The Very-Broad-Band Data Acquisition of the Long-Base Tiltmeters of Grotta Gigante (Trieste, Italy)

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Abstract The horizontal pendulums of the Grotta Gigante (Giant Cave) in the Trieste Karst are long-base tiltmeters with Zöllner type suspension. The instruments have been continuously recording tilt and shear in the Grotta Gigante since the date of their installation by Prof. Antonio Marussi in 1966. Their setup has been completely overhauled several times since installation, restricting the interruptions of the measurements though to a minimum. The continuous recordings, apart from some interruptions, cover thus almost 40 years of measurements, producing a very noticeable long term tiltmeter record of crustal deformation. The original recording system, still in function, was photographic with a mechanical timing and paper-advancing system, which has never given any problems at all, as it is very stable and not vulnerable by external factors as high humidity, problems in power supply, lightning or similar. In December 2003 a new recording system was installed, based on a solid-state acquisition system intercepting a laser light reflected from a mirror mounted on the horizontal pendulum beam. The acquisition frequency is 30 Hz, which turns the long-base instrument to a very-broad-band tiltmeter, apt to record the tilt signal on a broad band of frequencies, ranging from secular deformation rate through the earth tides to seismic waves. Here we describe the acquisition system, present the up to date long term recording, and the observation of a recent earthquake.

Key words Geodetic underground measurements, Secular crustal deformation, Tiltmeter

1 Introduction

The Grotta Gigante (Giant Cave) situated in the Trieste Karst (Latitude 45°. 7083 N, Longitude 13°. 7633E) bears the Guinness Award of greatest cave in the world, as it has an elipsoidal shape of 130m length, 65m width and 107m height. In 1959, Prof. Antonio Marussi had the brilliant idea to use the height of the cave to build a couple of long-base tiltmeters of the horizontal pendulum type with Zölllner suspension[1]. After this date, the design of the mechanical part of the instruments was completely overhauled and the present instrumentation was installed in 1966. The horizontal pendulums consist of a sub-horizontal pendulum arm suspended by an upper wire fixed at the vault of the cave and a lower wire fixed to the ground of the cave. The distance between upper and lower mountings is 95m. The total weight of the pendulum (including wires) is 18.7kg, the horizontal beam has a length of 1.4m, and the period of oscillation of the pendulum in the horizontal plane is of 6min [1,2,3]. A horizontal shift of the upper relative to the lower mounting of the pendulum (shear), a tilt of the cave or the inclination of the vertical are recorded as a rotation of the beam in the horizontal plane about the rotation axis, which lies on the line connecting the upper and lower mounting points of the pendulum. The static amplification factor for tilt is about 24 000. The original recording system was optical on photographic paper, with an amplification of 0.9msec/mm. This system is very reliable and has been recording without greater problems since the time of the installation. The pendulums have been overhauled in 1982/83 and in 1997, and some parts as the polyethylene tubes protecting the wires have been exchanged. Very recently, in December 2003, a new digital acquisition system was installed, which is supposed to replace the photographic recording in the future, once its reliability has been ascertained. The advantages given by the digital acquisition system are the automatic readout, a drastically increased time and signal resolution, wherefore the instruments acquire the characteristics of a very broad band tiltmeter.

In the sequel we give a short description of the acqusition system and show some example recordings, as the secular tilt over the full observation period and the observation of a seismic event.

2 The new acquisition system

The new acqusition system records the position of a laser light reflected by a mirror mounted on the horizontal pendulum beam in correspondence of the rotation axis. The sensor is an analogical position sensitive detector (PSD) made of a long P-N junction, which can be illuminated across a transparent metallization surface. The laser-light generates carriers that form the current i. The current that flows in the P-crystal is collected by the metallization, the current that flows in the crystal N is collected by the two electrodes located at the two extremes of the crystal, through which the currents i_1 and i_2 (with $i_1 + i_2 = i$) flow, respectively. The conduction, away from the junction, obeys Ohm's law, and therefore depends on the distance of the electrodes and the conductivity of the crystal. The position of the luminous point of the laser beam on the surface of the sensor can thus be expressed as a function of the ratios of the currents on the electrodes.

With ρ the resistivity of the crystal N, for the resistances R_1, R_2 and the currents i_1, i_2 of the circuit shown in Fig. 1, the following relation holds:

$$R_1 = \rho d_1$$
$$R_2 = \rho d_2$$
$$R_1 + R_2 = \rho D$$

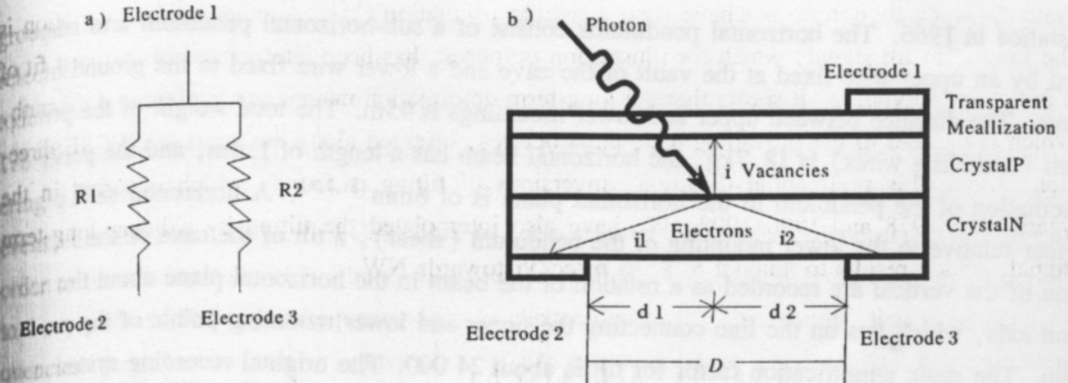

Figure 1 **Functioning of the PSD acquisition system, a) electronic circuit b) the interaction of the incoming light with the P-N junction creates a current, from which the position of the laser light can be determined.**

The following equation shows how from the currents across the electrodes 2 and 3, the position of the luminous point can be obtained. V is the Voltage applied to the circuit, d_1, d_2 and D are seen in Fig. 1:

$$\frac{i_1 - i_2}{i_1 + i_2} = \frac{V/R_1 - V/R_2}{V/R_1 + V/R_2} = \frac{R_2 - R_1}{R_2 + R_1} = \frac{\rho d_2 - \rho d_1}{\rho D} = \frac{d_2 - d_1}{D} = \frac{2d_2 - D}{D},$$

from which it follows that the position d_2 is given by:

$$d_2 = \frac{D}{2}\left(1 + \frac{i_1 - i_2}{i_1 + i_2}\right)$$

The currents which are output from the PSD are transformed into voltage, enter the A/D converter and are fed into the microprocessor for the arithmetical operations of sum and multiplication. The digital data are transferred to the serial port of the PC, and the data are saved on hourly files of 109600 samples by the acquisition software. The PC, running Linux, is accessible via ethernet, so the data are available in real time.

3 Secular crustal deformation for the years 1966 ~ 2004

The long period continuous observations of the tiltmeters are graphed in Fig. 2, which cover the remarkable time interval of nearly 40 years. The original data sampling of the photographic readout is hourly, which has been reduced to daily sampling after application of an anti-alias filter. One evident feature of the observations is the regular yearly oscillation, seen in all crustal deformation stations of good quality, and due mainly to the thermal influence of one year period on the deformation; to some extent it is also due to the yearly variation of the subsurface waters, which though do not have such a regular oscillation [4,5]. Another evident variation is the long-term tilt signal, which for illustration purposes, has been interpolated by the best fit of a 3rd order polynome. It shows that the long-term deformation maintains a preferential azimuth, which is parallel to the prevailing tectonic structures, oriented along the coast in NW-SE direction. Along this preferential direction, inversions of tilting is found, which occurred in the years 1976/1978 and 1996/1998. We have also interpolated the tilting by a linear long-term signal, which results to amount to 8.76 msec/yr towards NW.

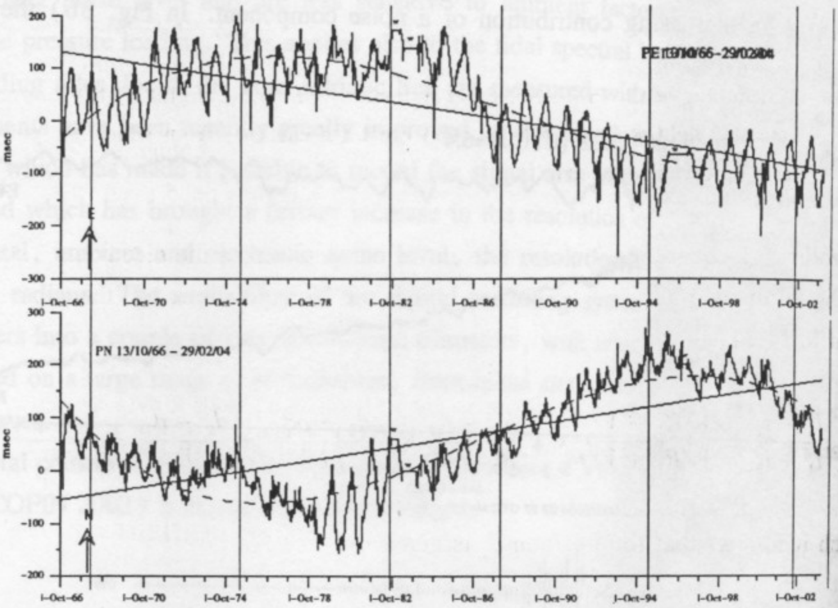

Figure 2 **The secular deformation of the cave as recorded by the long-base tiltmeters from October 13, 1966 to February 29, 2004. PE and PN refer to the EW and NS component, respectively. Interruptions longer than 75 days are denoted by an asterisk. Shown is the data curve (continuous line), the interpolation with a 3rd order polynomial (dashed line) and the interpolated linear variation (continuous heavy line). The linear variation amounts to 8.55 msec/year towards NW.**

4 Observations at seismic frequencies - the seismic event of Marocco, Feb. 2004

The increase in the signal and time resolution of the new digital acquisition system makes it possible to record the horizontal ground movement due to the passage of seismic waves with the long-base pendulums. The instrumental response function of the pendulums is that of a damped oscillator with damping factor of 0.85 and a reduced pendulum length of 134.32cm. The eigenfrequency of the pendulums being of 360sec, the transfer function for horizontal ground movement is flat at frequencies greater than about 0.025 Hz [6]. For illustration we have selected the recent seismic event of Marocco, which occurred on Feb. 24, 2004, with magnitude M = 6.4, at depth = 13km, and at the epicentral location with coordinates Latitude 35.178°N, Longitude 3.903°W [7]. In Fig. 3a the recordings of the original data are shown, covering the occurrence time of the seismic event. In order to isolate the observation of the seismic event, the origianl data are first detrended by least-squares fitting of a polynomial curve of 4 th order to the observation, then a band-pass filter is applied, with passing band from 60sec period to 4 sec period. The upper frequency limit is chosen due to the observation, that at higher frequencies there is an increasing contribution of a noise component. In Fig. 3b) the detrended and filtered data are shown.

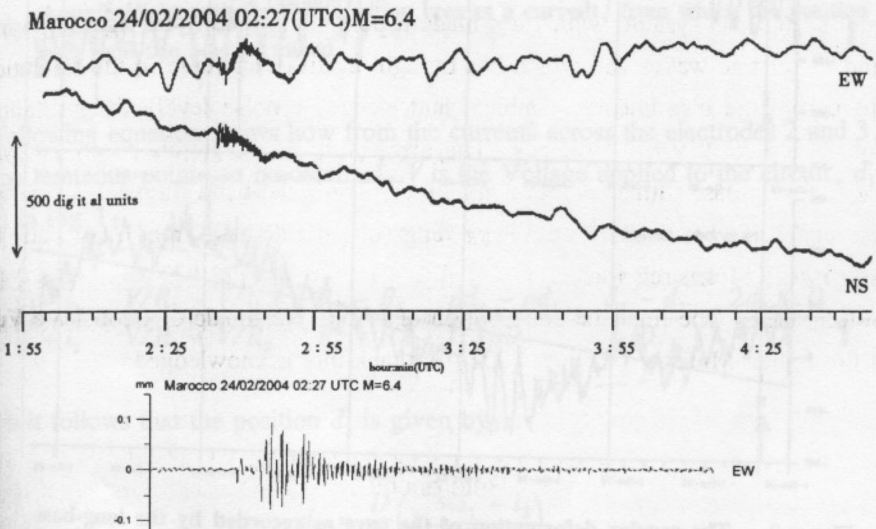

Figure 3 Example of the recording of a seismic event: Marocco, February 24, 2004. (M = 6.4, depth = 13 km, epicentral distance from station = 17.01°).
a) The original digital data. The time interval of 3 hours covers the occurrence time seismic event. b) the detrended and band pass filtered data.

5 Conclusions.

The Grotta Gigante (Giant Cave) in the Trieste Karst (Italy) has housed for almost 40 years a couple of long-base tiltmeters which have given a unique continuous record of long-term crustal deformation. As explained in previous studies [3,4,5], the comparison with the noise-spectra of traditional short-base tiltmeters operative in the same cave since 1999, showed that the long-base pendulums have lower noise level and are less sensitive to ambient factors as hydrologic effects and atmospheric pressure loading. This applies also to the tidal spectral band, where the earth tides and the loading tides due to the near Adriatic Sea are measured with high signal to noise ratio. The instruments have been recently greatly improved by the installation of a new digital acquisition system, which has made it possible to record the signal also in the frequency band of seismic waves and which has brought a further increase in the resolution of the signal. Apart from the instrumental, ambient and electronic noise level, the resolution of the digital acquisition is of 9×10^{-12} radians. The availability of the digital recording system has transformed the long-base tiltmeters into a couple of very-broad-band tiltmeters, with which the deformation signal can be recorded on a large range of periodicities, from quasi static deformations to the passage of seismic waves.

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References

1 Marussi A. The University of Trieste station for the study of the tides of the vertical in the Grotta Gigante. In: Proc. 3rd Int. Sympos. on Earth Tides, Trieste, 1960. 45 ~ 52

2 Braitenberg C. The Friuli (NE Italy) tilt/strain gauges and short term observations. Annali di Geofisica, 1999, 42: 1 ~ 28

3 Braitenberg C, Zadro M. The Grotta Gigante horizontal pendulums – instrumentation and observations. Boll. Geof. Teor. Appl. , 1999, 40(3/4): 577 ~ 582

4 Zadro M, Braitenberg C. Measurements and interpretations of tilt – strain gauges in seismically active areas. Earth Science Reviews, 1999, 47: 151 ~ 187

5 Braitenberg C, Nagy I, Negusini M, Romagnoli C, Zadro M, Zerbini S. Geodetic measurements at the northern border of the Adria plate. Millennium Issue of the Journal of Geodynamics, 2001, 32(1/2): 267 ~ 286

6 Rodgers PW. The response of the horizontal pendulum seismometer to rayleigh and love waves, tilt, and free oscillations of the earth. Bulletin Of the Seismological Society of America, 1968, 58(5): 1384 ~ 1406

7 NEIC. USGS Earthquake Hazards Program. http://earthquake. usgs. gov/, 2004