Anchoring elements for fiber optic sensor cables: part of a system for monitoring slopes surface movements

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***Abstract* — The fiber optic industry had a significant development from the late 80's. Besides communication, this technology is also being used for measuring a monitoring deformation, displacement, acceleration, pressure, temperature and chemical properties among others (MORIKAWA, 2004). Among the technological advantages of the use of fiber optic sensors, the most notable are: (i) sensing the possibility of several signals over a single optical fiber (multiplexing data), (ii) ease of reading of the signals (good value signal versus noise), (iii) measurements over long distances (remote sensing), (iv) immunity to electromagnetic fields, (v) absence of spark, and (vi) low weight and low material reactivity. The use of fiber optics as a tool for different kinds of geotechnical monitoring can become a highly attractive and cost effective when compared to conventional instruments such as piezometers, inclinometers, among others. A single fiber optic cable may cover a larger monitoring area compared to conventional instrumentation, and the possibility of monitoring more than one physical quantity with the same fiber optic cable. This paper covers all steps undertaken to define the size of one type of cable Anchoring Element (AE) for monitoring soil movement in natural hillslopes. To fulfill this objective laboratory tests were carried out in LACTEC, Curitiba-PR, and results and conclusions are shown in this paper.**

***Keywords*— DTSS, Fiber Optic, Brillouin, BOTDR, Geotechnical Monitoring, Mass Movements, Laboratory Experiment.**

I. INTRODUCTION

The fiber optic environmental robustness makes it possible to monitor large civil structures at low cost (KLUTH et at., 2014) and this technology, due to its characteristics and advantages, can be used in different areas to monitor different quantities.

According to Zeni et al. (2015), the main requirements for the implementation of geotechnical instrumentation in areas susceptible to soil movements are cost and reliability of the equipment, continuous monitoring and low probability of error. Taking this into account and the fiber optic distributed detection ability, such technology can be applied in the geotechnical instrumentation, making monitoring more attractive and cost effective when compared to the conventional instrumentation now used.

In the case of this research, the variations in the strain of an anchored fiber optic cable caused by laboratory-induced strains were evaluated, which helps in monitoring and understanding possible soil movements in natural hillslopes, besides implying a new geotechnical instrumentation.

II. DTSS

As commented by Goltz and Aufleger (2009) "the measuring principle of distributed fiber optic strain sensing is based on the fact that after sending a light pulse by a powerful light source (laser) into a glass fiber, a very small proportion of this light is backscattered at each point along the fiber". The scattered light undergoes a shift in frequency, called Brillouin frequency shift, which depends

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on the strain and temperature variations. Brillouin is an inelastic phenomenon, result of the interaction of incident light with fluctuations in the properties of the medium that are propagated in the material as acoustic waves or acoustic phonons (FEBBO, 2016). Fig. 1 illustrates the scattered light spectrum.

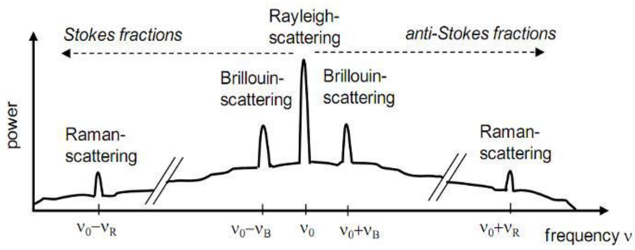

Fig. 1: Scattered light spectrum

The analyzed section of the optic fiber is determined with the commercially available Brillouin Optical Time Domain Reflectometer (BOTDR) system. With the knowledge of the light speed in the material it is possible to identify the corresponding Brillouin spectrum of each section. The reading unit used in the laboratory tests, called Distributed Temperature and Strain Sensor (DTSS), records both Stokes and anti-Stokes light portions of the Brillouin spectrum, shift and power. Analysis of this data allows the strain and temperature evaluation along the fiber or cable.

Other important characteristics of the available equipment are that the strain measurement corresponds to the average strain within 1 m spatial resolution, up to 24 km of optical fibers can be monitored, strain resolution is ±20 µm at 1 m intervals and a temperature resolution of ±1 °C at 1 m intervals.

The type of cable or fiber must be informed to the system, including characteristics such as those listed in TABLE 1, which define the cable used in this work.

Table 1: Optic cable parameters recorded in the DTSS system

Coefficient	**Description**	**Value**
Cvε	Brillouin shift coefficient with deformation	0,0481 MHz / µε
CvT	Brillouin shift coefficient with temperature	2,488 MHz / K
Cpε	Brillouin power change coefficient with deformation	-1,4 10-3% / µε
CpT	Brillouin power change coefficient with temperature	0,417% / K

The cable strength is limited to 3 kN guaranteed by the Kevlar material in its core. The external diameter is 5 mm and within the cable there are two singlemode and two multimode fibers (Fig. 2).

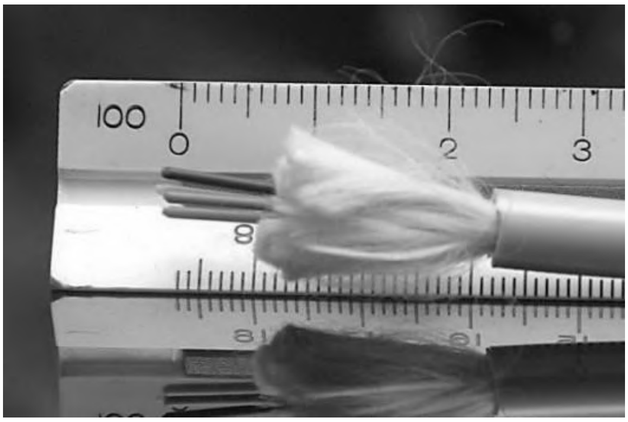

Fig. 2: Fiber optic cable

III. GEOTECHNICAL MONITORING THROUGH DTSS

In the recent years, the DTSS system has become a widely used technology. However, geotechnical applications of this technology are not well established yet. It considers that the combination of the optical fiber and the soil results in difficulties. Additionally, because of anisotropy and heterogeneity of soils and rocks, added to the complexity of local hydrological conditions, a series of uncertainties about soil deformation arise (ZHANG et al., 2014) and a deeper understanding of the geomechanical principles is necessary in order to achieve meaningful results when this technology is used.

Field measurements suggest that soil movements commonly exceed tolerable limits, causing the soil to suffer shear resistance reduction, which can lead to geomorphological catastrophes, causing hundreds of deaths and severe damage to urban infrastructure (GUERRA et al., 2017). An application of the DTSS method for detecting soil movements is to install fiber optic cables in excavated trenches with depth of approximately 15 cm. To ensure a good transmission of the movements for the cable, special anchors were installed along the optic fiber cables. They also used DTSS technology to detect shear surfaces using a direct

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installation in inclinometers casing (HOEPFFNER et al., 2008).

A novel monitoring technique which can be used for monitoring of hillslope movements with DTSS sensing. The limits and applicability of this monitoring technique was investigated for the evaluation of soil movement in natural hillslopes. To fulfill this objective laboratory tests were carried out in LACTEC, Curitiba-PR. The presented experiments and results showed on their work indicate the potentiality of this novel monitoring technique for evaluating soil mass movement conditions (LACERDA et al., 2011).

IV. LABORATORY EXPERIMENT

The laboratory tests were carried out at LACTEC/LAME – Laboratory of Materials and Structures.

4.1 Materials for the Pure Axial Strain Test

The initial testing facility setup is illustrated in Fig. 3, and it consists of a U-shape metallic structure with 5.60 m and special edges (1 and 2) for stretching cables and/or fibers (Fig. 4) and clamping (Fig. 5), respectively.

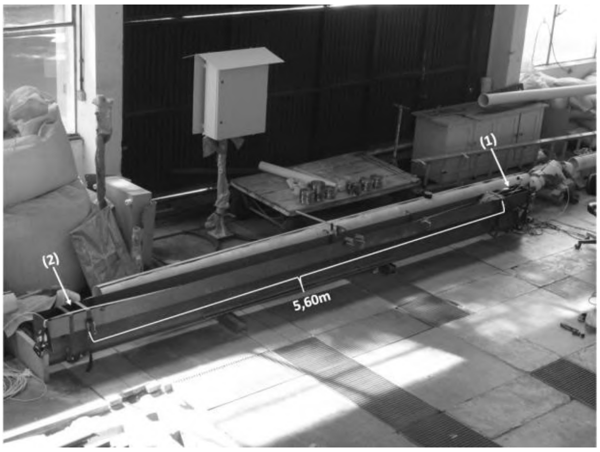

Fig. 3: U-shape metallic structure

Fig. 4: Stretching cables

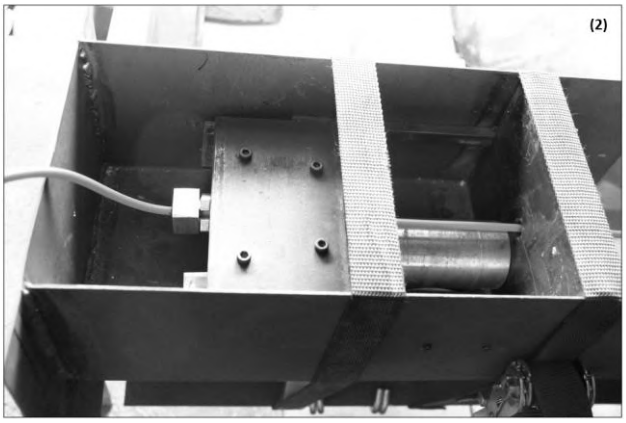

Fig. 5: U-shape clamping

The Fig. 6 shows the U-shape cross section with the fiber optic cable position on the tests carried out.

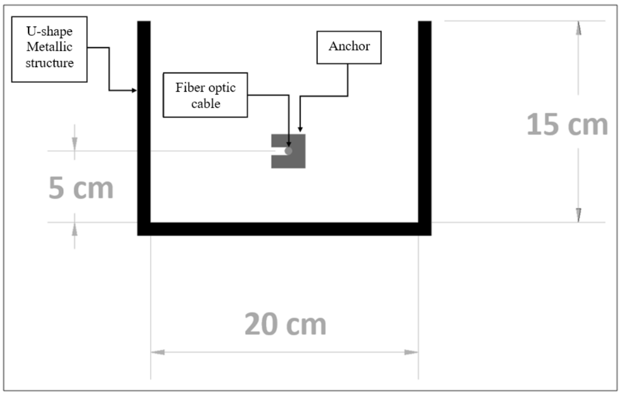

Fig. 6: Cross section U-shape metallic structure

4.2 Anchoring Elements for the cable

Aiming to detect mass movements, a fiber optic sensor cable installed in the subsurface must be well connected to the surrounding medium. Regarding this, tests were performed using elements which hold the fiber optic cable, named Anchoring Elements (AE) of the cable. The geometry of the AE had been largely studied until the idealization of the most appropriate shape.

Previous research conducted by the Institute for Technology Development (LACTEC) concluded that the simple settlement of the fiber optic cable directly on the ground would allow movement detection. However, the use of AE provides greater sensitivity for movement detection.

The AE are cubic metal parts that hold the fiber optic cable that can be manually installed in any position of the cable, without using any tools. In Fig. 7 it is possible to see an illustration of the AE.

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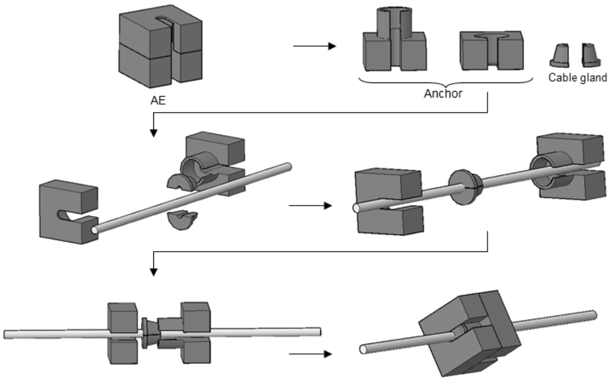

Fig. 7: Anchoring Elements applied to the cable

4.3 Sandy Soil

The soil selected for the experiments with the U-shape metallic structure refers to a sand with uniform particle size distribution with grain diameters between 0.50 mm and 0.90 mm. The procedures for testing the geotechnical characterization of the sand (grain density, particle size analysis and voids maximum and minimum) were executed in accordance with Brazilian standards ABNT NBR 6508:1984, ABNT NBR 12004:1990 and ABNT NBR 12051:1991. The results are shown in TABLE 2. All tests were conducted with dry sand.

Table 2: Basic soil data

Property	Result
Specific gravity (γs)	26 kN/m³
Maximum void ratio (e_{max})	0,80
Minimum void ratio (e_{min})	0,58

4.4 Pure Axial Strain Test

The pure axial strain tests were performed in the U-shape metallic structure. Initially, the structure was filled with a 5 cm thickness dry sandy soil. Then the cable was placed, and further sand was put till the top. To prepare the tests, it was decided to use the sand close to minimum void ratio (0.58). The procedures for testing were executed in accordance with ASTM D 4253/1983 (PRESTI et al., 1992). The cable was pulled to a strain close of 1500 microstrains. Fig. 8 illustrates the test being assembled.

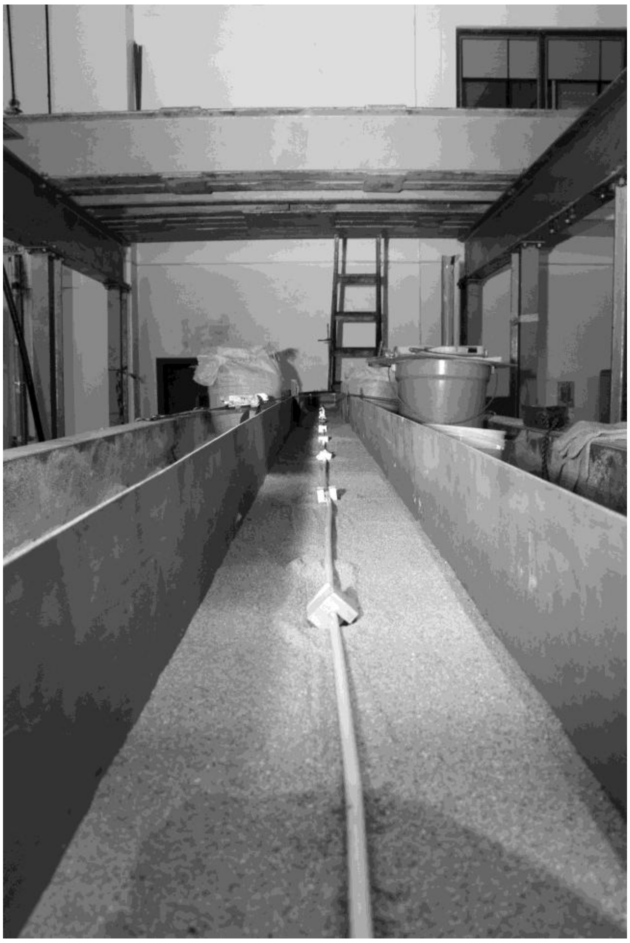

Fig. 8: Assembling of the fiber optic and the anchoring

Four AE spacing conditions (models) were evaluated as shown in Fig. 9. In the first model, no AE were used. In the second model, the AE was installed at 2.00 m spacing distances. In the third one, the spacing between AE was set to 1.00 m and in the last model, the spacing between AE was set to 0.50 m. The DTSS unit was configured to record data at a regular 2 minutes interval.

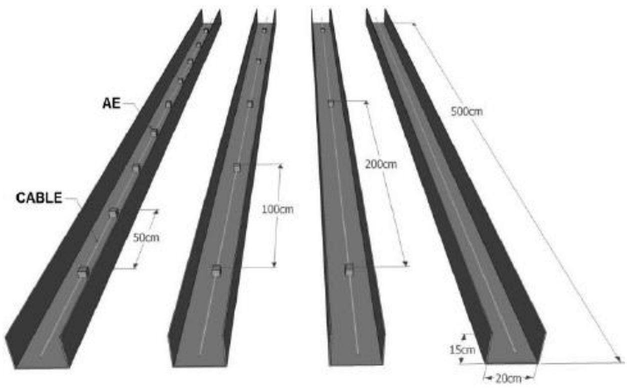

Fig. 9: Test configuration

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V. RESULTS AND DISCUSSION

In Fig. 10 it is possible to see the forces that work on cable-soil interaction. The results of the pullout tests are interpreted by analyzing the interaction between the fiber optic cable and soil and checking the level of maximum strain recorded in the DTSS unit. Fig. 11 shows a graph comparing results of the 4 tests.

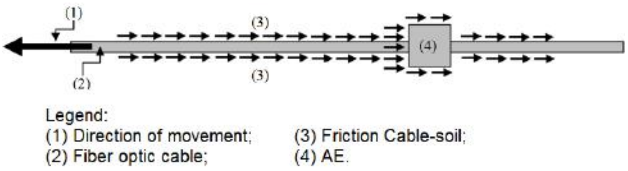

Fig. 10: Forces working on cable-soil

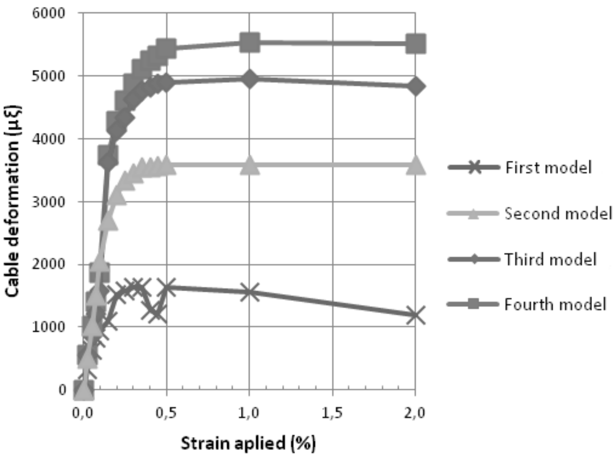

Fig. 11: Comparison between tests

The vertical axis shows the strain recorded in the DTSS unit and the horizontal axis shows the strains imposed on the system. Analyzing the first model (no AE) it is possible to note that the maximum strain recorded was near 1600 microstrains when 0.2% strain was imposed to the system. After this magnitude, the cable-soil bonding condition is changed (rupture) and further pulling does not imply in greater cable strain.

The installation of AE on the fiber optic cable increased the sensitivity for detecting the pullout movement. For the 2.0 m AE spacing (second model) the maximum strain recorded was approximately 3500 microstrains, yielding a gain of more than 100% in the strain signals. When AE were installed at smaller spacing conditions (third and fourth models) the recorded signals were even greater, making the system more and more sensitive to smaller movements.

VI. CONCLUSION

The results presented showed that the AE is efficient. It makes the DTSS monitoring system more sensitive to smaller mass movements. The AE amplify the recorded strain signals. However, a careful evaluation of AE spacing must be carried out for field installations since the fiber optic cables cannot usually strain beyond 15000 microstrains.

It is noted that the presented results are inherent to the applied testing conditions, including soil type. Further similar tests are being carried out with other soil types.

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