FO Tunnel Safety - Application Note

San Salvatore Highway Tunnel (source: La Regione)

San Salvatore Highway Tunnel (source: La Regione)

NYC subway Canarsie tunnel

TUNNEL SAFETY MONITORING WITH DISTRIBUTED FIBER OPTIC SENSING

THE BEST WAY TO MONITOR AND DETECT THE PRECISE LOCATION OF MOVEMENTS, CRACKS OR UNUSUAL DEFORMATION IS A DISTRIBUTED FIBER OPTIC SOLUTION.

New and existing tunnels can present structural risks related to surrounding geotechnical and hydrological conditions as well as unknowns related to design assumptions and construction materials. Such risks can materialize through the apparition of

- Unusual deformation
- Settlement
- Formation or development of cracks in concrete lining
- Joint movement
- Water ingress point
- Unusual temperature
- Tunnel liner collapse.

The localization of such events is a-priori unknown, so traditional instrumentation in chosen cross-sections is not effective for damage detection and localization. Smartec has developed fiber optic based solutions to detect movements using proven distributed fiber optic (FO) technology by applying advanced technologies such as Raman and Brillouin interrogation techniques. These solutions allow the **detection and localization of events** using precise measurement of temperature and/or strain **every meter** along a fiber optic cable installed longitudinally along the tunnel length at different positions around the section.

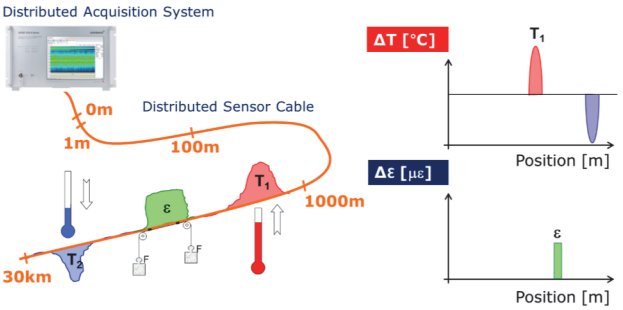
References

- NYC subway Canarsie tunnel deformation monitoring (USA, 2019)
- San Salvatore highway tunnel monitoring (Switzerland, 2018-2019)
- Highway A3 “Salerno-Reggio Calabria” Fossino tunnel monitoring (Italy, 2015)
- Penstock tunnel deformation monitoring (Switzerland, 2013)
- High speed railways tunnel in Barcelona (Spain, 2010)
- Cadia East Underground Project – Ore extraction tunnel deformation monitoring (Australia, 2015)
- Monitoring deformation around a simulated repository tunnel (Switzerland, 2013)
- Motol Prague Metro Line 5 tunnel extension monitoring (Czech Republic, 2008)

TUNNEL SAFETY MONITORING WITH DISTRIBUTED FIBER OPTIC SENSING

Technology

The most developed technologies of distributed fiber optic sensors are based on Raman and Brillouin scattering. Both systems make use of a non-linear interaction between the light and the silica material of which a standard optical fiber is made. If light at a known wavelength is launched into a fiber, a very small amount of it is scattered back at every point along the fiber. The scattered light contains components at wavelengths that are different from the original signal. These shifted components contain information on the local properties of the fiber, in particular its strain and temperature. For strain and deformation monitoring, Brillouin scattering is the only option, since Raman is only sensitive to temperature.

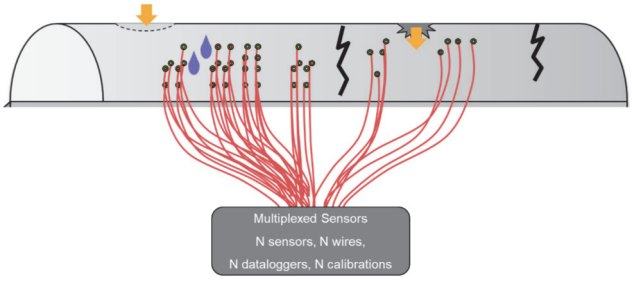


Brillouin Distributed Sensing Technology

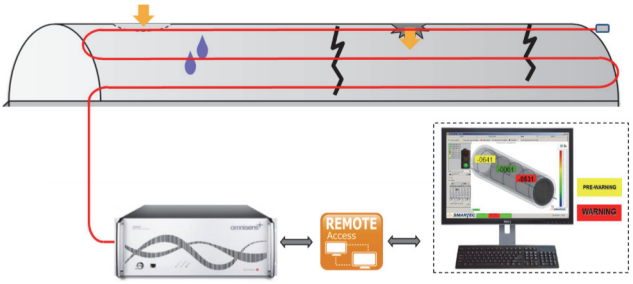
Benefits of Distributed Sensing

- Distributed Sensing
- Single fibre optic sensor (sensing cable)
- Every segment of sensing cable replaces discrete sensor
- Provides for location (where) and magnitude (how much) of the measures (average strain and/or average temperature)
- Complete measured profile obtained by single scan.

In the field of geotechnical applications such as tunnels, where both the large structure dimensions and damage location forecast represent a challenge, distributed techniques offer the capability of monitoring the whole length of the tunnel using a single fiber optic sensor. Typical needs in tunnel monitoring include: detection and localization of cracks in concrete lining, monitoring horizontal and vertical deformations, convergence monitoring, joint movements and localization of water ingress points. All those events are unpredictable in their location. It is therefore unpractical to address those using traditional point sensor installed at some predefined locations, since events can occur in-between those instrumented sections. Unlike electrical and localized fiber optic sensors, distributed sensors offer the unique characteristic of being able to measure physical parameters along their whole length, allowing the measurements of thousands of points using a single transducer.



Traditional method: multiple point sensors at predefined test sections

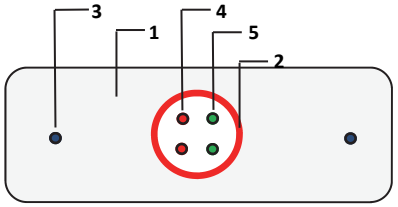


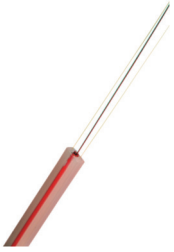
One optical fiber sensor replaces thousands of pin-point sensors

Sensing cables

Measuring distributed strain requires a specially designed sensor. A mechanical coupling between the sensor and the host structure along the whole length of the fiber has to be guaranteed. Different cable designs to measure strain and temperature are conceived for different tunnel installation.

SMARTProfile sensor for embedding and surface mounting on concrete





1. LDPE matrix
2. Loose tube
3. Strain SM fiber
4. Communication SM fiber
5. Temperature MM fiber

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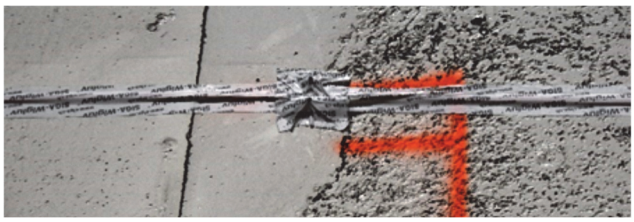
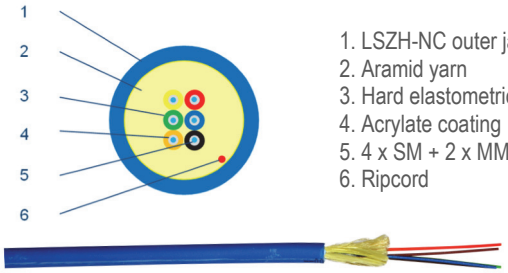


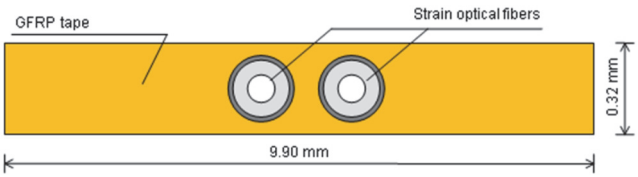
SMARTProfile sensor installed onto tunnel concrete liner



1. LSZH-NC outer jacket
2. Aramid yarn
3. Hard elastometric buffer
4. Acrylate coating
5. 4 x SM + 2 x MM fibers
6. Ripcord

Hydro & Geo sensing cable for embedding or shotcrete

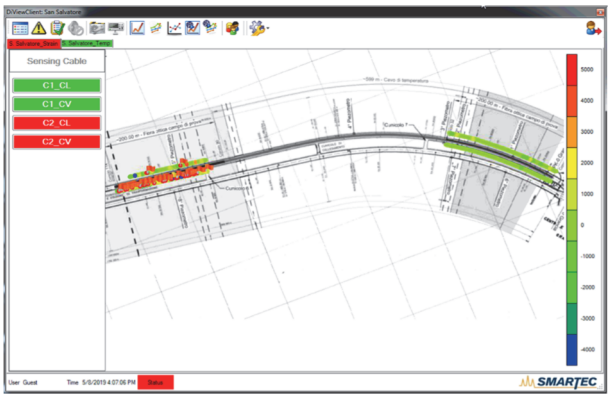
Hydro & Geo sensing cable installed onto the fiber mesh before shotcrete spraying (source: Newcrest)



SMARTape for installation on smooth surface as steel and concrete for crack detection.

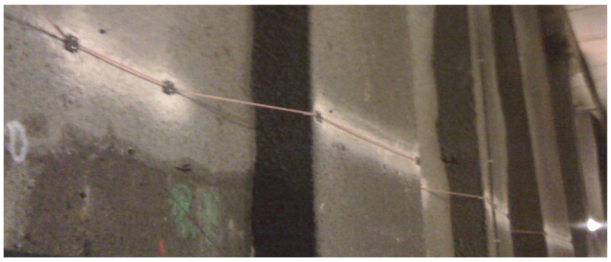
Data Management and GUI

The main functions of data management software are aimed to measure distributed sensors automatically and process the large amount of data automatically to detect and localize the undesired events. The operator can view in real time the sensors' measurement history in graphical form. Software is also able to trigger alerts (message, mail and phone call) and show warnings on the display. Warnings can be generated for different types of events, including: strain, temperature, leakage and cracks.



User Interface for the San Salvatore Tunnel distributed monitoring system. Colors indicate level of strain recorded as a function of position.

Typical Installations



Strain cable affixed onto the tunnel concrete wall using metal brackets

Strain sensing cable installation by gluing onto the tunnel liner

Strain cable installation by gluing onto the duct banks

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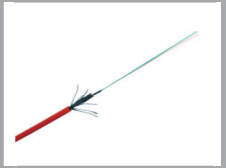
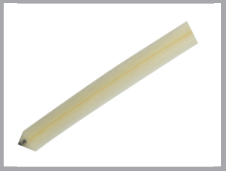
DiTest Dual
Brillouin Reading Unit
Strain & Temperature

DiTemp Light
Raman Reading Unit
Temperature

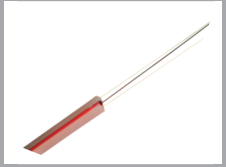
DiTemp Harsh+
Raman Reading Unit
Temperature



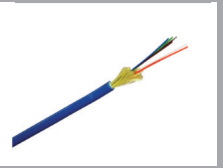
DiTemp
Ordinary Cable
Temperature



DiTeSt /
SMARTape II Cable
Strain



DiTeSt / DiTemp
SMARTProfile II Cable
Strain & Temperature



DiTeSt / DiTemp
Hydro & Geo Cable
Strain & Temperature

DiView Visualization
and Analysis Software

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MONITORING WITH
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Roctest

Roctest is featuring a complete line of conventional sensor-based solutions ranging from the ultra-robust traditional vibrating wire technology to state-of-the-art fiber-optic technology used for the measurement and monitoring of geotechnical projects and structural health monitoring (SHM) of critical assets such as: dams, tunnels, mines, buildings, bridges, nuclear power plants and many other structures too numerous to list.

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- Installation, Operation and Maintenance
- Data Management
- Data Analysis

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Available Application Notes

- Tailing Dams
- FO Leak Detection for Dams and Dikes
- Dam & Dike Instrumentation and Safety Monitoring
- Tunnel Instrumentation & Structural Health Monitoring
- FO Movement Detection in Tunnels
- FO Mining Safety
- Bridge Instrumentation & Structural Health Monitoring
- Building Instrumentation & Structural Health Monitoring
- Historical Monument Instrumentation
- Geotechnical and Structural Monitoring
- Nuclear Power Plant Instrumentation
- FO Leak Detection for Chemical Plants
- FO Leak Detection for Pipelines
- Storage Facility Instrumentation

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