Case Study

Shining a light on embankment dam safety

Using distributed temperature sensing to monitor dam integrity

The failure of an embankment dam through excessive water seepage or subsidence is always expensive, and has potentially catastrophic implications.

Yet such failures are inherently difficult to predict, as their causes are slow acting and remain hidden deep within the structure of the dam itself.

As an emerging leader in the technology of distributed temperature sensing (DTS) using fibre optic systems, Sensornet has been working with the Swedish dam monitoring company, HydroResearch, to demonstrate the feasibility of using Sensornet's DTS solutions to detect and monitor levels of water seepage in dams, and provide an early warning of potential problems.

It is intrinsic to embankment dam design that there is a gradual seepage of water through the core of the dam. This seepage keeps fines moving, plugging the core of the dam and creating a dynamic seal. What is less well known is that any change in the seepage rate will also show up as a change in the temperature profile within the dam. The nature of this change depends on the season – in winter, when the water in the dam is cold, an increased seepage rate will show as a cold spot; whilst in summer, when the water in the dam is warmer, any seepage will show as a warmer spot. These temperature variations can often be very subtle (often below 0.1°C), hence the requirement for a very fine temperature resolution DTS. Sensornet's Sentinel DTS system has demonstrated a temperature resolution below 0.01°C.

This is the basis on which temperature measurements can reliably detect internal erosion through water seepage. This seepage generally occurs through a process that is initially slow but accelerates up to the point where it either becomes self healing, or a sink-hole occurs.

Experience shows that seepage tends to be concentrated in horizontal layers or a cylindrical cross-section, where the flow may be 100 or even 1000 times higher than normal. Distributed sensors are uniquely placed to monitor dams as excess seepage may be very localised and may occur at any point. It is impractical to do this with point sensors as these would have to be placed exactly at the failure point – and the whole purpose of the measurements is to determine these points!

Installation of cable at Ajaure dam: the 1122m long cable was installed at two levels along the dam as a loop during construction.

TESTING THE WATER

Sentinel DTS and DTSS (distributed temperature and strain sensing) systems were installed on nine dams in Sweden between 1998 and 2004, with the objective of measuring either seepage or movement – or in one case a combination of both.





A number of different installation methods were trialled for the optical fibre. With regard to seepage measurements, in some cases the fibre was installed deep in the structure of the dam, whilst in other cases the fibre was installed in a more recently constructed toe berm. In one other dam, the fibre was installed in a downstream trench.
To detect and monitor movements, fibre was also installed at the crest of three dams, and inside a fourth dam. Fibre is also being used to monitor frost penetration in two of the dams.

The Sensornet equipment deployed on these dams is the Sentinel DTS and DTSS, both of which are widely regarded as the fastest and most accurate devices of their type currently available. Each system is self-contained in a rugged field-transportable 19" rack-mountable box with inbuilt PC, flip-up monitor, keyboard, uninterruptible power supply and network connection.

Sensornet developed a special-purpose optical cable for dam monitoring, with each cable containing two single-mode and two multimode fibres to enable both DTS and DTSS monitoring to take place at the same time, with spare capacity. This has been used on the Ajaure dam to enable movements on the crest of the dam to be identified by measuring changes in the strain in the cable.
Fibres can be up to 10km in length, and include as many as 10,000 measurement points to provide simultaneous distributed temperature and strain measurements along the full length. Sensornet is currently working to increase the range to beyond 30km.

The Sensornet data visualisation software has been configured to display data specifically for each dam site. The software also allows data to be downloaded directly into Excel spreadsheets. All raw data are saved for checking and validation purposes, and files are automatically date stamped for reference.

With its ability to measure both distributed temperature and strain independently, by analysing the full Brillouin spectrum at every point along extended lengths of optical fibre, the Sensornet DTSS system has proved particularly useful in this application.

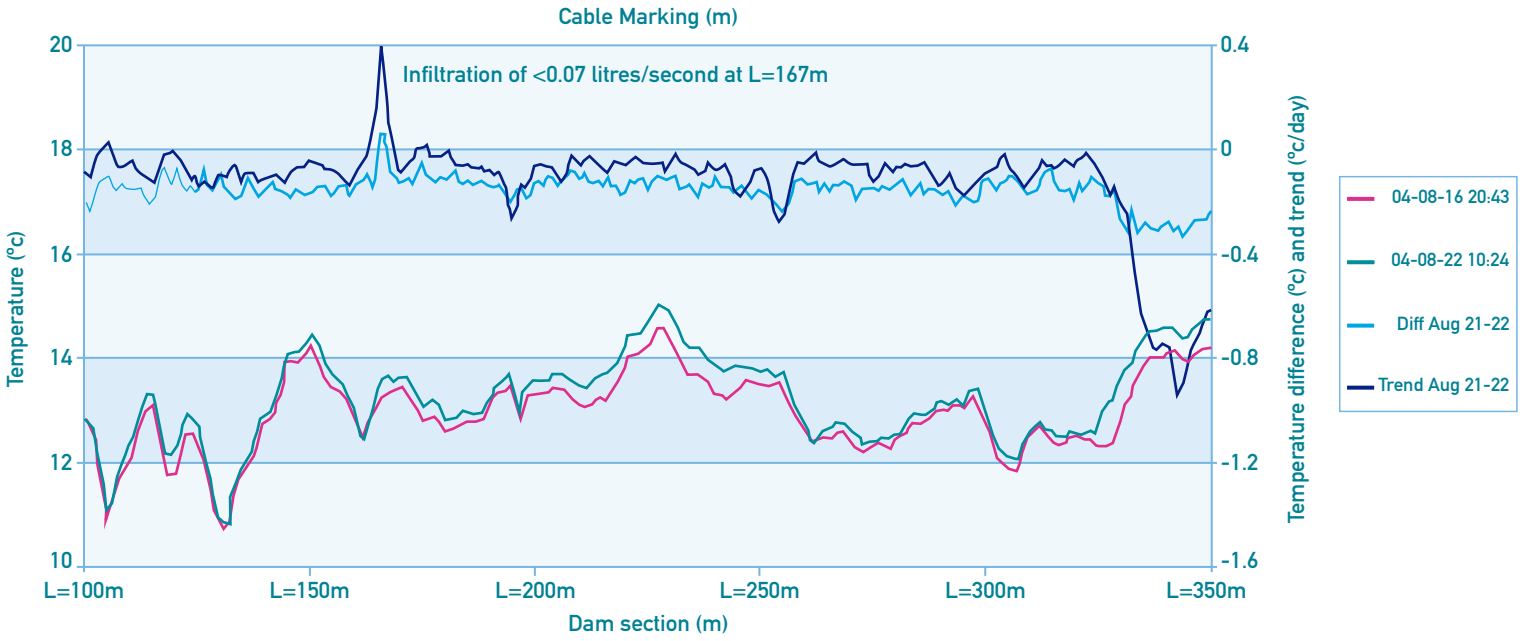
FUTURE POTENTIAL

This work clearly demonstrated the value of careful design of the cable for the particular application, and of installation of the fibre cable under close supervision to ensure an optimal position in the dam. In addition, it is valuable to install calibration points to enable verification of data for quality assurance purposes.

The Swedish trials proved the ability of the Sensornet DTS and DTSS systems to detect and monitor variations in temperature and strain indicating seepage inside dams.

The technology is already being widely used within the oil and gas industry – both on and offshore, as well as upstream and downstream – to provide accurate, fine-resolution measurements of temperature and strain in well casings and pipelines, and to carry out health checks on existing optical fibres used for down-well monitoring.
It has also been used to carry out mid-life checks on the condition of optical fibres in high-speed telecommunications networks, and is seen to be suited to a growing range of similar applications in the civil engineering and aerospace industries.

Distributed temperature measurements successfully identify a minute leak



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