INVESTIGATION OF DIFFERENT POSSIBLE AGENCIES CAUSING LANDSLIDES ON THE HIGH LOESS BANK OF THE RIVER DANUBE AT DUNAFÖLDVÁR, HUNGARY[1]

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Abstract: There are high, steep loess banks along the River Danube in Hungary. Landslides are causing a lot of damages on this area. Monitoring the surface displacements of the slope and measuring geophysical, geological, hydrological, meteorological, etc. phenomena by a multi-sensor system can provide valuable information for the development of a knowledge-based, early warning system. Dunaföldvár is a small town where a number of landslides occurred in the recent past accompanied by damages. That was the reason for the establishment of a geodetic test area here in 2001. Since that time yearly repeated GPS and levelling measurements have been carried out. Two biaxial borehole tiltmeters were installed on the test area in 2002. One was placed on the top and the other at the foot of the high bank. In 2005 a vertical borehole extensometer was also installed for monitoring the vertical movements of the high bank. The ground water level, the level of the Danube, the precipitation and the temperature were also recorded. Because the high bank is in "rest" between abrupt landslides, movements could only be detected by the tilt and extensometric measurements. The continuous tilt measurements showed a permanent SSW tilting with a rate of 47.3 µrad/year at the top and an eastward tilt with a rate of 3.1 µrad/year at the foot of the high bank. These tilts are of "atectonic" origin. Further the ground water, the water level variation of the Danube and the precipitation are in close connection with each other and cause tilt in the range of 1 - 20 µradian.

1. INTRODUCTION

Landslides are defined as a variety of mass movements occurring on sloping areas. Gravity is the most important driving factor but besides a lot of natural agencies take part in inducing landslides: tectonics, rock and soil characteristics, rock and soil weathering, chemical and mineralogical properties of the rock and soil, geotechnical features, geomorphic factors (slope

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gradient, shape, aspect, altitude of the slope), hydrological factors (precipitation, hydrological properties of the soil, infiltration, subsurface flow processes, ground water level variations), vegetation. In spite of this fact, relatively few attempts have been made for a complex investigation of the influences of the above mentioned factors (Siedle and Ochiai, 2006).

In Hungary there are several regions prone to landslide, especially the high banks along the right hand side of the river Danube are very dangerous (Kleb and Schweitzer, 2001). Landslides, on this area, cause a lot of damages resulting in severe human casualties, property losses and environmental degradation. Monitoring the surface displacements of a slope and other geophysical, geological, hydrological, meteorological, etc. phenomena by a multi-sensor measurement system can provide valuable information about the causes of abrupt slope movements and can serve as a basis for development of a knowledge-based, early warning system. That was the reason for the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences (GGRI) to establish a test area here for monitoring and studying of how different natural factors contribute to triggering landslides.

The research work was started in 2001 with the support of the Hungarian Academy of Sciences. First a geodetic monitoring system was established in Dunaföldvár, where yearly repeated geodetic measurements (GPS, EDM, precise levelling) and continuous tilt measurements were carried out. The investigations were continued between 2003 and 2006 in the frame of the EU 5 OASYS project. In 2005 a vertical extensometer was installed on the high bank. Beside the geodetic measurements, the geological structure, the geomorphologic and hydrologic situations, the seismic hazard of the test site and the meteorological influences were investigated in details during the OASYS project (Mentes and Eperné, 2004). The mass movements of the high bank measured by geodetic methods were very small in the period of the investigations. The displacements are in the error range of the measuring methods (GPS, EDM, precise levelling), so only the results of the continuous tilt and extensometric measurements can be used to investigate the connection between movements of the high wall and different natural factors, such as tectonics, water level of the Danube, ground water level, precipitation, temperature. The length of the tilt and extensometric records is unique in Hungary. This paper shows the results of our research work.

2. TEST SITE

The western bank of the river Danube is one of the largest areas in Hungary which are endangered by landslides. The banks are steep, 20-40 m high and built-up of loose sediments that are exposed to river erosion. Both old and new settlements are partly or fully built on the high loess bank and in their surroundings. Landslides cause a lot of problems in the small town of Dunaföldvár where many houses are built on the edge and at the foot of the high bank. Figure 1 shows the localization of Dunaföldvár in Hungary and the place and date of the largest landslides on this area. A part of the town is built on Felső-Öreg-hegy (Upper Old Hill) and Alsó-Öreg-hegy (Lower Old Hill) of the high loess bank (Fig. 2). These two units are separated by a 150-200 m wide erosion-derasion valley in NE-SW direction, and they are bordered by the NNW-SSE directed, 1-1.5 km wide Bölcskei valley from the west. The northern part of the high bank is Felső-Öreg-hegy (Upper Old Hill). Its height is 120-130 m above sea level and its border-line on the Danube is very steep and about 20-30 m high. This 400 m long section of the loess bank is prone to mass movements. Unfortunately a major part of the town is built on this area. In 1994 a large landslide caused damages here, so on the landslide history of the area the above mentioned 400m long section was selected as a test site for our investigations.

Figure 2 shows the measurement points of the monitoring network. Points 100-600 denoted by circles are the places of the monuments for GPS measurements. Triangles (1-21) mark the points of gravity and precise levelling measurements. The crossed circles denoted by I and V mark the location of the borehole tiltmeters. The tiltmeter denoted by I is on the top of the high bank about 8 m far from the edge of the high bank. The other instrument denoted by V is placed at the foot of the high bank about 10 m from the bank. Both tiltmeters are installed in a borehole with a depth of 3 m. The vertical extensometer is placed near to the tiltmeter (I) on the top of the high wall. Figure 3 shows the simplified geological structure of the test site and the zones of the geodetic benchmarks and tiltmeters.

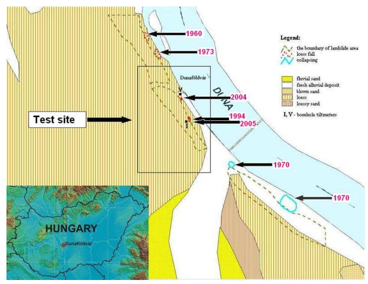


Figure 1 - Location of the test site at Dunaföldvár in Hungary

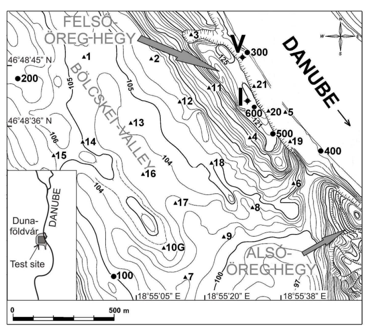


Figure 2 - The contour map of the test site. Circles denote the GPS points (100-600), triangles mark the gravity points (1-21), 10G is the gravity reference point, crossed circles denoted by I and V show the location of the borehole tiltmeters

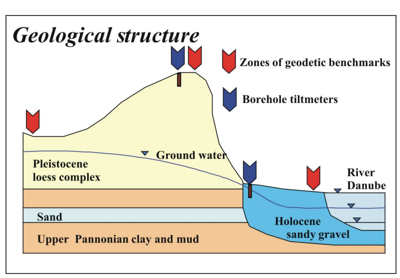


Figure 3 - Simplified geological structure of the test site

3. RESULTS OF THE TILT AND EXTENSOMETRIC MEASUREMENTS

On the test site continuous tilt measurements have been carried out by two tiltmeters Model 722A made by Applied Geomechanics Inc. since 6 June 2002. The tiltmeters have a dual-axis tilt sensor and a temperature sensor for measurement of the temperature of the instrument, which is equal to the temperature of the borehole and so to that of the soil. The tiltmeters have two measuring ranges: in “high gain” range the resolution is 0.1 µrad and in “low gain” it is 1 µrad. The tiltmeters are installed so that their +Y axis are perpendicular to the Danube and their +X axis is directed southwards. A vertical borehole extensometer was developed and installed near to the tiltmeter (I) to study the vertical movements of the loess wall due to variation of the water content of the loess between its dry and watery conditions. The extensometer has been working since 1 September 2005. The sampling rate of the continuous tilt and extensometric measurements is 1 sample/hour.

Figure 4 shows the daily averaged data measured from 06.06.2002 till 31.12.2007. Because the precipitation (P) and the water level of the Danube were given as daily averages the tilt, extensometer and temperature data were also averaged for the sake of comparison.

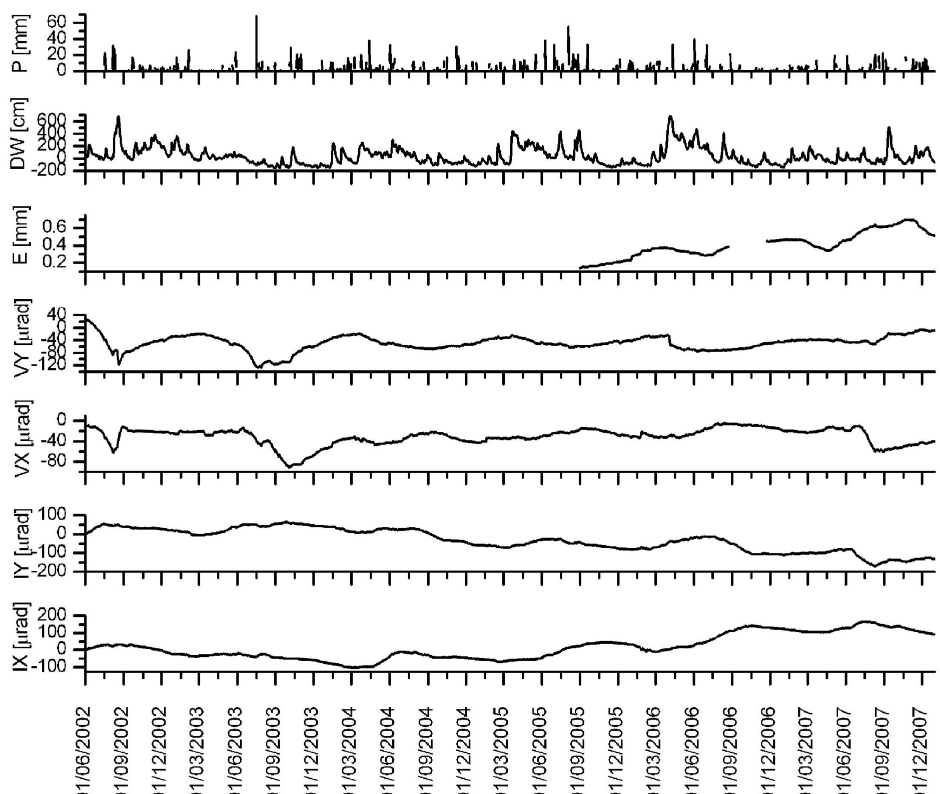


Figure 4 - Data recorded on the Dunaföldvár test site between 06.06.2002 and 31.12.2007. P = precipitation, DW = Water level of the Danube, E = Vertical borehole extensometer, VY = Y tilt component at the foot of the high bank, VX = X tilt component at the foot of the high bank, IY = Y tilt component on the top of the high bank, IX = X tilt component on the top of the high bank

3.1. Investigation of the Connection between Tilt Data and Geological, Geomorphologic Features of the Test Site

The trend of each tilt component was determined. Since the length of the data series is more than 5 years, this method filters the meteorological and seasonal effects automatically. So we can assume that the rise of the regression line is equal to the rate of the tilt. The resultant rate from the X and Y components was calculated. At the foot of the high bank the resultant tilt shows east and on the top of the high bank in SSW direction and the amount of the tilt rates are 3.1 μrad/year and 47.3 μrad/year, respectively (Fig. 5). The direction of the tilt measured at the bottom (V) of the high bank is in connection with the sinking of the Great Hungarian Plane on the left bank of the river Danube. The much higher tilt rate measured on the top than obtained at the foot of the high bank indicates that the tilt is in connection with the geomorphologic features rather than with the deep geological structure and recent tectonics of the test site.

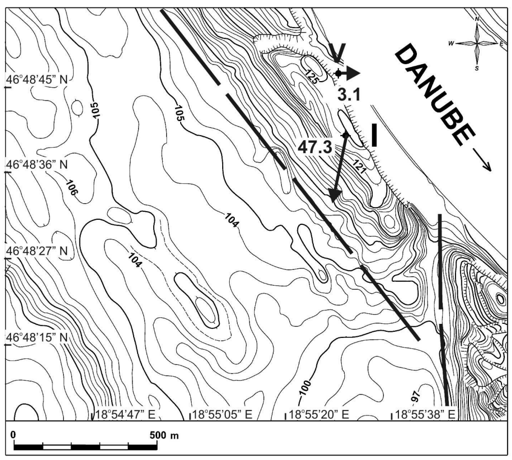


Figure 5 - Tilt rates measured on the top (I) and at the foot (V) of the high bank. Tilt rates are given in μrad/year

A possible explanation of the tilt results can be obtained in the knowledge of the geologic structure, tectonic processes and geomorphological features of the test site and its surroundings. The recent tectonic movements in the Pannonian basin are primarily governed by the northward drift and counter-clockwise rotation of the Adriatic micro-plate (Csontos és Nagymarosi, 1998). Consequently, this rigid crustal block is actively indenting and pressing the Pannonian lithosphere against the European foreland. The structure is dominated by NE-SW and E-W oriented thrust faults and an ENE-WSW oriented transpressional deformation belt (near to the test site). These structures are completed by perpendicular normal faults. From geomorphological point of view a radial pattern of valley network in Transdanubia determines the orientation of many sections of the Danube from Budapest to the south (Síkhegyi, 2002). The NW-SE orientated sections of the Danube follow pre-existing structural lines. At Dunaföldvár (Felső-Öreg-hegy), where the Danube flows also along an existing tectonically determined fault line (see thick pecked lines in Fig. 5), a receding river bank has been evolving due to permanent erosion and undercutting by the river. Felső-Öreg-hegy gradually losts its base support and it is slowly sliding into the Danube to ENE-NE direction with counter-clockwise rotation, causing a permanent SSW tilting with a high rate at the top of the high bank and with a low rate at the foot location. Our results indicate that the „atectonic" movements are tectonically initiated and determined.

3.2. Influence of the Ground Water

The ground water level variation is one of the most important landslide triggering factors. Unfortunately, we had only one observation well about 1.5 km far westward from the test site and this well functioned only till the end of April, 2004. So, we could use only data recorded between 01.06.2002 and 30.04.2004 for our study. During this period the observation was irregular, so the data were suitable only for rough investigations. Figure 6 shows the ground water variation (GWL), the tilt components VX, VY and IX, IY on the foot and on the top of the high bank, respectively. First, the tilt data was corrected by the temperature and then the trend was subtracted from the tilt data to enhance the variations. In some parts of the record the influence of the ground water level variation is visible (marked by vertical lines in Fig. 6). There is a lag between the change of the ground water level and the tilt of the high bank. In Fig. 3 it can be seen that the ground water level have a gradient in the direction of the Danube, therefore the pore pressure in the hind part of this bank is higher than in its frontal part. In the case of high ground water level this gradient is steeper since this level on the bank of the Danube is determined by the average water level of the river and so it can be supposed to be nearly constant on the bank. That is the reason why during high ground water level the bank is tilting (IY tilt component) in the direction of the Danube. The rising ground water level causes also a southward directed tilt (IX) of the high bank. Probably, this small tilt contributes to the sliding of the south end of this high bank section.

In the next part we can see that there is a connection between the water level of the Danube and the level of the ground water. These two factors mutually increase the influence of each other.

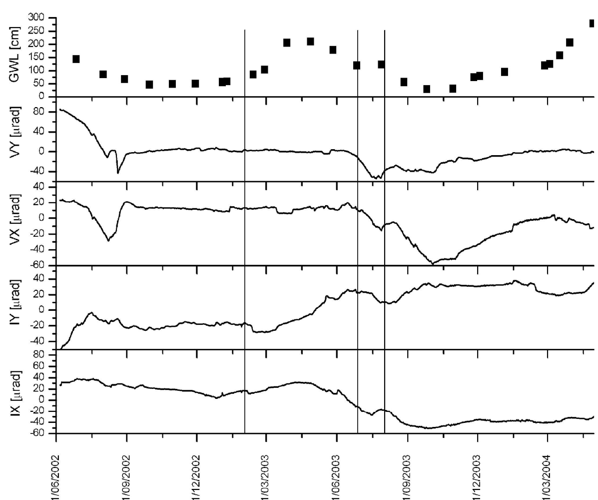
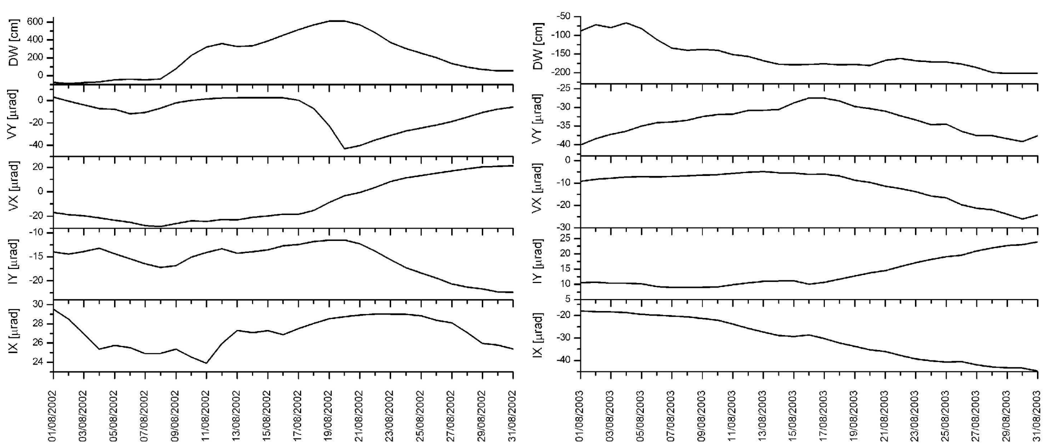


Figure 6 - The influence of the ground water onto the movements of the steep high bank. GWL = ground water level; VX, VY = tilt components measured at the foot of the high bank; IX, IY = tilt components measured on the top of the high bank

3.3. Influence of the Water Level Variations of the River Danube

The connection between the water level variations of the Danube and the measured tilt values of the high bank was analysed in detail. On the basis of the data series recorded from 01.06.2002 till 31.12.2007 no long-term correlation was found between the water level and the tilts of the high bank. On the other hand a close correlation can be disclosed between short-term variations. In Figure 7 two examples are demonstrated. One record was made during a high flood in August, 2002 and the other during a very low water level in August 2003.

Below the water level of the Danube many springs are rising from the high bank. Some of them can be seen during very low water level. The hydrostatic pressure of the high water level of the Danube obstructs the outflow of the water from the springs and therefore the increasing pore pressure of the ground water tilts the high bank towards the Danube. Tilt component IY changes in positive direction (Fig. 7a). During low water level of the Danube the high bank tilts in the opposite direction due to the decreasing pore pressure and ground water level.



a. b.

Figure 7 - Connection between the tilt of high bank and the water level variations of the Danube during a strong flood between 10.08.2002 and 25.08.2002 (a) and during a low water level between 07.08.2003 and 31.08.2003 (b). DW = water level of the Danube; VX, VY = tilt components measured at the foot of the high bank; IX, IY = tilt components measured on the top of the high bank

3.4. Influence of the Precipitation

The precipitation data are given as daily average values, so there is no information about the intensity of rainfalls – and what is more important – the rapidity of the snowbreak is also not known. It means that the infiltration, the outlet of the water cannot reliably estimated. Another problem is that the influence of the precipitation, the water level variations of the ground and the Danube are not independent of each other. Figure 8 shows an example for the interaction of the above mentioned factors. In contrast with the positive tilt direction due to increasing water level of the Danube shown in Fig. 7, here the tilt direction is negative as a consequence of the decreasing water level of the Danube between 25 May and 29 May. The reason is probably the rainfall between 26 and 30 May. This rainfall increased the ground water level which caused a tilt in positive direction. The effect of this precipitation can also be seen in the rise of the water level of the Danube. A heavy rainfall from 2 to 4 June caused additional elevation of the ground water table and the water level of the Danube. It resulted in a rapid southward tilt in the IX component. This component has a phase lag relative to the change of the water level of the Danube. It means that the smart rain on 6th of June probably caused a big change in the ground water table. This high and abrupt tilt explains also the fact that landslides occur on the south end of this high bank section. The IY component (tilting towards the river) shows a good correlation with the water level variation of the Danube. The tiltmeter results are in agreement with the NW-SE valley orientations (see e.g. Bölcskei valley in Fig. 2) and the joint lines of strike in loess deposits on Mezőföld geographical unit (westward from the test site) indicating main and secondary ENE-WSW structural directions (Horváth et al., 1990). This orientation determines the direction of water flow (brooks, streamlets) in the surroundings of the test site and this water flow direction is responsible for the connection between the precipitation and the ground water variations on the test site. Namely, the precipitation flows from NW towards the high bank and causes the rise of the ground water table which tilts the high bank in SE direction. In Fig. 8 IY tilt component is about 7 μrad in east and IX is approximately 13 μrad in south direction.

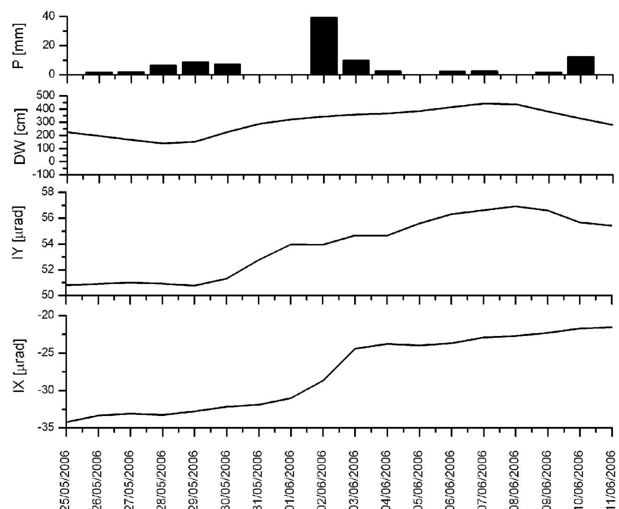


Figure 8 - Example for the influence of the precipitation. P = precipitation; DW = water level of the Danube; IX, IY = tilt components measured on the top of the high bank

3.5. Investigation of the Short Periodic Variations

The hourly sampled data were also investigated in detail. The temperature was measured in the borehole and it is can be observed in Fig. 9 that the daily variation of the temperature is negligible as it is below the resolution of the A/D converter of the data logger. It proves that the borehole ensures a stable place for the tiltmeters.

A daily variation was detected in the tilt and extensometric signals. Both the rising and the falling section of these signals change exponentially. The magnitude of the daily tilt signals is between 1 and 3 μrad. The variation of the extensometric signal is below 0.005 mm. An example is shown in Fig. 9. Such kind of signals are described by Kümpel et al. (1996). They measured ground tilt around a waterworks well in Nagycenk, Hungary. During turning on and off the water pump they measured an exponentially changing signal like depicted in Fig. 9. Rebscher (1996) recorded also similar signal investigating the connection between the transpiration of the vegetation and ground tilt. Kucsara et al. (2000) measured the water output of a streamlet and they obtained similar signals. On the basis of our example we could state that this tilt is caused by the transpiration of the vegetation but we recorded similar signal in winter time, too. So, we can assume that the recorded signal is in connection with the daily variations of the water level of the Danube and indirectly by the variations of the surface temperature.

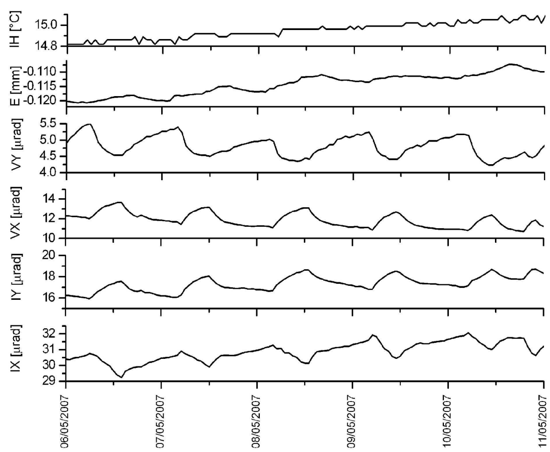


Figure 9 - An example for the short periodic variations in the tilt and extensometric signals. IH = the temperature in the borehole on the top of the high bank; VX, VY = tilt components measured at the foot of the high bank; IX, IY = tilt components measured on the top of the high bank

4. CONCLUSIONS

The trend analysis of the tilt signals show a permanent tilt with a rate of 47.3 μrad/year of the high bank in SSE direction which is in connection with the geomorphologic features and the indirect effects of tectonic movements. To prove this theory unambiguously the continuation of tilt monitoring and yearly repeated geodetic (GPS, precise levelling) campaignes are necessary.

The high precision tilt records revealed that the effect of the different hydrological factors is in close connection with the topography and geomorphology of the surroundings of the test site. In spite of the small scale of movements and deformations caused by these factors, the steady movements of the high bank can lead to slope failures. These factors can significantly strengthen the effect of each other and so they can contribute to a landslide triggering in case of slope failure.

The obtained results can also be used for the development of a knowledge based early warning system.

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References

Csontos, L. Nagymarosy, A. (1998). The Mid-Hungarian line: a zone of repeated tectonic inversions, Tectonophysics, 297, 51-71.

Horváth, F., Csontos, L., Erdélyi, M., Ferencz, Cs., Gábris, Gy., Hevesi, A., Síkhegyi, F. (1990). Paks környezetének neotektonikája. (Neotectonics of the surroundings of Paks). Research Report, MÁELGI, Budapest. (in Hungarian).

Kleb, B. Schweitzer, F. (2001). A Duna csuszamlásveszélyes magaspartjainak településkörnyezeti hatásvizsgálata. In: Ádám A, Meskó A (Eds.): Földtudományok és a földi folyamatok kockázati tényezői. (in Hungarian) Budapest, MTA, 169-193.

Kucsara, M. Mentes, G. Víg, P. (2000). Erdei patak vízhozamának mérése bukóval. Soproni Egyetem Tudományos Közleményei. (in Hungarian), Soproni Egyetem, 46, 81-91.

Kümpel, H.J. Lehmann, K. Fabian, M. Mentes, G. (2001). Point stability at shallow depths: experience from tilt measurements in the Lower Rhine Embayment, Germany, and implications for high resolution GPS and gravity recordings. Geophysical Journal International, 146, 699-713.

Kümpel, H.J. Varga P. Lehmann, K. Mentes G. (1996). Ground Tilt Induced by Pumping - Preliminary Resullts from the Nagycenk Test Site, Hungary. Acta Geod. Geoph. Hung, 31(1-2), 67-79.

Mentes, G. Eperné P.I. (2004). Landslide monitoring of loess structures in Dunaföldvár, Hungary. Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences, (ISBN 963 8381 21 3), Sopron, p. 84.

Rebscher, D. (1996). Nachweis von in-situ Bodenverformungen gravitativen und vegetativen Urschprungs mittels Neigungsmessungen in Bonn-Ippendorf. Dissertation, Math.-Nat. Fak., Univ. Bonn, 177.

Siedle, R.C. Ochiai, H. (2006). Landslides: Processes, Prediction, and Land Use. Water Resources Monograph 18. American Geophysical Union.

Síkhegyi, F. (2002). Active structural evolution of the western and central parts of the Pannonian basin: a geomorphological approach. EGU Stephan Mueller Special Publication Series 3, 203-216.

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