MATTER: International Journal of Science and Technology
ISSN 2454-5880

Fosalau et. al., 2018

Volume 1 Issue 1, pp.01-11

Date of Publication: July, 2015

DOI- https://dx.doi.org/10.20319/mijst.2015.11.0111

This paper can be cited as: Fosalau, C., Zet, C., & Petrisor, D. (2015). A Highly Sensitive Transducer for Landslide Monitoring. MATTER: International Journal of Science and Technology, 1(1), 01-11.

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A HIGHLY SENSITIVE TRANSDUCER FOR LANDSLIDE MONITORING

Cristian Fosalau
Faculty of Electrical Engineering Technical University of Iasi, Iasi, Romania
cfosalau@ee.tuiasi.ro

Cristian Zet
Faculty of Electrical Engineering Technical University of Iasi, Iasi, Romania

Daniel Petrisor
Faculty of Electrical Engineering Technical University of Iasi, Iasi, Romania

Abstract

The paper presents construction details and experimental characteristics of a transducer devoted to measuring soil displacement during landslides. It consists of a flexible rod on which special highly sensitive strain gages are glued so that rod deformation can be accurately measured. Beside its high sensitivity, the transducer is also characterized by the possibility of measuring soil levels displacements in depth, being thus useful for geologists to study the structure and dynamics of such a phenomenon.

Keywords

Landslide, Strain Gage, Amorphous Magnetic Micro Wire, Stress Impedance Effect

1. Introduction

Nowadays, landslides are classified among the most catastrophic natural disasters. They consist in sudden or progressive soil sliding from the top of a hill or mountain towards its foothill engaging huge masses of land, rocks and organic materials [1] [2] [3]. The main factors that determine occurrence of a landslide are the soil consistency along with the ground-to-water ratio into the soil. Landslide are strongly affected by the quantity of precipitation in a certain area, especially where soils are not consolidated with trees or plants roots. The most important parameter that measures the degree of humidity of a soil prone to a potential landslide is the pore water pressure (Wang and Sassa, 2003). In general, a landslide begins with a slow movement of the soil layers. If favorable conditions persist, the soil degradation increases, ending with an important mass of material rolling down the hill slopes. Monitoring the small displacement of a slope, especially during periods of heavy rain or during snowmelts and alerting authorities and geologists when these displacements occur or exceed a limit may avoid huge damages or even human lives losses.

There are several techniques of landslide monitoring available on the market and literature. They may be divided into two main categories: i) geometrical measurements on the land surface using optical interferometric methods or satellite and aerial techniques, in which modification of the surface configuration is assessed by precise measurements of relative distances between certain landmarks or by processing images acquired in time over the observed region [5] [6] [7] and ii) using specialized devices and transducers that are mounted in direct contact with the land prone to sliding, like: extensometers, inclinometers, piezometers, strain meters, pressure cells, geophones, tilt meters and crack meters (Dunnicliff, 1993). These are even more precise than the first ones (less than 20 mm accuracy) but they cannot assess the elongation and orientation of the landslide in depth, transversally to the soil layers.

However, whatever the gauging method, it is very important that the transducer be very sensitive in order to alert as early as possible a presumptive landslide initiation in a certain area. With this aim, we developed a new type of landslide transducer whose principle of operation is based on determining the degree of deformation due to landslide movements of a rod vertically mounted into a well in the earth. The novelty of our transducer consists of deformation measurement using highly sensitive strain gages (HSSG) built by our team on the basis of the stress impedance effect (SE) occurring in non-magneto strictive magnetic amorphous micro wires. This kind of strain gages exhibits gage factors as large as more than 2000, i.e. 1000 times bigger than that of a metallic strain gage, leading thus to a large value of sensitivity for the transducer (less of 2 mm). The transducer is designed to be included into a wireless sensor network emplaced in an area prone to landslide that automatically measure and remotely transmit information related to displacement and orientation of the prospective landslide. The transducer has also the advantage of providing the possibility of measuring in depth along to the soil layers the displacement and orientation of the landslide, offering this complete 3D information on a possible catastrophe initiation. The transducer has been tested in laboratory and on the field during a snowmelt period, providing good results in agreement with presumptive design data.

Landslide Transducer Construction

Fig. 1 depicts the functional scheme of our landslide transducer. It consists of a flexible rod made by polypropylene on which a number of measurement points (MP) are arranged along the rod axis according to the geological structure of the area to be monitored. The rod is vertically buried into the earth. It becomes deformed as soon as the soil layers begin to slide. An MP is composed of 4 highly sensitive strain gages (HSSG) orthogonally disposed along the N-S-E-W cardinal points and electrically connected in a Wheatstone bridge (WB). Each HSSG has a gage factor of about 2000, leading thus to a very high sensitivity of the MP and of the whole transducer (Fosalu et. al; 2013). The whole ensemble is supplied by a couple of solar panels mounted in the near neighborhood of the transducer.

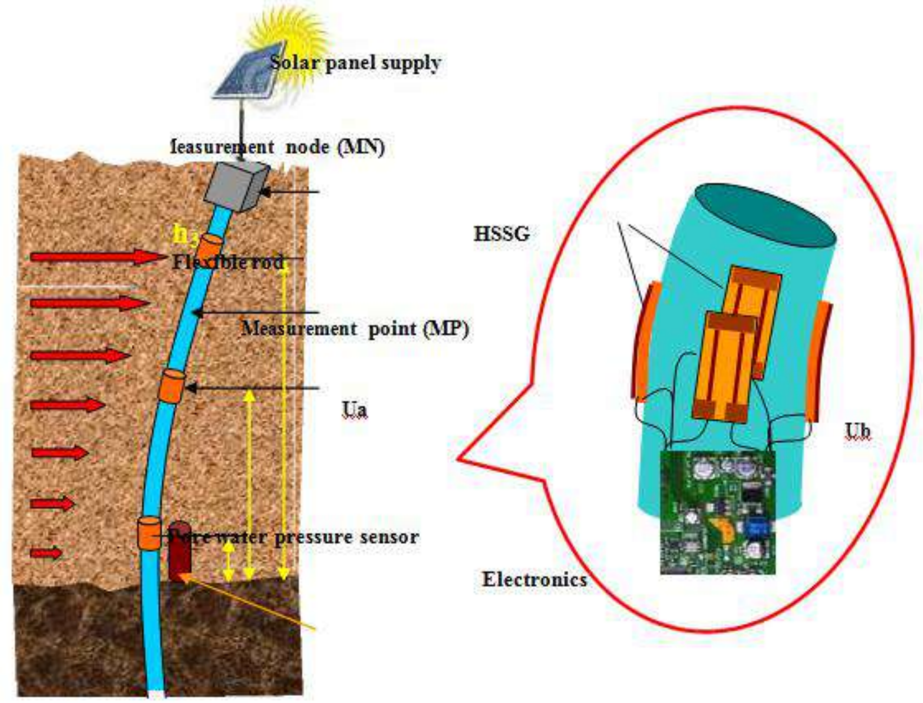


Fig. 1. Landslide transducer structure and principle of operation

Description of an HSSG

The main sensitive element of a HSSG is a magnetic amorphous micro wire (MAM) produced by in- rotating-water-quenching method having a diameter of 120 μm and composition (Fe0.06Co0.94)72.5Si12.5B15, being of non-magneto strictive type (Squire et. al; 1994). The wire exhibits the stress impedance effect, a kind of magnetoimpedance effect in which the wire impedance is changing as soon as it is subjected to an axial or torsional stress (Fosalu et. al; 2013; Shen et. al; 1997). The wire is fed by an ac current of frequency more than 100 kHz at a certain intensity. Such a wire is glued onto a plastic film which, in turn, is bonded to the rod surface, as shown in Fig. 2.

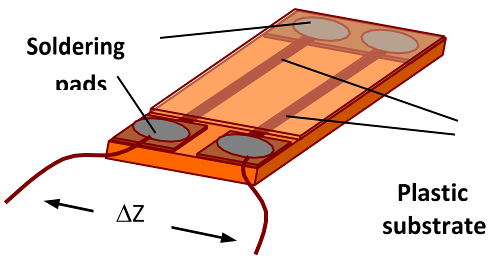


Fig. 2. Construction of an HSSG

When the surface on which the HSSG is bonded is deformed along to the wire axis (i.e. the rod surface under the landslide action), its impedance is changing accordingly as a measure of the surface deformation. A characteristic of the device representing the dependence of the impedance Z variation with respect to the applied stress, $\varepsilon = \Delta l/l$ is given in Fig. 3. The slope of the characteristic represents the gage factor k, which exceeds 2000 in a quasilinear region of ± 200 ppm, compared with the gage factor of a metallic commercially available strain gauge of 2, or even that of a semiconductor gage, of about 200. The characteristics are traced at different frequencies, at which the stress impedance effect occurs. We proved that the current intensity does not affect very much the characteristic. We have chosen in our approach the value of 5 mA for optimal power consumption.

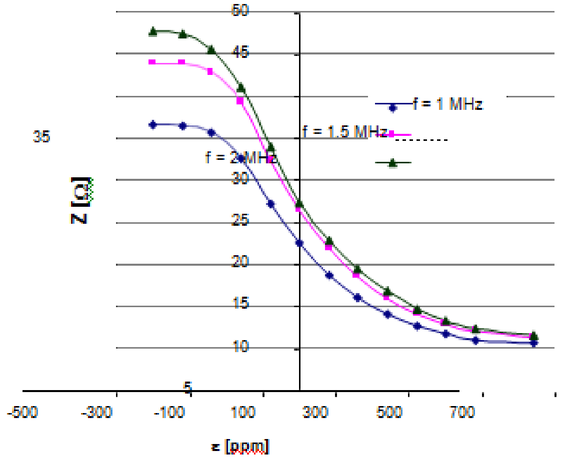


Fig. 3. Characteristic of an HSSG

Signal processing

The plastic rod is vertically buried into the earth so that the lowest part is embedded into the solid base soil layer (clay layer). The rest of the transducer is subjected to deformation due to the sliding. The MPs are mounted at different heights hi with respect to the base layer, on which the calculus of the displacement of sliding layers depends. As stated above, the gauges are mounted on the rod along two orthogonal directions forming a WB. Beside the complete WB, an MP also contains electronic conditioning circuitry devoted to processing the signals provided by the WB. An MP delivers two analog voltages, U_a and U_b converted in digital form by means of MSP430 microcotroller inputs that are, in turn, dependent on the rod deformation. The displacement D_h of MP of the h level under the landslide action and the angle of orientation α may be calculated in function of the two voltages U_a and U_b according to the following relationships:

$$D_h = \sqrt{\frac{h}{h_{\max}}\left[D_N^2(U_a U_b) + D_E^2(U_a U_b)\right]} \quad 2 \qquad (1)$$

$$\alpha = \tan^{-1}\left(-\frac{(k+2)U_a - U_S}{(k+2)U_b - U_S}\right) \qquad (2)$$

In the above relations, h is the height of the MP relative to the base layer, hmax is the total height of the transducer from the earth surface to the base layer, DN and DE are the displacements of the rod along two orthogonal directions on which the strain gauges have been mounted in pairs (e.g. N-S and E-W), that are dependent on Ua and Ub. Constant k depends on construction parameters of the HSSGs and on their gauge factor. US is the amplitude of the supply voltage of the bridge (400 mV).

The schematic of a MP for signal processing electronic circuitry is presented in Fig. 4.

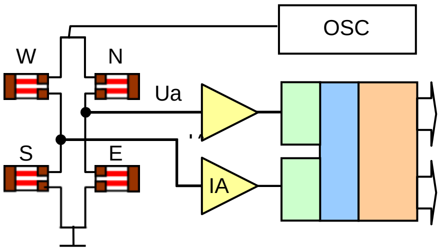


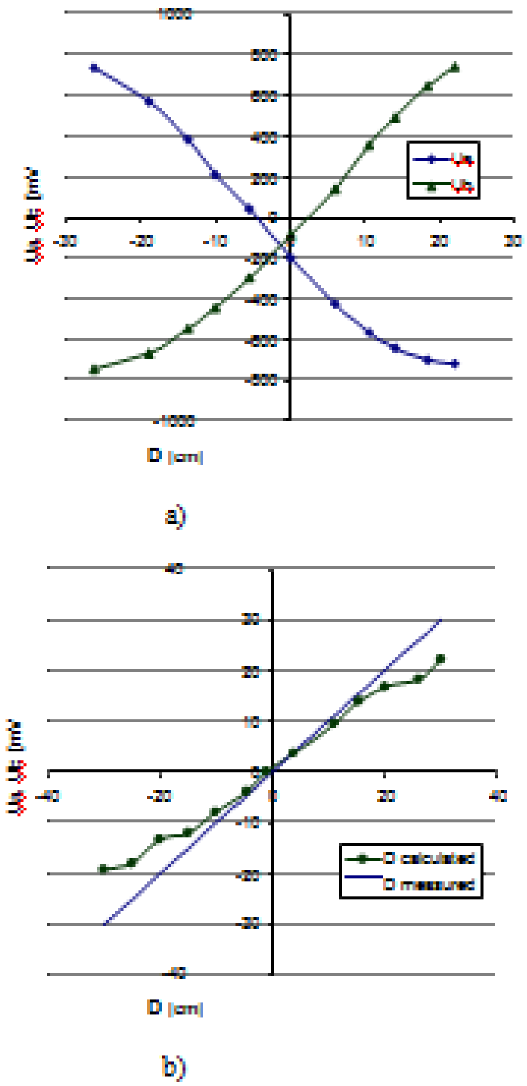
Fig. 4. Signal processing circuit at MP level

The WB is supplied with an ac current of 1 MHz frequency and 400 mV voltage amplitude delivered by a sinusoidal oscillator. The two sinusoidal voltages, Ua and Ub, proportional with the deformation of the four strain gauges are picked up from the two arms of the bridge. After amplification using large bandwidth instrumentation amplifiers, IA, the voltages are converted into dc current using the peak detectors PD. Then, the signals outputted by PDs are acquired by Texas Instruments MSP430 microcontroller through its analog inputs. The microcontroller has also the task to compute the values of the displacement D and of the orientation α of the landslide according to (1) and (2) at the corresponding MP level and to send them in digital form to the measurement node MN (see Fig. 1) that manages, in turn, data communication with all MPs of the transducer. The communication of the MPs with MN is done serially using RS485 protocol. To the same MN are also delivered information about the pore water pressure picked up from a PWP transducer mounted at the interface with the base solid layer and also values of temperature and humidity at every MP level. This transducer is part of a wireless sensor network (WSN) by means of the MN, which is endowed with a measurement node controller that nests a node server, responsible with data classification and communication with the coordination gateway (CG) (Takayama et. al; 2006).

2. RESULTS AND DISCUSSION

A. Laboratory tests

The transducer was first tested in laboratory in order to assess its metrological performances and characteristics. For this, an experimental setup was built with the aim to simulate a landslide at different soil levels. Fig. 5a) shows the results of a test in terms of Ua and Ub voltages dependence on the displacement of a measurement point, D, following the NW-SE direction, i.e. along a 45□ angle with the orthogonal orientation of the WB. Using these, the value of Dc has been calculated using (1) and represented together with the measured value, D (Fig. 5b).



a)

b)

Fig. 5. Dependence of a) the U_a and U_b voltages and b) calculated value of D_c on the MP displacement traced with experimental setup in laboratory

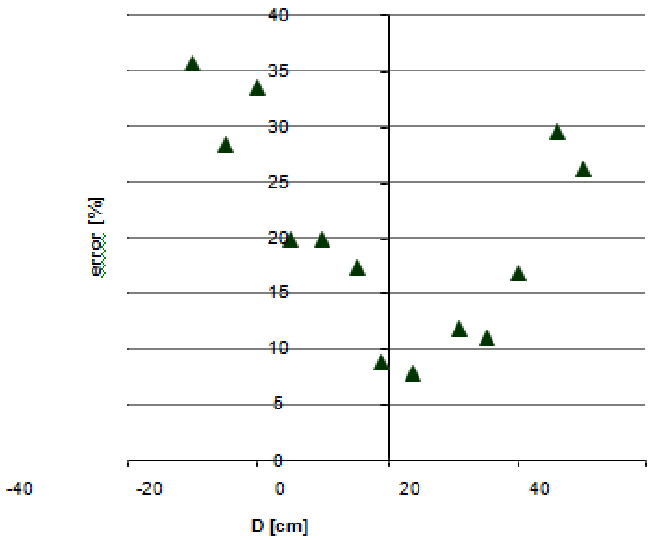


Fig. 6. Error evolution over the measurement range of *D*

With this information we calculated the errors of determining the value of landslide displacement under the chosen direction. The error evolution is presented in Fig. 6. As it may be observed, the measurement of the landslide displacement is not quite precise, as the errors rise to more than 30% for extreme intervals, but this is not really a drawback as the transducer is not devoted firstly to accurately measure the soil layers displacement but merely to detect as early as possible a landslide initiation in order to alert the population and authorities in that region.

In field tests

We tested our transducer working in real conditions in field by deploying a small wireless sensor network in the region of Central Moldavian Plateau, the Northern part of Madarjac village on the right side of Pietrosu Valley. Here is a well known landslide area studied by geologists for several years on which they dig two observing wells of which they studied the geological structure of the sliding layers. Fig. 7 depicts the cartographic emplacement of the network and Fig. 8 shows a detail of the old landslide and the network configuration.

The measurement node MN2 is far from the gateway (about 100 m) and for this the intermediate node MN1 had to be inserted. MN3 and MN4 communicate directly with the gateway in a star architecture. The measurements have been performed in a snowmelt period between 15th of February, 2014 to 25th of May, 2014. The winter of 2013-2014 was abundant in precipitation in that region and landslide were hoped to be produced. The data have been recorded onto the gateway memory during the whole interval. In Fig. 9 we present the recorded data for MN1 and MN2 points. As it may be observed, small displacements occurred mainly after 15th of March, most important being at MN1, that was emplaced on the very slope of the hill. From these recordings we prove the capability of the transducer to be sensitive to very small displacements. More analysis has been performed on data recorded from every MP along the transducers, showing the displacement and orientation for more than 3 meters in depth.

3. CONCLUSION

In the paper we presented construction and characteristics of a landslide transducer capable to detect and measure very small displacements of soil layers due to special highly sensitive strain gauges acting as sensitive elements. The device was tested both in laboratory and in the field, providing satisfactory results in terms of characteristic sensitivity and linearity. Further improvements are envisaged in power management and consumption reduction areas.

Acknowledgment

The results presented in this paper have been financially supported by the Romanian Ministry of Education and Research through the project PN-II-PT-PCCA-2011-3.2-0975, contract no. 63/2012.

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