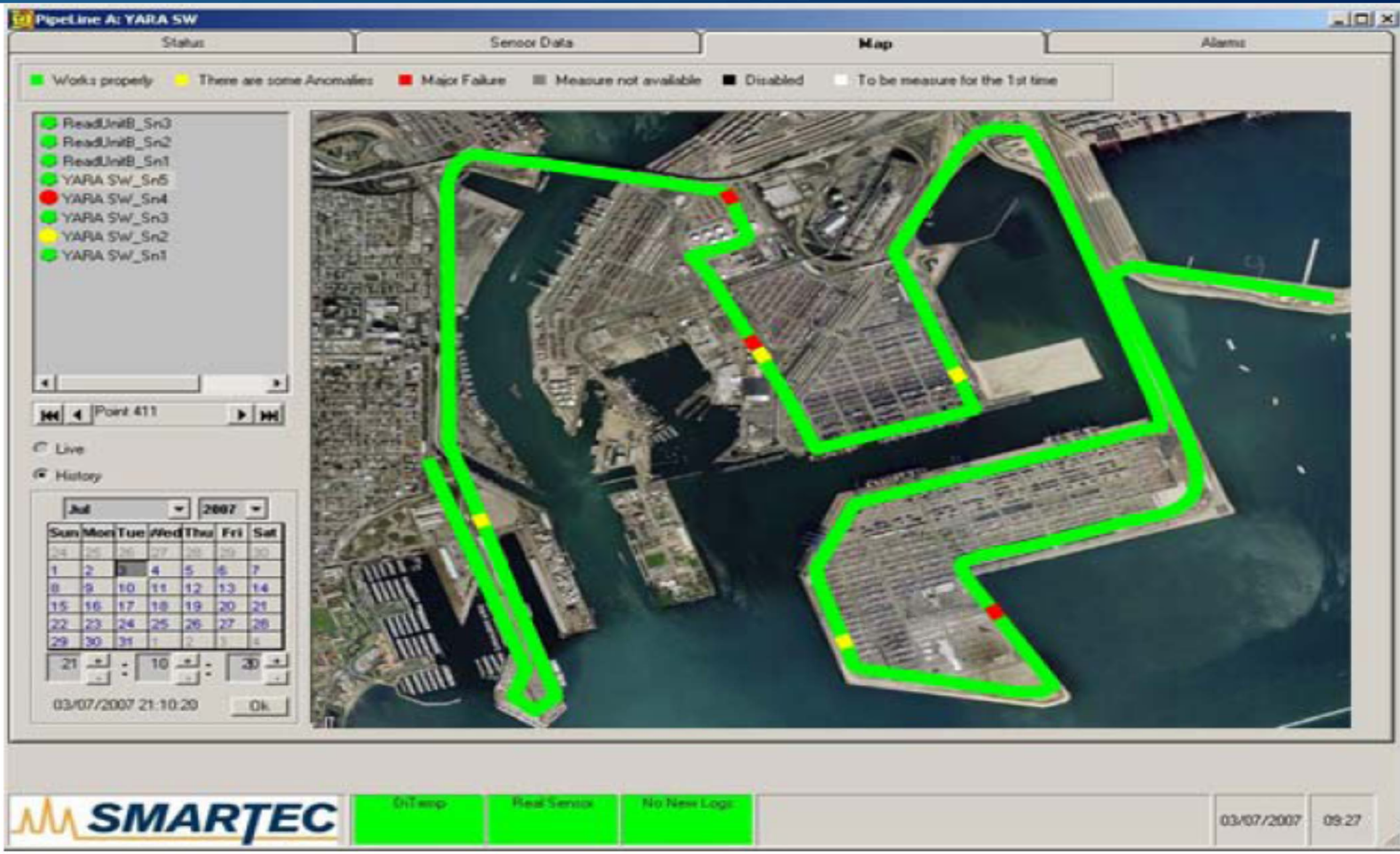
Tab view with colors coding for pre-warning and warning.

Map view with colors coding for pre-warning and warning.

Plot view with pre -warning and warning thresholds.

DiView Software

DiTeST / DiTemp – Distributed Sensing



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Case Studies

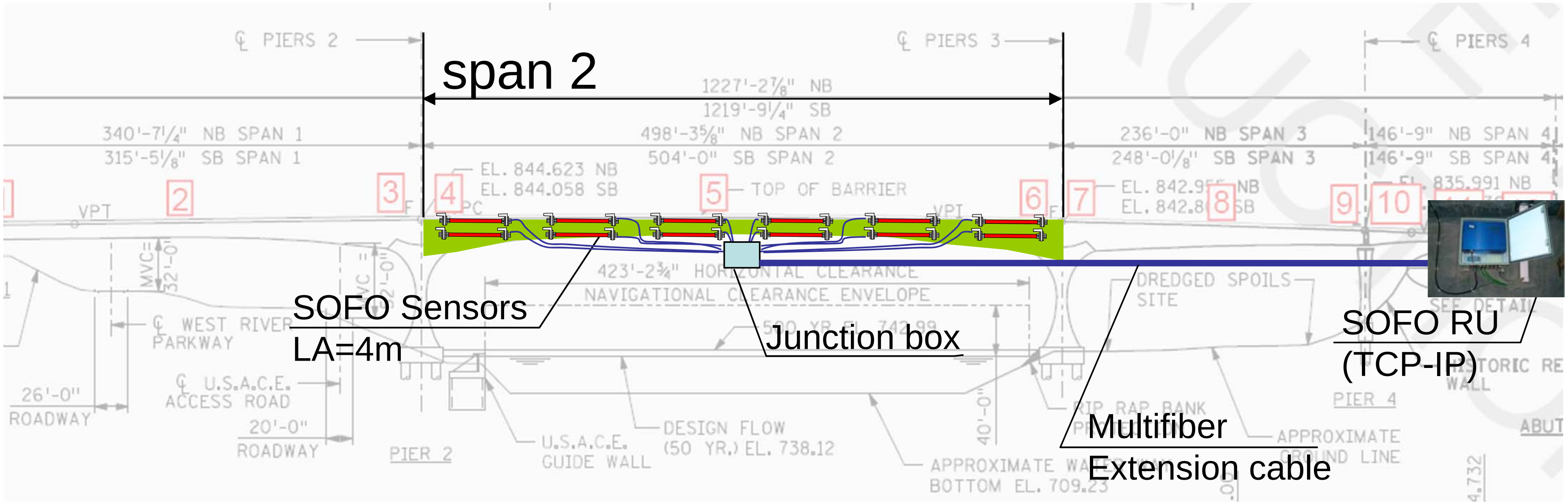
I-35W Bridge - Minneapolis
SOFO® Long Gauge Sensors

- ✓ **Design-build project completed in 339 days**
- ✓ **Multi-parameters instrumentation: vibrating wire stain gauges, accelerometers etc…**

I-35W Bridge - Minneapolis
SOFO® Long Gauge Sensor Topology

- Average strain and curvature
- Deformed shape
- Detection of cracks

- Dynamic Strains
- Dynamic Deformed Shape
- Vertical mode shapes
- Dynamic damping



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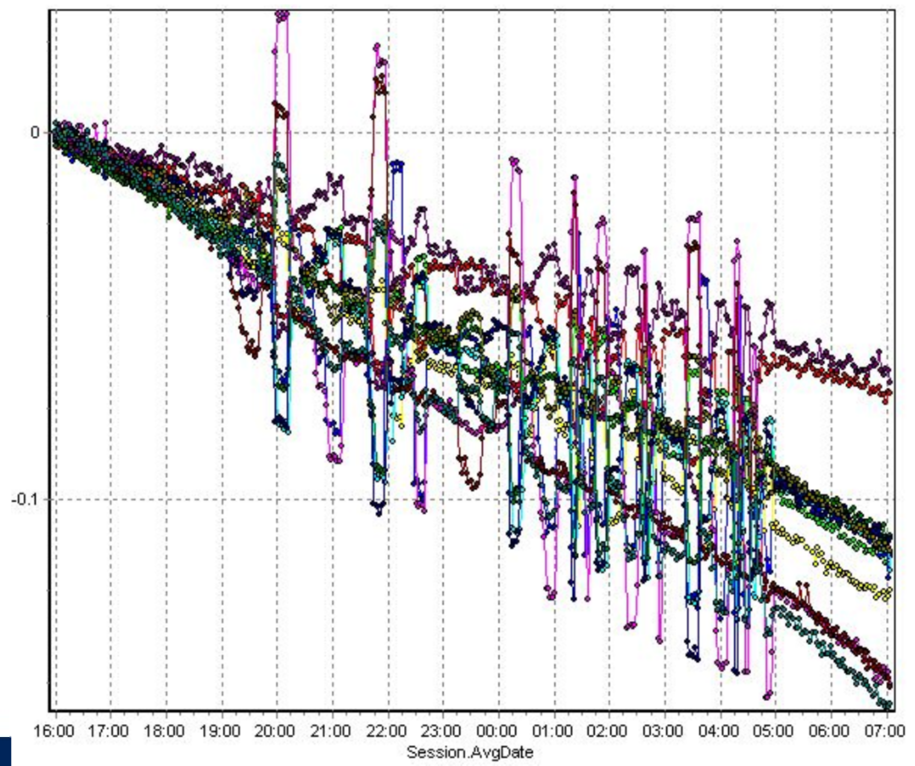
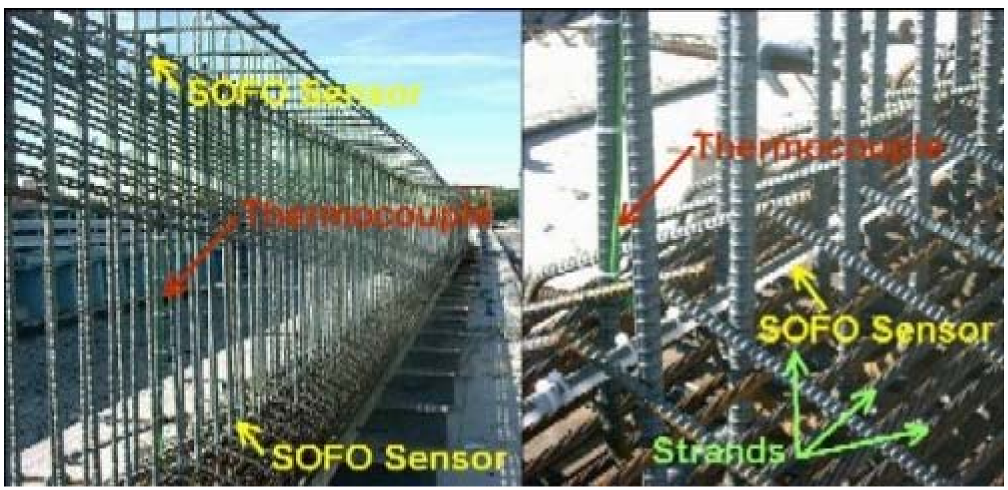
I-35W Bridge - Minneapolis Load Test

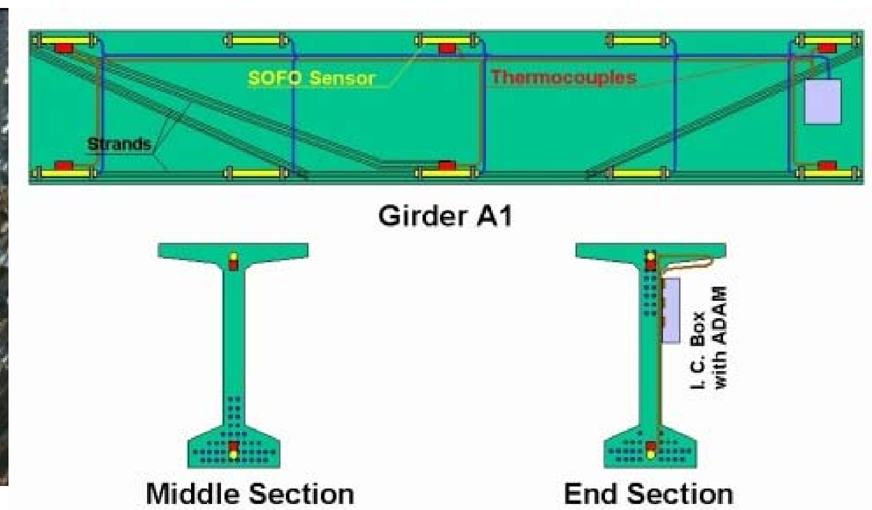


Rio Puerco Bridge – New Mexico (instrumented in 2000)

Rio Puerco Bridge – New Mexico SOFO® Long Gauge Sensors

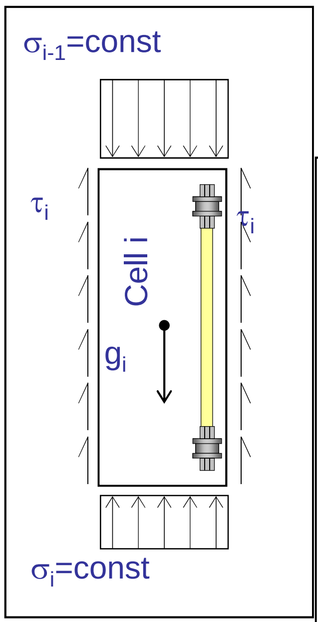
- **US Highway 40, approximately 10 miles west of Albuquerque.**
- **4 Girders were embedded with 64 Sensors.**
  - ***10 SOFO and 6 Temperature, per girder***
- **Configuration of sensors allows monitoring of deformation and curvature, and determination of thermal influences.**

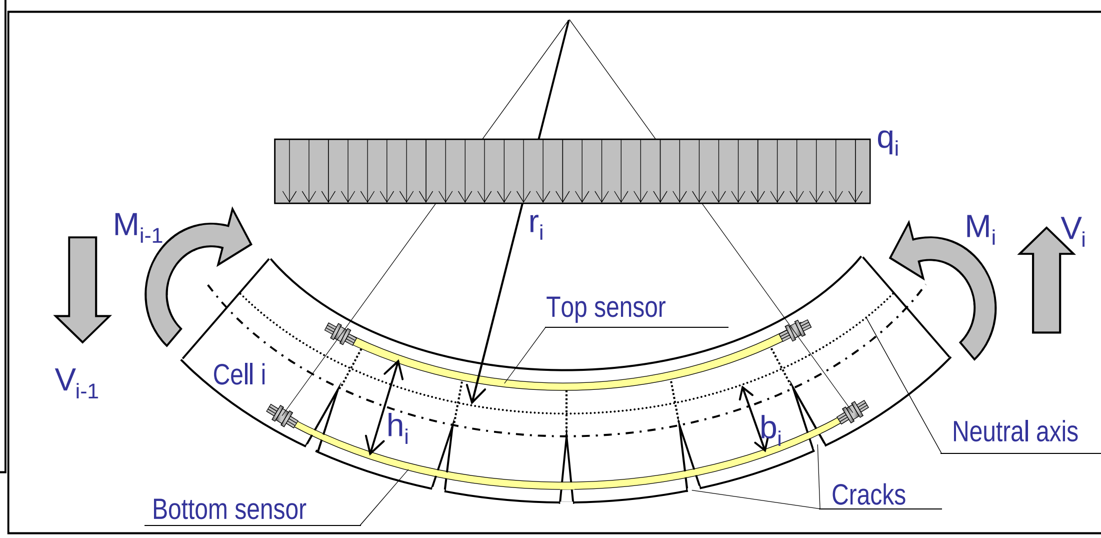


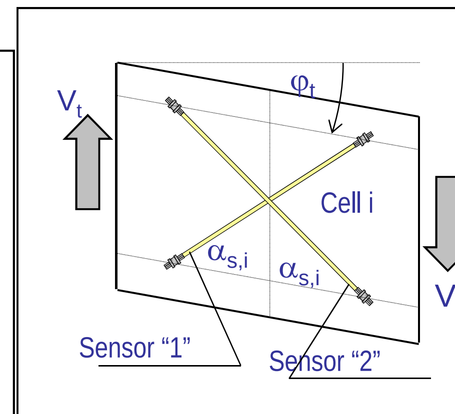


Sensor Topologies

- Simple Topology ⇒ Average Strain
- Parallel Topology ⇒ Average Curvature
- Crossed Topology ⇒ Average Shear Strain

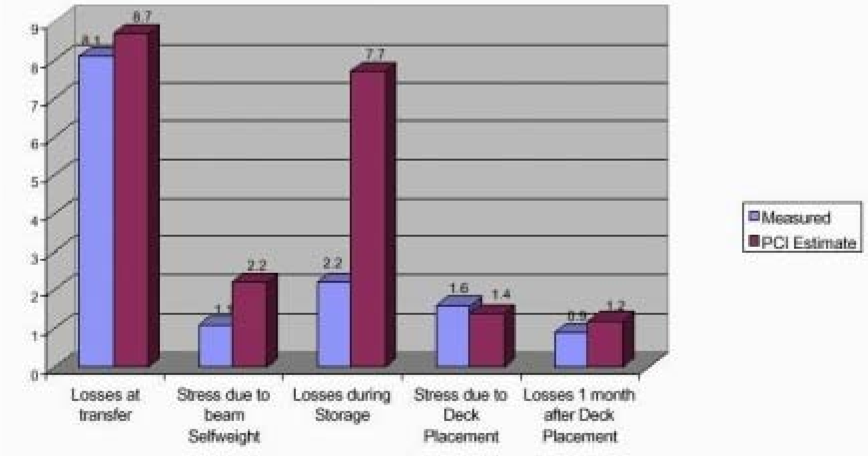




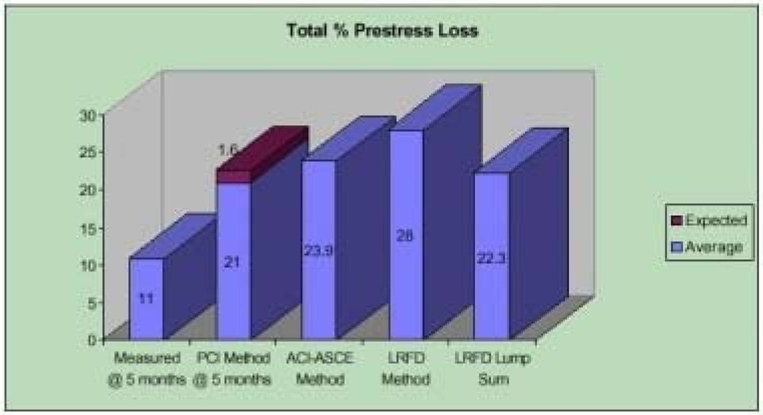


Rio Puerco Bridge – New Mexico Results

- Measurements started immediately after embedment, thereby measuring initial age deformation over a 3 day period.
- Deformation was subsequently recorded during the pre-stress phase. Thus, real initial strain state of girders was recorded.
- A period of continuous monitoring before transportation on-site, during transportation and during the pouring of the deck.
- The results helped compare different theoretical models and confirmed the design & construction conditions.



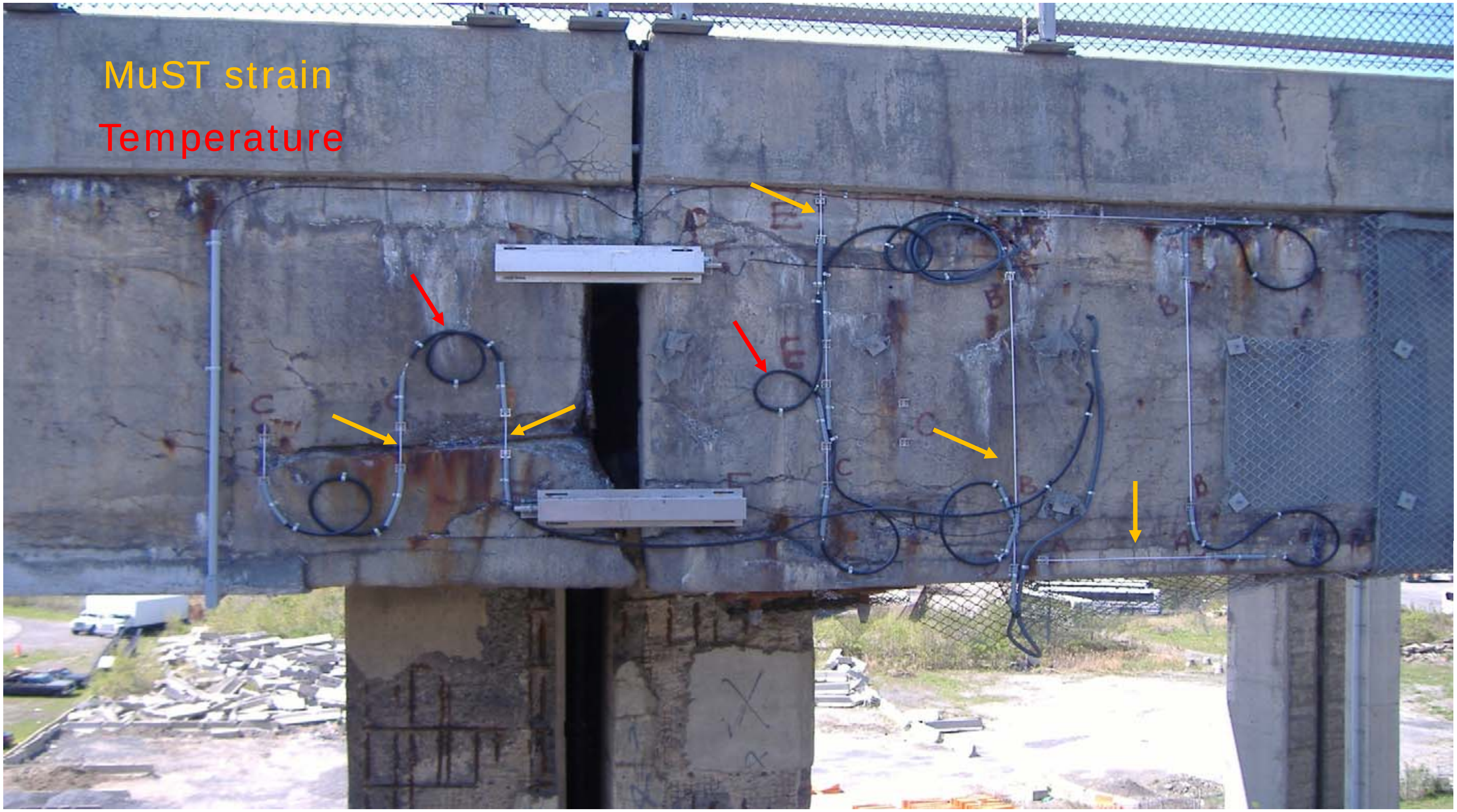
Field measurements vs. the PCI Method



Measured losses vs. losses estimated by various methods.

Turcot Interchange - Montreal
MuST Bragg Grating Sensors

Turcot Interchange
MuST Bragg Grating Sensors



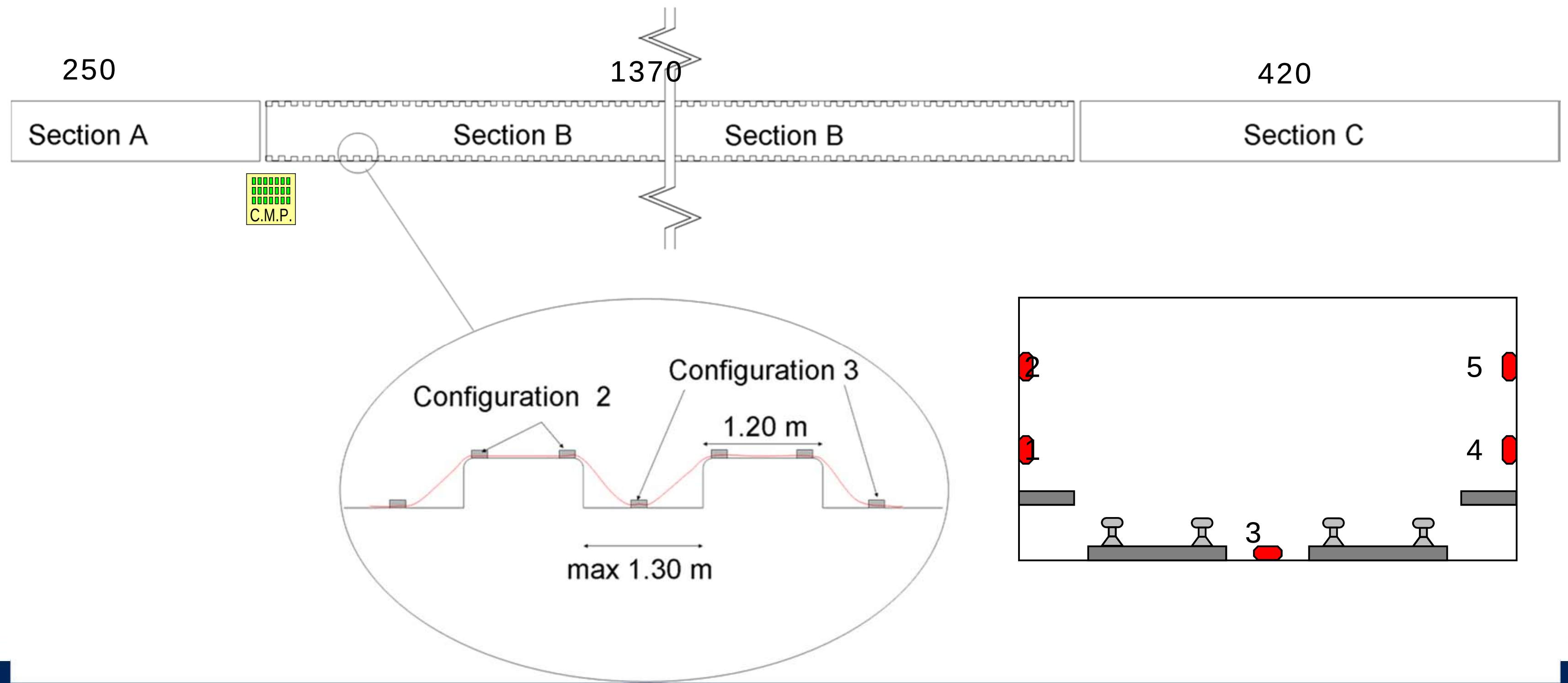
Turcot Interchange - Montreal
MuST Bragg Grating Sensors

High Speed Train Tunnel – Spain DiTeST

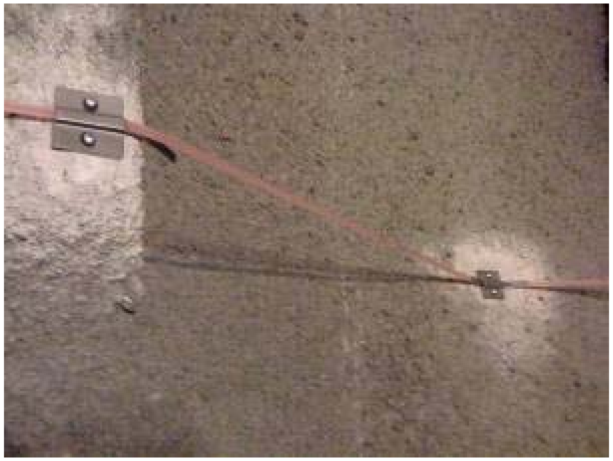
- **Accident in October 2007 before first use**
- **Reinforced with columns**
- **Column collapse and cracks observed**

High Speed Train Tunnel – Spain
DiTeST – Sensor Layout

- **5 Smartprofile per section**
- **12'200 m Smartprofile in total**



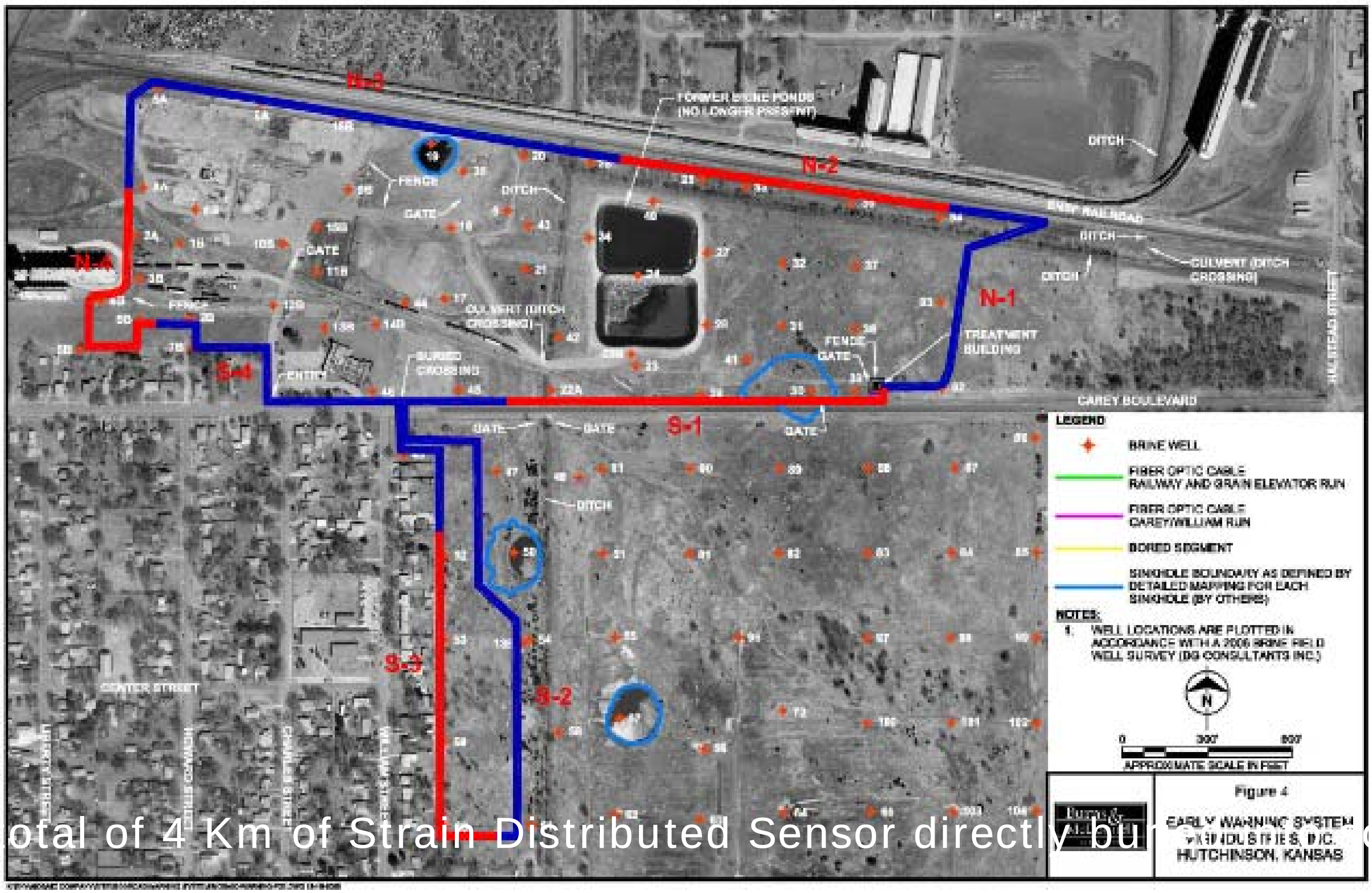
High Speed Train Tunnel – Spain
DiTeST – Sensor Installation

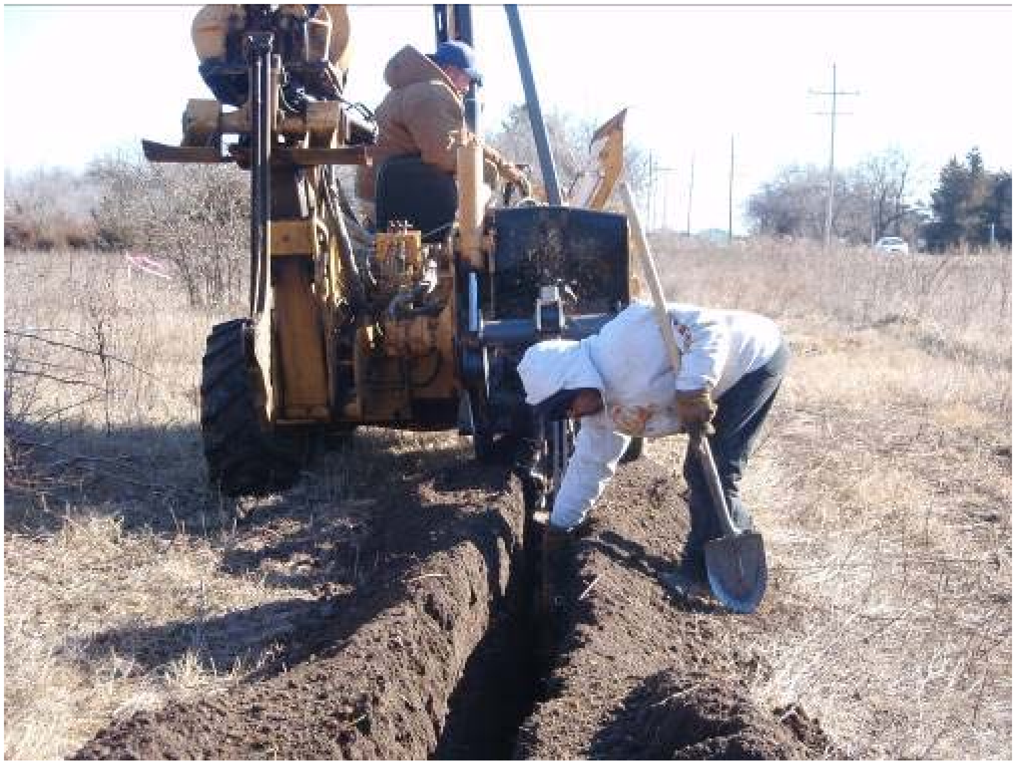


Sinkhole and Soil Settlement

Sinkhole Monitoring - Kansas
DiTeST – Sensor Layout



Sinkhole Monitoring - Kansas
DiTeST Sensor Installation



Digging of the trench where the sensor is deployed

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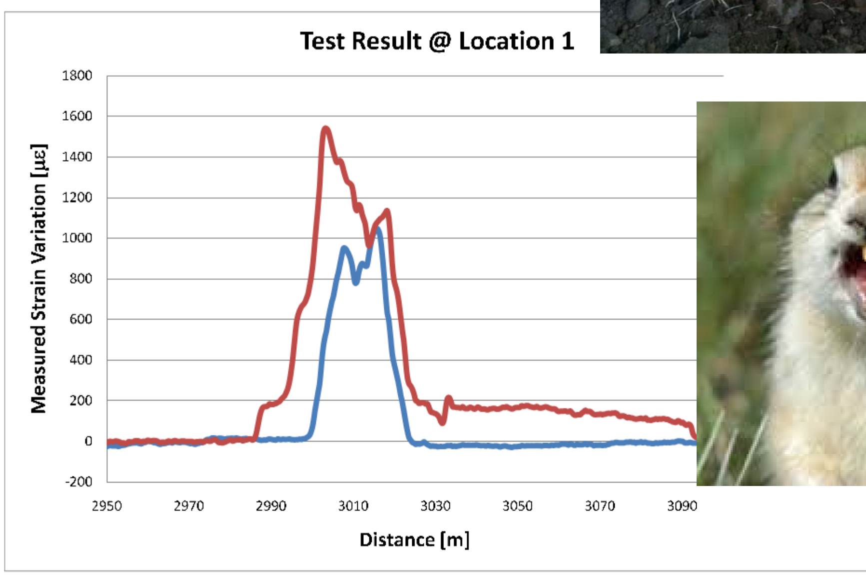
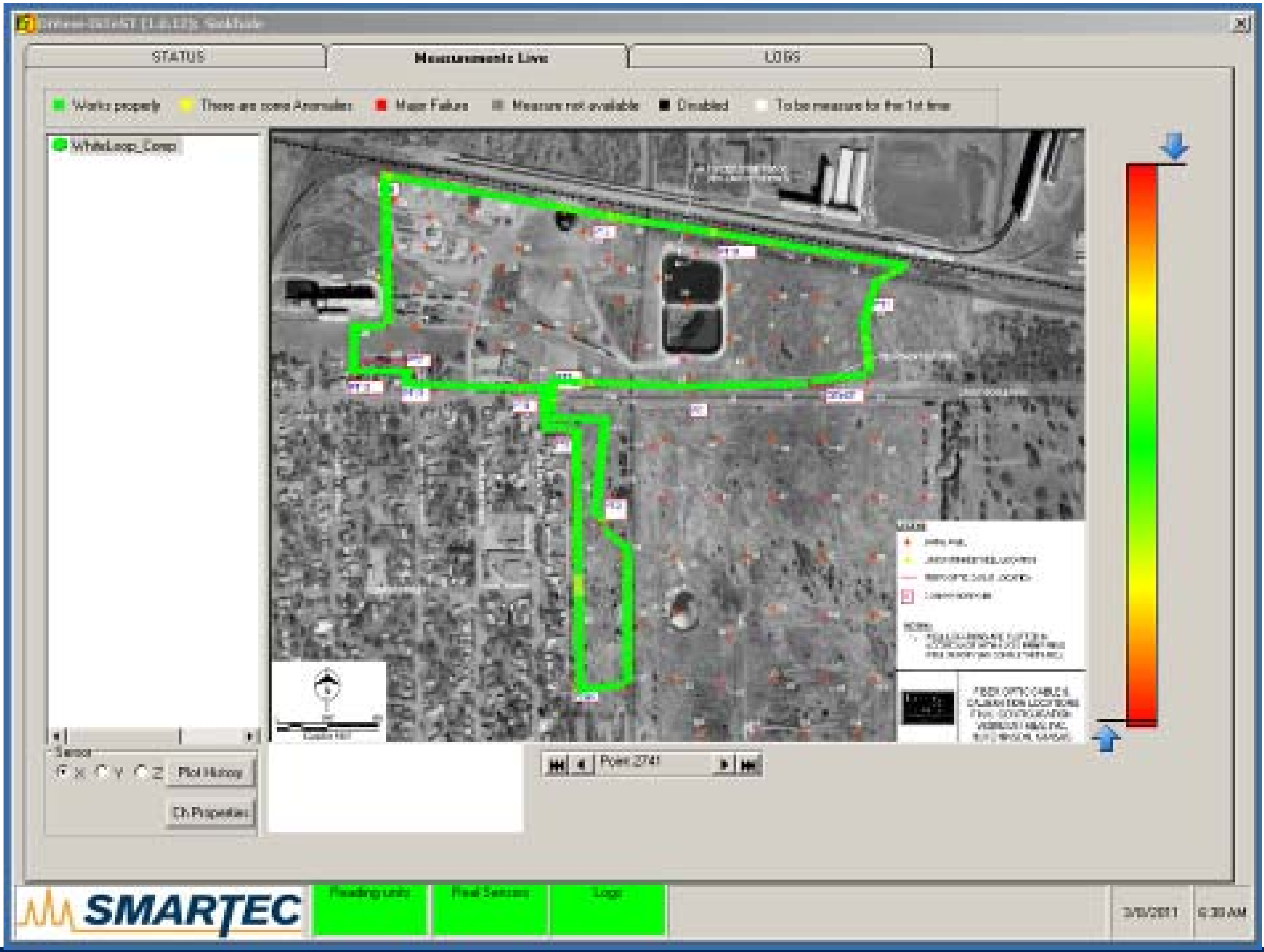
Sinkhole Monitoring - Kansas
DiTeST Sensor Testing

Site pulling test
@ different locations



Sinkhole Monitoring - Kansas
DiView Software Graphical User Interface



I-40 Slope Stability
Tennessee DOT - 2010

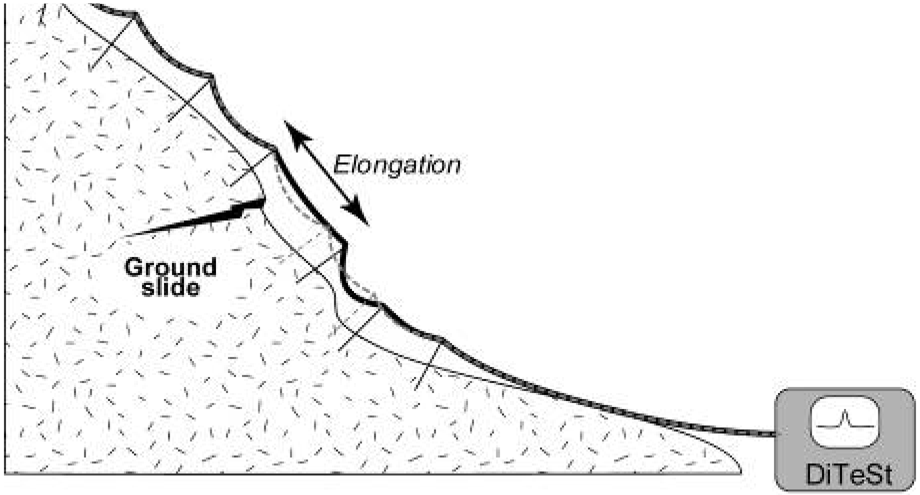
I-40 Slope Stability - Tennessee
Borehole extensometer (MPBX)

I-40 Slope Stability - Tennessee
Borehole Extensometer (MPBX)

Dangerous slope monitoring - Korea DiTeST

- **Landslide monitoring :predictive approach**

- Optical fiber attached to polls anchored in the ground
- Monitoring of the optical fiber deformation in relation with the land slide



Dangerous slope monitoring - Korea DiTeST

Thank you!

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