Contribution of Fibre-optic Geosynthetic Instrumentation for the Monitoring of Rehabilitated Failed Slope

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ABSTRACT
Instrumentation of geosynthetic reinforced soil structures is particularly useful to government authorities, quality and research agencies to monitor the behavior of soil structures and consequently to enhance learning. Unfortunately, the proportion of instrumented structures compared to those constructed is almost negligible. One of the main problems is the difficulty in providing reliable instrumentation on the geosynthetic itself. There are other issues too such as the complication of calibration of the measuring sensors to provide acceptable measurements, and that installation at site is usually cumbersome and logistically demanding. With the incorporation of fibre-optic technology for geosynthetic instrumentation, many of the problems faced using conventional method of measuring sensors are eliminated or minimized. These are presented in the paper together with the illustration on the basic concept of fibre-optic geosynthetic instrumentation. The aim of the paper is also to introduce the various applications for geosynthetic instrumentation using fibre optic and to provide a case history of such successful application highlighting the results and key features of the technology.

1 INTRODUCTION

Instrumentation on geosynthetics to monitor their behavior and their interaction with the soil, have been a challenging task for engineers despite the extensive use of geosynthetics for reinforcement of soil structures. This is because of the polymeric nature of the material and for some geosynthetics, due to their non-homogeneous characteristics. This makes reliable and robust instrumentation of geosynthetics difficult. The problem is compounded by the need to calibrate the strain sensors placed on the geosynthetics. This normally requires every sensor to be calibrated in order to establish some degree of accuracy and reliability on the measurements. Then there is also the problem of transporting and installation of the instrumented geosynthetics. Conventional instrumentation would require conductive wires running all over the place from the strain sensors and the need to have a data logger to acquire the data. The question of durability of the instrumentation then crops up as most of the instrumentation are electrically operated which corrosion and water resistant become a problem.

The technology of using optical fibre incorporated into a geosynthetic has made the reinforcement and monitoring of soil structures simultaneously, possible. Optical fibre complete with strain sensors can be ‘implanted’ inside the geosynthetic using special manufacturing technique. In so doing, the geosynthetic is enhanced with the ability to determine the strain exerted in the reinforcement.

This technology allows the incorporation of strain sensors in the geosynthetics without the need of cumbersome calibration. It offers huge advantages to engineers and makes instrumentation of geosynthetic reinforced soil structures and soil structures effortless. It also provides opportunity for remote data acquisition and the implementation of early warning system to help mitigate disaster in the event of potential failure problems. This paper provides information on the technology and shows the simplicity of the technology in providing accurate and reliable measurements. Several application examples are given to demonstrate the versatility of the geosynthetic in reinforcing and monitoring of soil structures.

2 OPTICAL TECHNOLOGY AND GEOSYNTHETIC INSTRUMENTATION

The use of optical fibres for monitoring engineering structures expanded in the 1980s. Various monitoring devices were developed. The sensors in the optical fibre used for the strain measurements of geosynthetics employs the technique of Fibre Bragg Gratings (FBG).

FBG is diffracting element printed in the photosensitive core of a single mode optical fibre. If light of a broadband source (large spectral width) is transmitted into an optical fibre with a FBG, only the spectral component satisfying the Bragg relation will be reflected by the grating. The grating reflects a spectral peak based on the grating spacing; therefore, changes in the length of the fibre due to tension or compression will change the grating spacing and the wavelength (λ) of light that is reflected back (Briançon *et al*, 2004). As a result, quantitative strain measurements can be made by measuring the centre wavelength of the reflected spectral peak (Figure 1).

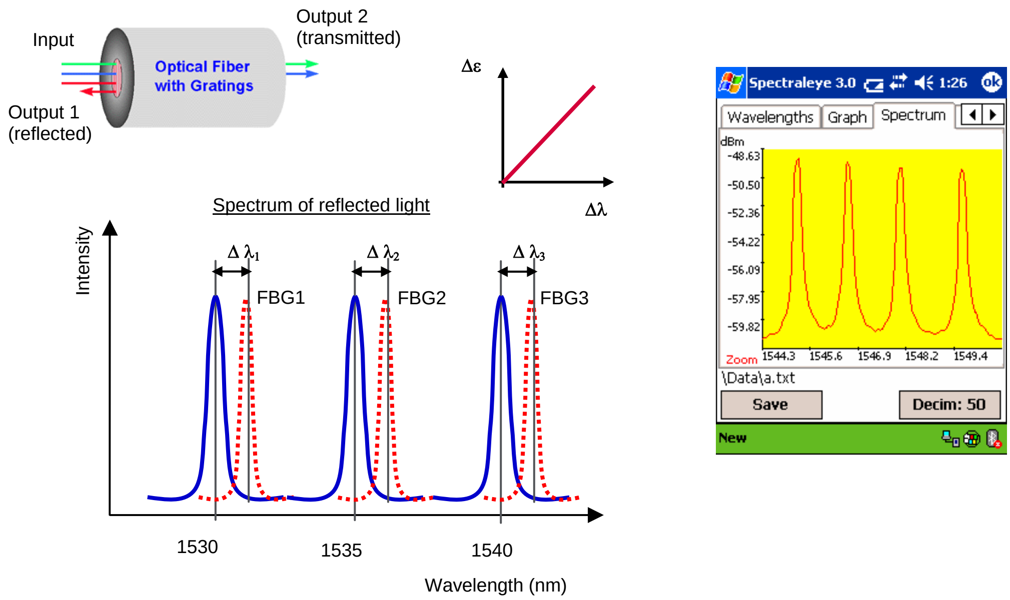


Figure 1. Principle of Fibre Bragg Grating (FBG) sensors.

An interesting feature of the optical fibre technology is that several FBG sensors of different wavelengths can be incorporated in a single fibre optic. By using different wavelengths (λ_1, λ_2, λ_3 etc.), signal from each individual FBG sensor can be identified and distinguished. The wavelength or wavelength-shift in each individual sensor can be measured using an interrogation unit within a specific wavelength domain. Because each sensor has its own characteristic wavelength and the sensors being integrated in series (at regular spacing interval) along one optical fibre line, several sensors can be measured simultaneously and the location of the strains along the fibre optic can be identified.

To integrate the strain sensors so as to become an intrinsic part of the geosynthetic, and thus making an 'intelligent' geosynthetics, continuous length optical fibre impregnated with FBG sensors, is inserted into a reinforcing geosynthetic using special manufacturing process (Figure 2). As the FBGs are laser impregnated in a controlled laboratory condition, the characteristics of every FBG is consistent to one another and calibration of wavelength versus strain need only be conducted on a single FBG. In this way inconsistent placement of sensors on the geosynthetic as would have been in conventional strain gauges is avoided and therefore eliminating the complication of calibrating every sensor. The accuracy of measurements is therefore not compromised. The accuracy and reliability of the measurements using this technology has been established by Kongkitkul *et al*, (2006) and the construction survivability of the 'intelligent' geosynthetic has been illustrated by Loke *et al*, (2007).

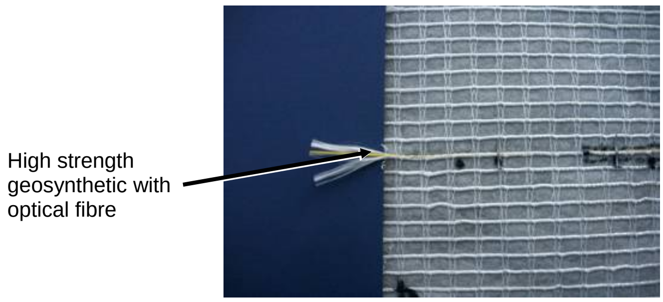
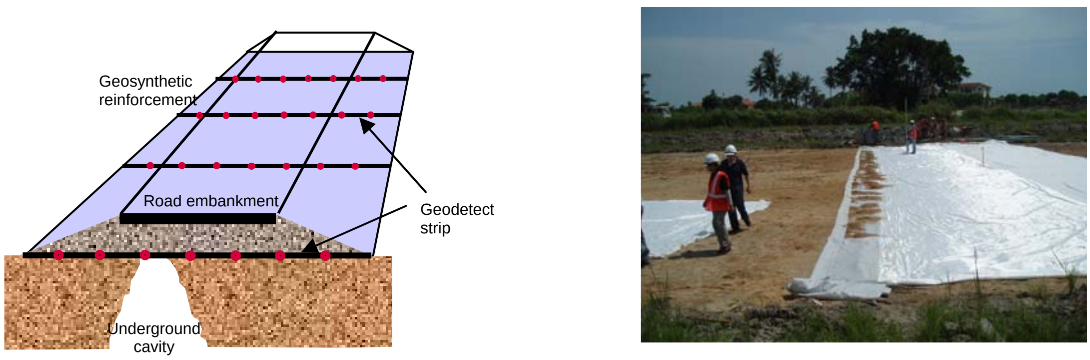


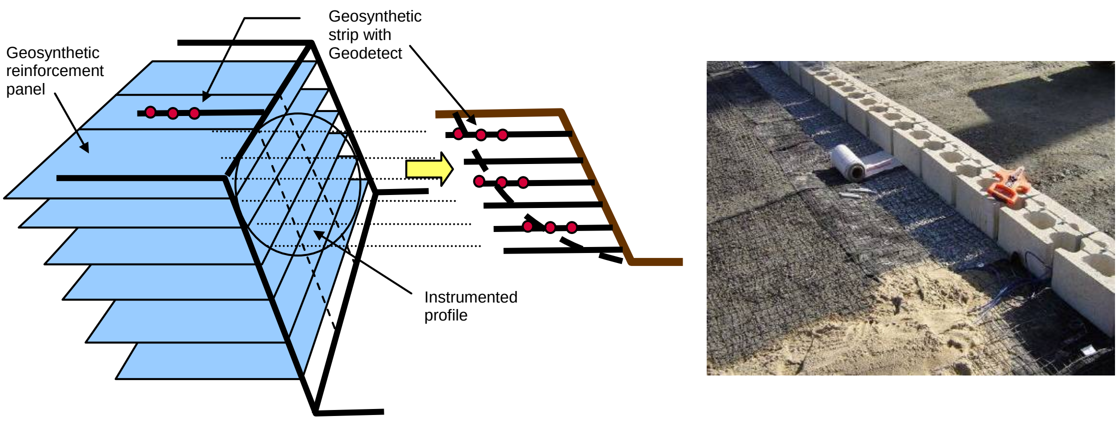
Figure 2. 'Intelligent' geosynthetic with optical fibre inserted into a reinforcing geosynthetic through a special manufacturing process.

3 CONTRIBUTIONS OF FIBRE OPTIC GEOSYNTHETIC

The contributions of fibre optic geosynthetic in reinforcing and monitoring of soil structures have been realized in many civil engineering projects such as reinforced soil slopes and walls, basal embankment reinforcement, piled embankment and hydraulic structures (Loke *et al*, 2007). Given below are some illustrations where 'intelligent' geosynthetic has been used for monitoring of soil structures (Figure 3).



Monitoring of geosynthetic reinforced basal embankment, piled embankment and soil subsidence area.



Monitoring of wall and slope (fill and cut slopes) structures.

Figure 3. Some successful applications of 'intelligent' geosynthetic for monitoring of soil structures.

Presented in this paper is a case history where results of the measurements have been obtained with permission from the parties involved.

3. Monitoring of reinforced soil slope at Maehongson, Thailand

3.1.1 Description of the reinforced slope and instrumentation

Since 2005 numerous slope failures have occurred in the north of Thailand, Maehongson Province. The highway route leading to the north comprised of roads that were constructed on deep terrains and hilly areas. Due to the nature of the terrains and the potential slope failure problem, the Bureau of Road Research and Development, Department of Highways (DOH), Thailand is tasked with the rehabilitation of failed slopes and the sustainability of the rehabilitated slopes against further failures. One of the rehabilitation works was a 13m high slope that had failed and was restricting access to the north (Figure 4).

The rehabilitation worked involved the reinforcement of the slope, constructed in two berms, using geosynthetic tensile strength varying from 80 to 300kN/m according the height of the slope. Due to the nature of the project, it was deem necessary to monitor the behaviour of the slope. The used of geosynthetic as the reinforcing element allowed the application of the ‘intelligent’ geosynthetic that was just ideal for such situation. Figure 5 shows a typical cross section of the reinforced slope and the location of the fibre optic strain sensors. Three strips of ‘intelligent’ geosynthetic were placed at the 4th, 9th and 17th layer of the reinforcement position from the base of the slope. Each strip of the ‘intelligent’ geosynthetic had 5 sensors of different wavelengths and was placed adjacent to the existing reinforcement layer. In order to establish strength compatibility to the adjacent reinforcement layer, the width of the ‘intelligent’ geosynthetic strip was adjusted accordingly. The strain sensors were positioned to intersect the plane of minimum factor of the safety based on the slip circle analysis carried out during the design of the slope.

During the placement of the ‘intelligent’ geosynthetic, the strip was covered with a thin sand layer to avoid damage due to compaction of the backfill (Figure 6). The fibre optic coming out of the ‘intelligent’ geosynthetic strip was encased in flexible sleeve and directed to a casing where the terminal of the fibre optic was housed and protected from moisture and vandalism. The measurement of strains was carried out by inserting the terminal into a hand-held spectrometer and all the sensors in that single fibre optic can be measured simultaneously. The incorporation of multiple sensors into a single fibre optic has made site installation effortless as compared to conventional method where the many wires from the strain gauges are delicate to handle, confusing and requires expert installer.

Figure 4. Slope failure at Maehongson and rehabilitation of the slope using geosynthetic reinforcement.

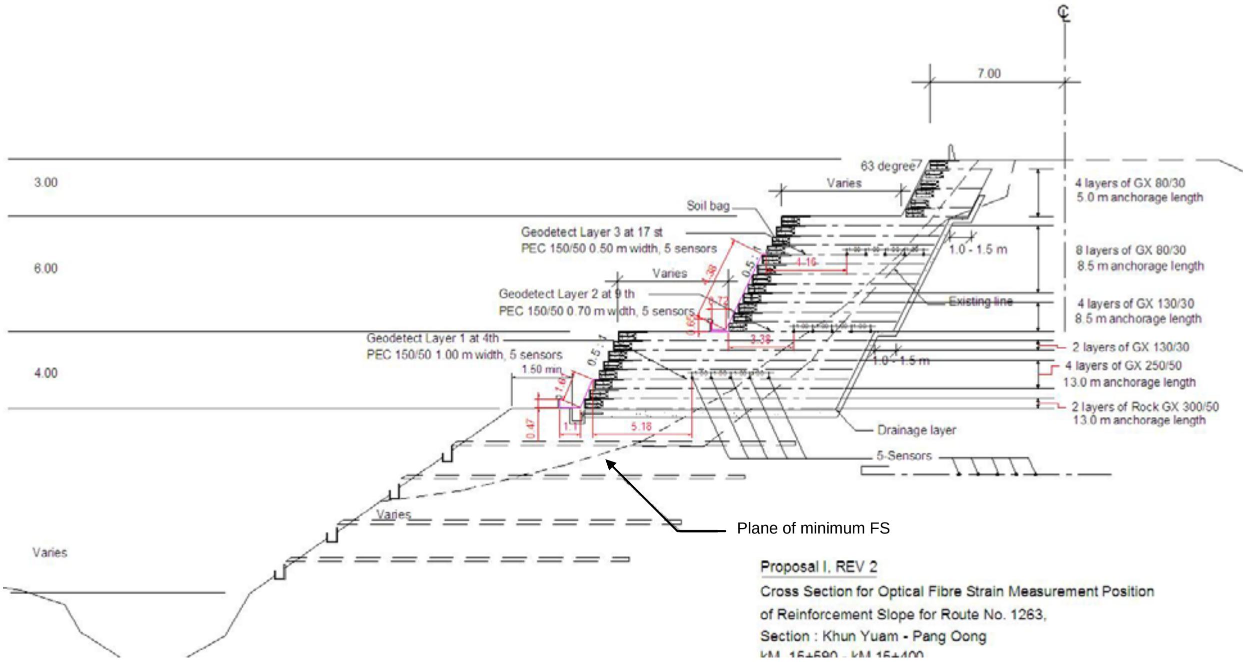


Figure 5. Typical cross section of the reinforced slope and the location of the fibre optic strain sensors.

Figure 6. Placement of the 'intelligent' geosynthetic strip.

3.1.2 Strain measurements in the reinforcement

The strains on the three layers of geosynthetic with fibre optic sensors were monitored throughout the construction of the slope. Figure 6 shows the strain measurements along the three layers of reinforcement at the end of construction, 7 months and 1¼ years after construction. The increased in strains in the reinforcement from the 7th month to the next 8 months after the end of construction were very small. It is interesting to observe that the maximum strain measured in the reinforcement occurs near the plane of minimum factor of safety.

The rehabilitated reinforced slope is still being monitored by the DOH today, some two years after the end of construction (the latest results are not available at the time of writing of this paper). This shows the robustness and durability of the fibre optic instrumentation system which is water resistant and non-corrosive.

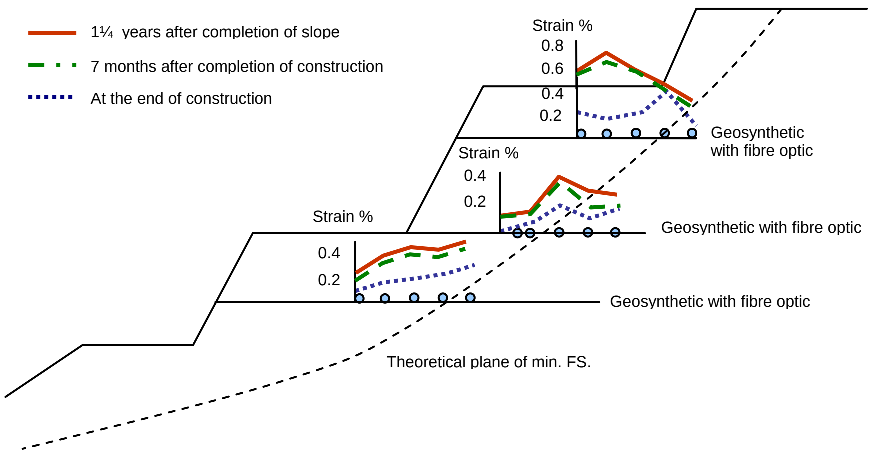


Figure 6. Strain measurements along the geosynthetic reinforcement.

4 CONCLUSIONS

The concept of fibre optic technology implemented into geosynthetic has been illustrated. By doing so, the functionality of geosynthetic is enhanced in both as a reinforcing element and soil/geosynthetic monitoring. When applied as reinforcement in soil structures, the in-built strain sensors in the geosynthetic through the insertion of fibre optic, help monitor the strains developed in the geosynthetic. With the integration of telemetry system, any strains developed in the ‘intelligent’ geosynthetic can be transmitted to a remote computer terminal for remote data acquisition. This system allows strain threshold limits to be set and thus an early warning system can be activated when the threshold is reached prior to the failure of the earth structures. Constant monitoring and post construction management of civil engineering structures can be conducted thus mitigating impending failures and disaster.

Important highlights of the fibre optic technology in geosynthetic instrumentation are the ease and accuracy of measurements without the need of complicated calibration. Multiple strain sensors can be integrated into one single fibre optic making site installation and taking of measurement easy with less error and damage to the sensors. Fibre optic technology is also resistant to moisture and electrical interference making the instrumented geosynthetic robust and durable for long term monitoring.

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REFERENCES

Briançon, L., Nancey, A., Caquel, F. & Villard, P. 2004. New technology for strain measurements in soil and the survey of reinforced earth constructions. Proc. of the 3rd European Geosynthetics Conference (EuroGeo 3), Munich, Vol. 2, pp. 471-476.

Loke, K.H., Kongkitkul, W. & Tatsuoka, F. 2007. ‘Fibre Optic Technology in Geosynthetic Instrumentation for Monitoring of Soil Structures’, Proc 6th Southeast Asian Geotechnical Conf., 8-11 May 2007, Kuala Lumpur.

Kongkitkul, W., Kanemaru, T., Hirakawa, D., Tatsuoka, F. & Loke, K.H. 2006. 'Load relaxation in polymer geosynthetic reinforcement arranged in sand under sustained load', Proc. of the 41st Japan National Conf. on Geotechnical Engineering, JGS (Kagoshima), No. 331, pp.661-662.