# Experiences from Seepage Monitoring using Distributed Temperature Sensing in Optical Fibres

## Erfahrungen aus der Sickerwasserüberwachung durch den Einsatz des faseroptischen Temperaturmessystems DTS

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## Abstract

Seepage measurements based on temperature measurements have been used in about 40 Swedish dams since 1987. As a result of extensive research, funded by the power industry in Sweden (Elforsk AB), the method is now well established. The use increased when Distributed Temperature Sensing using optical fibres was introduced in Sweden in 1998 by HydroResearch and Sensornet. This monitoring technology allows seepage information along the entire dam, with a sensitivity better than 0.01 l/s and metre.

## Zusammenfassung

Sickerwassermessungen, welche auf Temperaturmessungen basieren, werden seit 1987 in etwa 40 schwedischen Dämmen genutzt. Aufgrund umfangreicher Untersuchungen, welche von der Schwedischen Energiewirtschaft (Elforsk AB) gefördert wurden, hat sich diese Methode gut etabliert. Ihr Gebrauch intensivierte sich 1998, nachdem faseroptische Temperaturmessysteme (DTS) durch HydroResearch und Sensornet installiert wurden. Diese Überwachungstechnologie liefert Sickerwasserdaten entlang des gesamten Dammes, deren Sensitivität bei über 0,01 l/s und Meter liegt.

## 1 Seepage monitoring using temperature

The seepage monitoring method uses the natural seasonal temperature variation that occurs in all surface water (such as lakes, reservoirs and rivers). The seepage flow causes a seasonal temperature variation inside the dam. This seasonal temperature variation can be measured in the dam and used to evaluate the seepage flow. The method described below is based on the research about thermal processes for temperature evaluation in dams which was presented by Johansson [1] as a result of several research projects founded by the Swedish Power Association/ Elforsk between 1988 and 1996.

Temperature measurements has proved to be sensitive and can detect small seepage flow changes. The fundamentals for the method are:

- Seasonal temperature variation in the water creates seasonal temperature variation inside the dam.
- Larger seasonal temperature variations and shorter time lag between the temperature in the water and inside the dam indicate higher seepage.

– Increasing seepage causes increased annual temperature variation, and shorter time lag between the temperature in the water and inside the dam.

Generally, a constant temperature will indicate a small seepage, while large seasonal variations may indicate significant seepage. At increasing seepage flows, the temperature in the dam will be changed, and the seasonal variation will increase. This variation is dependent on seepage flow, the seasonal variation at the inflow boundary, and the distance from the boundary to the measuring point. Evaluation can be made by FEM simulations of the temperature field, or by using DamTemp, a software developed by HydroResearch based on the theory presented in [1].

## 2 Distributed Temperature Sensing in Optical Fibres

Distributed sensing takes advantage of the fact that the reflection characteristics of laser light, travelling down an optical fibre, vary with temperature and strain. The sensor consists of a length of standard telecoms optical fibre, normally housed in a protective cable. The measuring instrument uses a laser to emit pulses of light into the sensing fibre. A detector measures the reflections from the fibre as the pulse of light travels down its length. Measuring the change in power and colour of these reflections against time allows the instrument to calculate temperature and/or strain at all positions along the fibre. The key feature is that the fibre itself is the sensor and it can be used to measure along its entire length. The fundamentals of the method is described by Dakin et al. [2], and Parker et al. [3].

**Figure 1**: Sensornet Sentinel DTS.

Sensornet is one of the leading manufactures and offers a range of measurement instruments, including the Sentinel DTS that can measure temperature to a resolution of 0.01 °C over a distance of 10 km with a spatial resolution of just 1 m (**Figure 1**). This means that for a 10 km length of cable you have the equivalent of 10 000 point sensors. The system has been found reliable and all measurements presented here are made with Sensornet systems. The company also provides the DTSS (Distributed Temperature and Strain Sensor), a instrument capable of measuring strain to a resolution of 10 μσ, independently of temperature, over a distance of 10 km again with a spatial resolution of 1 m. Measurements in four embankment dams in Sweden are carried out within a research project. Experiences and results from these measurements can be found in [3].

# 3 Fibre optic Installations

**Installations in Sweden**

To date, optical fibres for monitoring of seepage and/or movements have been installed in about 40 dams, dykes and tailing dams at 30 different dam sites in Sweden. Different installation techniques have been developed depending on the dam and its required monitoring as shown below. This new technology is being recognized an effective way to detect seepage flow changes with high sensitivity all along the entire dam, and is therefore almost a standard in Sweden at repair and upgrading works. Three different ways of installations are briefly summarized below.

**Downstream toe**

Installation of fibres in the dam toe is the most common application in Sweden, especially when new toe berms are constructed. Normally a new drainage system is also constructed, and an optical fibre cable is then placed upstream the drainage pipe. The temperature of the water that passes towards the drainage pipes will then be measured. This type of installation will be used as complement to existing monitoring weirs, in which the drainage water is measured. After a first base line temperature measurement, following measurements will be performed depending on the need of the actual dam.

For Hylte dam and dyke, a permanent system was installed in 2006 for continuous temperature monitoring. The cable was placed in a trench downstream the dam, especially made for these measurements. Initial result from the some of the first repeated measurement is presented in [4].

**New dams**

The first two installation of fibre optic cables were made at repair works of the embankment dam at Lövön in 1998 and the tailings dam at Aitik (2000), as described in [4] and [5]. When constructing new dams the cable can be placed at an optimal location, further improving the sensitivity of the method. During 2007 such installations will be made in two new Swedish dams.

**Standpipes**

Optical fibre can also be installed in standpipes to measure the temperature profile with depth. This allows an effective way of measuring the seepage flow at different levels. By combining data from a line of standpipes along the dam a good coverage of the seepage flow can be achieved over the entire dam.

# 4 Measurements and evaluations

**Bergeforsen**

The Bergeforsen power plant in the river Indalsälven was built in the early 1950's. However, no seepage measurements have been possible because of a high downstream water level. A complementary installation was made in 2005, where 17 new standpipes were drilled from the downstream berm down to the bedrock in order to measure the temperature in the seepage water. Optical fibres were installed in the new standpipes, in five old standpipes, and also in the upstream water. A DTS unit was installed in September 2005, when continuous measurements also started.

Initial measurements indicate excellent results which are necessary to detect the small expected

At small seasonal temperature variations (in this case less than 1ºC) a high temperature monitoring accuracy is required. Measurements are performed both going down and up in each standpipe. The total measured length is about 4.5 km. Measurements are performed four times a day.

The temperature in the dam is homogeneous and no significant temperature anomaly has been detected. The temperature seems to be slightly higher at the first standpipes close to the spillway (**Figure 2**). A general increasing temperature with depth is seen for all standpipes, as well as an higher mean temperature close to the spillway. The annual varies between 0.3 ºC and 0.6 ºC over the main part of the dam, except from the left abutment (about chainage 150 m) where the variation is about 0.9 ºC due smaller depth to the ground water level. The temperature measurements indicate normal homogenous conditions and low seepage flow. The total flow over the monitoring area is estimated to about 1 l/s.

**Seitevare**

The Seitevare dam is located on the Lilla Luleälven River in the northern part of Sweden. The dam is 106 m high and 1450 m long. An optical fibre cable was installed along 1300 m of the dam toe just upstream of the drainage system. Measurements have been performed on six occasions since September 2005, for periods as short as a few hours up to two months.

Seepage evaluations (one example is shown in **Figure 3**) have been made after each measurement, indicating a seepage flow rate varying between $10^{-5}$ and $10^{-4}$ $m^3/(m,s)$ along the dam, using the theory behind the DamTemp software. The total evaluated seepage flow varies between 50 and 80l/s, depending on the number of measurements included in the calculations. These results are promising, and in accordance with the flow registered by the conventional seepage flow measurements, which varies between 10 and 100 l/s depending on the water level in the reservoir. However, further comparisons will be made when a new conventional seepage monitoring system will be taken into operation.

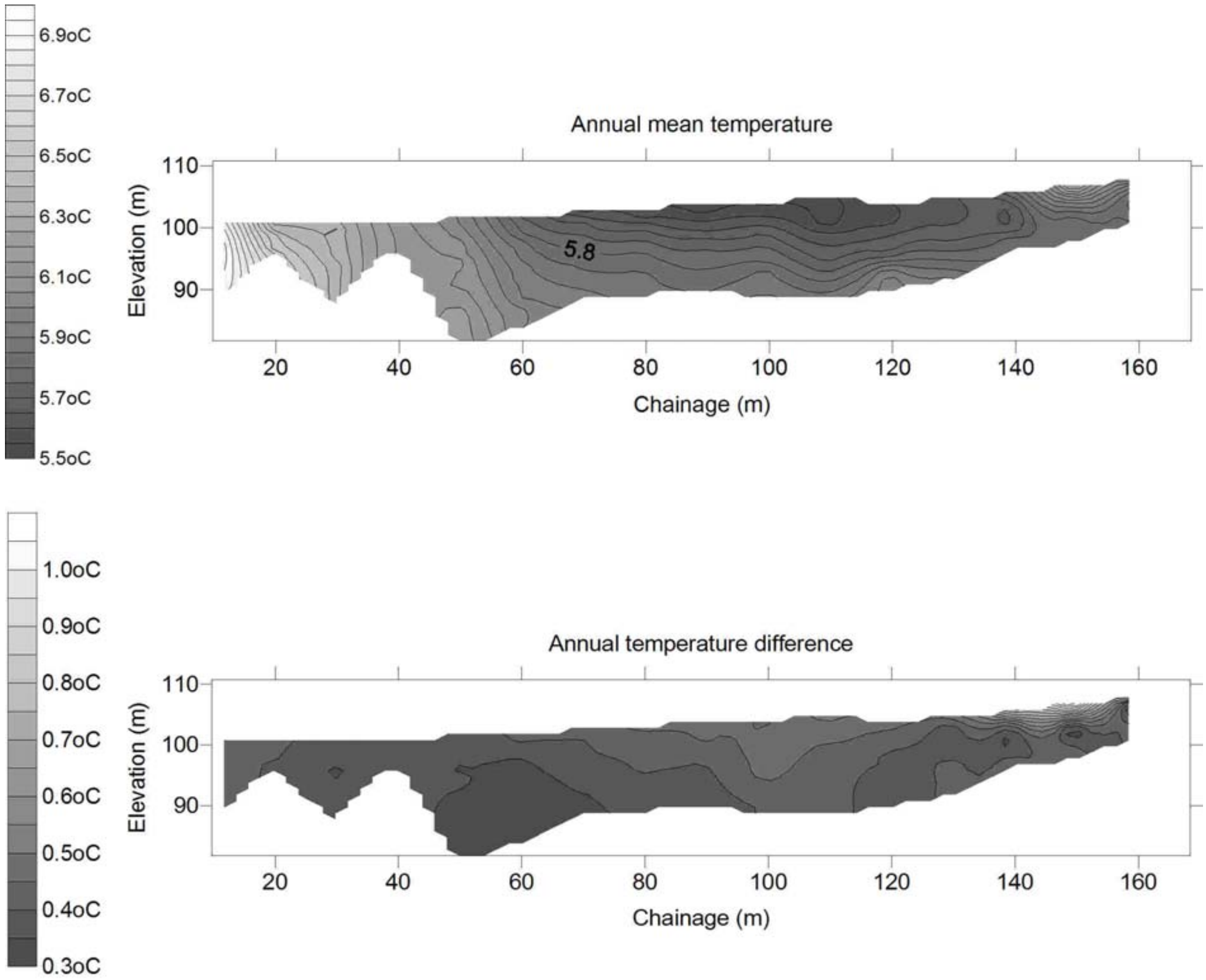


**Figure 2**: Mean temperature and annual temperature difference at Bergeforsen dam, from September 2005 to September 2006 (downstream view).

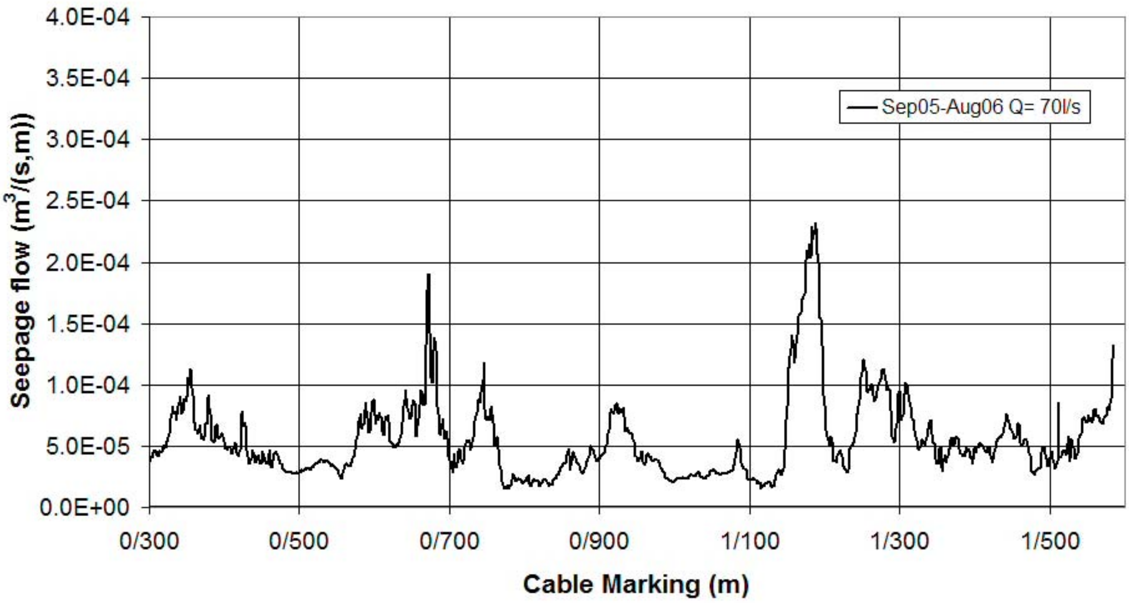


**Figure 3**: Evaluated seepage flow along the dam toe at Seitevare dam based on all measurements. The total flow is

## 5 Conclusions

The experience gained from the installations in Sweden show the potential of this monitoring technology, and installation of optical fibre is now almost a standard at repair and upgrading of embankment dams. The seepage monitoring capability is similar to conventional methods, but has a much higher spatial resolution. Small seepage flow changes, as a result of internal erosion, can be detected and located at a early stage.

## Literature

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