

Retrofit of Fibre Optics to existing Dams

Permanent Monitoring of Leakage and Detection of Internal Erosion

Jürgen Dornstädter, GTC Kappelmeyer, Karlsruhe, Germany

David Dutton, GTC Kappelmeyer, Watford, UK

SYNOPSIS The experience of the last 20 years has shown the great advantage of the use of fibre optics for the efficient monitoring of dams. More than 100 large dams have been equipped during construction or major refurbishment. But old existing dams have been excluded until now from the use of this valuable technique.

In 2014 GTC developed a new fibre optic cable with optimized fibres which could be inserted into small diameter tubes. The fibres in these cables form an internal loop, allowing light to travel in both directions in the same cable. The well-established GTC's temperature sounding method is used to install high grade steel probes into the earth fill dam along its axis, and down into the foundation if required. The new cables are inserted and connecting cables form a "light pass" from one end of the dam to the other. Thereby a 2 dimensional view of the temperature distribution within the dam is obtained which can be monitored remotely and in real time.

In 2015 three dams were equipped with this new technique, two in England and one in France, all 3 are monitored permanently. The cables have been installed to a maximum depth of 30m and a crest length of 430m. At one site the recorded data shows the successful sealing of a leak in the dam by a new slurry trench cut-off wall.

The new technique is described, the installation process is shown and results from permanent monitoring are demonstrated.

INTRODUCTION

Internal erosion is one of the most frequent causes of failure and deterioration of embankment dams. Internal erosion is strongly influenced by construction properties (e.g. filter and drain design, grain and pore sizes) and hydrodynamic conditions within the dam.

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Whilst construction properties are usually known, information is rarely available on the local hydrodynamic situation within the embankment. The most critical hydrodynamic parameter inducing internal erosion (material transportation phenomena) is the pore velocity of the seeping water. The onset of internal erosion starts at low pore velocities. Thus the detection of seepage zones of low pore velocities within a dam can prevent the development of damage and possible failure of the structure.

The existence of reliable methods for the detection of internal erosion is indispensable to anticipate the failure of embankment dams. The development and cross-tests of different geophysical and hydrogeological methods in the last 30 years has proved the high reliability of ground temperature measurements for the detection of leaks in embankments and foundations at reasonable cost.

The use of seepage water temperature as a tracer, applied to dams first in 1953 by Kappelmeyer (1953), has been shown to be a reliable method to detect and monitor in-situ the seepage flow conditions, even at extremely low velocities, and for detecting internal erosion at an early stage of development. With the ability to record temperatures over a period of time the technique can also now be used to estimate the leakage rate.

The development of this technique started in the 1950s with temperature measurements in boreholes and piezometer stand pipes. In 1992 GTC Kappelmeyer introduced greater accuracy and reliability by measuring in-situ ground temperatures with an array of purpose-designed small diameter temperature probes which were rammed vertically into the crest of a dam at regular intervals (Dornstädter, 1997). As an alternative measurement technique, since 1995, optical fibres have been incorporated into dams and into foundations but only during construction or major refurbishment (Aufleger *et al*, 1998). They can provide a continuous record of temperatures and can be remotely monitored.

Fibre optic temperature sensing operates by sending a short laser pulse (< 10 ns) into an optical fibre. The backscattered light is analysed with Raman spectroscopy, providing Stokes and anti-Stokes intensities. The ratio of Stokes to anti-Stokes intensities is proportional to the temperature at the point of reflection (the measuring point). The distance of the measuring point along the fibre is calculated from the returning time interval of the backscattered

light and the velocity of light. The method provides a temperature profile distributed along the entire optical fibre.

NEW DEVELOPMENT

In 2014 new fibres were developed which facilitate the combination of temperature probes and fibre optics, thus providing the advantage of easy installation of fibre optic cables into existing dams and allowing a retrofit of 2 dimensional seepage monitoring based on fibre optic (Patent DE19621797, 2011).

The key to the new solution are bend optimized fibres, which can be bent to a very small radius without too much attenuation of light intensity when a laser pulse travels through them. The cable with typical outer diameter of 4 to 6mm including armouring and water tight protection has a minimum of two fibres inside it. At the far end of such a cable one of the internal fibres is bent through 180° and welded to a second fibre by fusion splicing. The splice and bend (or 'optic loop') are then protected against mechanical damage by a cover with a typical outer diameter of 8mm. This cable with fibre optic loop at the far end is inserted into the small diameter tube of a temperature probe that has been previously installed into the dam.

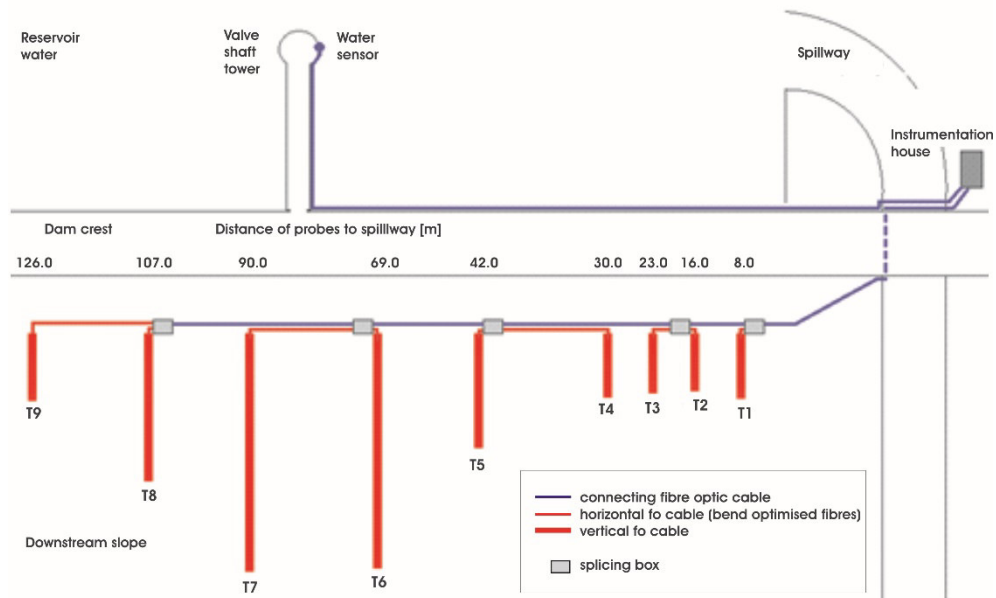


Figure 1. Sketch of a typical layout of fibre optic cabling

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For the tube installation the well-established temperature sounding method is used, by which high grade steel probes of less than 25mm outer diameter are vibrated into the earth fill dam and foundation along the dam's axis. Maximum depth ever reached is 45m. Individual cables are inserted in each probe and, in a shallow cable trench, a connecting cable runs from probe to probe and finally to the instrumentation house/cabinet. The fibres of each individual probe are spliced to the fibres of the connecting cable in a way that allows the laser pulse from the Distributed Temperature Sensing (DTS) instrument to travel along the connecting cable, running down and up each probe from one end of the dam to the other as shown in figure 1. For high precision measurements and calibration reasons it is recommended a complete "light pass" loop is formed starting and ending at the DTS instrument. With this configuration of cables so called double-end measurements can be carried out. If less precision is acceptable it is sufficient to do single-end measurements with an open ending of the light pass.

Since the attenuation loss of light on each bend is not negligible this must be taken into account when selecting the "laser power" of the DTS instrument. If many probes are to be monitored along a dam, there is always the option of creating several "light passes" by using a connecting cable with a large number of fibres with each pair of fibres connected to a group of probes forming a "light pass". Typically 8 to 10 probes can be put together in one pass. More "light passes" require multi-channels in the DTS system and are measured one after another by multiplexing.

The new cables are available in two versions, one only for temperature measurements with fibres in a central stainless steel tube, surrounded by a strength member of stranded steel wires and a polyamide outer mantle. The second type has, in addition, two co-axle layers of electrical conductors around the central tube, by which means the cable and the probe can be heated so that the heat pulse, or active method of leakage detection can be employed (Dornstädter *et al*, 2010).

EXAMPLE OF APPLICATION

At the end of 2014 a first site was equipped with the new technique on an embanked river in France. The embankment of the river is about 11m high and has a long history of leakage and transport of fines.

For the detection of the leakage zones inside the embankment and its foundation a total of 37 GTC temperature probes were installed to a depth of 16m along a 430m long section of the dam. The profile follows the downstream edge of the embankment's crest (Figure 2).

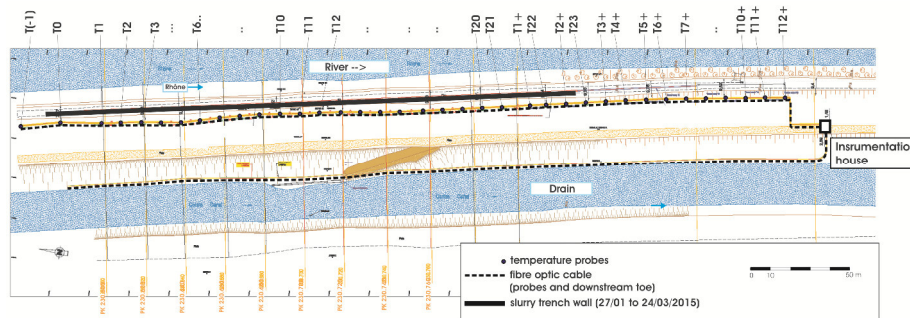


Figure 2. Site plan – 37 temperature probes

Fibre optic cables were installed in all 37 probes and connected by a cable in a small trench. Four light passes were built each ending at the instrumentation house (figure 3) situated on the downstream berm. Additional to the probes along the crest a fibre optic cable was installed from the instrumentation house in a trench along the downstream toe close to the open wide drain. The system is operated by solar power with a diesel power generator inside the instrumentation house as a back-up power supply for the batteries.

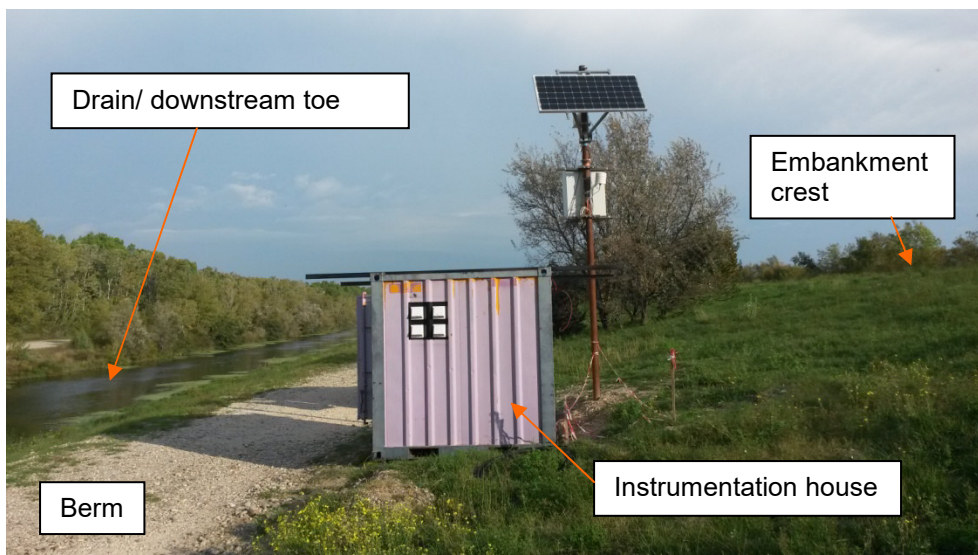


Figure 3. Instrumentation house on embankment berm

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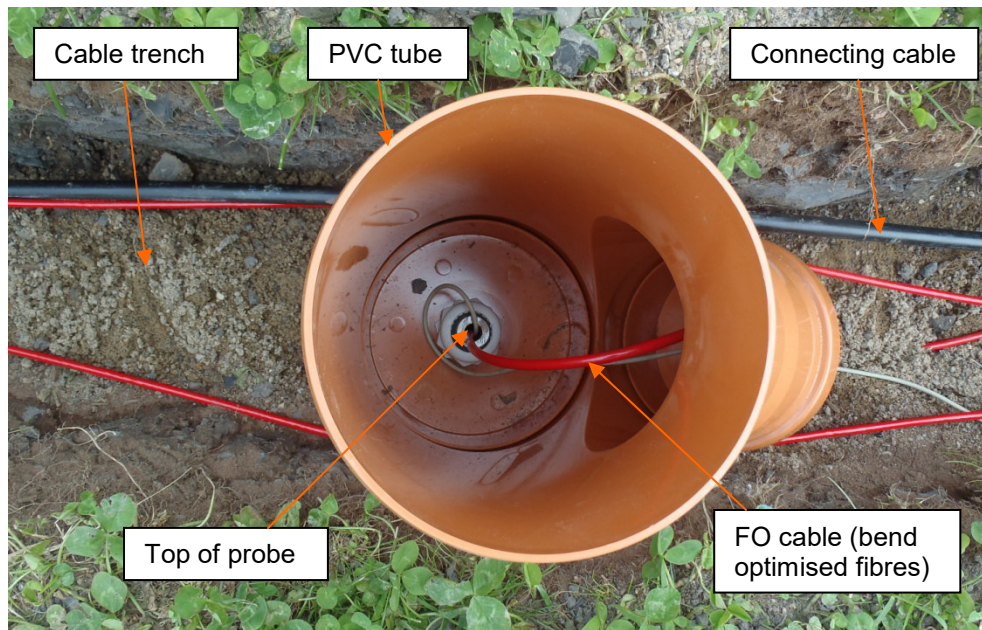


Figure 4. Installation situation

Figure 4 shows the position of one vertical probe. The small red cable with bend optimised fibres is inserted into the high grade steel probe, protected by a large diameter PVC tube. In the upper part of the figure the black connecting cable connecting all probes in a small 30 cm deep trench is visible.

Since the site was having leakage problems combined with transport of fines the client decided to build a slurry trench cut-off wall in Spring 2015. The remotely operated fibre optic monitoring system was installed in Autumn 2014. The 2-dimensional temperature distribution of 4th January 2015 about 3 weeks before the start of construction of the new cut-off wall is shown in Figure 5. In the centre a strong temperature anomaly is indicated by the blue colour corresponding to the low water temperature of the river in winter. The strongly percolated area extends from probe T6 to probe T21 from 7m to 14m depth below crest level, showing severe leakage flow through the lower part of the dam and through its foundation.

Two minor percolated areas were detected at T2/T3 and from T5+ to T7+ at the interface between the embankment and its foundation.

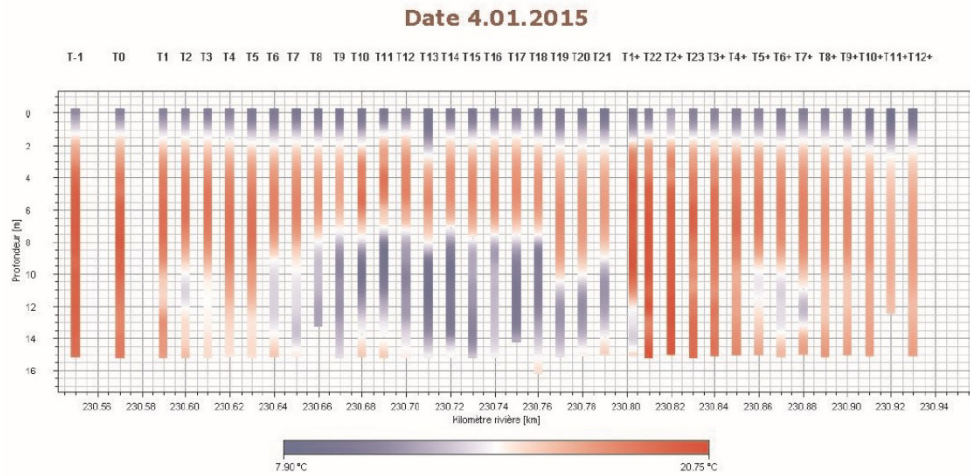


Figure 5. Temperature distribution before construction of cut-off wall

The temperature evolution before, whilst and after the construction of the cut-off wall was remotely monitored with automatic data analysis. During the construction procedure the client followed the success of the construction by the automatic temperature monitoring system. Figure 6 shows the temperature distribution some months after completion of the cut-off wall which was constructed along the array of probes between T0 and T2+.

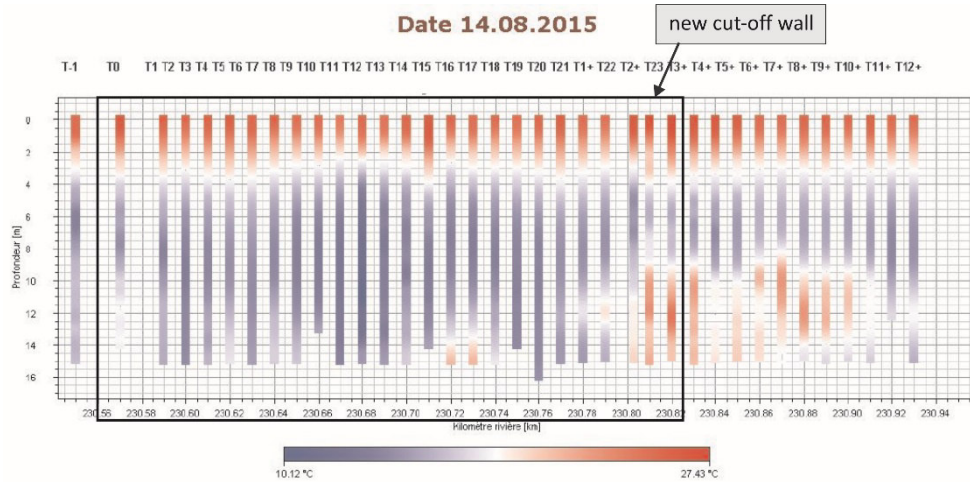


Figure 6. Temperature distribution after construction of cut-off wall

The result shows the appearance of an anomaly at the downstream end of the cut-off wall which indicates a lateral change in the direction of the seepage flow. Furthermore the previous minor leakage flow in the vicinity of probe T6+ has increased since the leak

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between probes T6 and T21 has been stopped. By stopping the leakage flow—the hydraulic pressure upstream of the cut-off wall has increased and this has caused the stronger flow around the downstream end of the wall.

CONCLUSION

Recent developments in the manufacture of fibre optic cables have enabled two well-proven ground temperature leak detection techniques to be combined, providing a means whereby fibre optics can be readily installed deep within the body of an existing dam.

This retrofitting of a leakage detection system has now been successfully undertaken at three sites and brings with it the advantages and possibilities of remote, continuous recording and real time monitoring, both for routine surveillance purposes and checking the efficacy of leakage remedial works. The temperature data obtained from the installation can be used to locate seepage areas and estimate pore velocities thereby assisting in the early detection of the onset of internal erosion.

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