Fiber Optic Structural Health Monitoring for Dams

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Intro

Nowadays fiber optic is one of the technologies used for structural and geotechnical monitoring projects. Fiber optic sensors are normally classified as point, multiplexed, long-base or distributed sensors. Each of them is based on a different principle: Fiber Bragg Gratings, SOFO, Fabry-Perot, Raman, Rayleigh and Brillouin. The distributed sensing cable are widely used in structures with important horizontal or vertical developments due to their intrinsic characteristics. The fiber optic distributed sensing cables are able to localize and quantify on a long distances strain and temperature values. The sensor is a special cable with inside optical fibers and the cable itself is the sensor. These sensors can provide information in real-time, every meter and over distances of up to several tens of kilometers of sensing cable. This allows a permanent observation and the early detection, localization and sizing of defects and degradations such as leakages, settlements, erosion and soil liquefaction. Since globally the main failure modes of a dam concern slope instability, earthquake, overtopping, seepage, foundation and structural issues a mix of different monitoring techniques is preferable. In this scenario, distributed fiber optic sensing cable is playing the role of protagonist and the temperature sensing cable ca be used for leak detection.

1. Main features of distributed fiber optic monitoring system

Unlike electrical and fiber optic point sensors, distributed sensors offer the unique characteristic of being able to measure physical parameters along their whole length and allow the measurements of thousands of points using a single transducer [1]. Unlike contactless sensors the distributed fiber optic technology offers the opportunity to study the dams internally, where the critical issues can happen and not only on the surface.

The most developed technologies of distributed fiber optic sensors are based on Raman and Brillouin scattering [2]. The 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 injected into a fiber, a very small amount of it is scattered back at every point along the fiber. The scattered light contains components of the wavelengths that are different from the original signal and are called the Brillouin and the Raman scattering components. These shifted components contain information on the local properties of the fiber, in particular the strain and temperature. While Raman scattering is only sensitive to temperature variations, Brillouin scattering can detect both strain and temperature (Fig. 1) [3].

A distributed fiber optic monitoring system consists of one or more unique fiber optic sensing cables and a unique readout device. The area of coverage can be up to 50 km continuous length with one system. The sensor cables can easily be deployed either during or after construction, and it is possible to retrofit on existing structures for extending their life [4].

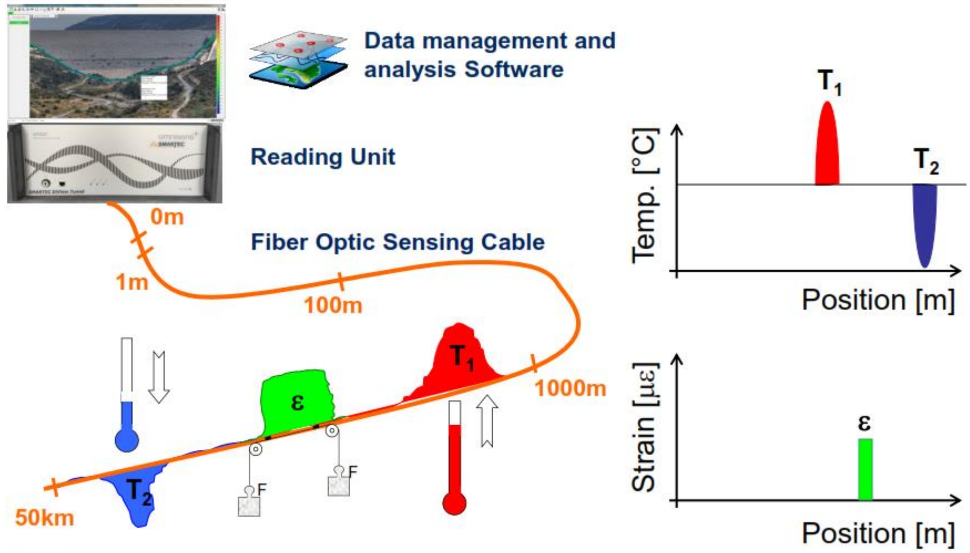

Fig. 1. Distributed fiber optic strain system: sensing cable, DiTeSt Reading Unit and DiView Software

Typically a temperature resolution in the order of 0.1°C, a strain resolution of 2 με and a spatial resolution of 1 m over a measurement range up to 50 km are obtained with commercially available interrogators. SMARTEC commercializes a system based on Brillouin sensing and named DiTeSt, and a system based on Raman sensing and named DiTemp (Fig 2).

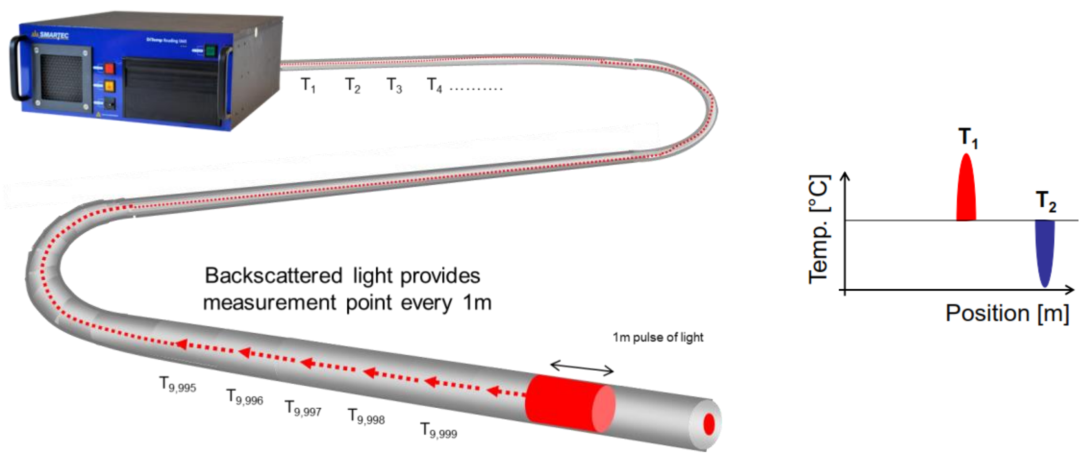

Fig. 2. Distributed fiber optic temperature sensing system: DiTemp

Distributed sensing instruments can return a huge amount of data. As an example, it is possible to measure every minute the temperature at 30'000 points along a single cable. Data management and analysis therefore becomes a very important task, since it is often impossible to manage and analyze the data manually, especially if the measurement is automated and continuous. Dedicated data management, analysis and visualization software has therefore been developed to help in those tasks. This software can allow the representation of data superimposed with location maps and using colors to represent strain/temperature or levels of alerts as a function of position. An example of such representation is shown in Fig. 3.

This software has been specifically developed to manage distributed data coming from the DiTeSt and DiTemp units, provides system status report informing the final user about the status of each single component, reading unit, sensor and software itself. It has been developed to work continuously 24 / 7 without the necessity of an external operator. When configured the DiView software can trigger alerts to a dedicated user recipient. Warning thresholds are set during commissioning phase. It provides an easy remote access to the implemented monitoring system offering possibility of remote troubleshooting and off-line data processing. Last it offers a friendly Graphical User Interface with data displayed on maps.

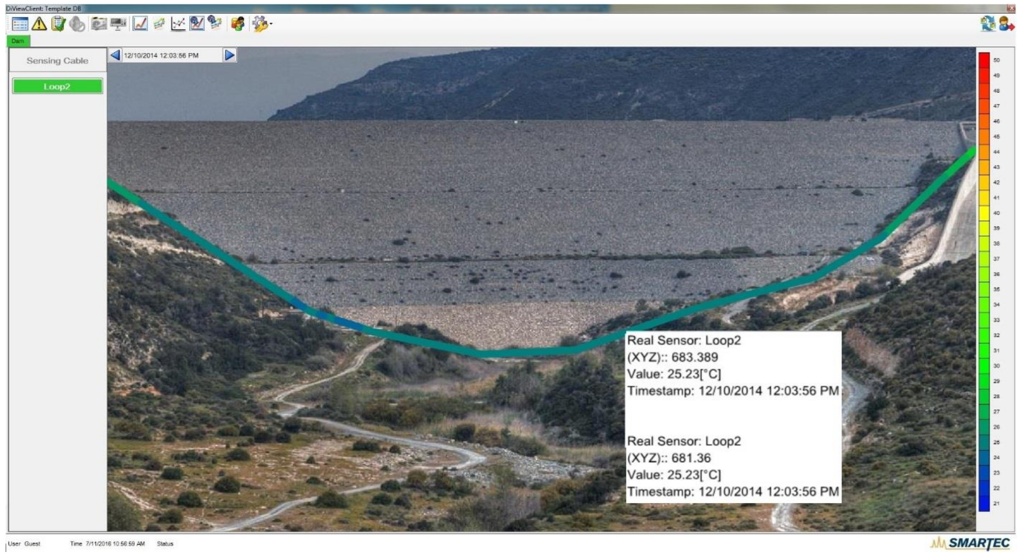

Fig. 3. DiView Data management and analysis software interface, showing temperature distribution

1.1 Long-term monitoring of dams and levees

A distributed sensing system installed in a dam or levee is able to detect the following failure [5]: structural movement, overtopping, under levee seepage, through levee seepage, piping (internal erosion), external erosion, differential settlement and landslides.

Unlike "discrete monitoring systems" there are no coverage "gaps" between sensors, providing seamless coverage. The system collects data day and night, 24 hours a day. Using current internet technologies, effective warning systems can be integrated into current management methods. Sensor cables can be retrofitted on existing levees and dams by means of trenching the cable into the face of the structure, on either the upstream or downstream side. Often trenching is only necessary to a depth of protection for the cable itself. The location of the cable will depend on many different factors that must be carefully considered by the engineer.

Location of the sensor cable is critical for detecting both strain (settlement) and seepage (temperature change). With regard to strain, the sensing cable must be placed where changes in the shape of the structure will physically occur, directly transferring strain to the cable. The same is true for seepage. The sensing cable must be placed in a location where water is moving close to the cable, creating trends in temperature directly to the cable.

A levee or dam is in many ways like a chain, only as strong as its weakest link (or lowest point). An individual levee can be many miles long and can meander through urban, rural, remote, inaccessible and sometimes dangerous areas. Vegetation, sheer size and scale, can limit levee access and mask indicators from even the most well trained inspectors. Areas of structural weakness, even when relatively obvious, are difficult to identify. The DiTeSt system can not only detect structural failures, but also detect very slight differential settlements that can be considered as early warning of future issues.

1.2 Heat Pulse Method working principle

A fiber optic distributed system can work in two different configurations; the passive and active methods.

The so-called passive method relies on direct detection of temperature anomalies induced by liquid spilling. This method is typically used when a gradient of approximately 5°C between the liquid and the sensing cable can be assured.

The so-called Heat Pulse Method or active method is on the other hand used when the gradient between the liquid and the sensing cable is negligible and smaller than 1°C. In order to ensure a reliable detection the sensing cable, and in particular the self-heating cable, is heat up and forced to change its natural temperature. Heating is provided by flowing electrical current on the sensing cable, current injection is controlled by a dedicated module that is part of the system when this detection method is selected.

When forced to change temperature the cable will need a certain time to arrive at a certain temperature, defined as T-heating in the plot, and as well a certain time to go back in its initial condition. Studying the cooling transient and the value of the maximum temperature reached during the heating phase the DiView software figure out automatically if some events are occurring. DiView system is controlling the heating as well as the analysis; the detection algorithm is applied to all the points of the sensing cable.

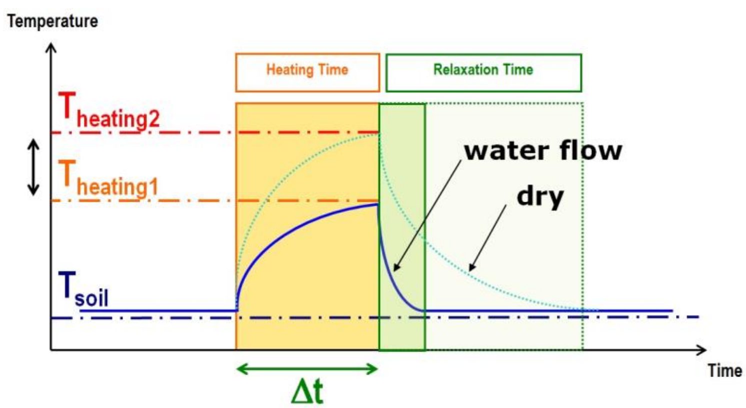

Fig. 4. DiTemp Heat Pulse Method working principle

2. Siah Bisheh upper dam, Iran

The Siah Bisheh Pumped-storage Hydroelectric Power Project is the first of this type in Iran. Located 125 km from Tehran it has an installed capacity of 1000 MW. The plant is intended to play a vital role in stabilizing the entire North Iran power grid, ensuring the safe operation of thermal power plants in the surrounding provinces.

2.1 Purpose of monitoring

The main aims are seepage at plinth level and active detection system with Heat Pulse Method technique.
Beside this direct detection the monitoring system can offer an effective analysis of the evolution of the detected anomaly, and a way to define reasonable threshold and trigger alerts if they are overcome.
Moreover fiber optic systems are easily integrated with already existing traditional / standard monitoring systems. Distributed sensing offers the unique capacity of locating precisely the event using only few distributed sensors.

2.2 On-site implementation

Two independent systems are developed to monitor the existing dams. A dedicated control room where the instrumentation rack is located is specifically built on the crest of each dam (Fig. 5). The rack contains a display the DiTemp unit with its accessories, the server PC where the DiView software is installed and the heating module necessary to heat up the cable at scheduled times. All the system is plugged into a network stabilizer and UPS in order to prevent general functionality in case of power breakdown.

Fig. 5 Sensing cable installation at the plinth of the upstream face of the upper dam and one monitoring cabinet

2.3 Distributed sensing system performances

Accuracy and repeatability tests were carried out during implementation phases (Fig. 6 and Fig. 7).

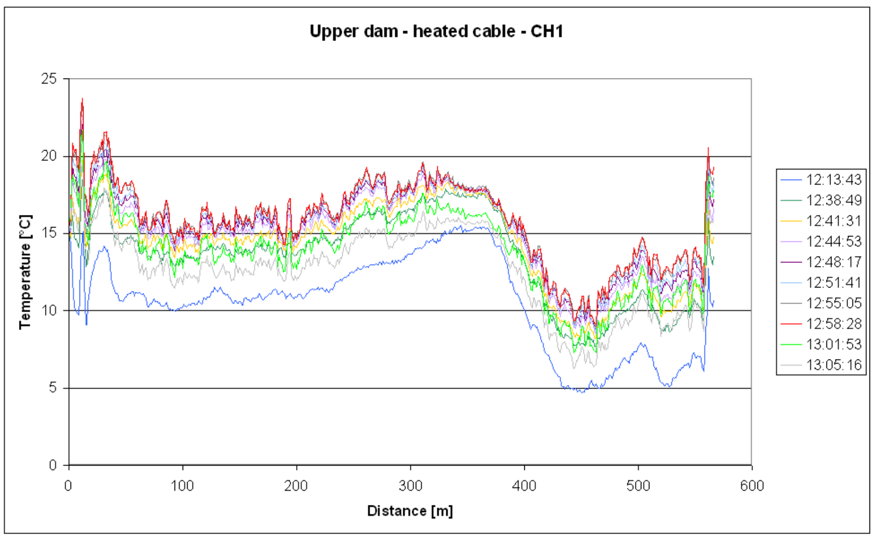

Fig. 6 Absolute temperature measurements during heating

It is possible to evince how temperature resolution is in the order of + - 0.2 °C. The initial section showing higher deviation refers in fact to cable section not yet concreted and exposed to the environment. Thanks to the DiView customized visualization software it is possible to follow in real time any variation in the temperature profiles of the two sensing cable, launching a warning in case of any seepage or leakage.

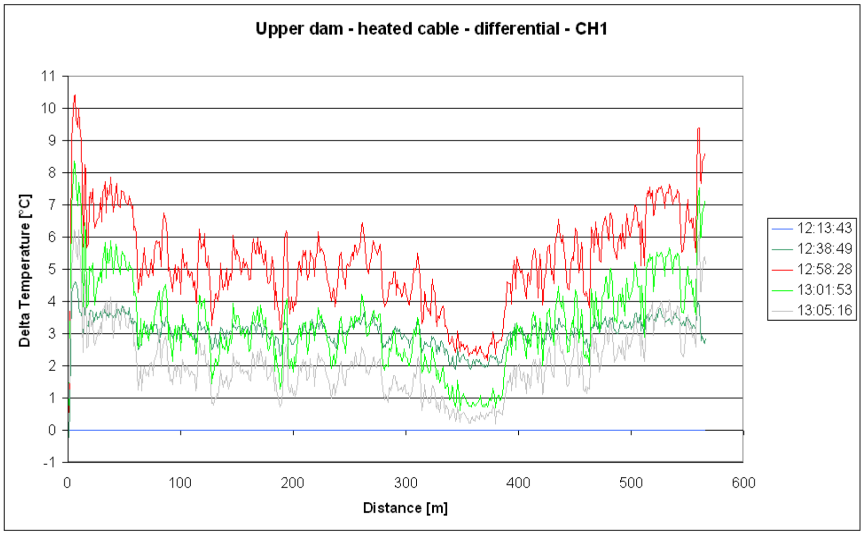

Fig. 7 Differential temperature measurements during heating

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