STABILITY INVESTIGATIONS OF THE HIGH BANK OF RIVER DANUBE IN THE AREA OF DUNAFOLDVAR

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Abstract

The results of geodetic design, measurements and data processing techniques are presented which are developed for the stability investigations of the high bank of river Danube in the area of Dunaföldvár. According to the available techniques the results of geometric levelling and the full roving GPS measurements are summarised in more details.
It was experienced in the investigated area that, the changes larger than 1 mm determined by rapid geometric levelling and the changes larger than 4-5 mm determined by GPS technique can be interpreted as a significant value at the 95% probability level. The continuous borehole tilt meter observation shows a large correlation with the borehole temperature and the water level of the river Danube.

1. Introduction

In Hungary one of the most serious sources of geological risk is the sliding of the high loess banks of river Danube in the area of different villages and towns (Kleb and Schweitzer, 2001). In the town of Dunaföldvár a lot of money is spent regularly to stabilise the loess wall to protect human life and properties (Fig. 1).
In this project different geodetic methods were tested to establish a fast and effective monitoring system starting from the building of universal benchmarks, getting experienced with different measurement techniques and at the end developing a proper Geographic Information System to help the town in the necessary decisions of the prevention.

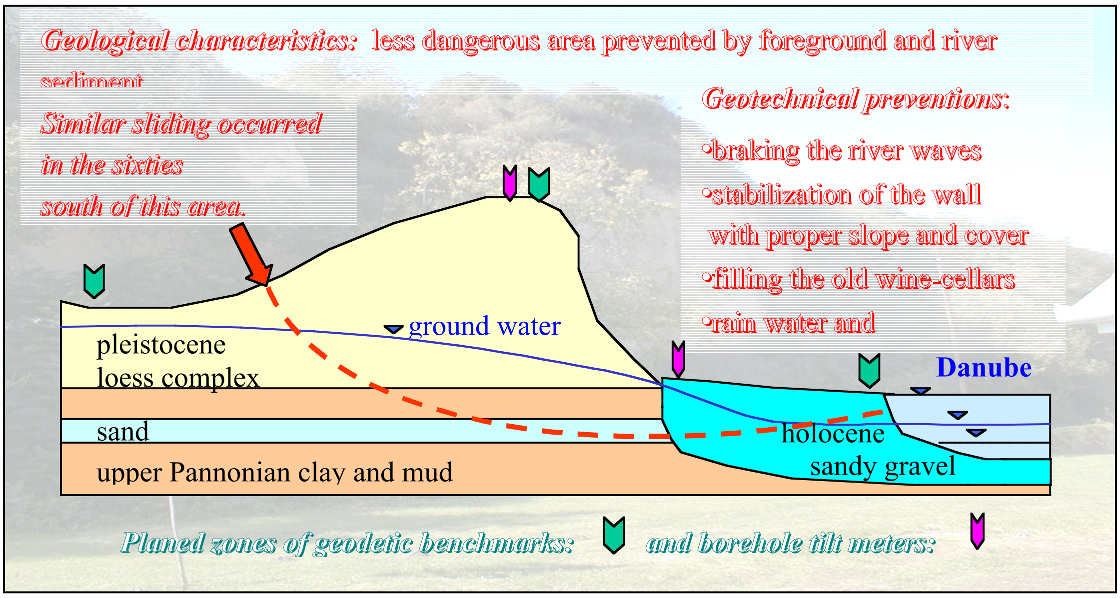

Fig. 1. Geological setting and geotechnical prevention in the area of Dunaföldvár

2. Planning of the monitoring system

According to the geological circumstances and the earlier sliding south of the investigated area, where small island appeared in the bed of the river Danube, zones of the geodetic benchmarks were defined in three different belts (Fig. 1). The first is west of the wall farther from the possible sliding shell, the second is in the top of the wall and the third is in the foreground near the recent bank of the river. Because we had only two borehole tiltmeters available during the planning period one of them (I) was placed at the top, and the second (V) at the foot of the high wall. The final network can be found in Fig. 2.

Because of the urban environment we could not apply traditional geodetic devices for the horizontal investigations. The applications of GPS technique was not ideal, also, and this fact set limits to the possible places of the geodetic benchmarks.

Universal benchmarks were built for precise levelling, GPS and gravity observations. The 4-6 m deep boreholes were filled with reinforced concrete and special half balls with central circles were cemented at the top (Fig. 3). In the case of the benchmarks 300 and 400 the half balls were cemented into proper reinforced concrete objects available at the foreground.

Heavy concrete pillars would be more ideal for horizontal observations. It was not applied here because of gravity measurements and we did not want to load the edge of the high wall additionally. It was thought that the benchmarks hidden near to the surface are in larger safety against of human interest.

Because the ground water plays a great role in the development of the sliding shells we planed the indirect monitoring of this water level by gravity observations and the comparison with the height level changes of river Danube that is registered daily near to the benchmark 400.

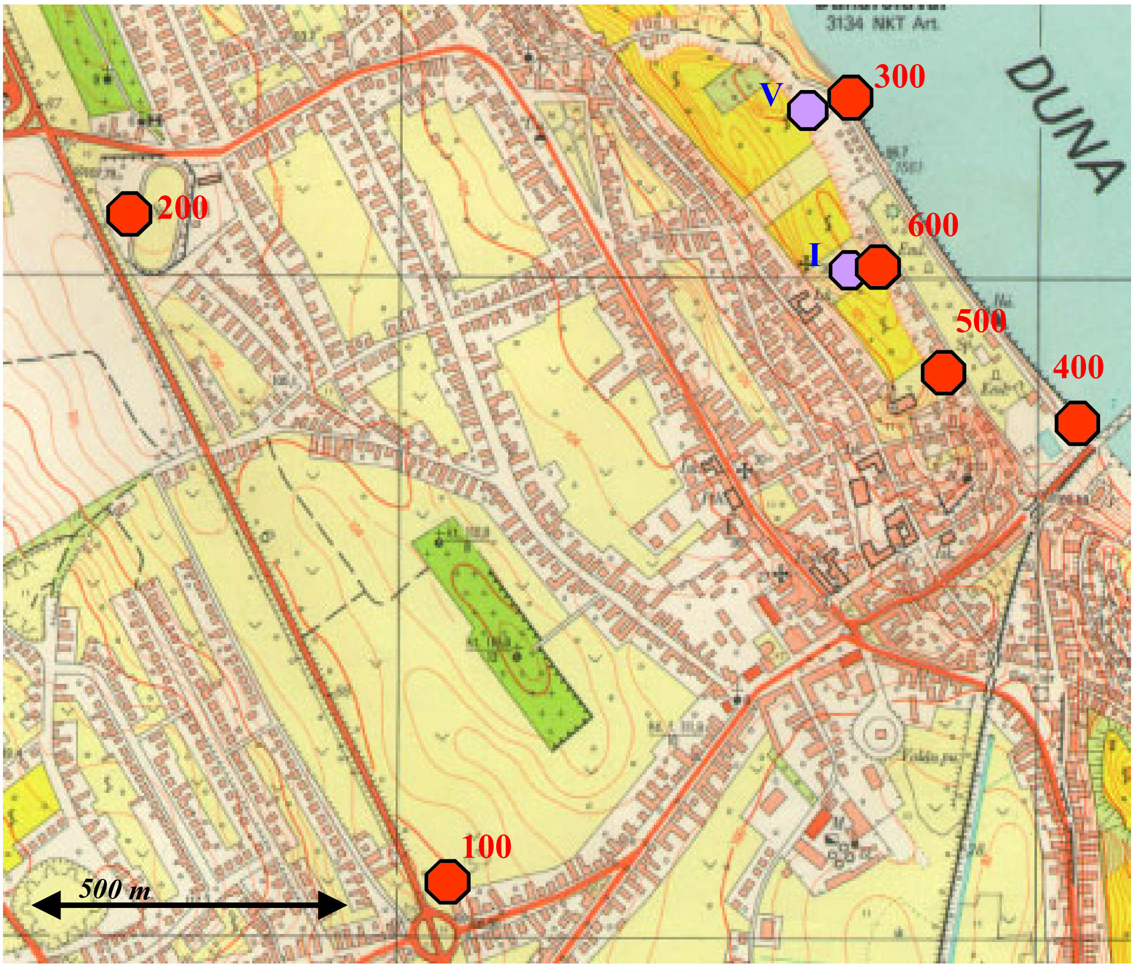

Fig. 2. The geodetic network of the monitoring system

Due to the geotechnical preventions this area is thought to be less dangerous at the moment, therefore only yearly levelling, GPS and gravity measurements were planed together with a continuous tilt meter and water level registrations of river Danube. The datasets analysed in proper Geographic Information System may lead to the detection of the supposed slow changes. The project however can be used to control the results of the preventions carried out in Dunaföldv_r and getting experienced with different theoretical possibilities.

Fig. 3. Universal benchmark in borehole

3. GPS observations and data processing

For the horizontal observations six Trimble SST GPS receivers were used simultaneously. In the case of one measurement epoch, which consists of observations from two consecutive days, a full roving observation strategy and processing concept may be applied (Bányai, 2000).
If the stations are occupied with different receivers in the second day according to the scheme of Fig. 4 the station coordinates can be estimated together with the main phase offsets of the GPS antennas by the GPS-NET baseline adjustment software. The baseline components as input data have to be estimated in every combinations using e.g. Bernese or GPSurvey software.

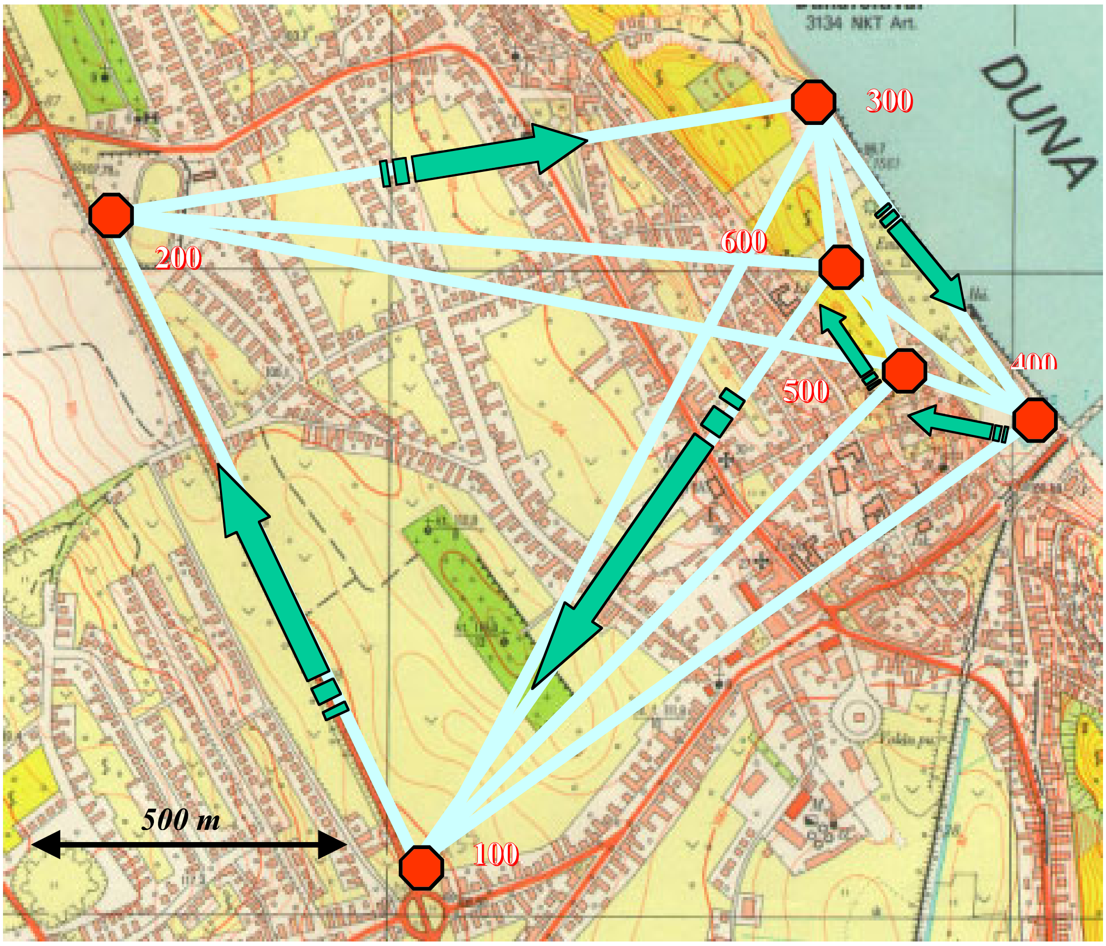

Fig. 4. The full roving GPS observation scheme

The GPS-NET software support the free network adjustment concept, that can be used to handle a three datum defects of the 3D network and the additional three datum defects of the antenna phase offsets, therefore it can be ideally used for deformation monitoring purposes, also.
The processing of the GPS campaigns carried out in the autumn of 2000 and 2001 with the same instrument shows that the urban environment was not so ideal. The estimation of phase offset biases had improved the solution, which overestimated the precision of the station coordinates, as it is known in the GPS data reduction.
In the presented results the baseline components were estimated with the GPSurvey software using L1 linear combinations because of very short baselines. The estimated phase centre offsets and their main square root errors (σ) are given in table 1. In spite of the fact that the magnitudes of the estimated offsets are satisfactory they are not consistent in the case of the consecutive years. It may be a consequence of the different circumstances and the lack of very precise centring of the antennas.
To minimize the centring problem adjusted optical plumb lines ware used, the heights were measured very carefully and the tripods were fixed to the ground with hardwood pegs.
Because of the over estimated precision the horizontal components were rescaled according to the 1.0 mm constant and 1.0 ppm distance dependent requirement of the baseline lengths. The vertical components were rescaled according to the comparison of levelling results (see later).
The results of the GPS deformation analysis are given in Table 2. According to the statistical tests a north component of the station 100 proved to be significant at the 95% probability level, therefore the change of this point was not minimized in the last run of the free network adjustment.

3. Geometric levelling and data processing

To speed up the measurements the hard rules of the precise geometric levelling were relieved. It was partly compensated by the 0.15 mm measurement tolerance of the Leica NA3000 precise digital levelling instrument.
The levelling route was minimized among the universal benchmarks and it was sectioned with additional half balls cemented in different object along the route (Fig. 5).
The actual distances between the rod and the instrument were chosen according to the circumstances during the forward levelling. In the urban environment levelling shoes were used but the standing points of the instrument and the rod were signed in the pavement. During the backward levelling the same standing points were used, which makes possible the cancellation of possible biases from the mean values.
Statistical investigations were carried out using the forward and backward measurements. In both observation epochs, at the autumn of 2001 and 2002, the precision of 0.3 mm/km were achieved. It was possible to carry out measurements by one measuring group within less than 4 days.
The height changes between the two epochs were determined according to the free network approach theoretically at the same way as in the case of GPS measurements.
According to the statistical tests a height change of the station 100 proved to be significant at the 95% probability level (Table 2).

	Phase centre offsets - 2001						Phase centre offsets - 2002					
Receiver	North	σ	East	σ	Up	σ	North	σ	East	σ	Up	σ
1	0,7	0,1	-0,7	0,1	0,8	0,7	-1,2	0,1	0,7	0,1	-0,6	0,8
2	0,8	0,1	-2,3	0,1	-2,0	0,7	-0,3	0,1	1,2	0,1	-0,9	0,9
3	-0,8	0,1	1,3	0,1	-1,7	0,7	2,0	0,1	-1,5	0,1	2,0	0,9
4	-0,7	0,1	1,0	0,1	-0,4	0,7	1,2	0,1	-0,4	0,1	2,3	0,9
5	-1,1	0,1	0,2	0,1	0,6	0,7	-0,9	0,1	-0,7	0,1	0,6	0,9
6	0,7	0,1	0,1	0,1	-3,1	0,7	-2,4	0,1	0,7	0,1	-1,6	0,8

Table 1. The estimated phase centre offsets (mm)

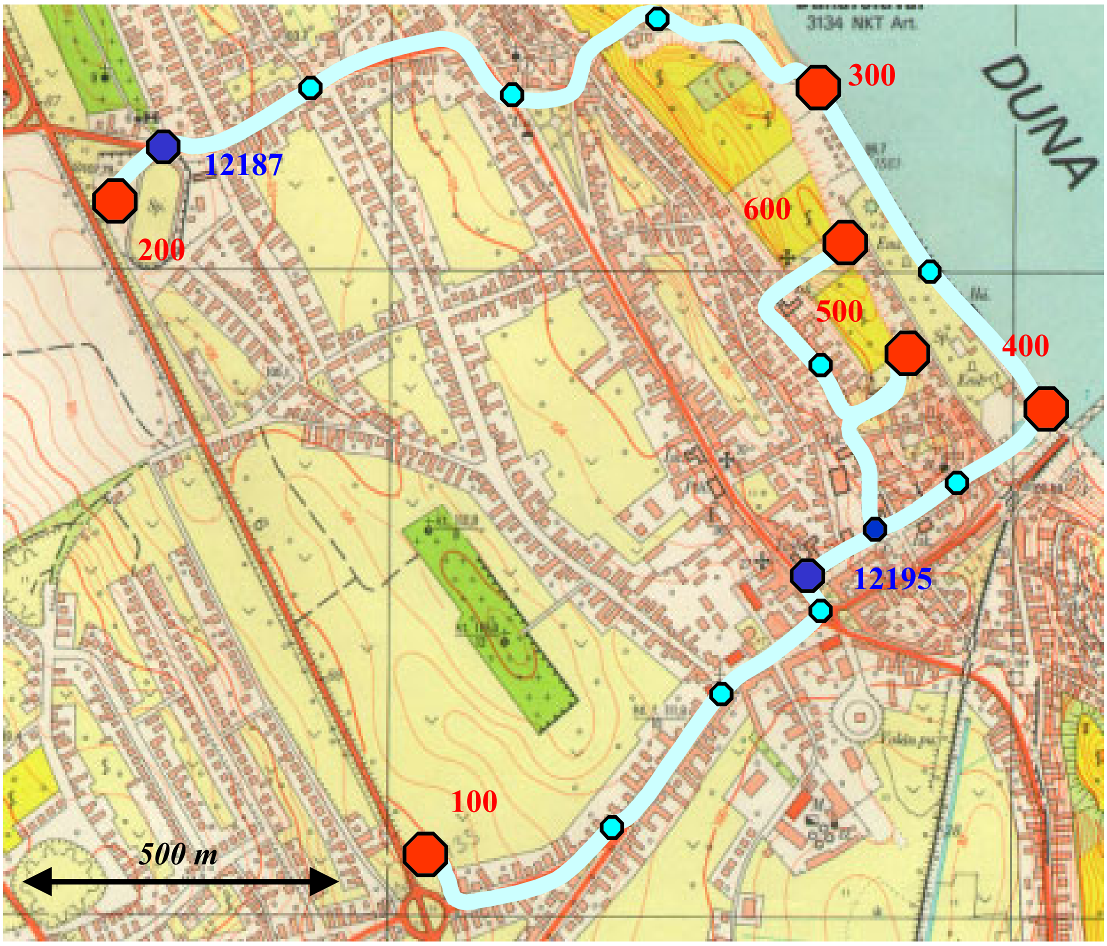

Fig. 5. The minimised levelling route with additional tying points

Benchmarks	GPS derived changes						Levelling	
	Δ North	σ	Δ East	σ	Δ Height	σ	Δ Height	σ
100	**-5.8**	2.0	-0.6	1.5	-5.6	3.1	**-2.7**	0.3
200	-1.8	1.9	2.2	1.5	-3.4	2.9	-0.1	0.3
300	-0.5	1.8	2.5	1.3	3.5	2.8	0.1	0.2
400	2.6	1.8	-1.3	1.3	-2.6	2.8	0.0	0.1
500	-0.6	1.8	-1.1	1.3	-0.2	2.7	0.4	0.2
600	0.2	1.9	-2.3	1.3	-2.6	2.9	-0.4	0.2

Table 2. Estimated coordinate changes between 2001 and 2002 (mm)
using the free network approach

4. Gravity measurements and tilt registrations

The universals benchmarks and additional points were determined by La Coste-Romberg G949 relative gravimeter in 2001 using the tying stations known in the national system (Fig. 6).
The precision of the adjusted gravity values (0.05 mGal) are less than the expected value. This is the consequence of the large traffic in the town. The measurements in night time had better characteristics. Because of instrument failure the measurements were not repeated in 2002.
The tilt and borehole temperature registrations between 2002.06.01 and 2002.11.28 are given in Fig.7. The x component of the tilt meters is parallel and the y component is perpendicular to the direction of river Danube.

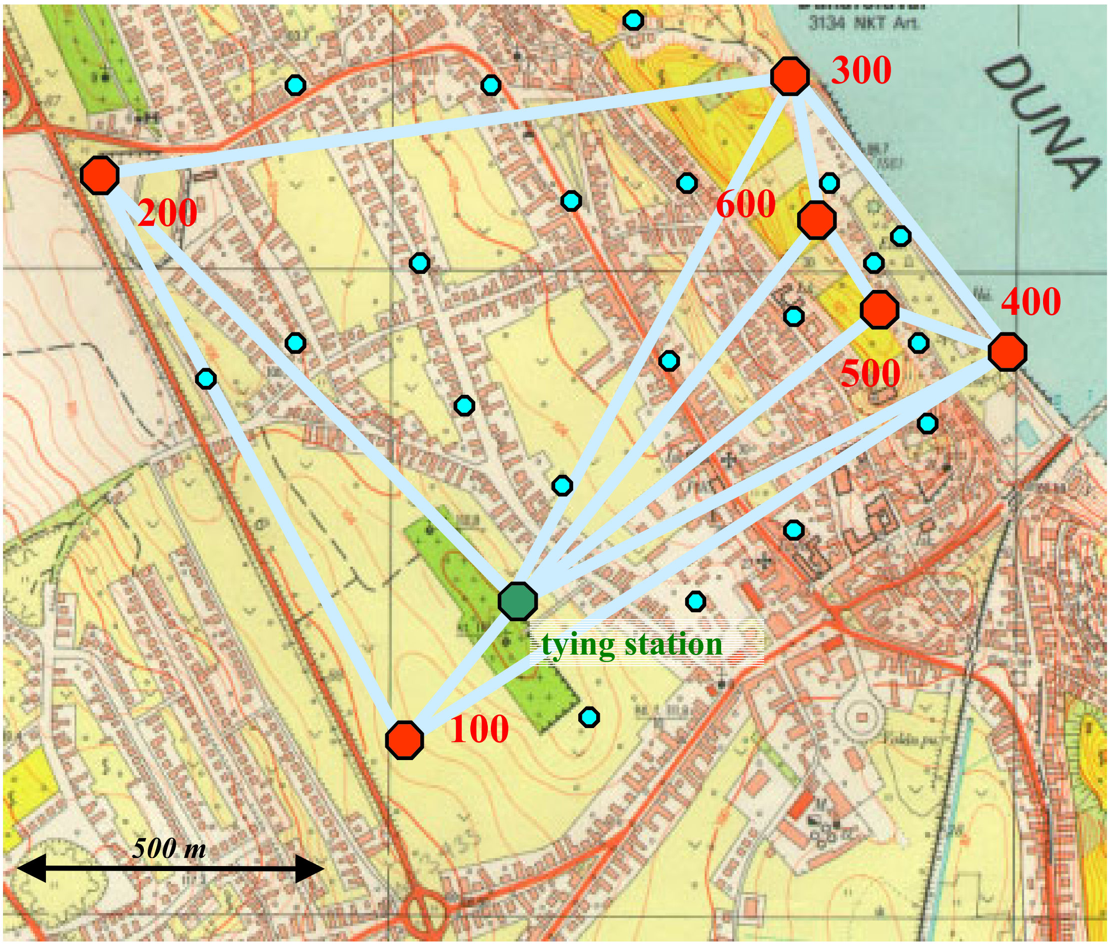

Fig. 6. The measured gravity network

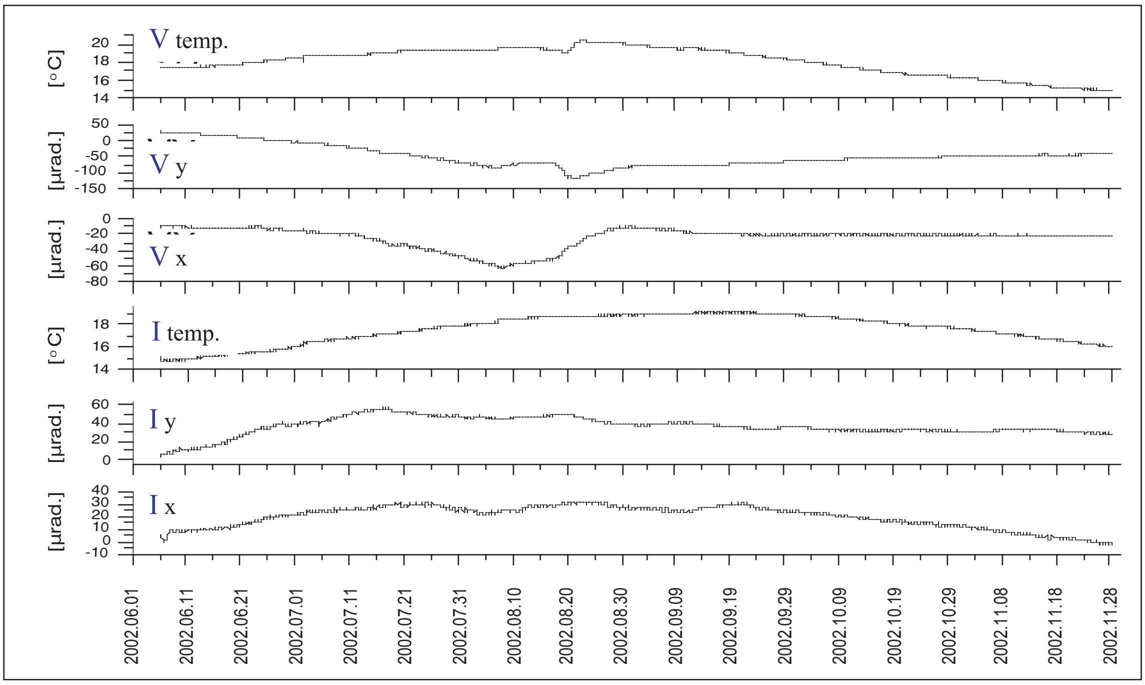

Fig. 7. Tilt and borehole temperature registrations

The larger changes at the foot of the wall (Vx,Vy) between 2002.07.11. and 08.30.2002 are due to the very high water level (flood) of the river Danube. These changes may be recognised at the top of the wall, also, but they are not so characteristic.
The detailed descriptions of borehole registrations can be found in Mentes (2001, 2002 and 2003).

4. Summary

In spite of the more rapid measurements the precision requirement of the precise levelling was demonstrated (0.3 mm/km) and the changes larger than 1.0 mm can be interpreted as a significant value at the 95% probability level in the given network.
Because of urban environment the GPS measurements were noisier and the changes larger than 4-5 mm can be interpreted only as a significant value.
Unfortunately (or not?) it turned out that the estimations are reliable because a boom machine crossing the area really pushed station 100.
The quality of GPS observation can be better using more up-to-date receivers with better multi path resistant antennas, however the urban environment remains the largest limiting factor.
The proper interpretation of the complex problem can be concluded only after a significantly longer observation period. The time series analysis of the coordinate and gravity changes, tilt registrations and the water level changes of the river Danube involved in proper Geographic Information System may lead to the proper strategy to handle such geological risks in the future.

Acknowledgments. The investigations were partly initialised by the Hungarian Academy of Sciences and by the help of the Hungarian State Research Foundation (OTKA T 029052).

References

Bányai, L. (2000). Calibration possibilities of GPS receivers (in Hungarian). *Publications in Geomatics, III*, 65-69.

Kleb, B. and Schweitzer, F. (2001). Effects study on landslides risks of Danube river walls in the surroundings of settlements (in Hungarian). *In the Workshop Studies of the Hungarian Academy of Sciences - Earth sciences and risk factors of geoprocesses.* Ed. Ferenc Glatz. ISBN 963 508 3173, ISSN 1419-1822. 169-193.

Mentes, Gy. (2001) First experiences of monitoring tectonic movements of the Mecsekalja fault by shallow deep borehole tiltmeters in Hungary. In: Zhenglu, Z. Retscher, G. Guo, J. (Eds.*): Proceedings of the IAG Workshop on Monitoring of Constructions and Local Geodynamic Processes*. 18-24.

Mentes, Gy. (2002) Monitoring of Local Geodynamical Processes by Borehole Tiltmeters in the Vicinity of the Mecsekalja-fault in Hungary. In: Kahmen, H. Niemeier, W. Retscher, G. (Eds.): *Geodesy for Geotechnical and Structural Engineering II., Department of Applied and Engineering Geodesy, Institute of Geodesy and Geophysics, Vienna University of Technolgy, Vienna, Austria,* (ISBN 3-9501492-1-X). 278-287.

Mentes, Gy. (2003). Monitoring local geodynamical movements and deformations by borehole tiltmeters in Hungary. *(In this issue)*