Recurring Mass Movements on the Danube's Bank at Dunaszekcső (Hungary) Observed by Geodetic Methods

Gy. Mentes*, L. Bányai, G. Újvári, G. Papp, K. Gribovszki, V. B. Bódis

Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences,
Csatkai E. u. 6-8, H-9400 Sopron, Hungary - (mentes, banyai, ujvari, papp, kgribovs, bvberenike)@ggki.hu

KEY WORDS: Landslide, GPS, Tilt, River bank

ABSTRACT:

In September 2007 a geodetic network based on GPS measurements, precise levelling and continuous borehole tilt measurements was established for surface displacement monitoring on the high bank of the River Danube at Dunaszekcső where a serious landslide began to develop at that time. The landslide took place on 12 February 2008. After rapid, enormous movements, which resulted in significant subsidence (8-10 m) and lateral displacements (4-5 m) on the high bank at Dunaszekcső and the emergence of a peninsula consisting of clastic material in the Danube's bed, the deformation rates significantly dropped. This observation was explained by the secondary metastable equilibrium of the moving blocks at that time. However, our subsequent geodetic data clearly showed that slow post-event movements (mainly subsidence, 0.5-1.0 cm/month) on both the northern and southern sliding blocks have been occurring for the last two years, which means that the sliding blocks did not reach an equilibrium in the mentioned period. At the same time, measurements on our extended geodetic network in the second half of 2010 referred to a possible southward spread of sliding (southern part of the Vár hill) in the near future. Later on (spring 2011), field observations were also indicative of the initiation of movements on the southern part of the Vár Hill as predicted by the geodetic measurements. The areal extent of the block becoming unstable closely corresponds with the danger zone assigned by GPS observations.

1. INTRODUCTION

The right bank of the Danube has been affected by landslides since centuries (Lóczy et al., 1989; Juhász, 1999). After some years of seeming dormancy, active phases commenced owing to the likely interplay of high water stands of the Danube, increased precipitation input and anthropogenic activity (Horváth and Scheuer, 1976; Moyzes and Scheuer, 1978; Scheuer, 1979). The remains of these historical landslides can be found along the bank of the Danube at Dunaszekcsö and its surroundings as well (Újvári et al., 2009a). The last active phase was happened here in the nineteen seventies followed by a period without considerable mass movements. This dormant phase was suddenly ended by the initiation of a huge bank failure in 2007. This year a GPS network was established and tiltmeters were installed to observe the deformations of the affected high bank (Újvári et al., 2009b; Figure 1). Subsequently, the southward spread of movements was recorded which endangers several public properties. The present paper provides a short overview and interpretation of the geodetic data for the time interval 2007 to 2011 and briefly discusses the possible causes behind the bank deformations.

2. METHODS

The GPS network, established in 2007, consisted of 4 reinforced concrete pillars for reference measurements and 21 smaller concrete benchmark points for the active deformation monitoring on the high bank. After considerable movements in 12 February, 2008, some benchmark points were lost and the measurements of several points became impossible owing to restricted visibility of GPS satellites. For this reason, new benchmark points were fitted into the network and it has been extended to the south (Figure 2). The horizontal and vertical displacements were measured first by two Leica 1200 GPS receiver pair and subsequently by five parallel running GPS receiver. Precise levelling was carried out on the same network to check GPS height determinations and correct them. The position of benchmark points on the sliding blocks of the high bank were also measured by total station Leica TC2002 and all of these data were processed together in network adjustments.

Two dual-axis borehole tiltmeters (Model 722A, Applied Geomechanics Inc., USA), installed in shallow boreholes at a depth of 3 m, were used for tilt measurements from 2007. The instruments have dual-axis tilt sensors and built-in sensors for temperature measurements. They operate in two measuring ranges: the resolution for the "high gain" range is 0.1 μrad while that for the "low gain" range is 1 μrad. The tiltmeters were installed so that their positive *x* tilt axes point to the east and their positive *y* axes to the north. One was placed on the southern sliding block (T2) and another on the stable part of the high bank (T1). After mass movements on 12 Feb 2008, the tiltmeter on the southern sliding block went beyond its measurement range and must have been re-installed in an adjacent borehole. Tilt measurements by tiltmeter T2 were started only in November, 2009 and continued till May, 2010, since the tilts were higher than the measuring range of the instrument. The second re-installation of the instrument was in August, 2010. Together with the extension of the GPS network a third instrument (T3) was placed on the southernmost part of the affected high bank (see Figure 2).

* Corresponding author

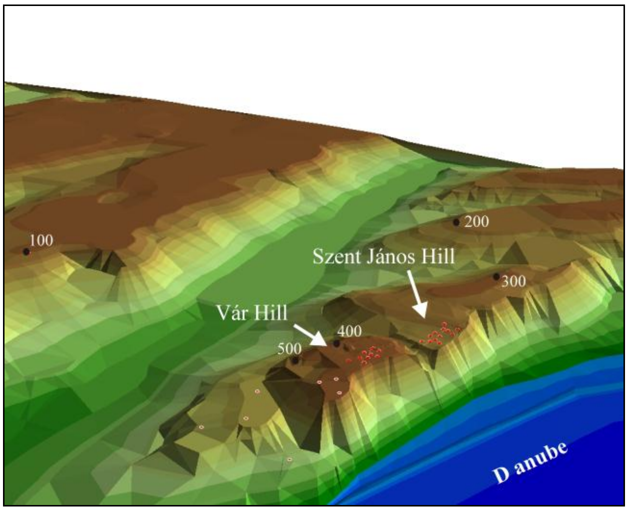

Figure 1. Digital terrain model of the Danube's high bank at Dunaszekcső and the GPS network (black dots: reference pillars, red dots: smaller benchmark points).

The source of the digital terrain model shown in e.g. Figures 1 and 2 was a topographic map at the scale of 1:10,000, which was improved and specified by the measurement of 433 points on Vár and Szent János Hills using GPS, a Wild T-3000 digital thedolite and a DI 2002 high precision electronic distance meter.

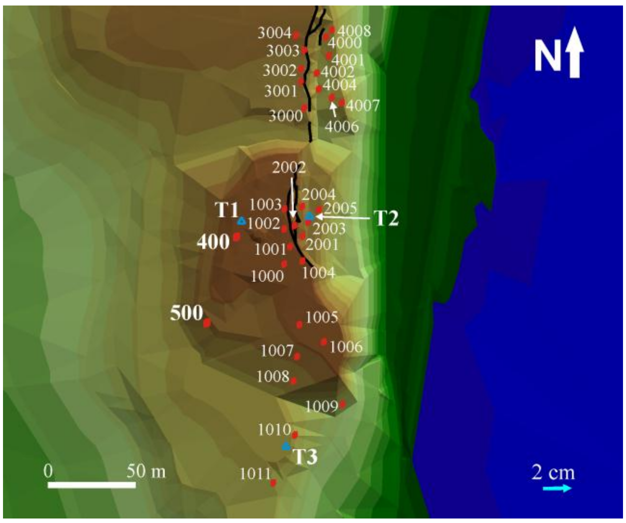

Figure 2. Study site and the geodetic network. Legend: 400-500: reference pillars, 1000-4008: smaller benchmark points, T1-T3: tiltmeters, black lines show the main ruptures after sliding on 12 February, 2008.

3. RESULTS

From October to mid-December 2007, horizontal movements were fluctuating, but generally they amounted to 0.3-1 mm/day with directions of ESE to SE on the northern and ENE to NE on the southern sliding block. For the same time interval (from October to December) the subsidence was in the range of 5 to 11 cm. In January, 2008 movements accelerated which then resulted in enormous subsidence (6 to 10 m) and horizontal displacements on both sliding blocks on 12 February, 2008 (Figure 3). Tiltmeter T2 clearly showed a significant backward (SW) tilt of the southern moving block before that day (Figure 4). For March, 2008 horizontal movements decreased to the same magnitude (0.3-2 mm/day) as it was measured during October and November, 2007. In three consecutive years horizontal displacements were in the range of 1 to 4 cm/year with a clear eastern component (towards the Danube) which matched well with the record of tiltmeter T2 (Figure 5). In winter 2009 tiltmeter recorded some oscillations which meant that the southern block lost its balance and it could not get into a new equilibrium state. As a consequence of this, the block tilted very strongly in NE direction and this tilt also continued after the second re-installation of the instrument in 2011. The subsidence of the block amounted to 2 to 5.5 cm/year and the southern block showed slightly larger movements than the northern. For the autumn and winter of 2010 and during the spring of 2011 deformations accelerated again and spread towards the southern part of the Vár Hill as it is shown in Figure 6.

Figure 3. Oblique aerial view of the high bank at Dunaszekcső after landsliding on 12 Feb 2008. The movements spread toward the south in 2010 and 2011 (area indicated by 'Endangered Zone')

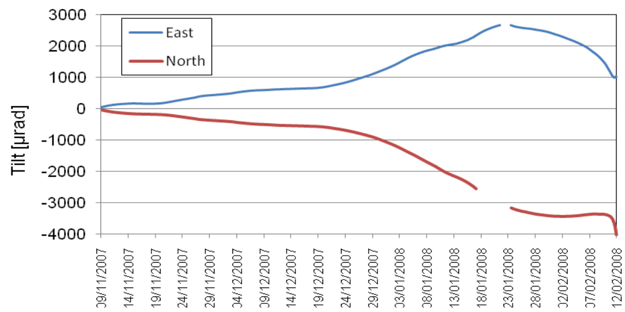

Figure 4. Tilt data recorded by the tiltmeter T2 from 9 November, 2007 till 12 February, 2008. Tilting the east and north components in positive direction means tilt in east and north direction, respectively.

Figure 7 and 8 show tilt data measured by the tiltmeter T1 from 9 November, 2007 till 31 December, 2008 and from 22 April, 2007 till 7 July, 2011. It can be seen that after the slump of the unstable block on 12 February, 2008 (Figure 7) the remaining part of the southern block moved by oscillating tilting till October, 2009 (Figure 8) and then it was tilting in SE direction pushing the unstable section and the endangered zone of the high bank (Figure 3). The observed tilt is in very good coincidence with the horizontal displacements measured by GPS (see Figure 6).

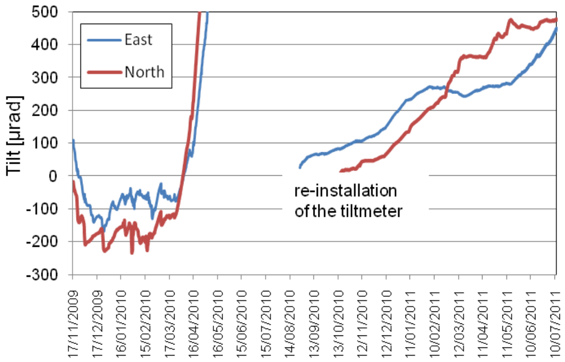

Figure 5. Tilt data recorded by the tiltmeter T2 from 17 November, 2009 till 12 July, 2011. Tilting the east and north components in positive direction means tilt in eastern and northern directions, respectively.

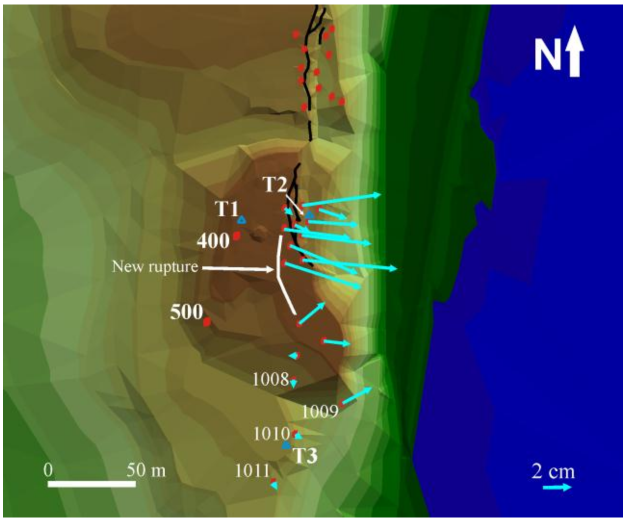

Figure 6. Horizontal displacements as shown by GPS vectors for the time interval 22 March, 2010 – 18 April, 2011. Note that the movements of the northern block are not presented here.

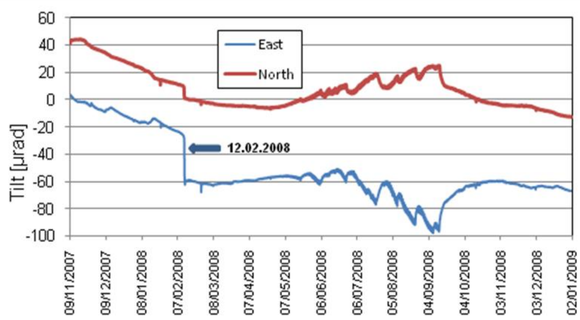

Figure 7. Tilt data recorded by the tiltmeter T1 from 9 November, 2007 till 31 December, 2008. Tilting the east and north components in positive direction means tilt in eastern and northern directions, respectively.

Figure 9 displays tilt data recorded by the tiltmeter T3 on the endangered zone from 29 September, 2009 till 22 April, 2011. This diagram shows a considerable tilt in east direction and a small alternating tilt in N-S direction. The GPS measurements indicate a NE horizontal movement at the point 1009, while almost no horizontal movements were detected at points 1010 and 1011.

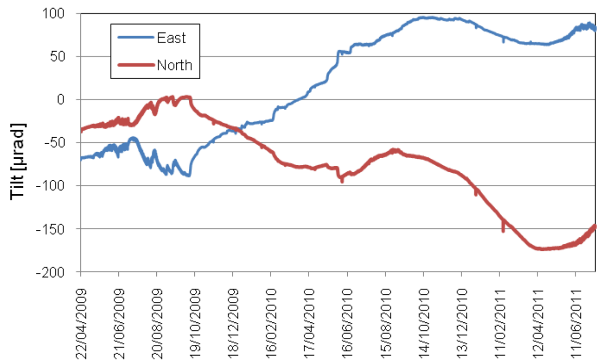

Figure 8. Tilt data recorded by the tiltmeter T1 from 22 April, 2007 till 7 July, 2011. Tilting the east and north components in positive direction means tilt in east and north direction, respectively.

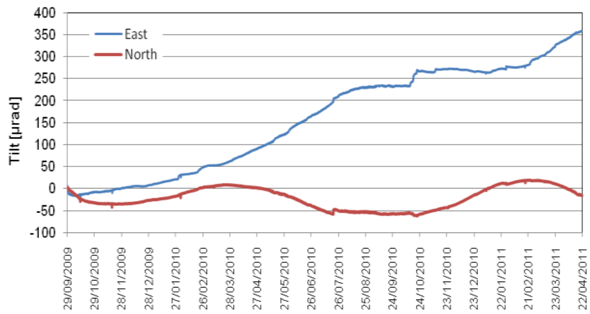

Figure 9. Tilt data recorded by the tiltmeter T3 from 29 September, 2009 till 22 April, 2011. Tilting the east and north components in positive direction means tilt in east and north direction, respectively.

4. SUMMARY

GPS, levelling and tilt records provided insight into the nature, evolution and some physical mechanisms behind the deformation of the high bank at Dunaszekcső. GPS data yielded valuable information on the spatial development of the sliding bodies, thereby aiding the delineation of potentially hazardous areas in 2007-2008. At the same time, tilt data proved to be useful to gain a better understanding of the temporal evolution of the bank failure. Further, changes in tilt direction and accelerating tilting of the southern block indicated the advent of rapid movements several weeks before they really occurred (12 February, 2008). Based on this knowledge and the latest geodetic observations we argue for the possible southward spread of significant movements on the high bank at Vár Hill, where these deformations endanger houses and public properties. Our GPS and tilt data also demonstrate that the southernmost part of the high bank will likely to remain stable, at least for the short-term.

REFERENCES

Horváth, Zs., Scheuer, Gy., 1976. A dunaföldvári partrogyás mérnökgeológiai vizsgálata (Engineering geological investigation of the bank collapse at Dunaföldvár). *Földtani Közlöny* 106, pp. 425–440 (in Hungarian with German abstract).

Juhász, Á., 1999. A klimatikus hatások szerepe a magaspartok fejlődésében (Role of climatic effects in the development of high banks). *Földtani Kutatás* XXXVI, pp. 14–20 (in Hungarian).

Lóczy, D., Balogh, J., Ringer, Á., 1989. Landslide hazard induced by river undercutting along the Danube. In: Embleton, C., Federici, P.R., Rodolfi , G. (Eds.), *Geomorphological Hazards, Supplements of Geografia Fisica e Dinamica Quaternaria*, Vol. 2, pp. 5–11.

Moyzes, A., Scheuer, Gy., 1978. A dunaszekcsői magaspart mérnökgeológiai vizsgálata (Engineering geological investigation of the high bank at Dunaszekcső). *Földtani Közlöny* 108, pp. 213–226 (in Hungarian with German abstract).

Scheuer, Gy., 1979. A dunai magaspartok mérnökgeológiai vizsgálata (Engineering geological investigation of the high banks of the Danube). *Földtani Közlöny* 109, pp. 230–254 (in Hungarian with German abstract).

Újvári, G., Mentes, Gy., Bányai, L., Kraft, J., Gyimóthy, A., Kovács, J., 2009a. Evolution of a bank failure along the River Danube at Dunaszekcső, Hungary. *Geomorphology* 109, pp. 197–209.

Újvári, G., Bányai, L., Gyimóthy, A., Mentes, Gy., 2009b. A dunaszekcsői földcsuszamlás geodéziai mozgásvizsgálatának eredményei (Results of the geodetic deformation measurements of the Dunaszekcső landslide). *Geodézia és Kartográfia* 61, pp. 11-17 (in Hungarian with English abstract).

ACKNOWLEDGEMENTS

This study was supported by OTKA K 78332.