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Set up of a warning system integrated inside a reinforced geotextile for the survey of railway

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ABSTRACT: After the detection of a perpendicular fault to a railway and to avoid any risk that a train circulates on a collapsed area, the French railway service decided to reinforce the structure by geosynthetics that was considered as the best solution to avoid a long interruption of the traffic. Additionally, it was decided to install a new warning system called "Geodetect", which combines reinforcement and strain measurement, in order to check his behaviour on real site condition. Particularly, the resistance during installation and the level of strain measured during the traffic were the main parameters to be followed. Considering the geometry of the structure and the various loads, the reinforcement part of the geosynthetic was designed to allow the respect the surface settlement criterions. The optical sensors network was designed to optimize the number of sensors and to ensure the detection by a minimum of one sensor. To not disturb the traffic of the trains in the daytime, geosynthetic was laid during the night.

1 INTRODUCTION

More and more an accurate monitoring in civil engineering works is required, to survey the behaviour of a structure, which may be susceptible to change with time. This is the case for railways, where the risk of failure due to underground cavities may affect the structure.

The French railway service (SNCF) detected a perpendicularly fault to a railway track between Mouchard and Bourg located in the French northeast region.

The SNCF decided to reinforce the structure with a geosynthetic to prevent a sudden collapse and to limit the surface settlement. Compared to traditional solution like concrete slab, the geosynthetic reinforcement was considered as the most economic solution, considering that it induced only a short interruption of the traffic and no costly material.

The SNCF took advantage of this work site to install a new warning system to ensure the detection of holes and to survey the deformation of the soil, this to avoid any risk that a train circulating on a collapsed area. This new warning system, result of a research program called "Geodetect", obtained the label Eureka (Σ! 2579/F958) in 2001. It combines the reinforcement given by a geosynthetic and a monitoring system based on optical technology.

Details of the reinforced platform, warning system, installation techniques are presented in the following sections.

2 EXISTING SUPERSTRUCTURE

The SNCF evaluates that the fault could cause localized sinkholes of 1.2m to 1.5m diameters. Two stiffening rails were placed to reinforce temporarily the area where the risk was identified. (Fig.1)

Figure 1. The concerned area of the railway track

The length of the concerned area is 50 meters and the width of the railway is 5 meters. The embankment under the railway consists of a 25 cm ballast layer and a sub-base of 50 cm thickness (Fig.2).

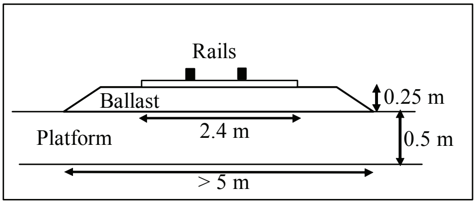

Figure 2. Existing superstructure

3 REINFORCEMENT DESIGN

The geosynthetic was designed by an analytical method (Villard et al., 2000) developed during the RAFAEL project, which was launched to study the behaviour of the geosynthetics on cavities. A vertical collapse and a decompaction of the embankment are considered as shown during the experimentation on real site.

The design parameters considered were:

- An expansion coefficient in the embankment layer $C_{ce} = 1.1$,
- The stress applied on the platform without train (structure + ballast layer) $q_0 = 6$ kPa,
- A load of 225 kN per axle distributed on 3 rail sleepers,
- A cavity of 1.2m to 1.5m in diameter.

With these parameters, the maximum stress applied on the geotextile is equal to $q_{max} = 45$ kPa; it is the case for a cavity localized under a railway when a train runs. Then, the geosynthetic chosen is a composite product: a Rock Pec 300 with a tensile strength of 300 kN/m made from a non-woven needle punched and polyester yarns.

As soon as a hole is detected, a more complete reinforcement is necessary to insure long-term stability. The geosynthetic reinforcement is a temporary solution, the hole that reach the level of the structure can be enlarged during time, thus invalidating the hypothesis of design.

For thick structure, or when the reinforcement does not allow seeing that a hole has appeared, a warning system is required.

4 WARNING SYSTEM

This system combines the reinforcement aspect with the warning aspect based on the optical technology inserted in a geosynthetic (Fig.3). The idea consists to follow the deformation of the geosynthetics and to launch an alarm when a predefined threshold is reached (Nancey et al., 2005). In the case of reinforcement above cavities, the strains are at a low level when the product is installed, but as soon as a hole reaches the geosynthetic, the strain increase very quickly at the level needed to mobilize enough strength in the product to support the weight of the structure.

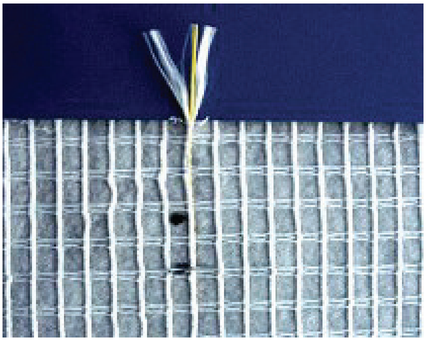

Figure 3. FBG inserted inside geotextile

4.1 *Optical technology*

The warning system uses the technique of the Fibre Bragg Gratings (FBGs). 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 or compression will change the grating spacing and the wavelength of light that is reflected back (Fig. 4). Measuring the centre wavelength of the reflected spectral peak allows quantitative strain measurements.

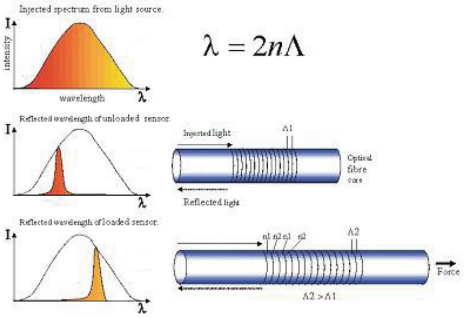

Figure 4. FBG response as function of strain

The interest is that by using different wavelengths on which the mirrors are reflecting, signals of various FBG sensors can be identified.

The wavelengths and wavelength-shifts of these so-called mirrors can be measured with a fibre optic unit allowing demultiplexing them in the wavelength domain. In this way, the space-distributed sensors are identified and distinguished. Because each sensor has its own characteristic wavelength, the sensors can be connected in series on one optical line or a star configuration can be made. In this way (by using an optical switch) several hundreds of sensors can be measured with a relatively small low cost interrogation unit.

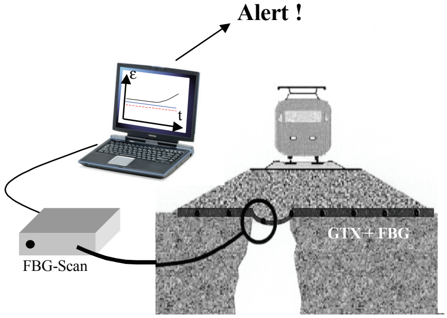

Figure 5. The Geodetect system

4.2 *The "optic fibre" system properties*

To ensure the water-tightness of the monitoring device, a flexible sheath protects the optical fibres. Thanks to this sheathing and the intrinsic behaviour of the fibre, the system is:

- Immune to lightning strikes,
- Corrosion resistant,
- Free of electromagnetic,
- Radiation resistant,
- Explosion proof (no risk of sparks).

The measurement system consists of data collection device (Spectrometer) and of a computer (or laptop) allowing the following of the optical fibres spectral answer (Fig.5). The Spectrometer is also available in a hand-held version connectable to a PDA for punctual checking on instrumental earthworks. This is an interesting solution for the follow-up of structures, when the risk cannot justify a continuous survey. The system 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 especially studied and validated.

4.3 *Warning system design*

The design of the complete system consisted of:

- Determining the best reinforcement solution to ensure the stability of the structure above a sinkhole,
- Designing the optimised Fibre Bragg Gratings network to ensure the detection of localized sinkhole.

The design criterions are geometrical criterions at the surface imposed by the French railway service:

- Warning criteria for a surface settlement $s_W = 6mm$,
- Slowdown criteria for a surface settlement $s_s = 9mm$,
- Intervention criteria for a surface settlement $s_i = 21mm$.

The stiffness of the geosynthetic was designed to respect the "intervention criteria", but the sensitivity of the Bragg sensors allows launching a signal as soon as the strain will reach the "warning criteria".

The Fibre Bragg Gratings network was designed to optimise the number of sensors and to ensure the detection by a minimum of one sensor above the cavity. 5 fibres spacing of 0.85m constitute the network with also 0.85m between the FBG's sensors along each line. So the warning system contains 297 Bragg gratings (Fig.6).

A triangular network was chosen because it allowed a better detection than a rectangular network. With a rectangular network, 28 % of cavities are detected by one sensor and 72 % by two sensors. With a triangular network, 20 % of cavities are detected by one sensor, 71 % by two sensors and 9 % by three sensors.

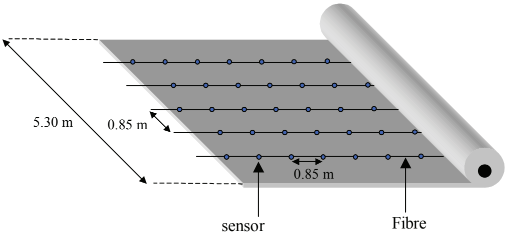

Figure 6. Fibre Bragg Gratings network

To localise the sinkhole, each fibre contains three series of 20 Bragg gratings (two series of 20 Bragg gratings and one series of 19 Bragg gratings for the fibres with 59 Bragg gratings) reflecting three distinct wavelengths. This configuration allows localising a sinkhole in an area of 16.7m lengths. Every two fibres, the Bragg gratings series are shifted of 8.3m to increase the localisation when the sinkhole is detected by two or three Bragg gratings located on different fibres (Nancey et al., 2004).

5 CONSTRUCTION WORKS

5.1 *Installation of the equipped geosynthetic*

The earthworks were planned during the night between the 18th and the 19th of October 2004, to not disturb the traffic of the trains in the daytime. The traffic was cut at 11PM and the line had to be reopened at 6AM. The rails, the ballast and 50 cm of subgrade were removed before the installation of the geosynthetic equipped with the optic fibres and 2 connections cables (fig.7). The conditions were particularly harsh due to the small space, darkness, limited time and wet conditions, and the movement of the mechanical digger and bulldozer. However, thanks to the preparation done in advance at the factory, the installation of the equipped roll did not slow down the progress of the contractor.

Figure 7. Installation of the roll during the night

5.2 *Installation of the equipment*

A special weatherproof box was build to give a correct protection to the measuring devices. This box was installed in August 2005 and immediately after all the material needed for the continuous survey of the lines (Fig. 9):

- The optical source and an optical switch to connect the different lines,
- An industrial lap-top,
- A cooling and heating unit.

Figure 8. Installation of the material

Special software was designed to follow and to show the strain measurements with all the needed parameters defining the threshold values of the warning (Fig.9).

The warning system by FBGs inserted to a geotextile developed by Bidim Geosynthetics / Polyfelt Geosynthetics and ID-FOS is now working under a railway where a risk of soil subsidence has been identified.

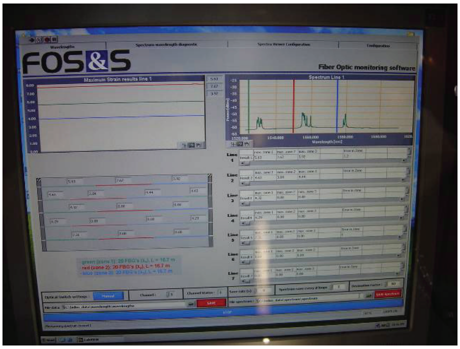

Figure 9. Control screen with the different optic lines

6 CONCLUSION

A warning system by FBGs inserted to a geotextile has been set up under a railway where a risk of soil subsidence has been identified.

The installation of the instrumented geosynthetic in October 2004 in a difficult environment confirms that a complete preparation of the roll is absolutely necessary. Particularly, all the connections have to be realised in advance. This was the case for this job in Arbois and the timing fixed to realise the earthworks was respected.

The monitoring equipment was installed in August 2005. An analysis of the first results and the feedback on the behaviour of the system after few months of functioning is going on and will be the subject of other publications.

REFERENCES

Briançon, L., Nancey, A., Caquel, F. and Villard, P. 2004. New technology for strain measurements in soil and the survey of reinforced earth constructions. *Proc, EUROGEO 3*, March 01-03 2004, Munich, Germany, pp. 471-476

Nancey, A., Briançon, L., and Villard, P. 2004. Geodetect: The first “intelligent” geosynthetic for the measurements of strain in soil and the survey of reinforced earth construction, *Proc., Railway Engineering* - 2004, July 6- 2004, London, UK.

Nancey, A., Voet, M. and Vlekken, J. 2005. Geodetect: a new step for the use of fiber optic Bragg Grating technology in soil engineering. *Proc., 17th International Conference on Optical Fiber Sensors*, Bruges, Belgium, 2005 May 23-27, pp. 214-217

Villard, P., Gourc, J.P. and Giraud, H. (2000) A geosynthetic reinforcement solution to prevent the formation of localized sinkholes. *Canadian Geotechnical Journal*, **37**, n° 5, pp. 987-999