Fiber Optic Applications for Deformation Monitoring

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• **Sensor Types**
  o Traditional
  o Fiber Optic

• **Fiber Optic Sensor Technologies**
  o Point Sensors
  o Quasi Distributed
  o Long Gage
  o Distributed

• **Readout Units**

• **Software**
  o SDB – SOFO/MuST
  o DiView - Distributed

• **Case Studies**
  o I-35 - Minneapolis
  o Rio Puerco – New Mexico
  o Turcot Interchange - Montreal
  o High Speed Train Tunnel – Spain
  o Sinkhole Monitoring – Kansas
  o I-40 Slope Stability – Tennessee
  o Dangerous 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)
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: $n_{\text{core}} > n_{\text{cladding}}$
• 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
- Displacement
- Pressure
Fiber Optic Sensor Technologies
Types of Sensors by Gauge Length

Point Sensor:
- FISO Fabry-Pérot

Max. gauge length 10 m
- Long gauge Sensor: SOFO sensor

Max. gauge length 2 m
- Quasi distributed (multiplexed): MuST Fiber Bragg Sensor (FBG)

Spatial resolution 1 m
- Distributed: DiTeSt / DiTemp Brillouin and Raman scattering
  Max range 45 km
Fabry Perot Point Sensors

To Readout

10 mm

d

Optical Fiber

Mirror

Microcapillary

Fabry-Perot Cavity
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.

\[ \Delta W L \sim \Delta \varepsilon \text{ or } \Delta T \]

Before strain or temp. variation

After strain variation \( \Delta \varepsilon \) or temp. variation \( \Delta T \)
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
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

Standard multi-mode optical fiber

Backscattered light provides measurement information at 0.5, 1, or 2 m spacing

1m pulse of light
Distributed Sensing
Light Scattering Effect

Brillouin and Raman Scattering of Light

Laser, $\lambda_0$

Anti-Stokes components  |  Stokes components

Rayleigh

Raman  |  Brillouin  |  Brillouin  |  Raman

$T, \varepsilon$

Wavelength

Scattering medium
Distributed Sensing Cable Design

SMARTape: Strain sensing

SMARTProfile: Strain & Temperature

Temperature Cable

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 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.
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

SOFO Sensors
LA=4m

Junction box

Multifiber Extension cable

SOFO RU (TCP-IP)
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.
Turcot Interchange
MuST Bragg Grating Sensors

MuST strain
Temperature
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
Total of 4 Km of Strain Distributed Sensor directly buried into soil.
Sinkhole Monitoring - Kansas
DiTeST Sensor Installation

Digging of the trench where the sensor is deployed
Sinkhole Monitoring - Kansas
DiTeST Sensor Testing

Site pulling test
@ different locations
Sinkhole Monitoring - Kansas
DiView Software Graphical User Interface
I-40 Slope Stability - Tennessee
Borehole extensometer (MPBX)
I-40 Slope Stability - Tennessee
Borehole Extensometer (MPBX)
• Landslide monitoring: predictive approach

- Optical fiber attached to poles 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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