A fiber optics textile composite sensor for geotechnical applications

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ABSTRACT

The fiber optics in structural health monitoring systems for civil engineering applications have been widely used. By integrating fiber optic sensing into a geotextile fabric, the TenCate GeoDetect® system is the first designed specifically for geotechnical applications. This monitoring solution embodies fiber optics on a geotextile fabric, e.g. a textile used into the soil, and combines the benefits of geotextile materials, such as high interface friction in contact with the soil, with the latest fiber optics sensing technologies. It aims to monitor geotechnical structure and to generate early warnings if it detects and localizes the early signs of malfunctioning, such as leaks or instability. This is a customizable solution: Fiber Bragg gratings, Brillouin and Raman scattering can be built into this system. These technologies measure both strain and temperature changes in soil structures. It can provide a leak and deformation location within accuracies resp. 1 l/min/m and 0.02%. The TenCate GeoDetect® solution provides objective, highly precise, and timely in-situ performance information, allowing the design professional and owner to understand system performance in addition to providing alerts for negative "geo-events" (subsidence) and other potentially deleterious events.

Keywords: Brillouin, Raman, Bragg, Geotextile, Strain, Leak, Temperature, Monitoring

1. INTRODUCTION

The understanding of the geosynthetic behavior in soil, especially when placed in civil engineering works, has always been a critical request and of great interest for owners and users. Also monitoring of earthworks and structures using soil materials is necessary to have a better knowledge of the processes involved. An accurate monitoring of civil engineering works allows one either to evaluate their actual safety level and optimize the design, or to survey the behavior of a structure which may be susceptible to change during time. For example, the instrumentation of geosynthetic reinforced soil structures (reinforced slopes and walls, embankments on soft ground) has been done for many years through traditional systems such as strain gauges or displacement sensors. These systems are generally only used for experimentation or during the construction stage for a short period of time. Limitations to these traditional instruments are both the time-consuming installation and a short service life of only a few months. They are also only discrete monitoring points, making the survey of large areas difficult due mainly to the installation itself. Furthermore, the installation and adhering of the sensors on the geosynthetics may have a negative influence on the measurement accuracy due to their size. Additionally, the durability of these traditional devices is generally very limited if sophisticated protection is not used. Today, the need of survey and instrumentation justify the research and development of more accurate tools, easy to install and allowing long term performance. In this context, a new type of textile composite fiber optics sensor named TenCate GeoDetect® was developed for civil engineering applications, combining the performance of the technical geosynthetic and optical technology for measurement of strain and temperature in soil and for the survey of reinforced earth construction. This paper will discuss the system performances gained from several experimental projects and the understanding from actual civil engineering applications.

2. THE TEXTILE FIBER OPTICS COMPOSITE SENSOR

The result of several years of development started in 2002 within two European Eureka projects and presented herein, consists of a high strength textile manufactured with optical fibers included in its production.

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The TenCate GeoDetect® solution embodies a geocomposite fabric, fiber optics, software and instrumentation to provide a innovative solution for the multi-functional requirements of a geotechnical application e.g. in-plane drainage capability, anchoring interface with the soil, protection of the optical fiber, reinforcement, separation, filtration in addition to data capture. It combines the benefits of geosynthetic materials with the latest sensing and measurement technologies to provide owners with unique information that drives risk reduction and, in some cases, cost reduction.

The fiber optic lines are attached in a mechanical process which creates a very strong bond with the textile and therefore an accurate measure of the soil elongation (Figure 1). Thus, the TenCate GeoDetect® sensor offers an accurate measurement system that can be easily adapted to monitoring very large areas or areas of reduced size based on project specific requirements.

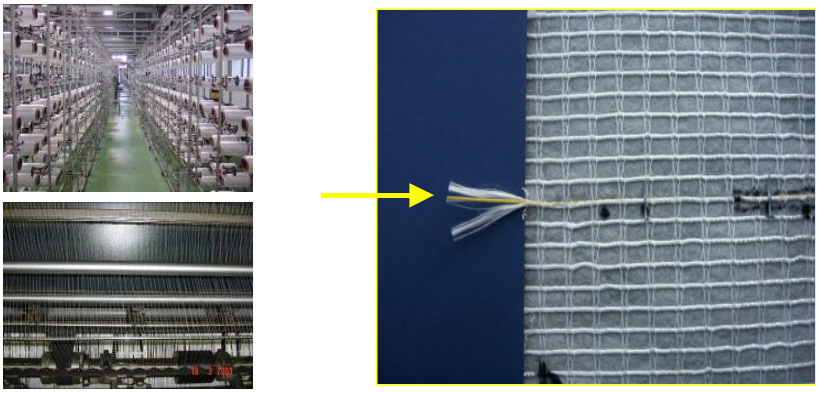

Figure 1. Optical fiber inserted during production.

It is a customizable solution that is created to meet the unique requirements of each individual project. Fiber Bragg gratings (FBG), Brillouin scattering and Raman scattering are all proven fiber optic technologies that can be built into this sensor. These technologies measure strain, strain & temperature or temperature only changes in soil structures. It also offers the possibility of inserting a number of fiber optic lines for different purposes at different locations. After the development phase, this new solution of measurement was installed at more than 20 sites, some of them were experimental projects from which its in-situ performance was assessed.

3. PERFORMANCE IN STRAIN MEASUREMENT

3.1 Strain measurement with Fiber Bragg Gratings

In order to better investigate the performances of the system under field conditions, in particular its behavior during installation, during the compaction of soil material and during subsoil collapse, experiments were carried out at the Regional Laboratory of the Bridges and Roads of Nancy (LRPC Nancy).

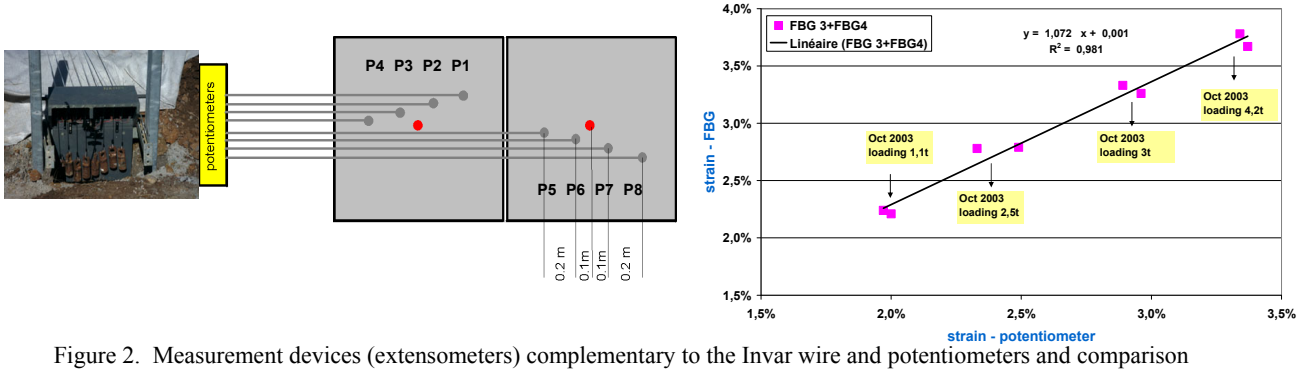

Figure 2. Measurement devices (extensometers) complementary to the Invar wire and potentiometers and comparison between measurements and potentiometers and those with optical fibers (red/purple dots).

The experiment consisted of installing a TenCate GeoDetect® S-FBG sensor equipped with two optical fibers 0.5 m apart with each one composed of thirty FBGs sensors with a spacing of 1m. A local collapse of the sub-soil was simulated by deflating and removing two balloons installed under the sensor, and loading it using concrete blocks, on the surface of the ballast layer over the cavity to further observe the deformation of the textile. In order to check the accuracy of the deformations registered by the textile composite sensor, an INVAR wire and potentiometer system of measurement was also installed (Figure 2). Four sheathed rigid cable extensometers were affixed to both sides of the points to be measured and at the center of each air bag and coincident with the FBG sensor locations. The displacement of the extensometers makes it possible to evaluate the deformation by differences. For each wire couple, one can calculate the deformation and compare it with the measurements taken by the FBG sensors. Figure 2 shows the correlation between measurements of the two FBG's sensors located at the top of the cavity and those measured with potentiometers for a gauge base of 60 cm. The correlation between the two measurement systems is very good with a low dispersion around the average curve.

The TenCate GeoDetect® S-FBG type was for example installed to monitor a bridge abutment reinforced by geotextiles. Three strips with eight FBG sensors each were installed in the soil fill during the construction of the wall. From the construction stage in 2004 till today, it was possible to follow the strain into the sensors from 0.02% till about 1%. Monitoring is still working 6 years after installation.

3.2 Strain measurement with Brillouin distributed scattering

The TenCate GeoDetect® solution was installed inside the dyke built for the IJkdijk (Smart Calibration Dyke) - Macrostability project focused on the structural stability of earth dykes. It was placed under the revetment, to measure the strain of the embankment. During the test, the global factor of safety of the dyke was decreased till failure occurs. The monitoring system worked perfectly by being the first solution among a tenth of other monitoring techniques to detect and to localizing the border of the instable zone. Stains inside the dike body as low as 0.02 % were detected allowing to localize the failure zone about two days before the dike collapsed (Figure 3).

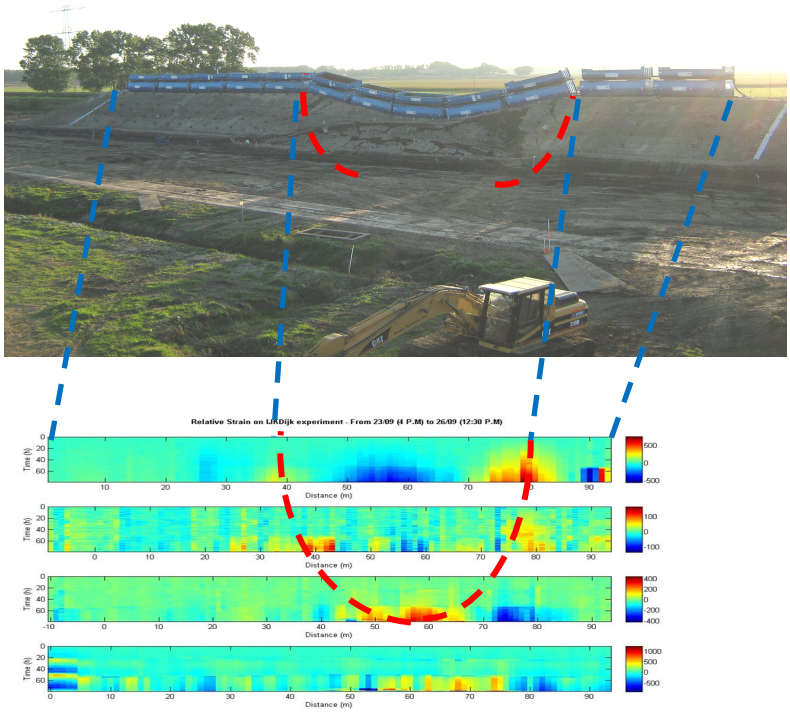

Figure 3. The experimental IJkdijk dyke after failure and the corresponding measurement of the strain several hours before failure.

4. PERFORMANCE IN TEMPERATURE AND LEAKAGE MEASUREMENT

To test and validate the TenCate GeoDetect® BR solution to detecting and quantifying leaks through the dike body of real structure using the distributed temperature measurement (Raman or Brillouin), an experimental basin was built on the Cemagref site in Aix-en-Provence, France. The main result from the experimental program is today the possibility to detect leaks through a dike with the order of magnitude of less than 1 l/min/m.

Another experimental dyke was built within the second phase of the Dutch IJkdijk project related to piping effects to test the ability of sensoring systems to detect the first signs of internal erosion. The piping channel was detected from 2 days to 5 days before collapse, depending on the data processing level.
Another important application for water resources management in waterways is leakage detection through a thin geomembrane lining system. The ability of the GeoDetect® system to perform this function was assessed within a trial carried out at the Cemagref basin. Leaks of the order of magnitude of 0.2 l/min per meter through the liner were detected.

Temperature and strain measurements are combined on the same TenCate GeoDetect® sensors to enhance the detection sensibility of the geo-events precursors of possible collapses.

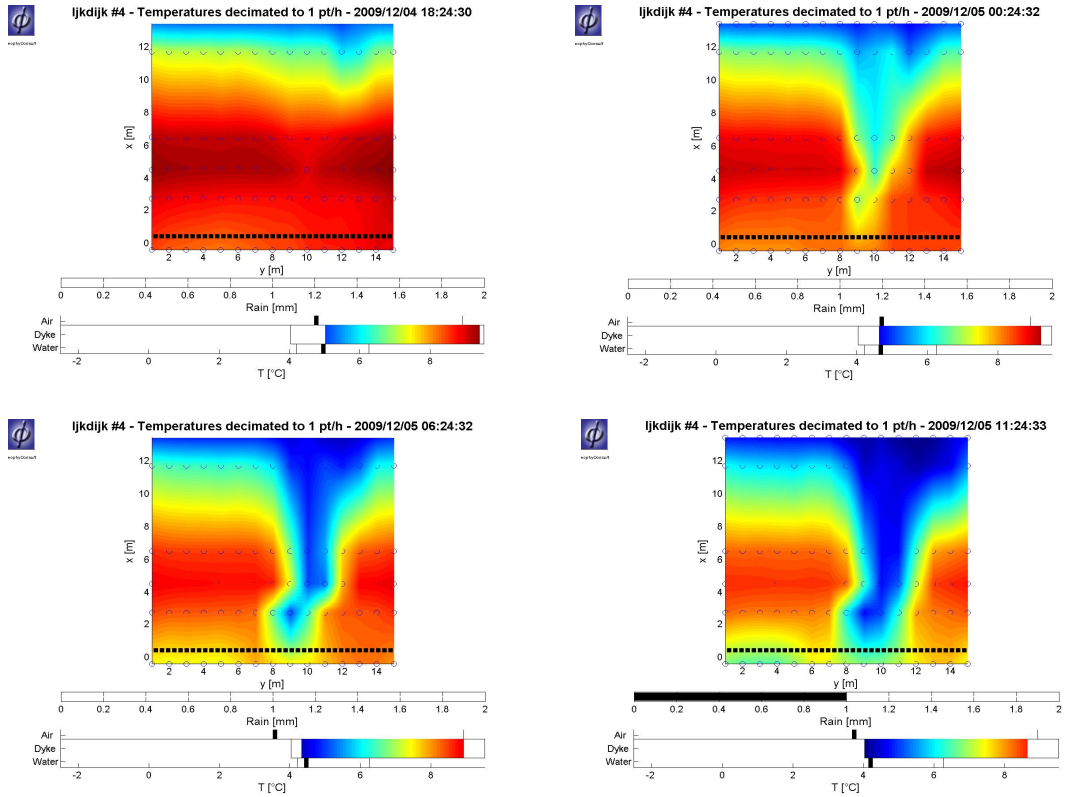

Figure 4. The TenCate GeoDetect® temperature profiles analyzed with the EDF/geophyConsult model at different time, resp. 17 hours, 11 hours, 5 hours before failure and at the failure, from the top left to the bottom right. View from the top of the dyke, upstream side at the bottom of the pictures.

5. CONCLUSION

The TenCate GeoDetect® solution is an innovation that combines the benefits of geosynthetic materials with the latest sensing and measurement technologies. It is fast and easy to implement. This customizable solution provides objective, highly precise, and timely in-situ performance information, allowing the designers and owners of earth and hydraulic works to understand system performance in addition to providing alerts for negative “geo-events” (subsidence) and other potentially deleterious events.