USE OF MEMS TECHNOLOGY IN MASS WASTING RESEARCH

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1. INTRODUCTION

Mass movements are a major threat to human life. Their growth depends on many factors. The main factor causing the surface mass wasting is the gravitational force, but the conditions in which this force can act, arise in different ways: it may be undercutting of slopes by erosion or weathering, deep relaxation of the layers forming the edge or slope overload by rain or snow. Often, all these factors interact (Książkiewicz 1959, Migoń 2009). The material speed movement down a slope can be very slow, in the manner that is difficult to observe as well as suddenly and violently at a high speed. Methods permitting the monitoring of areas at risk of movement are geodetic, geotechnical and geophysical technics. The most popular method to investigate the movements of the soil layers is to use the inclinometer probe. However, this application requires a large effort involving the execution of specific wells, set up columns and the most expensive item inclinometer probe. Measurements using this technique are periodic and not fully reflect the processes occurring beneath the surface. To improve result several probes can be connected together, admitted to the same hole and registering readings in a real time. The cost of installation often exceeds the project budget. In this paper authors want to put attention to the possibility of using miniature measuring devices such as accelerometers, which are working in low-g ±2g, to detect the force of Earth's gravity, distributed into three axis X, Y, Z. This allows calculating the direction of the deflection from X, Y axis and the deviation from the vertical line.

Using several measuring devices an active control-measurement network can be created to investigate in real-time across all depths of slope (Figure 1).

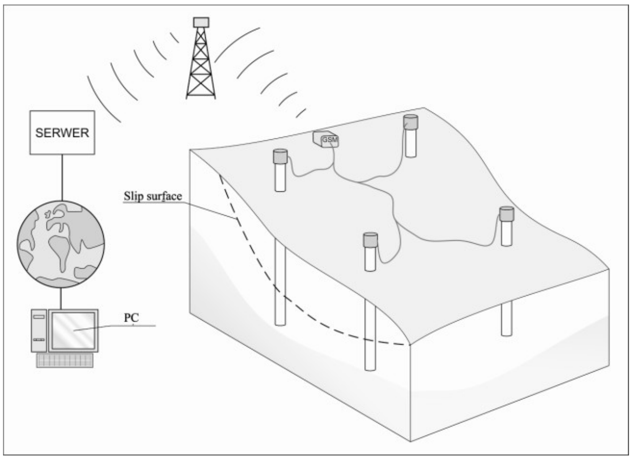

Figure 1. Scheme of control points network.

2. CONSTRUCTION AND OPERATION OF THE ACCELEROMETER

The accelerometer can measure linear or angular acceleration. Today's accelerometers are manufactured in MEMS technology (Micro-Electro-Mechanical Systems), they are closed in single hermetically sealed boxes. Inside box there is a measuring acceleration chamber and often DSP (Digital Signal Processor). The most common mounting type is surface (SMD) and accelerometer dimensions are in range of 4x4x2mm.

The measuring chamber is a structure in which, an semiconductor material (polycrystalline silicon) sets of beams (both fixed and movable) is formed by masking end etching technology. Any movements of measuring chamber will result in movable beams deflection value of which will correspond with acceleration (figure 2).

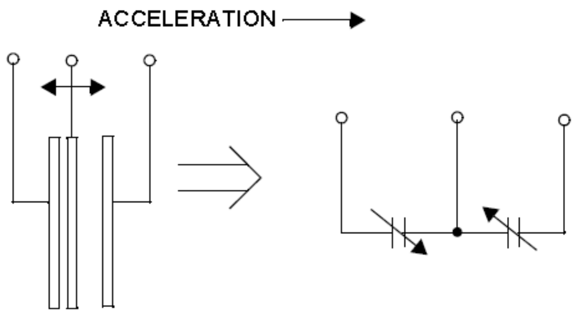

Figure 2. Work principle of a capacitive accelerometer (Freescale Semiconductor, 2009*).*

When the beams attached to the central mass move, the distance between them and fixed beams on one side will increase on the other side will decrease by the same value, depending on the acceleration of the system. The beams form a chamber electrically connected to two series capacitors (figure 2). Any movements of beams will result in changes their capacity. The system processes and filters the signal, giving the output voltage proportional to acceleration (Pyka 2010).

3. PROTOTYPE

After evaluating components currently available, low cost device integrated with analog digital converter, has been selected for further experiments. Figure 3 shows a schematic construction of a MMA8451Q Freescale accelerometer. As mentioned earlier, the system consists of several blocks: measuring, ADC unit (Analog Digital Converter), DSP unit (Digital Signal Processor), and transmission unit.

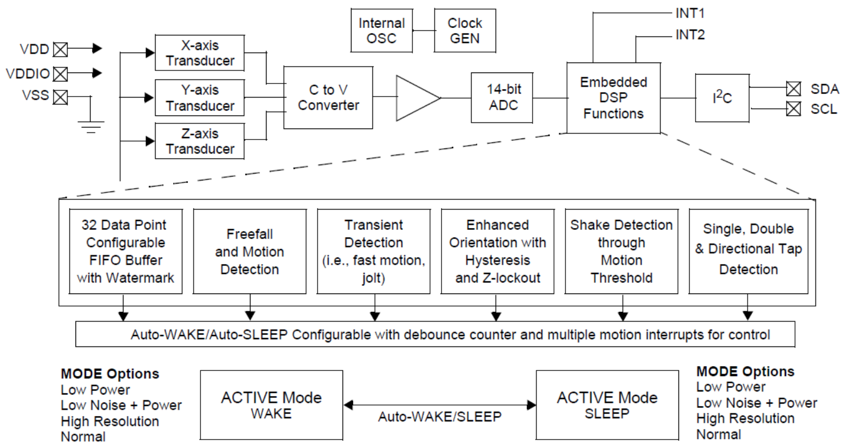

Figure 3. Block diagram of MMA 8451Q manufactures' Freescale.

Figure 4 shows how vertical inclination ϕ can be decomposed into two component angles θ, ψ (pitch and roll).

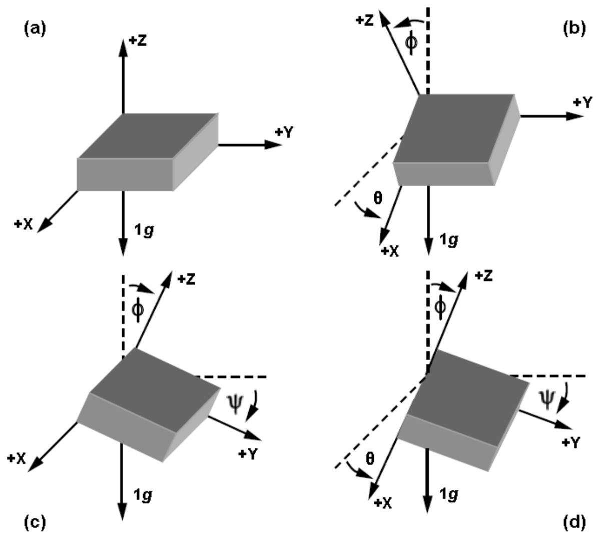

Figure 4. Angles of independent inclination sensing: g – gravity acceleration, ϕ - deviation from zenith, θ - deviation from X axis, Ψ - deviation from Y axis (Fisher Ch.J.)

The individual components of deviation angles from the vertical line, along X and Y can be calculated according to simple trigonometry formulas 1, 2, 3 (Clifford, Gomez 2005, Łuczak 2008, Fisher).

$$\theta = \arctan\left(\frac{A_{xOUT}}{\sqrt{A_{yOUT}^2 + A_{zOUT}^2}}\right) \quad (1)$$

$$\Psi = \arctan\left(\frac{A_{yOUT}}{\sqrt{A_{xOUT}^2 + A_{zOUT}^2}}\right) \quad (2)$$

$$\phi = \arctan\left(\frac{\sqrt{A_{xOUT}^2 + A_{yOUT}^2}}{A_{zOUT}}\right) \quad (3)$$

where: A_{xOUT}, A_{yOUT}, A_{zOUT} – raw acceleration reading obtained from the accelerometer

Formula 3 has inversed character for the reason that the device (accelerometer) is placed upside-down in a steel tubes in relation to the gravity force.
Still tubes will be

Test device will be placed in steel tubes sections connected by flexible joints (Figure 5). Connected steel sections will be set in the borehole and any reaming free space between sections and borehole will be filled with a betonies or similar material.

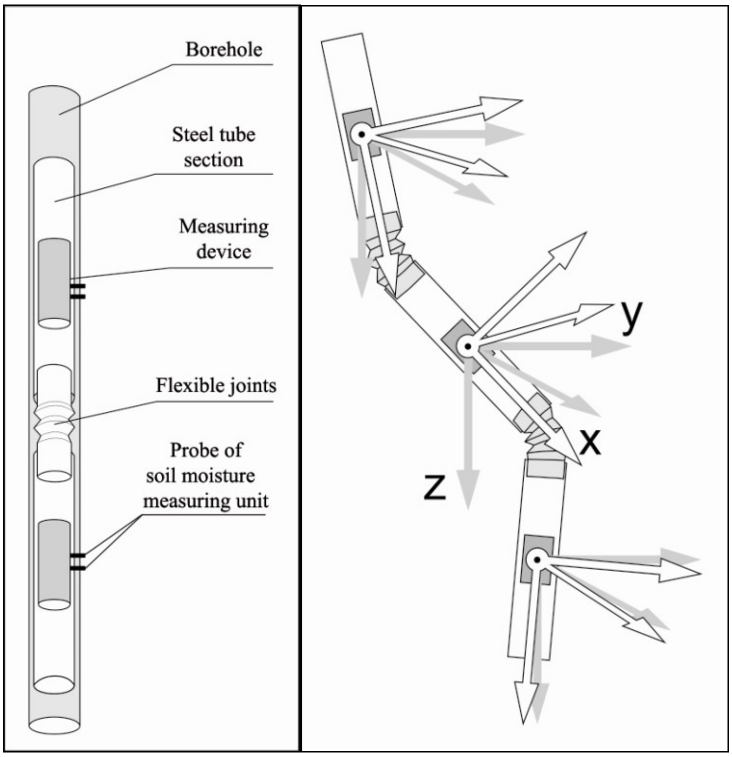

Figure 5. Schematic construction of the measuring sections.

The measuring device mounted in the steel sections is equipped with the following components: a digital accelerometer Freescale MMA8451Q characterized by a resolution of 14bit reading (0.25 mg), serial communication module based on the RS485

interface, an electronic thermometer DS18B20 from Dallas Semiconductor and additional elements for measuring the soil moisture (Figure 6.)

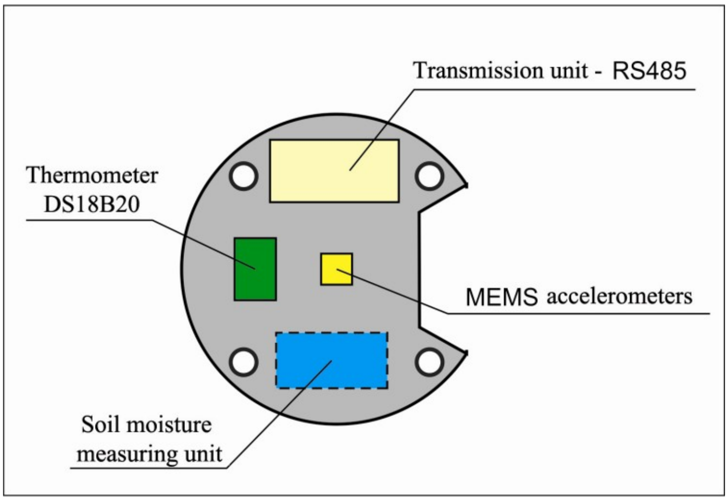

Figure 6. The block diagram of the measurement device.

4. RESEARCH TESTS

Thus prepared, the measurement device was tested. To check the angular accuracy, stability and repeatability of the reading, the experimental stand has been arranged as shown on Figure 7.

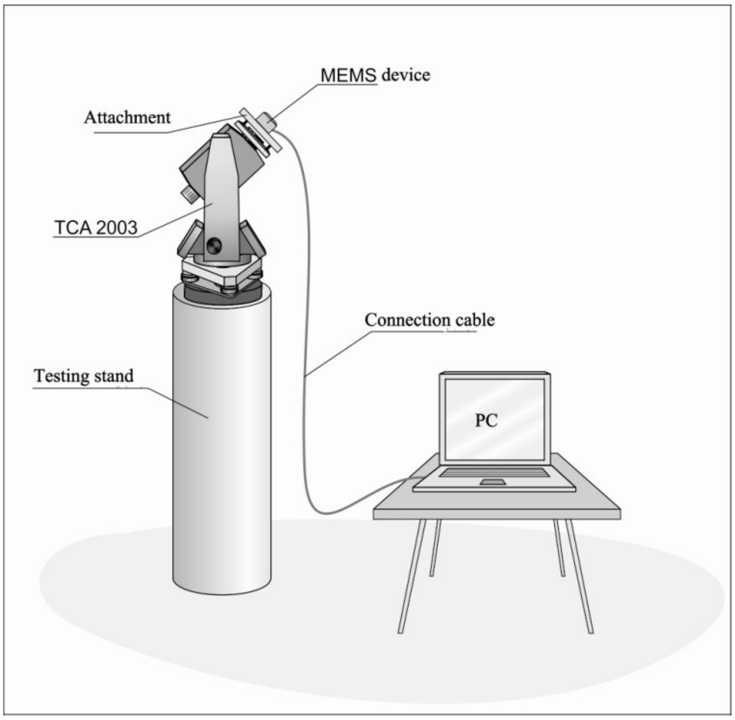

Figure 7. Experimental stand.

Motorized total station Leica TCA2003 which achieves angular accuracy at the level of 1.5^{cc} (0.5'') was used to test the measuring device accuracy. For testing measuring device has been made special attachment mounted on the end of telescope (Figure 7).

Constructed measuring device provided to be so sensitive, that it reacted even on movements of laboratory staff around experimental stand. Therefore a special application has been developed in order to remotely control the total station from PC (Figure 8).

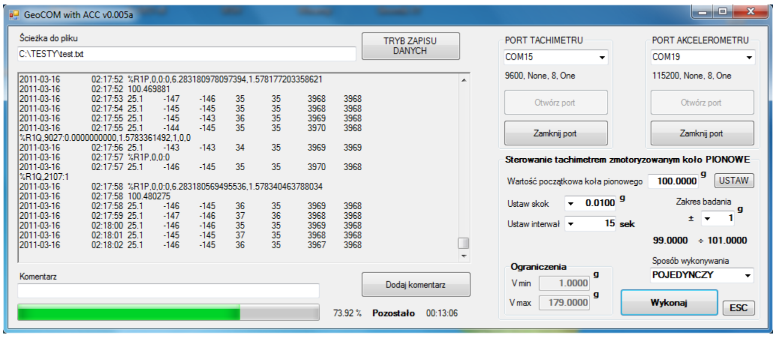

Figure 8. Author's software for testing accelerometer.

The software allows to setting the instrument at a given vertical angle, and simultaneously reading data from the accelerometer, which, together with control of the angles of the instrument readings were saved to a text file. Further analyses were carried out in a spreadsheet.

The first test was to check the stability of readings from the accelerometer. The assumed test conditions were: measuring time 24 hours data recording with 1 sec interval, the temperature range from 21.1 °C to 22.0 °C. In the experiment 86400 data records were registered. The statistical analyses of this data are presented in table 1.

Table 1. Stability reading of various angles - gravitational acceleration vector components, and deviations from the vertical line

	θ [g]	$\theta_{śr}$ [g]	ψ [g]	$\psi_{śr}$ [g]	ϕ [g]	$\phi_{śr}$ [g]
Minimum	-0.0321	0.0000	-0.0160	0.0000	0.0000	0.0000
Maximum	0.0963	0.0482	0.0963	0.0642	0.1134	0.0802
(Max-Min)	0.1284	0.0482	0.1123	0.0642	0.1134	0.0802
Average	0.0327	0.0260	0.0441	0.0370	0.0566	0.0460
Standard deviation	0.0148	0.0096	0.0136	0.0087	0.0145	0.0099
	mm/m	mm/m	mm/m	mm/m	mm/m	mm/m
Standard deviation	0.23	0.15	0.21	0.14	0.23	0.16

As can be seen, reading are and oscillated stable at around 0.23 mm/m for angles calculated from the individual readings, but for the calculated average angles (out of 30 samples), the stability of reading stood at 0.15mm/m.

The next step was to check the experimental reproducibility of obtained readings for a given angle. The testing procedure consisted of setting in total station the zenith angle at 0^g, then switching it to 25^g and in the next step, switching it back to 0^g, and finally setting

out 375^g. The procedure was repeated 200 times and resulted with statistical analysis are presented in table 2.

Table 2. Repeatability test readings obtained

	25^{g}0000		0^{g}0000		375^{g}0000	
Series of n = 200	Angle [g]	Avg. angle [g]	Angle [g]	Avg. angle [g]	Angle [g]	Avg. angle [g]
Minimum	25.0145	25.0178	0.0365	0.0442	375.0202	375.0284
Maximum	25.0253	25.0236	0.0642	0.0447	375.0392	375.1363
Average	25.0211	25.0217	0.0503	0.0444	375.0292	375.0336
(Max-Min)	0.0108	0.0058	0.0277	0.0005	0.0190	0.0079
Standard deviation	0.0058	0.0033	0.0139	0.0003	0.0096	0.0046

Also in case of repetition of the readings can be noted that the angular values obtained from averaging angles (from 30samples on 1sec) are about 40% accurate.

The last test was conducted to verify the characteristics of the accelerometer. The test procedure consisted of rearranging the telescope facility with mounted device in the range of ±100^g in increments of 2.5^g and the test results are shown in Figure 9.

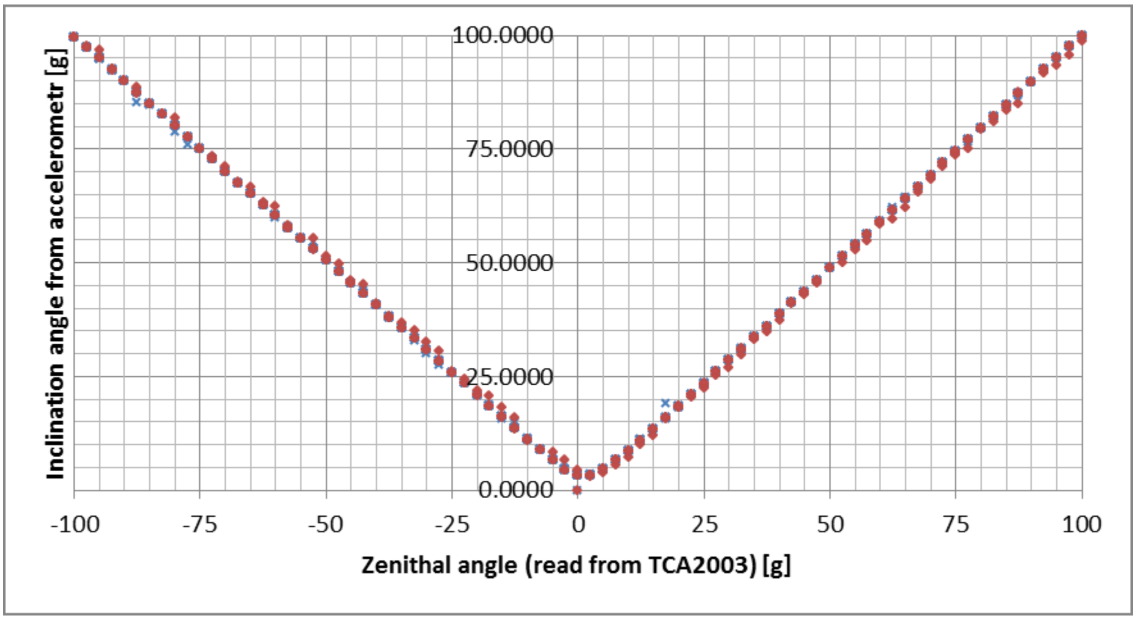

Figure 9. Characteristics of the accelerometer in the range ±100^g.

5. SUMMARY

Components used in the testing device produced the following results:
- 0.23 mm/m stability of readings
- repeatability of readings no worse than 2^c in the case of individual readings,
- repeatability of readings no worse than 1^c in the case of averaged readings,
- accuracy of averaging reading from accelerometer are better for about 40%.
Characteristics of the accelerometer in the range of ±100^g are in a linear fashion. Such an angular range is sufficient for monitoring of soil mass movements.
Application of MEMS technology to study soil mass movement allows for constant monitoring of the slope.
The data gathered using the presented experimental set-up will allow for verification of existing knowledge in the field of landslide movements.
Installation costs are relatively low compared to traditional monitoring techniques soil mass movements.

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