Geosynthetic Enabled with Fiber Optic Sensors for MSE Bridge Abutment Supporting Shallow Bridge Foundation

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ABSTRACT

Integrating fiber optic sensors into a geosynthetic reinforcement geotextile is an innovative system for strain and temperature measurement of soil structures. Using this technology allowed for the monitoring of a geosynthetic reinforced bridge abutment supporting shallow bridge foundations in St. Saturnin, France. Integrating the fiber optic sensor into the geotextile creates an intimate bond with the soil and allows for an accurate monitoring of civil engineering works. This allows engineers to evaluate the actual safety level and optimize their design or to survey the behavior of a structure which may be susceptible to change during time. Today, the need for instrumentation justifies the research and development of more accurate tools that are easy to install and allow for long term performance. In this context, a new type of geosynthetic was developed for civil engineering applications. It combines the performance of the technical geosynthetic and optical technology for measurement of strain in soil and for the survey of foundation and earth construction. This paper will discuss the geosynthetic enabled fiber optic sensor system and the case history of its use to monitor the bridge abutments for 5 years for the project in St. Saturnin, France.

INTRODUCTION

The new bypass along the RN 38 at Saint Saturnin near Le Mans in France required a bridge structure in order to cross a small river. To keep construction costs down, the bridge was constructed using a geosynthetic reinforced abutment. A 9.5 m (31 foot) high geosynthetic reinforced segmental retaining wall (SRW) was constructed to service the bypass. The facing system of the abutment consisted of small dry-cast concrete blocks to provide an aesthetic bridge structure.

Use of geosynthetic reinforced SRW's as a bridge abutment to support shallow bridge foundations was an emerging technology and had not been common in France. This solution was chosen and designated as a reference project by the owner, the local representative of the French Ministry of Transport, to evaluate more economical bridge solutions and more aesthetic bridge structures. Therefore, a monitoring system was required, allowing the measurement of the deformations of the wall both during construction and after completion, at reasonable cost. This allows the system to verify that the deformation of the soil remains below the design values. This paper will describe more precisely the structure and the fiber optic measurement device, and the results obtained, in relation to the durability and performance of the system.

ST. SATURNIN BRIDGE PROJECT

The abutment comprises of a main 7 m (23 foot) high geosynthetic reinforced SRW that supports the shallow foundations of the bridge. At the rear of the bridge foundation there is an 2.5 m (8 foot) high tiered SRW also reinforced by geosynthetics to support the roadway approach. The bridge abutment was design using traditional mechanical stabilized earth (MSE) wall design using geosynthetics. The total area of the 2 bridge abutment walls consisted of 900 m² (9700 ft^2) of facing, comprised of small 26 kg (57 lb) concrete blocks called "Leromur Blocks" which provides a facial aesthetic of an "old stone wall".

The reinforcement of the reinforced abutment was provided with a high-strength knitted polypropylene geotextile with an ultimate tensile strength of 150 kN/m (10,275 lb/ft). The wall design indicated a minimum embedment length of 6.5 m (21 feet) for the reinforcement extending back from the face of the wall. The vertical spacing of the geotextile reinforcement layers was 39 cm (15.4 inches) which corresponds to three courses of facing blocks. The geosynthetic reinforced SRW was selected because it provides a more economical and aesthetic bridge structure, and does not require heavy construction equipment or cranes to install the wall.

Measurement Device

Principle of measurement

Fiber optic sensors have been used in various applications for many years. These applications were mostly limited to affixing sensors to structural elements, like steel and concrete. More recently the incorporation of a fiber optic sensor into a geosynthetic material, allows for the use of these sensitive and highly precise sensors into soil structures and geotechnical design applications.

The design philosophy was to monitor the deformation of the geosynthetics through the strain measured directly on an optical fibre. This is possible using either the technology of the Fibre Bragg Gratings (FBGs) or the distributed Brillouin scattering technology. Fibre Bragg Gratings are diffracting elements printed in the photosensitive core of a single-mode optical fibre. This grating reflects a spectral peak based on the grating spacing, thus changes in the length of the fibre due to tension will change the grating spacing and the wavelength of light that is reflected back (Fig. 1). Quantitative strain measurements can be made by measuring the centre wavelength of the reflected spectral peak.

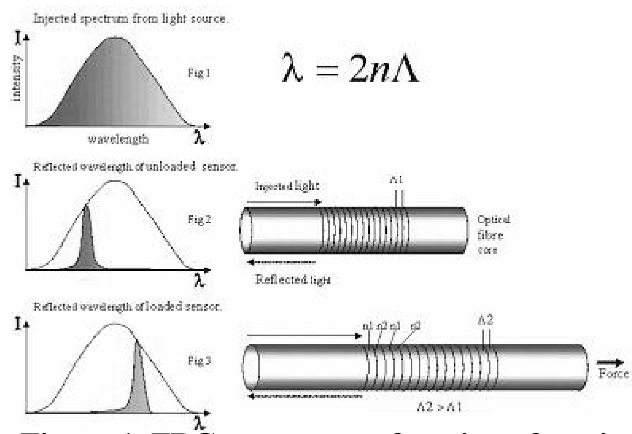

Figure 1. FBG response as function of strain

Signals of various FBG sensors can be identified by using different wavelengths on which the mirrors are reflecting. The wavelengths and wavelength-shifts of these so-called mirrors can be measured with a fibre optic unit that allows their demultiplexing in the wavelength domain. In this way, the space distributed sensors are identified and distinguished. As each sensor has its own characteristic wavelength, the sensors can be connected in series on one optical line with a relatively low cost measurement unit. The advantage of embedding fibre optics into a technical textile is the very good strain transfer from the soil to the fibre optic cables due to the very good friction properties between the geotextile and the soil Embedding the fiber optic into the geotextile during production creates a very strong link between the geotextile and the optical fibre for sensitive measurement of soils structures by the GeoDetect® system. The use of optic fibres embedded in a geosynthetic was tested both in small scale in the laboratory and in full-scale (Briançon et al., 2004). The resistance to the installation stresses and practical performances were studied and validated particularly at the LRPC Nancy (public laboratory of bridges and roads - France) and at LTHE (University of Grenoble - France). It was shown that the strain measured by the optic technology corresponds to the deformations of the geosynthetic (Nancey & al., 2004).

The total system is composed of the sensor enabled geotextile, along with the data acquisition and analysis devices. The measurement devices consist of a data collection device, call a Fiber Optic Interrogator and a laptop computer for data collection. The Interrogators are available with a variety of options, including the number of channels and the kHz of the device for static or dynamic readings. Most Interrogators come with their specific software to collect and analyze the data. These systems can include full-time or periodic; permanent or temporary; static or dynamic monitoring

Construction

The construction of the bridge was achieved in three stages. The earthwork was completed in 6 weeks during July and August 2004; the foundations of the bridge were placed in March 2005 and the bridge itself was installed in May 2005.

The bridge abutment was equipped in July 2004 with three TenCate GeoDetect® fiber optic sensor strips to measure the strain and deformations within the embankment during the construction of the structure (Figure 2). Each strip is 7 m (23 feet) long and 38 cm (1.25 feet) wide with 8 FBG sensors spaced at 85 cm (2.8 feet). The strips were anchored 25 cm (10 inches) between the facing blocks (Figure 3), similarly to the geotextile reinforcement. The first strip was placed between two layers of geotextile within the free-draining backfill at the bottom of the embankment. The second and third strips were installed at the level of a geotextile layer in the upper part of the reinforced structure where a smaller gravel backfill was used. The 3 strips were protected with 5 cm (2 inches) of a clean coarse sand.

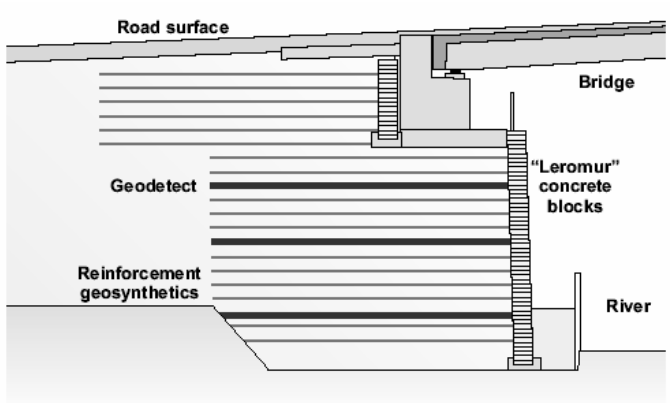

Figure 2. Distribution of strips within the northern abutment

The geosynthetic sensors were shipped directly to the construction site ready for installation. Installation consisted of preparing the area, unrolling the strips and connecting the cables. Compared to other systems, installation time was very short: less than one hour was required for a single strip, including preparation of the place, the installation of the strip with the connection cable, the fill placement and compaction of the top soil layer.

Figure 3. The GeoDetect® strip No. 2 installed

The fiber optic geosynthetic mats are connected to a data collection device (Figure 3), in this case a hand-held version with a PDA integrated for sporadic checking was used. The data collection system can also be set-up as a full-time remote access system for constant monitoring. For this project, periodic monitoring during construction events and at regular intervals after completion was sufficient for the structure.

System Measurement

Strains were monitored continuously during the installation of the strip, placement of the overlying fill, and its compaction. The evolution of the strain measured on the first strip can be seen on Figure 4. No values greater than 0.5% were recorded during compaction. After installation, the strain values stabilised between 0 and 0.3%.

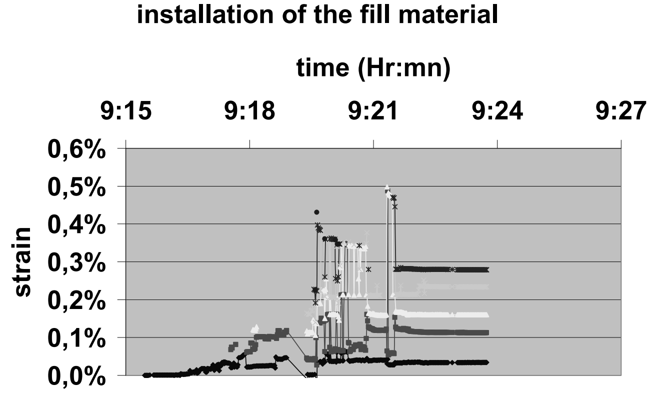

Figure 4. Measurement during installation of strip No. 1

All strips show the same type of behaviour.

Evolution of the strains during time

Following construction of the embankment, further measurements were undertaken in September 2004, February 2005 and June 2005.

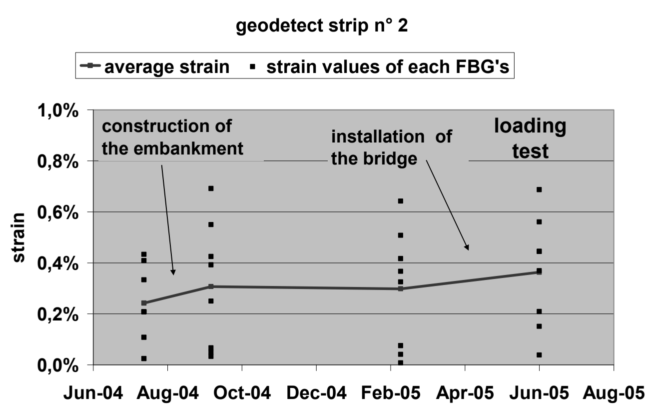

Figure 5. Evolution of strains measured on strip n°2 during construction.

These highlight the effect of the different loading phases, with a clear increase of the relative elongation of the strip that corresponds to the average strain of all the sensors (Figure 5). From September 2004 to February 2005, no construction was carried out on the embankment. It can be noticed that the average strain is totally stable during this period.

The strain is not uniform along the strips, with a minimum on sensor #1, placed at the furthest point from the facing. At the opposite end, sensor #8, the closest point to the facing, shows the greatest values.

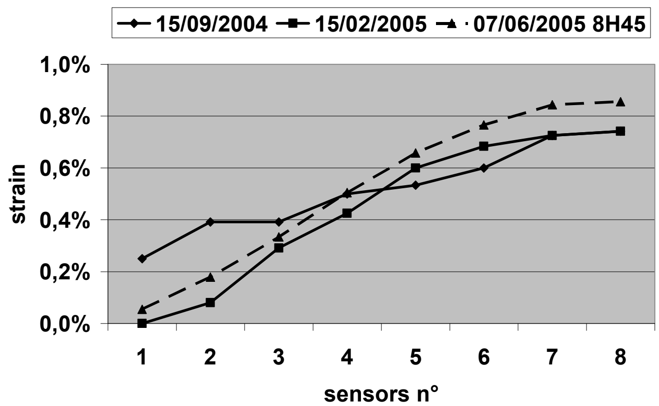

Figure 6: Strain profiles of strip No. 1 at different times

Distribution of strains in the reinforced structure

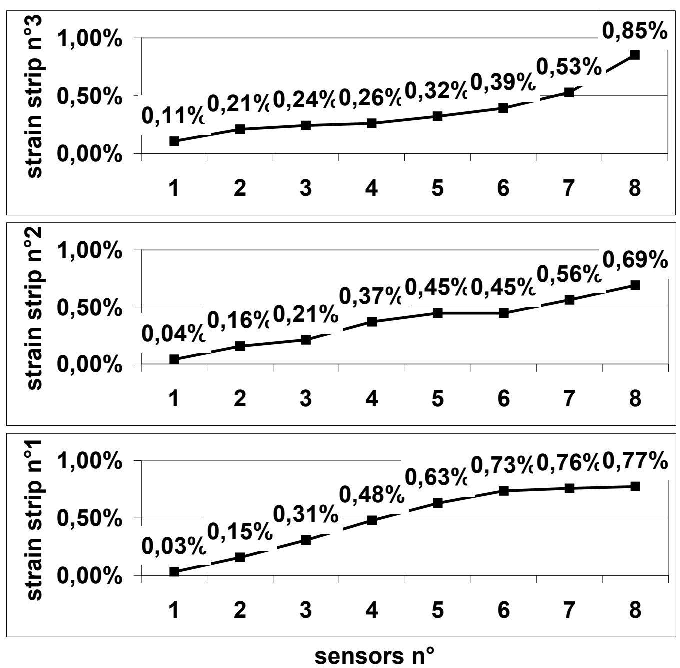

Figure 7: Strain profiles of the 3 strips – June 2005

Figure 7 shows the distribution of the strain in the reinforced structure measured in June. The strain levels of the different strips are in the same range, below 0.9% at the maximum. The average strains are equal (0.4% strain) for Strip No. 2 and No. 3, and 0.5% for the first strip.

The project has continued to be monitored by the fiber optic sensors for the past six years. Prior to the development of these fiber optic sensors, mechanical strain gages were used on geosynthetics with low levels of success. The gages typically would only last 6 months to a year if they survived installation. Fiber optic alternatives are already showing high levels of durability for instrumentation devices and continue to provide useful readings for several years after installation.

Figure 8 shows the sensor reading from initial construction in 2004 to several years after completion in 2009. No significant increase in strain was observed after the completion of construction. This confirms that inextensible reinforcement is not required to support bridge structures.

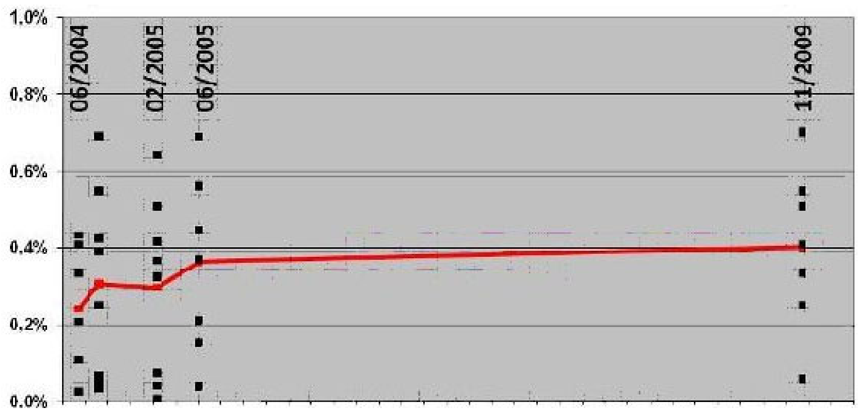

Figure 8: Average Strain profile of the 3 strips – 2004 to 2009

CONCLUSION

The bridge abutment constructed in Saint Saturnin is particularly remarkable. In France, this is one of the first geosynthetic reinforced walls that directly supports the weight of a bridge. Until now this type of structure was realized with more traditional methods like cast-in-place concrete structures. One of the assumed disadvantages of using geosynthetic was the level of strain of the structure due to the use of an extensible material. A completely new measurement device based on the optic fiber sensor inserted in geosynthetic strips has been installed to verify performance of the structure. Compared to the conventional sensors, the TenCate GeoDetect® system offers many advantages: quick installation, durability and accuracy. Thanks to this new system, the survey of the deformation inside the reinforced abutment was easily performed. It shows clearly that the strains are limited at levels lower than 0.9% at the maximum or at 0.5% if the average strain of a strip is considered. It was also observed that these strains developed mainly during construction. Fiber optic sensors offers designers an additional tool to evaluate the performance of soil structures to provide more economical solutions.

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