Relationships between Short Periodic Slope Tilt Variations and Vital Processes of the Vegetation

Gy. Mentes[*], V. B. Bódis

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

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ABSTRACT:

A lot of publications deal with the effect of root network of the vegetation on near surface slope movements but the effect of the vital processes of the vegetation has been less investigated till now. In this presentation relationships between vital processes of the plants and small movements of the slope are shown. For monitoring streambank movements, two geodetic test sites were established on the high loess bank of the River Danube at Dunaföldvár and Dunaszekcső in Hungary. At both sites two highly sensitive borehole tiltmeters were also installed for continuous monitoring of movements. The records of the tiltmeters show a daily variation with variable magnitude in the range of some microradians. From our previous research we know that these small movements are in close connection with the ground water variations. Vegetation maps were made for both test sites. The temperature and precipitation was continuously recorded. On the basis of these data and the vegetation map the potential evapotranspiration was calculated for both sites. Values of the potential evapotranspiration and precipitation were compared to the micro-tilts of the high loess banks at Dunaföldvár and Dunaszekcső. It was pointed out that the daily tilt amplitudes are in close connection with the vital processes of the plants. Our investigation showed that the vegetation can play an important role in hindering landslides occurrence since by planting appropriate vegetation on slopes the infiltration of the precipitation into the deep layers of the slope and so the moistening of the high bank can be significantly diminished.

1. INTRODUCTION

Vegetation on areas prone to mass movements plays a very important role in the slope stability. Relationships between vegetation and geomorphology (Marston, 2010), the effect of the vegetation on the soil erosion (e.g. Pizutto et al. 2010; Zheng 2006) and the mechanical and hydrologic effects of root networks of vegetation on slope stability (e.g. Simon and Collison 2002) were intensively studied till now. However we are not aware of such works which examine the relation of the vital processes of the plants to slope movements. Since we are unable to measure all parameters which are in connection with the different vital functions of a plant, not to mention the measurement of these parameters on each individual plants or on one individual plant from each species, we investigated the connection between ground movements (tilts) and potential evapotranspiration (PET) of the investigated area (Rey, 1999). Evapotranspiration is the mass of the water transferred to the atmosphere in the form of vapour by either evaporation from the soil and plant surfaces or transpiration. Since PET contains the transpiration it is in close connection with the vital functions of the vegetation. Beside the effect of the PET on ground movements the effect of the precipitation was also investigated. The precipitation has both a direct and an indirect effect. The precipitation infiltrating into the soil changes the pore pressure in the soil and causes ground movements (direct effect). On the other hand both the potential evapotranspiration and the vital processes of the vegetation are influenced by the precipitation (indirect effect). As we know the small movements of the upper layer of the soil due to effect of precipitation and evapotranspiration were not investigated till now. In this paper the methods of the measurements, data processing and analysis are described and relationships between PET and rainfall data are presented.

2. TEST SITES AND METHODS

2.1 Test Sites

High (10-60 m) and steep loess bluffs susceptible to landslides are along the right side of the River Danube in Hungary. Our measurements were carried out in two test sites established for monitoring mass movements on the loess bluffs in Dunaföldvár and Dunaszekcső. Figure 1 shows the location of the two test sites where several landslides occurred during the last decades. The geological settings of the Dunaföldvár test site is given by Mentes et al. (2009) and the Dunaszekcső area is described by Újvári et al. (2010) in detail.

In both test sites geodetic network was established for repeated GPS and precise levelling measurements and borehole tiltmeters were installed for continuous monitoring the movements of the loess bluffs. Figure 2 and 3 show the Digital Terrain Model with the location of tiltmeters and GPS monuments of the Dunaföldvár and Dunaszekcső test sites, respectively. We only used the continuous data series registered by the high sensitive tiltmeters for our investigations. In Dunaföldvár two tiltmeters were installed: one on the top and the other at the toe of the loess bluff. The tilt measurements have been carried out since June, 2002. In Dunaszekcső three tiltmeters were installed on the top of the loess bluff: one on the stable and two on the unstable parts of the wall. The measurements began here in October, 2007.

[*] Corresponding author.

Figure 1. Location of the test sites in Hungary

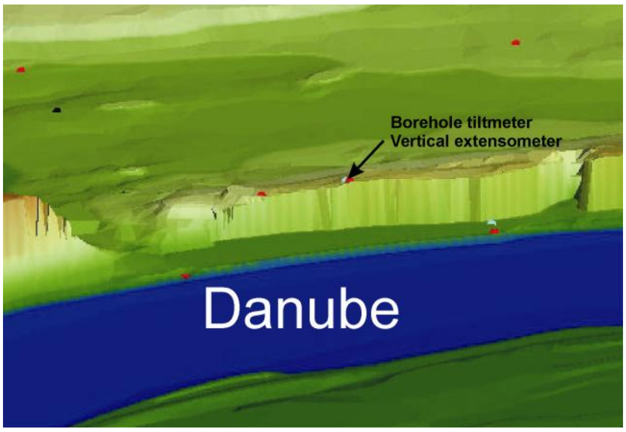

Figure 2. Digital Terrain Model (DTM) of the Dunaföldvár testsite. Red points denote the GPS monuments, blue points show the location of the tiltmeters

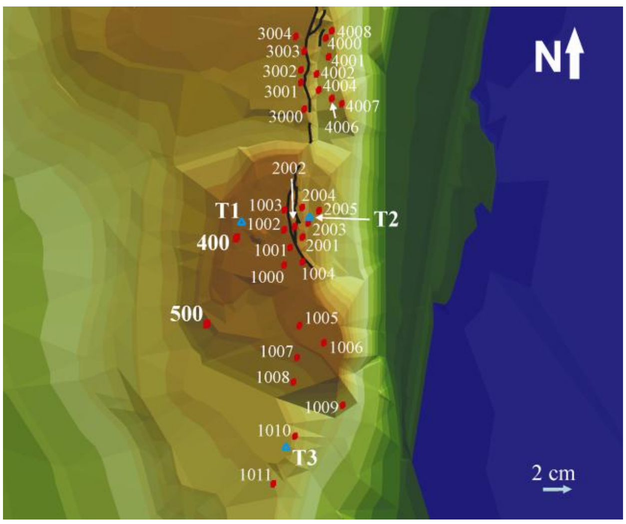

Figure 3. DTM of the Dunaszekcső test site with the location of tiltmeters (T1 –T3) and GPS monuments (red circles)

2.2 Tilt Measurements

Borehole tiltmeters, type of Model 722A from Applied Geomechanics Inc., were used for the measurements. The instruments were installed in boreholes at a depth of 3 m to ensure stable temperature. Further details of the installation of the tiltmeters are described by Mentes (2003). Tiltmeters have a dual-axis tilt sensor and a temperature sensor for measurement of the borehole temperature. The resolution of the tilt sensors in "high gain" range is 0.1 µrad and in "low gain" range is 1 µrad. The sensitivity of the temperature sensor is 0.1 °C. Data were recorded by Campbell Scientific CR10 and CR10X dataloggers with a sampling rate of 1 sample/hour.

In Dunaföldvár the tiltmeters are installed in such a way that their *y* axes are perpendicular to the River Danube and their *x* axes are parallel to the river and they point to the south. Positive *y* axes of tiltmeters in Dunaszekcső point to the north and their positive *x* axes point to the east.

Tilt data series recorded by the tiltmeter installed on the top of the loess bluff in Dunaföldvár (see Figure 2) and the tiltmeter in the location T1 (Figure 3) in the Dunaszekcső test site between 1 December, 2007 and 31 December, 2009 were involved in our investigations. Figure 4 shows a typical one-year long tiltmeter data record measured in Dunaföldvár. It can be clearly seen that short-periodic small movements are superposed on the long-periodic tilts.

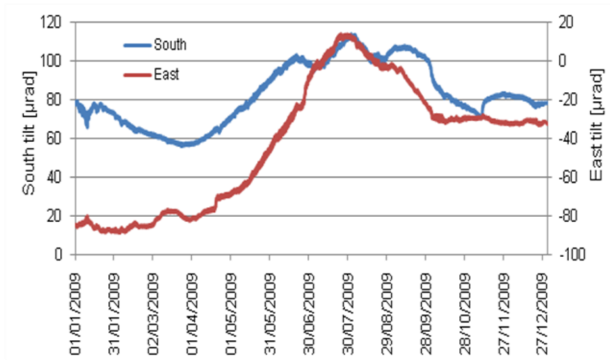

Figure 4. South (above) and east (below) tilt components of the tilt record made in Dunaszekcső in year 2009

In order to study which factors give rise to daily periodic tilt variations, tilt data series were filtered by a high-pass filter with a cut-off frequency of 0.02 1/day. Figure 5 shows the filtered daily tilt variations of some days.

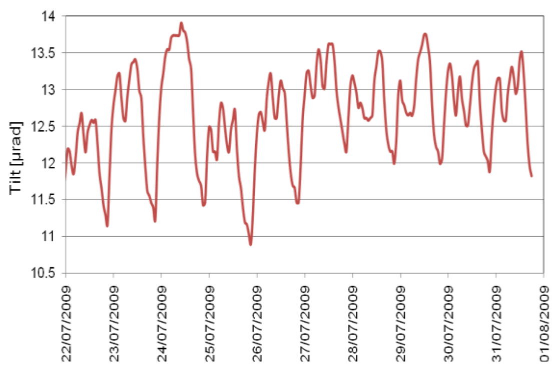

Figure 5. Daily tilt variations (east component) in Dunaszekcső

Such kind of tilt signals with exponential rising and falling edges can be detected due to the pore pressure variations of the ground caused by ground water table variations (e.g. Kümpel et al., 1996). This is why the daily amplitudes are compared with the evapotranspiration of the area which also causes a periodic variation of the pore pressure in the soil. In Figure 5 "exponential impulses" with daily period are modulated by short-periodic signal of unknown origin in the daytime.

Monthly averages of the daily tilt amplitudes were calculated from the high-pass filtered tilt data to compare with PET.

2.3 Vegetation Map and Calculation of the PET

Vegetation maps of the test sites were made for estimation of the transpiration of the plants. Surveying of the plants was carried out during field trips on the test sites. The location of the plant species were represented in 10x10 m sections of a grid network fitted to the cadastral map of the test site. A table was made to each grid in which the main features of the characteristic plants were described, e.g. the estimated age of trees, dimensions of their foliage, tree stratum and the estimated dimension and quality of root network, etc. Naturally the accuracy of such vegetation maps is limited due to the large variety of the plants. Furthermore there is no well defined boundary between species and the vegetation of an area shows temporal variation. In spite of the above mentioned facts these vegetation maps are suitable for estimation of the evapotranspiration of the test sites and for comparing mass movements due to different vegetations.

Since we only had daily air temperature values on the test sites we used the Thornthwait method (Rey, 1999) for the calculation of the PET:

$$PET = 1.6\left(\frac{10T}{I}\right)^{a} \text{ [mm]}, \qquad (1)$$

$$I = \frac{T^{1.514}}{5}, \qquad (2)$$

$$a = 0.000000675 \cdot I^{3} + 0.0000771 \cdot I^{2} + 0.01792 \cdot I + 0.49239 \qquad (3)$$

where T = monthly average temperature
I = thermal index
a = function of I

Nowadays, the Thornthwait method is not often used as it does not take the humidity of the air into consideration but it can be used very well to compare evapotranspirations of different areas. The PET values calculated by formula (1) were multiplied by the ratio of the area of the test site and the evaporating surface. This latter was estimated by means of the number of leaves of individual plants on the basis of the vegetation map. Since the PET is calculated on the basis of monthly average temperature data we get a PET value for every month. Figure 6 shows PET values of the Dunaföldvár (Df) and Dunaszekcső (Dsz) test sites. PET values are about four times higher in Dunaszekcső than in Dunaföldvár.

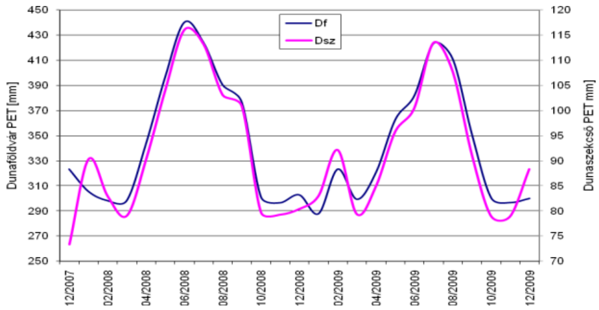

Figure 6. Comparision of the PET values of the Dunaföldvár (Df) and Dunaszekcső (Dsz) test sites

3. RESULTS AND DISCUSSION

Figures 7 and 8 show the north and east components of the amplitudes of short periodic (daily) tilt variations. From both figures it can be seen that the tilt amplitudes are higher in sunny and dry periods than in cool and wet periods. High amplitudes at the Dunaszekcső test site in February, 2008 are due to the movements of the loess bluff before and after the slump of the unstable part of the wall.

In both test sites the tilt amplitudes increase in April and decrease in October. This period coincides with the active transpiration period of the vegetation. This yearly period is slightly modified by the precipitation (see Figures 9 and 10).

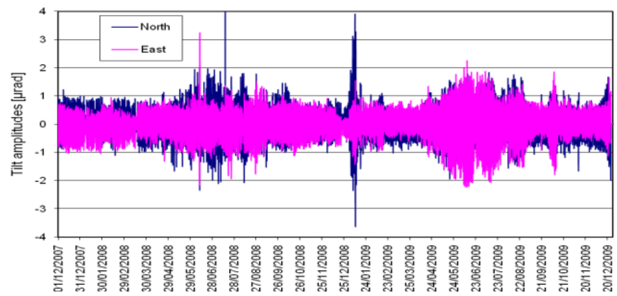

Figure 7. High-pass filtered tilt data measured at the Dunaföldvár test site from 1 December, 2007 till 31 December, 2009

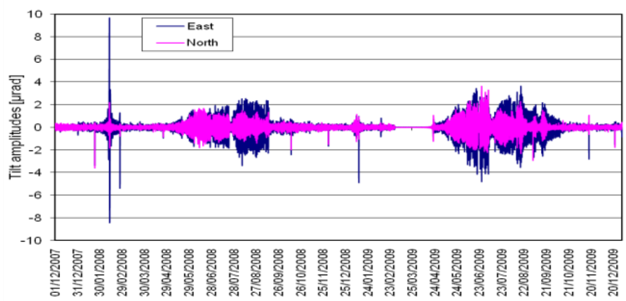

Figure 8. High-pass filtered tilt data measured at the Dunaszekcső test site from 1 December, 2007 till 31 December, 2009

Figures 9 and 10 show the relationships between PET, and the monthly averages of the precipitation and tilt amplitudes in the two test sites. The Figures demonstrate very clearly that during higher potential evapotranspiration the tilt amplitudes are also high. It can also be observed that in dry periods when the amount of the precipitation is small the tilt amplitudes are higher than in the rainy seasons. In rainy periods the upper layer of the soil is saturated by water and assuming a constant evaporation rate the water is evaporated from smaller soil volume than in the dry periods and so the daily tilt amplitudes due to the small pore pressure variations are also small. At the same time in dry periods the plants draw the water for their life processes from larger soil volume causing higher pore pressure variations and consequently higher tilt variations in the surrounding soil than in wet periods.

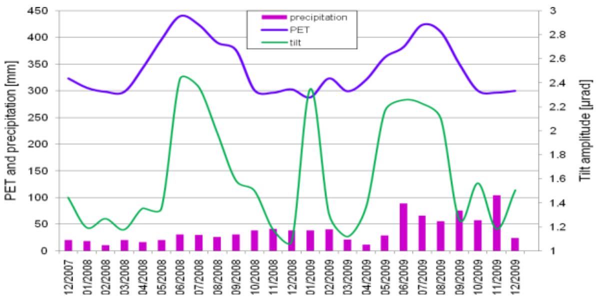

Figure 9. Relationships between PET, monthly averages of the precipitation and tilt amplitudes in the Dunaföldvár test site

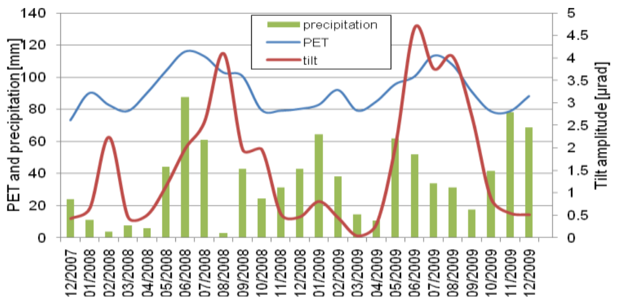

Figure 10. Relationships between PET, monthly averages of the precipitation and tilt amplitudes in the Dunaszekcső test site

4. CONCLUSIONS

Our results prove that short-periodic (daily) tilt amplitudes show a clear seasonal characteristic which coincide with the active (from April till October) and passive (from November till March) periods of the vegetation. The effect of precipitation on the seasonal variations of the tilt amplitudes is of minor importance which means that the vegetation has a very important role in the water balance of the upper layer of the soil. This role can be drawn up such as the vegetation with intensive transpiration considerably diminishes the infiltration of the precipitation into the deeper layer of the soil and hereby prevents development of slope failures.

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