Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 14 (2016) 1875 – 1883

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

Innovative approach in the use of geotextiles for failures prevention in railway embankments

Clemente Fuggini [a,]*, Donato Zangani [a], Aleksander Wosniok [b], Katerina Krebber [b], Petra Franitza [c], Luciano Gabino [d], Frank Weigand [c]

[a]*D'Appolonia S.p.A., Via San Nazaro Nazaro 19, 16145 Genova, Italy*
[b]*Federal Institute for Materials Research and Testing (BAM),* [c]*Sächsisches Textilforschungsinstitut e.V. (STFI),* [d]*Alpe Adria Textil*

Abstract

Maintenance and renewal costs of a typical railway, track and substructure represents 50–60% of the total costs of such infrastructure over its entire service life. Innovations in track and substructure are therefore fundamental to achieve a significant impact on the overall cost reduction for the railways. Therefore new solutions for track improvements that are effective and that can minimize the interruption of traffic are needed.

Moreover, failures of railway embankments happened recently in different regions of the world. Such events, such as the one happened in UK in February 2013 (http://www.bbc.co.uk/news/uk-england-south-yorkshire-21441070), are showing the importance of monitoring track and infrastructure coupled with the use of numerical models for the localization of the critical areas and the design of appropriate countermeasures. Indeed embankment failures, landslides and uneven settlements and similar events are becoming much more common than in the past due to climate changes, and this requires the infrastructure managers to look from a different perspective infrastructure maintenance issues. What was previously consider as "extreme" is now "common" and thus actions need to be taken to be ready when such events will happen. The aim is to mitigate their effects on the infrastructure and to minimize disruptions to train services and reduce maintenance costs to restore the normal service conditions. If this mental change happens, then the need for solutions and techniques for global asset monitoring and ground stabilization will probably increase. Among the others, geotextiles and geogrids for soil reinforcement used in combination with condition monitoring techniques have the potential for minimizing catastrophic events, whilst at the same time providing a good balance among costs and benefits (i.e. sustainability).

---

* Corresponding author. Tel.: +3902 51800562; fax: +39 02 51800563.
E-mail address: clemente.fuggini@dappolonia.it

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.154

The paper describe a case study where the use of multifunctional geotextiles, able to provide both strengthening and monitoring functions, has been tested along a railroad near the city of Chemnitz (Germany). The results are here reported to show the potential use and the innovative aspect of this solution.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: Geotextiles; self-monitoring; railway embankment; prevention

---

1. Introduction

As previously mentioned and looking at the figures below, the focus of the paper is in analysing the potential use of innovative geotextiles for the protection of railway embankment that are more and more subjected to failures, landslides and uneven settlements due to natural hazards (e.g. heavy rain, floods, earthquakes, etc.) and climate changes effects that are increasing the disruptive potential of common hazards. In this context was previously consider as “extreme” is now “common” and thus actions need to be taken to be ready when such events will happen. This is made most apparent when dealing with slopes since slope failure can often be catastrophic, occurring suddenly with little to no warning; however, it should be noted that progressive slope failure can also occur, and that massive shear failure can occur suddenly on flat ground as well as sloped. Such events show the importance of monitoring the track and the infrastructure in order to detect any anomaly, prevent failure and repair the structure minimising disruptions to train services and reduce maintenance costs to restore the normal service conditions.

This requires a mental shift moving to advanced assets management solutions for railway infrastructures that involve the adoption of both monitoring and retrofitting solutions and techniques. Among the others, geotextiles and geogrids for soil reinforcement and embankment protection, used in combination with long-term condition monitoring techniques, have the potential for minimizing catastrophic events, whilst at the same time providing a good balance among costs and benefits (i.e. sustainability).

Fig. 1. Collapse of railway embankment along Plymouth Rd, Ann Arbor, US, in May 2011 after an heavy rain on already saturated ground (left); Massive landslide in Hokkaido leaves railway tracks hanging in mid-air, April 2012 (right).

Fig. 2. Landslip rail line in UK, February 2013: view of the railway (left); top view of the area (right).

2. Sensors Integrated Geotextiles

What is previously mentioned and depicted, clearly shows the impact of disruptive events on the railway infrastructure and how the substructure of it is very much prone to both progressive (easily monitored) and sudden failures (in this case requiring a dedicated solution to detect early warning features). In the first case (e.g. progressive failure) the use of static sensors can be helpful in understanding the trends of soil settlements and therefore keeping under control the situation, whilst highly precise and dynamic measuring sensors are requested in the second case when early warning information are of paramount importance to take appropriate decision (e.g. stopping the traffic) and therefore preserve either the trains and human life's. However, in both case it is clear the need of combining sensors (providing updated data) and reinforcing solutions so that on one side be informed about the current situation and on the other side act with a mitigation measure that may prevent further disruptive consequences.

In this sense and to optimized subgrade reinforcement, the attention is focused on the use of multifunctional geotextiles, able to provide both strengthening and monitoring functions (Zangani, 2008).

2.1. Classical use

The classical use of geotextiles in embankments on relatively soft soils is to reduce settlement and to increase the bearing capacity and slope stability. Geotextiles are normally placed at the bottom of the embankment, about 50 cm above the original ground surface in one or more layers. In recent years a new kind of foundation, the so-called "geosynthetic-reinforced and pile-supported embankment" has been developed (see Figure 3) and it is now in use in practice. Pile-like elements are placed in a regular pattern through the soft soil down to a load-bearing stratum above which a reinforcement of one or more layers of geosynthetic (mostly geogrids) is placed before the embankment is filled. The stress relief in the soft soil results from an arching effect in the reinforced embankment over the pile heads and a membrane effect of the geosynthetic reinforcement.

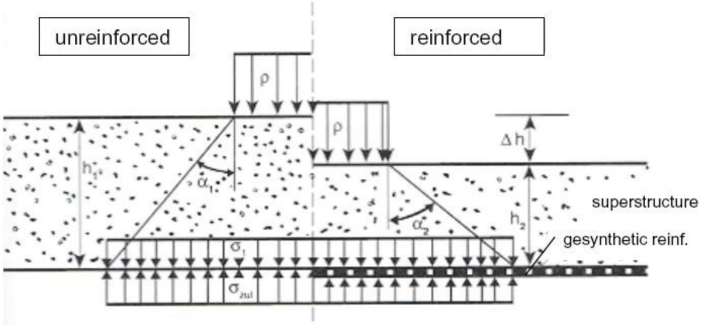


Fig. 3. Use of geotextiles for soil reinforcement.

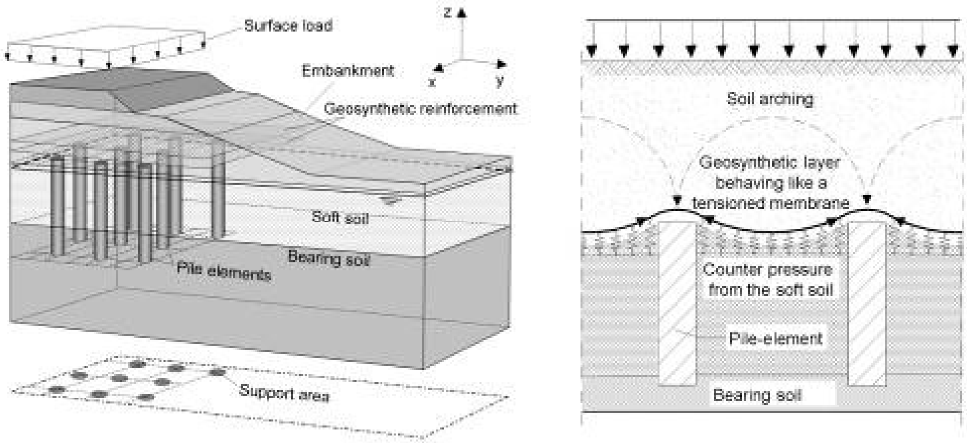


Fig. 4. Geosynthetic-reinforced and pile-supported embankment.

2.2. Innovative use

Up to date design and construction standards require the installation of systems to monitor the stability and serviceability of geotechnical structures. New multifunctional geotextiles are nowadays introduced in geotechnical engineering practice since they provide, at the same time, both the stability and monitoring functions. The multifunctional geotextile includes protection of the railway substructure against the increased loads induced by heavier vehicles travelling at higher speed by strengthening and stabilisation of the existing structures and the monitoring of their performance with the possibility of the infrastructure owner being alerted by an alarm before structural failure occurs.

Among the others, Sensor Integrated Geotextiles (Zangani et al., 2015) have been developed to offer the chance to monitor the infrastructure where such materials are integrated in addition of the usual functions geotextiles perform (strengthening, filtration, stabilisation, separation, drainage). The Structural Health Monitoring (SHM) capacity of this system is the result of the integration with the structure of distributed Fiber Optics Sensors (FOS), whose response can be collected and processed almost continuously or can be carried out at predetermined time intervals. An efficient signal processing technique is used to process the raw sensor measurements and draw from them an estimate of the damage size and location, being able to distinguish the damage from other perturbations caused by environmental disturbances. The system automatically generates warning alarms when there is a structural risk, or when maintenance is required. The monitoring function is performed thanks to a distributed optical fiber embedded within the geogrid (see figure below). The optical fiber itself is the sensing element which can be used as local sensing element or as distributed sensing cable, with sensing lengths up to several kilometres along a low-attenuation single-mode silica glass fiber.

To perform the above functions and in order to satisfy the demanding requirements of cost and resistance required for the intended applications, geotextiles are generically made from plastic materials and mostly polypropylene, and polyester, but fiberglass are used. Sewing thread for geotextiles is generally made from any of the above polymers. Using warp knitting technology to construct geotextiles makes it possible to provide reinforcement with easy sensor incorporation, thus opening up new design opportunities for multifunctional geotextiles (MFG).

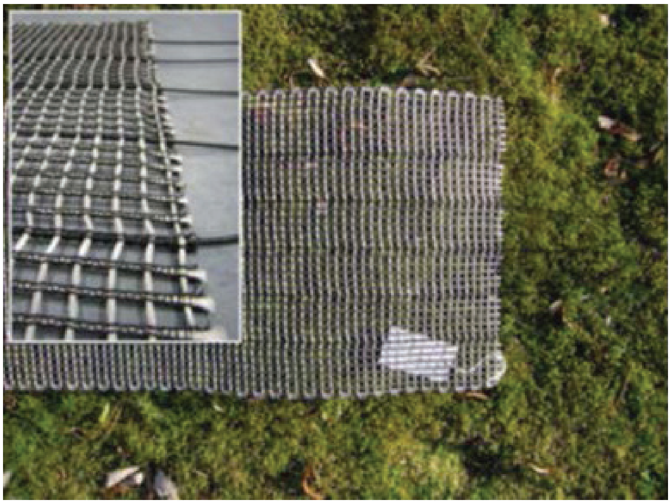


Fig. 5. Innovative Sensors Integrated Geotextiles.

The benefits of using the proposed innovative Sensors Integrated Geotextiles within the railway substructure can encompass:

- Indicate impending failure and provide a warning
- Reveal unknowns
- Evaluate critical design assumptions
- Assess contractor’s means and methods
- Minimize damage to adjacent structures
- Provide data to help select remedial methods to fix problems
- Document performance for assessing damages
- Inform stakeholders
- Satisfy regulators
- Reduce litigation
- Advance state-of-knowledge

It is important to recognize that this approach only provides an organized way to help make rational decisions based on quantified information. Geotechnical instrumentation by itself does not change the outcome but can minimise the impact of a particular event. Placing geotechnical instrumentation in an embankment to monitor stability does not alter the factor of safety of the embankment. It is only through the intelligent use of the data from the geotechnical instrumentation that engineers can better foresee potential outcomes and take appropriate actions to alter the events or reduce the consequences.

3. Testing the performance

3.1. Lab Testing

The above figure (figure 4) shows an example of prototype of Sensors Integrated Geotextiles as initially developed within the EU-funded research project Polytect (Zangani 2008), and then tested in the EU-FP7 project Sustrail (www.sustrail.eu), both of them coordinated by the main authors.

The prove the effectiveness of the proposed solution a series of laboratory tests have been carried out in order to verify their behaviour under different loading scenarios. A simple test rig has been prepared, as shown below, where a roll of the geotextile was used. The sensor type for the test is a distributed single-mode Glass Optical Fiber (GOF), with silicone-based sheet, produced by Fiberware. The Reading Unit produced by Luna Technologies uses the so-called swept wavelength interferometry (SWI) to measure the Rayleigh backscatter as a function of length in optical fiber with high spatial resolution. Furthermore, external factors like temperature or strain changes cause temporal and local shifts in the Rayleigh backscatter pattern along the sensor fiber which can be measured and scaled giving a distributed temperature or strain measurement. Thereby, a temperature and strain resolution as fine as 1 µstrain and 0.1 °C is to achieve with sub-centimeter-scale spatial resolution up to 70 meters of the sensor fiber.

The test evaluated the strain measured by the sensor due to a load supported by the geotextile. First (figure 6) a single load was applied, whose effect is shown by peaks in the reading data; afterwards (figure 7) multiple loads have been applied to simulate more realistic conditions. The tests have been replicated with multiple loads and multiple positions of the load over the geotextile to identify the correlation among the measured data and the effective strain.

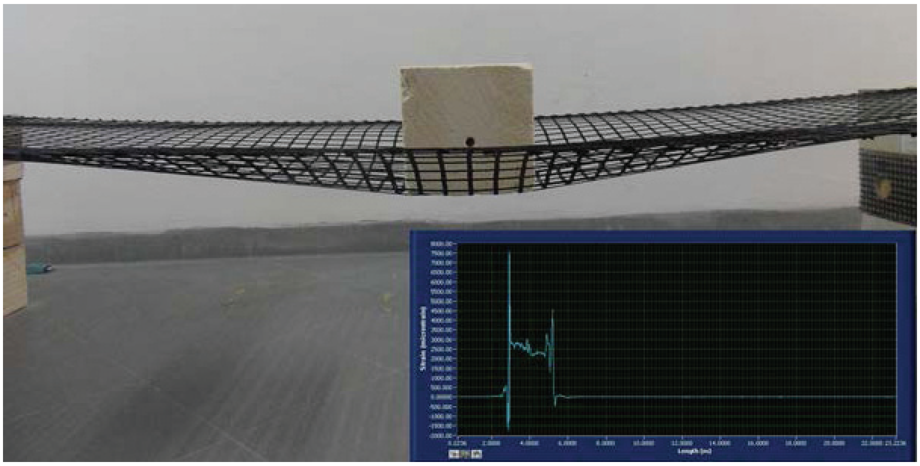


Fig. 6. Acquisition of strain induced by an imposed load corresponding to a single stone block.

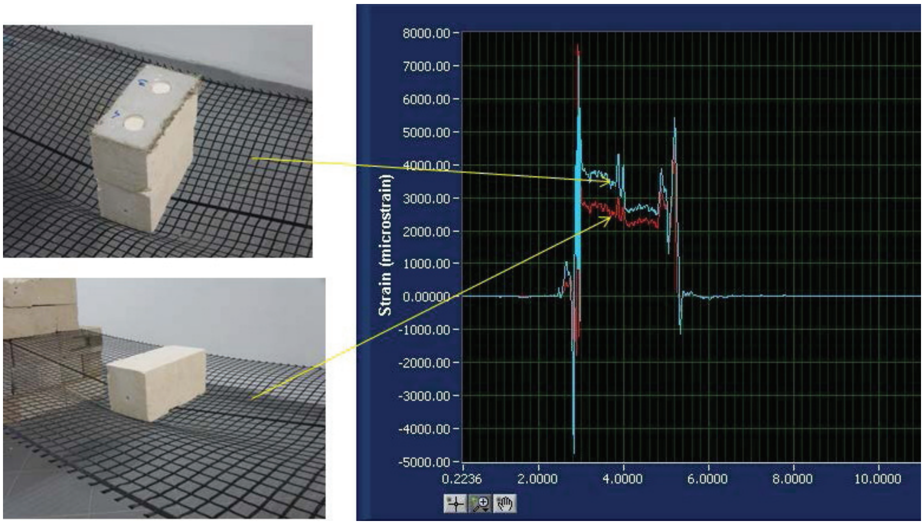


Fig. 7. Acquisition of strain induced by an imposed load corresponding to a double stone block.

3.2. Field testing

Following the laboratory tests, field tests have been performed. The location of the test is in correspondence of a curve of a railroad near Chemnitz (Germany), as depicted in Figure 8 and 9. The traffic volume in the nearby rail track is very high. The portion of the embankment is more than 100 years old, reconstructed in 2007-2008. The motivations for the field test include:

- Availability of a real construction site to expose the multifunctional geotextiles, after the installation, to the dynamic loads induced by real railway traffic;
- Development and test of an installation method and specification of special application-related conditions,
- Long-term test: investigation of the influence of weather conditions during installation (the weather was from dry to extremely rainy and then snowy and temperatures below 0°C) and for long-time measuring in time intervals.

Fig. 8. View of the test site near Chemnitz (google maps).

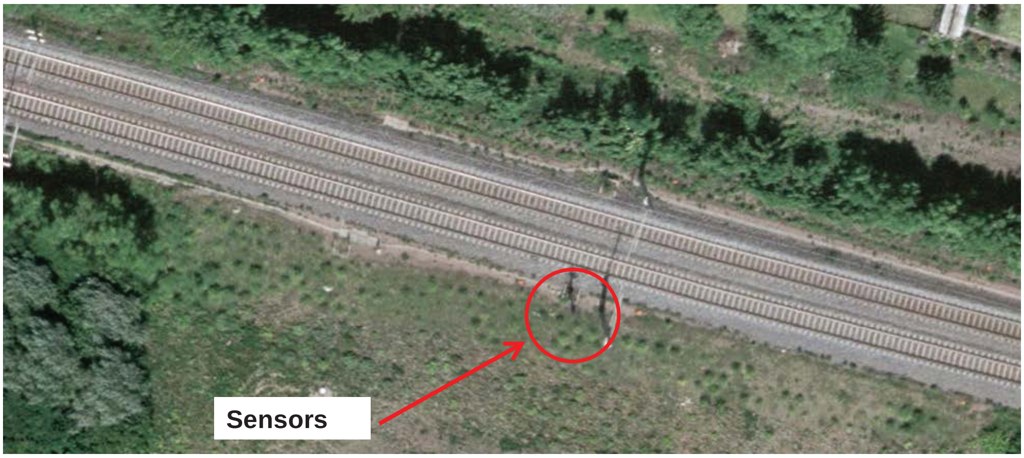
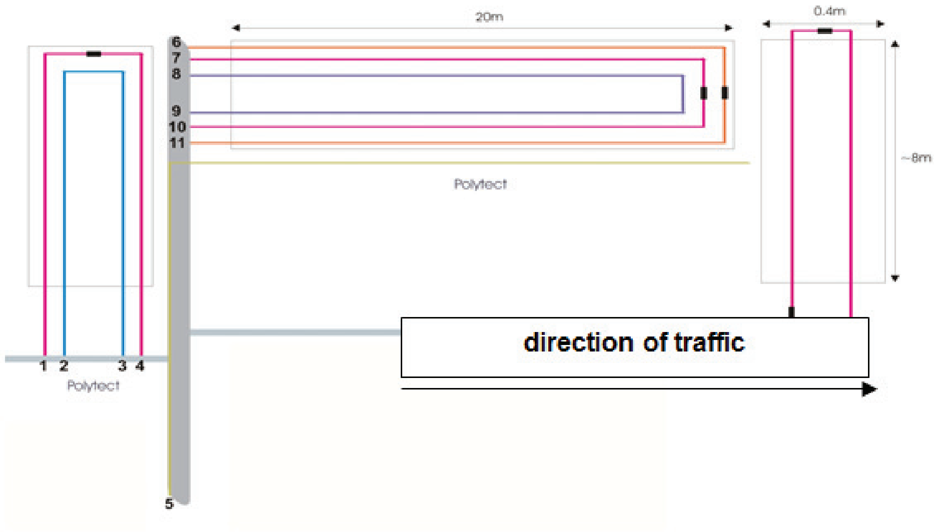


Fig. 9. View of the test site near Chemnitz with sensors location (google maps).

The placement of the sensors is as depicted below, following the initial design made in the Polytect project.



1 – 4, 12 - 13	installed transversally (90° to the tracks)
5	installed for measurements partly in transversal and longitudinal direction
6 – 11	installed parallel to the tracks (longitudinal measurement)

Fig. 10. Position of the sensors in the test side.

How the sensors and the acquisition unit looks like is shown in the next picture.

Fig. 11. View of the sensors and acquisition unit at the test side.

Tests have been periodically realized from 2007 up to 2014, being the sensors still in use. Summary results are provided in the following pictures for sensors 1-4 installed transversally to traffic direction on the railway line (Figure 12) and for sensors 6 and 11 installed parallel to the direction of the traffic (Figure 13). Main finding of this long-term testing campaigns are:

- no negative influence of moisture on sensor fibers (no increase in optical attenuation observed)

- “recovery” of sensor fibers due to relaxation processes in polymer optical fibers (lower optical attenuation in comparison to previous measurements)
- damaging event can be detected for the sensor in position one

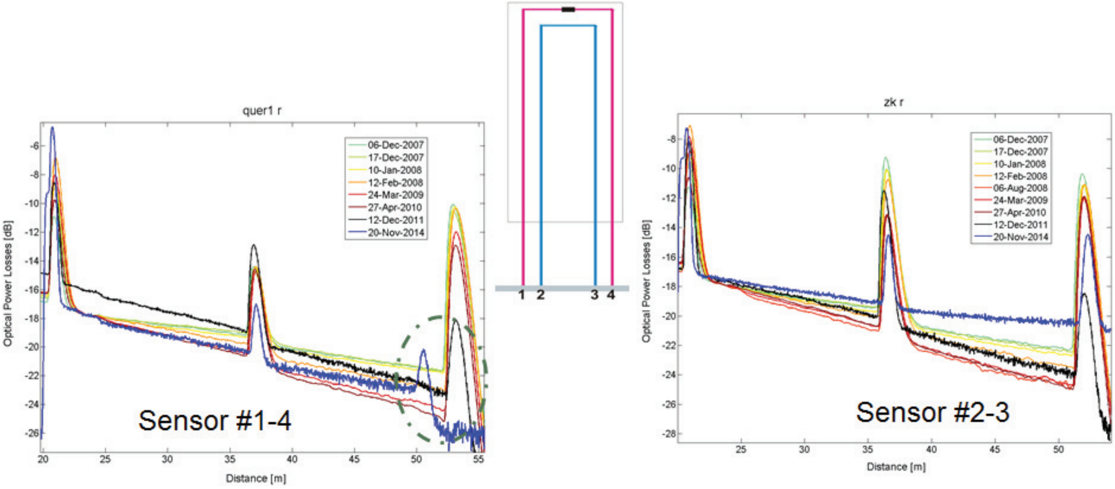


Fig. 12. Results from sensors 1-4.

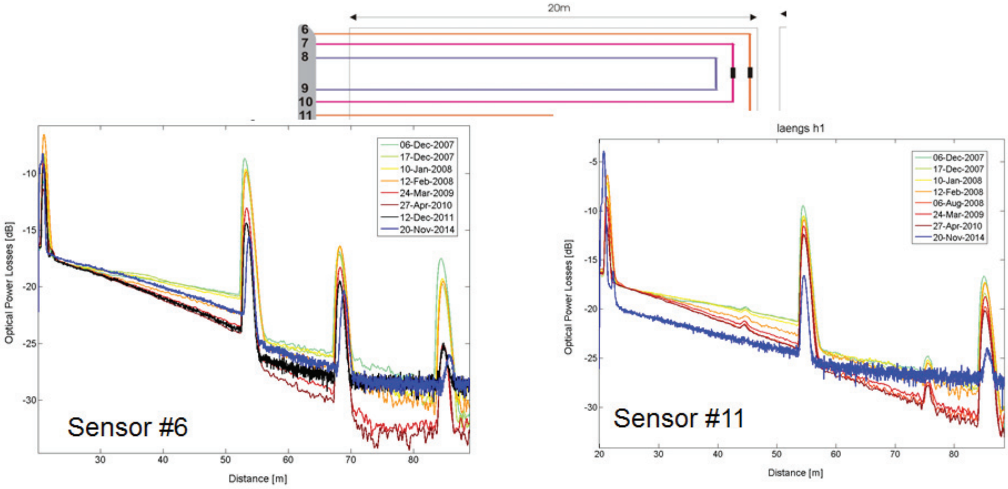


Fig. 13. Results from sensors 6, 11.

References

FP7-EU Project SUSTRAIL: www.sustrail.eu_zmia

Zangani D., 2008, “Multifunctional Textiles for Protection against Natural Hazards”, in Advances in Science and Technology, Vol. 56

Zangani D., Fuggini C., Loriga G., Electronic textiles for geotechnical and civil engineering, in Electronic Textiles – Smart Fabrics and Wearable Technology, Edited by T. Dias, n°166, Chapter 13, pp. 275-300, 2015