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MONITORING LOCAL GEODYNAMICAL MOVEMENTS AND DEFORMATIONS BY BOREHOLE TILTMETERS IN HUNGARY

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Abstract

In Hungary there are two test sites for monitoring local geodynamical movements and deformations by means of borehole tiltmeters. One was established at the Mecsekalja-fault in Southwestern Hungary for monitoring the movements of the fault near to a planned deposit for radioactive waste of low and medium activity. This measurements have been carried out since autumn 1997. The other was established in the town Dunaföldvár in 2002. In this place the high loess bank of River Danube endangers human lives and buildings. The aim of the measurements is the development of an early alert system to forecast landslides in the frame of the EU project "OASYS". The high sensitive tilt measurements are disturbed by a lot of global and local effects e.g. earth tides, tilt caused by ground water level variations, transpiration of the surrounding vegetation, etc. superposed on the tilt signal. The paper shows some of these effects which can also be used to prove the quality of the coupling between the instrument and the ground. Beside the continuous tilt measurements different geodetic measurements (GPS and electronic distance measurements (EDM), precise leveling) were also carried out. The paper compares the results of tilt measurements with the ones of the geodetic measurements and shows that the results of the repeated geodetic measurements have also seasonal variations which was not obvious till present.

1. Introduction

Local geodynamic deformation measurements play a very important role in the investigation of crustal, sediment and mass movements in the vicinity of large industrial objects, e. g. dams, nuclear power stations, deposits of dangerous materials, etc. The geodetic measurements (GPS, EDM, precise leveling) give results with low accuracy and poor time resolution. To study the physics of the above mentioned processes and to forecast dangerous movements and deformations for prevention of disasters continuously recording methods are needed. For these purposes high sensitive borehole tiltmeters can be used because their installation is of relatively low cost and boreholes ensure a very stable place for the instruments.

In Hungary there are two test sites where borehole tiltmeters are used for continuous monitoring of movements and deformations. Geodetic measurements are also carried out twice a year, in spring and in autumn. One test site is at the Mecsekalja-fault in Southwestern Hungary. Here the continuous monitoring of the movements of the fault is very important because the establishment of a deposit for radioactive waste of low and medium activity is planed. The other test site is in a small town, Dunaföldvár built on the high river wall of the Danube. The aim of the measurements is the development of an early alert system to forecast landslides.

The high sensitive tiltmeter measurements are disturbed by local effects which can be in the same or higher order of magnitude than the movements of the fault or the ones of the river wall. The disturbing effects of tilt measurements are the variations of environmental parameters, as the variation of temperature, barometric pressure, ground water level, etc. (Kümpel et al., 2001, Rebscher, 1996). Some disturbing effects as earthquakes, earth tides, tilts caused by the variation of the ground water level and transpiration of the surrounding vegetation give us information about the coupling of the instrument and the ground. The local influences must be separated from the tiltmeter data to obtain the movements being in question. For this reason the results of the complex geological, geophysical, hydrological and geodetic investigations carried out at both test sites are also used.

2 The tiltmeters and their installation

The tilt measurements have been carried out by the dual-axis borehole tiltmeters Model 722 made by Applied Geomechanics Inc. (AGI), Santa Cruz, California. This tiltmeter consists of a cylindrical stainless steel body (85 cm long, 5.4 cm in diameter) containing two orthogonal electrolytic precision tilt sensors, amplifiers and signal filters for each of them and a temperature sensor. The tiltmeter is connected to the data logger via submersible steel-reinforced cable and an external switch box. The resolution of the instrument in a measuring range of ±200 μrad is 0.1 μrad and in a range of ±2000 μrad 1μrad. The instruments are calibrated by the method developed at the Geodetic and Geophysical Research Institute in Sopron (Hungary) and at the Geological Institute, Section Applied Geophysics, Bonn University. (Mentes et al., 1996).

The tiltmeters are usually installed in shallow boreholes at depths between 2 and 8 m. The borehole has to be drilled with a diameter of about 30 cm, its casing is a PVC pipe that is coupled to the surrounding formation by concrete. Inside the pipe the instrument is fixed by quartz sand in order to obtain a strong coupling to the ground. The signal is transferred via cable to the switch box which is placed in a trunk at the surface together with the power supply and a data logger (Fig. 1.).

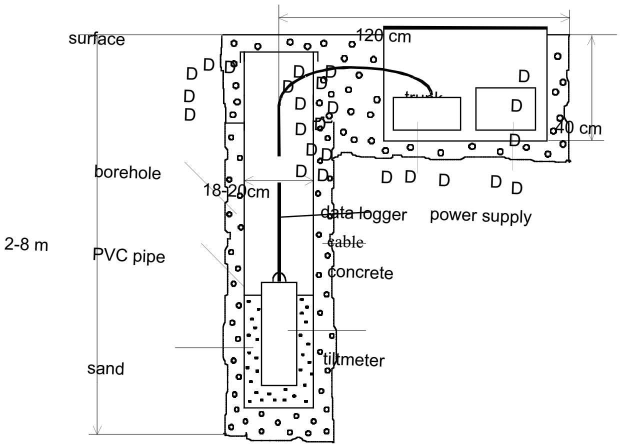


Fig 1. Installation of Model 722 tiltmeter in the borehole

3. Tilt measurements at the Mecsekalja-fault

Fig. 2 shows the site of the measurements at the Mecsekalja-fault (pecked line in the map). The pillars for the GPS and EDM measurements (point numbers: 2052, 4366, 4371, 4466) are marked by squares and the circles designate the leveling line. The end points of the leveling line (point numbers: 1001, 1004) are placed directly on the bedrock. Two other points of the leveling line (point numbers: 100, 200) and the GPS points are deep founded concrete pillars. The tiltmeters are placed at the ends of the leveling line. At the point D1 the whole borehole is drilled in the bedrock and it has a depth of 3.6 m. At the point D2 the borehole has a depth of 8 m. The deepest part of the borehole is in the bedrock (0.8 m from the bottom) and its upper part (7.2 m from the surface) is in loess. The borehole is here at the bottom of a hill. The place of the

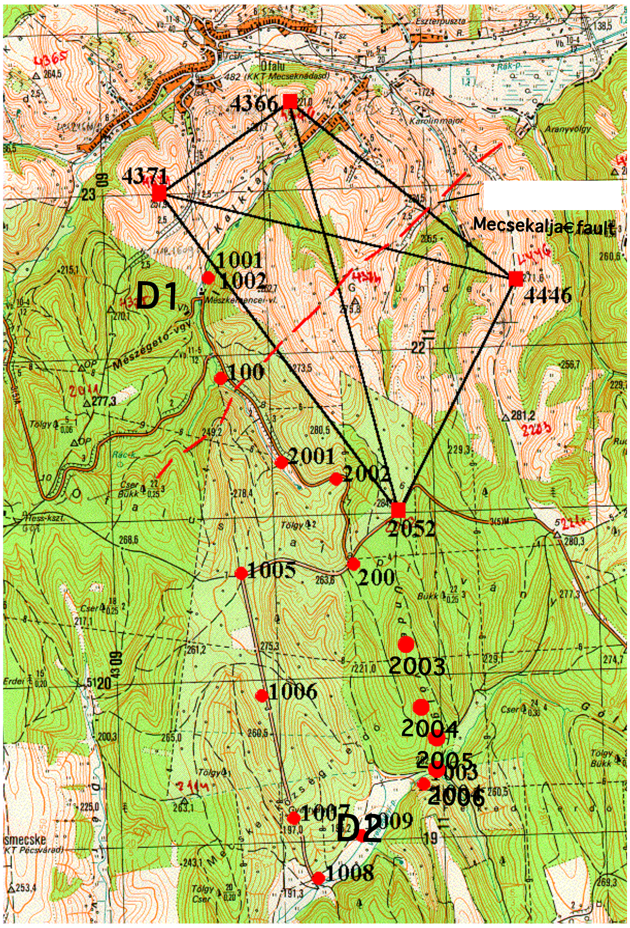


Fig. 2. Map of the test site at the Mecsekalja-fault

instrument is surrounded by the hill from North and partly from West and by a meadow from the other sides.

North of the fault the bedrock is Jurassic limestone and south of it, granite. The Y-direction of both tiltmeters is N-S, so both tiltmeters record tilts of the same directions. The sampling period of the tiltmeters is 1 hour. The tiltmeters were installed in October, 1997 and the measurements have been carried out continuously since 13.10.1997.

Fig. 3 and 4 show the raw data recorded at the points D1 and D2 respectively from 01.01.1998 till end of 2002. The figures show that the tilts at the point D1 are in both directions in the range of about some microradians till end of 1999 and after it began a much higher change, especially in the direction X. The borehole at this point was overrun by water during a heavy rainfall in the spring of the year 1999 and after it this tiltmeter became much more unstable but the reason of the steep change is still unknown.

At the point D2 the tilt variation was within 50 microradians in the direction X (East) and in a range of about 30 microradians in the direction Y (North). Here the tilt variation was very large at the beginning of the recording. The reason of this was that the borehole was not made water-proof. The tiltmeter is operating here under groundwater and therefore the stabilization of the instrument needed much more time than that of the tiltmeter at the point D1.

The temperature in the borehole D1 (temperature of the instrument) varies between 9 °C and 14 °C because the depth of this borehole (3.6 m) is not sufficient to ensure a stable temperature compared to the point D2 where the depth is 8 m and the temperature (average value: 12.8°C) varies less than 0.5 °C. Despite of the shallow depth of the borehole D1 there is no correlation between the tilt and temperature data, as in the borehole D2. In the recording period the change of the outer temperature was about 25 °C (the values in the diagrams are relative and not the absolute values). It means that shallow boreholes damp temperature variations significantly. The

jumps in the signal of the instrument temperature are of instrumental origin and they occur when changing the battery of the instrument.
The tilts of point D1 and D2 can be better surveyed if we plot tilt Y against tilt X. Fig. 5a and 5b show the tilts of the points D1 and D2 respectively. Fig. 5a shows a tilt towards north-east. Fig. 5b shows a "circular" tilt. The diameter of the "circle" is depending on the local disturbances. The greater is the diameter the greater are the local disturbances. If the tilt has a near circular (nearly closed) form – that means no significant tilt occurred in any direction - then we can suppose that there are no tectonic movements at the point.

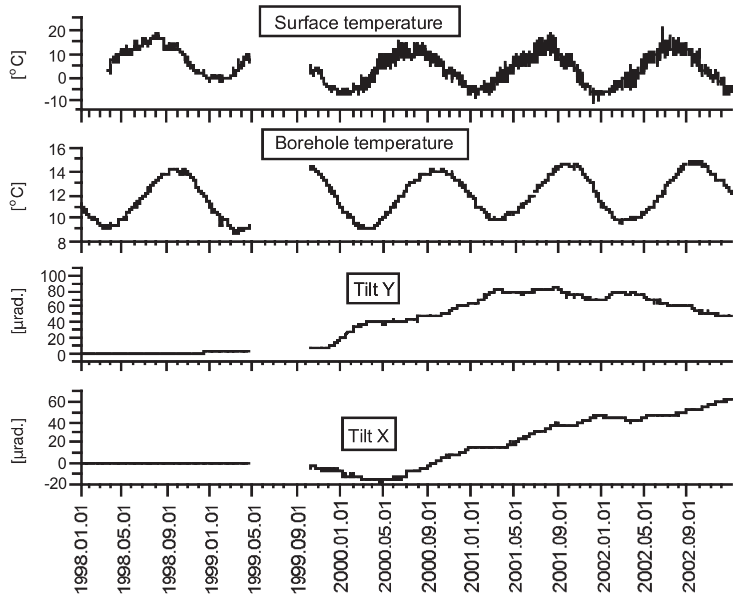


Fig. 3. Raw data recorded at the point D1 from 01.01.1998 till 31.12.2002

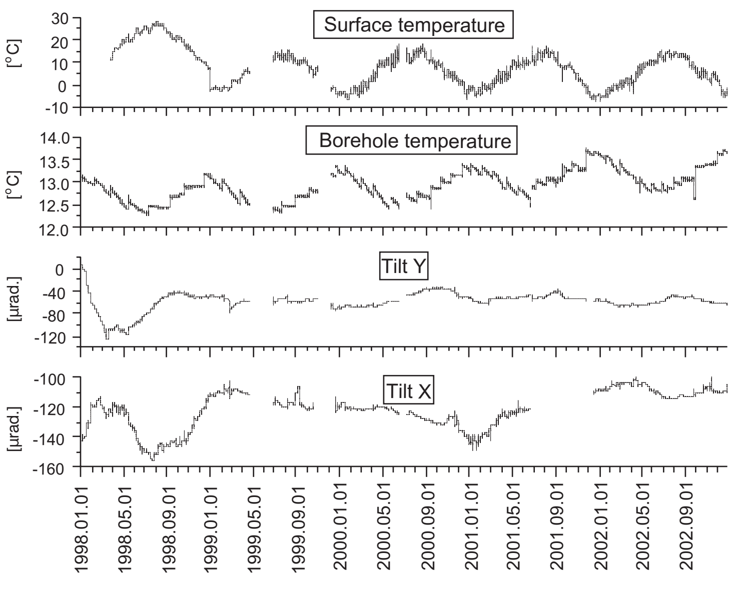
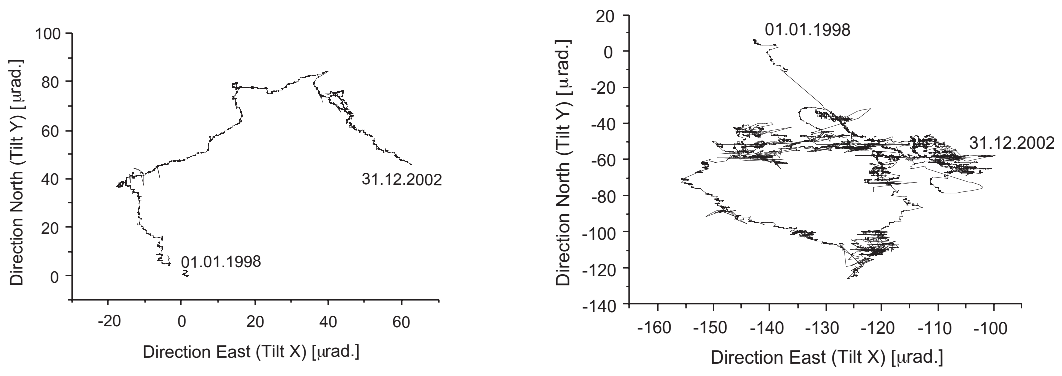


Fig. 4. Raw data recorded at the point D2 from 01.01.1998 till 31.12.2002



a. b.

Fig. 5. Tilt of the point D1 (a), tilt of the point D2 (b)

Fig. 5a. and Fig. 5b. show clearly that the tiltmeter D2 is much more disturbed by local effects than D1. The reason of this is that the whole length of the borehole is almost in loess and therefore the instrument is much more sensitive to local effects than the instrument at the point D1. Fig. 6. shows some landslides taking place on the surrounding hills. The processes of landslides are diverse. In the case of the recorded landslides the upper layer of the soil slides after rain and tilts the tiltmeter moving the upper part of the borehole in direction downward, parallel to the slope. Somewhat later the lower layer of the soil will be also wet and will slide down moving the bottom of the borehole downward decreasing the tilt of the borehole caused by sliding of the upper layer. But it is also possible that the recorded landslides are not real slides, because the recorded tilts are very small. In this case the increased pore pressure in the upper layer causes tilt and after the seepage of the ground water into the lower layers the pore pressure decreases and the tiltmeter comes back into its original position. To prove these processes longer tilt records and measurements by other methods (e.g. extensometers, hydrological, geophysical and precise geodetic measurements with a high repeatability rate) are needed. Landslides occur always in the seasons with a lot of precipitation, especially in early spring and in autumn. A close correlation cannot be found between landslides and the precipitation (Kümpel et al. 2001). Fig.7 shows tilt variation caused by the transpiration of the trees of the surrounding forest. The period of the signal is 24 hours. The level of the ground water slowly decreases due to the transpiration of the trees and causes a ground tilt. During night the transpiration of the trees decreases and the ground water returns to its original level.

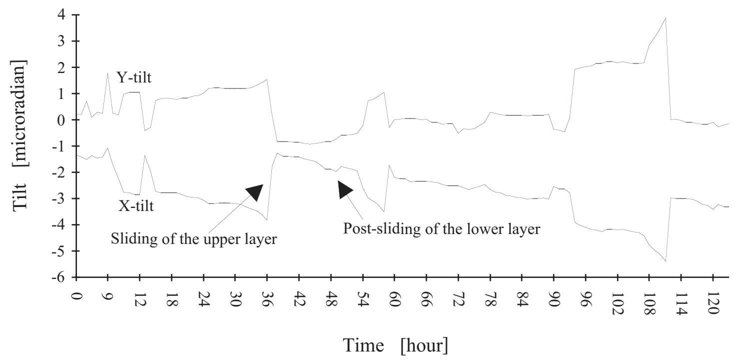


Fig. 6. Landslides recorded at the point D2 from 24.03.1998 till 29.03.1998

The results of the yearly twice repeated geodetic measurements show that this measurements have also seasonal variations with an annual period. Fig. 8 shows for example the distance variation between points 4366-4371 measured by GPS (L_1, L_2, L_1/L_2) and by electronic distance meter DI2002. The trend of the measured data shows a very slow displacement which is very small, smaller than the resolution of the measurements, therefore no tectonic movements can be assumed till now. Similar results were obtained by the precision leveling. Fig. 9 shows the height variations of the two endpoints of the leveling line. The results of the geodetic measurements are presented with more details by Bányai (2003a).

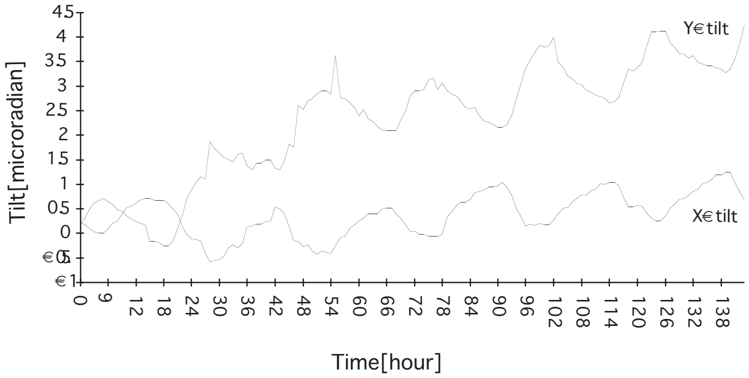


Fig. 7. Tilt caused by the transpiration of the trees recorded at the point D2 from 11.08.1998 till 17.08.1998

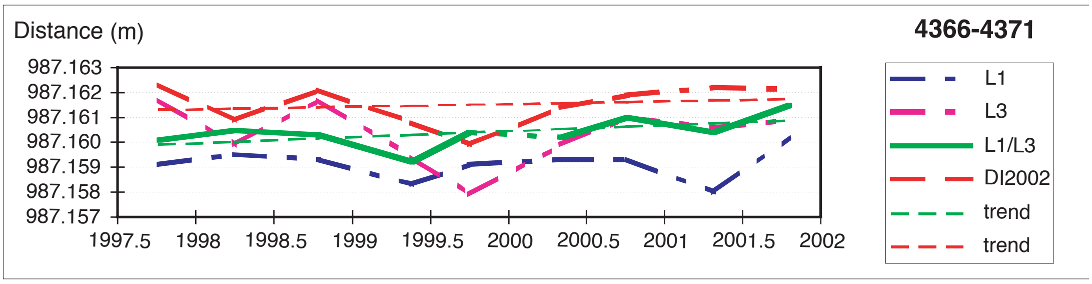


Fig. 8. The distance variation between points 4366-4371 measured by GPS (L_1, L_2, L_1/L_2) and by electronic distance meter DI2002.

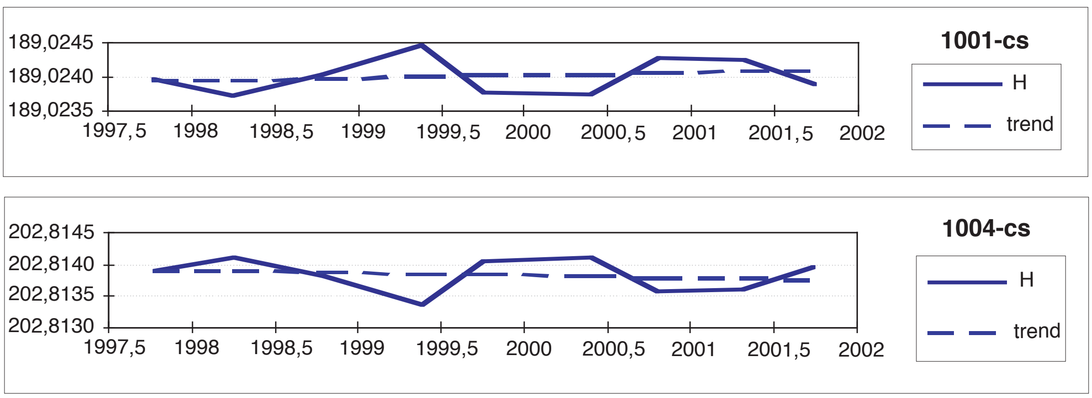
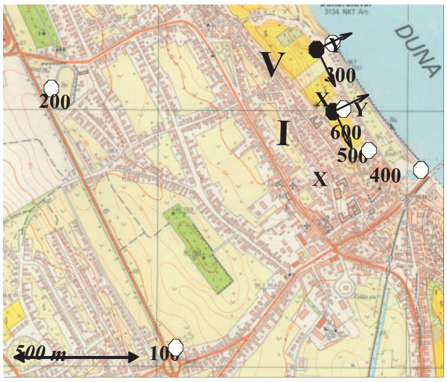


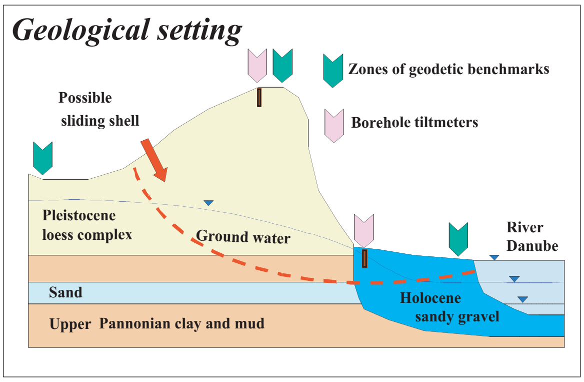
Fig. 9. The height variations of the two endpoints of the leveling line.

4. Investigation of the sliding of the high loess bank of River Danube

A part of the town Dunaföldvár in Hungary is built on the high loess bank of River Danube. Sometimes landslides occurred here e.g. in 1971. That was the reason why a test site with different measurement techniques was established to develop an early alert system. Fig. 10a. shows the map of the town and Fig. 10b. the geological structure of the high wall. The white circles mark the universal benchmarks (100-600) established for levelling, GPS and gravity measurements. The black circles denote the boreholes where continuous tilt measurements have been carried out from June 2002. The tiltmeters are installed in a depth of 3 m which ensures a high temperature stability for the instruments. The x axis of the tiltmeter is parallel and the y one is perpendicular to the direction of Danube. "V" marks the tiltmeter at the foot of the wall, in a distance of about 30 m from the Danube. "I" marks the tiltmeter on the top of the high wall.



a.



b.

Fig. 10. Map of the test site in Dunaföldvár (a), geological structure of the high bank

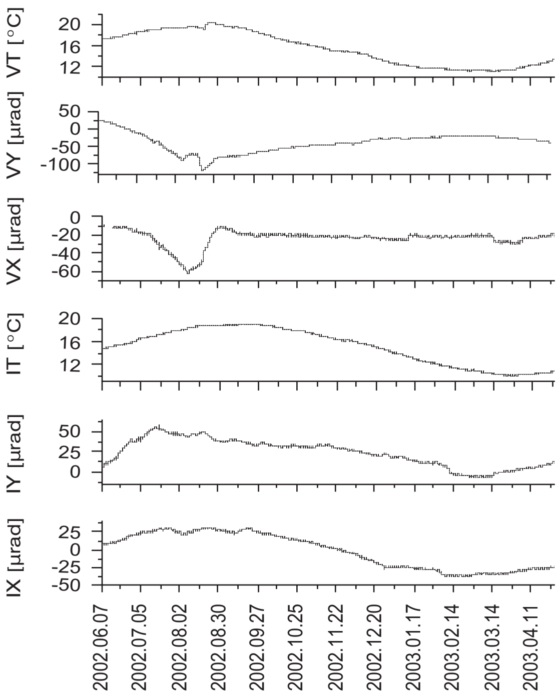


Fig. 11. Tilt data recorded at the high loess bank of River Danube

The recorded tilt data are seen in Fig. 11. VX, VY, VT designate the tilts in the directions X, Y and the borehole temperature at the foot of the wall, respectively. IX, IY, IT designate tilts and temperature at the top of the wall. The sampling rate of the data is 1 hour. Both tilt data at the foot and at the top of the wall show a good correlation with the borehole temperatures. In August 2002 the high tilt changes at the foot of the wall (VX and VY) are due to the flood of the Danube. The highest water level was on 19th August. The tilt changes at the top due to the flood are not identifiable at the first glance because they are much smaller than the ones at the foot of the wall. There is a jump in the temperature VT during the highest water level. This time the water of Danube reached the instrument. In summer time the water of the river is much warmer than the ground water and this caused the jump of the temperature of the borehole. The length of the data series is too short to recognize any dangerous movements of the high bank.
The geodetic measurements were repeated twice till now. The results are given in (B**á**nyai 2003b). A complex interpretation of the measurements (geodetic, geophysical, geodynamic hydrological, seismological, etc.) will be made after an observation period of many years.

Acknowledgements

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