UNIVERSITY OF WEST HUNGARY

KITAIBEL PÁL PHD SCHOOL OF ENVIRONMENTAL SCIENCES

PROGRAM: GEO-ENVIROMENTAL SCIENCES

THESES OF PhD DISSERTATION

THE ROLE OF THE VEGETATION IN THE DEVELOPMENT OF LANDSLIDES

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I. The actuality and the antecedents of the research

The number of landslides and the damage caused by them is increasing year by year, and even the effects of climate change enhance this tendency. The problem has arisen not only on the tropical climate but also in mediterranean areas. It became topical to get to know better this type of mass movement, and to investigate the parameters which have an effect on it, as well as to develop such environmentally friendly protective methods, with which the caused damages can be efficiently reduced.

An ever-increasing number of articles are published nowadays dealing with the role of the environmental parameters on landslides prone areas. At the same time there are only a few studies which investigate also the short-period, such as daily motions besides the longer-period ground motions. What is more, the number of researches analysing the relation between the environmental parameters, the physiological processes of the vegetation and the landslides, are particularly low.

In studies connected with the prevention the artificial methods were mostly prevailing for a long time, however nowadays more and more examinations focus on the natural and landscape-fitting solutions, thus on the vegetation. These studies take the root network as a basis and they do not take into consideration the living processes of the vegetation which play a huge role in the water balance of the soil. This way they have a great effect on the cohesive force between the soil particles, which are key factors regarding the slope stability.

As also in Hungary there are landslides which are increasing year by year both in number and in the volume of soil moved (Dunaszekcső 02.12.2008., Szentendre 15.05.2010., Kulcs 17.01.2011., Dunaszekcső 04.04.2011.), they can be considered as the most important hazard point in our country. This is why the MTA CSFK Geodetic and Geophysical Institute has chosen the investigation of this group of ground movements as one of their main research topics, and this is why it became the topic of my PhD thesis too.

The study was made more difficult by the fact that the landslides can react sensitively to the smallest change in their environment, so I had to examine the environmental parameters not only as independent factors, but as a connected system, and thus prove the joint effect of more ambient parameters on the slope tilt values.

During the course of my 1,5 year long university and 4 year long PhD work I have investigated the effects of different meteorological and hydrological parameters on vegetation-covered slopes which are endangered by landslides, and in addition I have studied what type of effects do the different plant species have on the stability of sloped areas.

II. Objectives

My research had two main goals. First, to acquire more comprehensive knowledge about those environmental parameters (hydrological and meteorological) which can affect the stability of the vegetation-covered slopes. I also wanted to study the separate effects of different parameters, and to demonstrate to which extent their separate effect changes in case we analyse them as a unit (environmental system) while taking into consideration the vegetation coverage of the areas.

My other goal was to lay down the foundation-stones of a method, with which it will be possible to classify the slope-stability influencing effects of the plant species based on their different characteristics (height, root volume, evaporative surface, etc.). Thus establishing the basis of a natural protective method, which could be used more efficiently than the preceding ones to stabilize the areas which are prone to landslides; and in addition which can meet the requirements better of the ever-increasing severity of environmental regulations.

Based on the above mentioned factors my concrete objectives were the following:

- The examination of the daily and longer periodical tilting values at different types of areas which are endangered by landslide. The analysis of the possibly occurring tendencies and extraordinary values and to explain them with the different meteorological and hydrological parameters.
- To determine what kind and how great effects do the different separate environmental parameters have on the measured tilting values. To study the effects of the wind and the vegetation evaporation besides the precipitation, soil moisture and temperature factors.
- To determine which meteorological and hydrological parameter has the greatest effect on slope areas.
- To find out how and to which extent the ambient factors are modified, if other factors (for example the relation between precipitation – soil moisture – ground water content – air temperature) are taken into consideration.
- To find out how and to which extent the effects of the hydrological and meteorological parameters are modified if the vegetation is also taken into consideration during the examinations.
- To establish a classification system, with which it will be possible to detect which plant species have a positive or negative effect on slope stability.

III. The theses about the independent research results

In the course of my work the recorded tilting data set of three research areas, the measured environmental parameters and the different vegetation made it possible for me to study the sensibility of landslides to the change of vegetation and to the change of the ambient parameters which take their effect via the vegetation. In addition I was able to study and to categorize the effects of different plant species on the slope stability.

On my test areas I filtered the tilting records with low-pass or high-pass filter, according to the frequency of the investigated phenomenon. The measured and the filtered data lines were subjected to different statistical methods to make it possible to study the effects of the parameters impressed directly and via the vegetation. In order to be able to demonstrate which parameter has the greatest effect on the slope stability, I used principal component analysis. To detect the relation between the parameters and the tilting values I carried out Pearson correlation and Spearman rank correlation. I carried out the processing and evaluation of the data with the appropriate functions of the Microsoft Excel and the MATLAB program.

I can summarize the different phases and the results of my PhD work in the following theses:

1. The preceding surveys assigned a great significance to the soil-loosening effect of the precipitation, however in the course of my **examinations I demonstrated that while the precipitation remarkably changes (decreases) the course of the short-term (hourly, daily) tilting values (Figure 1.), it does not cause a change directly in the values of longer-term tilts.** In this case it impresses its modifier effect by increasing the ground water content. I calculated the precipitation intensity and the change of the ground water content for the Hidegvíz Valley area, by means of which I proved my above statement.

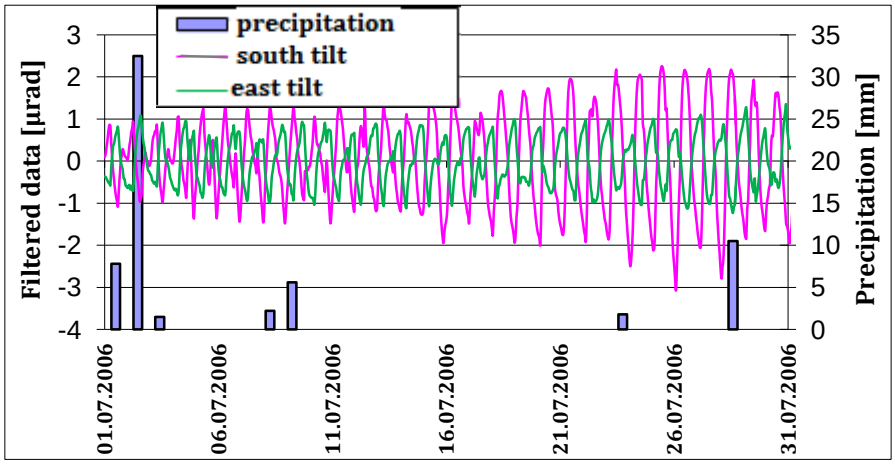

Fig.1. *The effect of precipitation onto tilt amplitude (Dunaföldvár)*

2. **By the means of principal component analysis I proved that from all of the studied parameters the ground water content has the greatest effect on the slope tilt value.** The air temperature had the second greatest effect. I supported this with the results of Spearman correlation and also with Pearson rank correlation (table 1.). With the help of the data from the Hidegvíz Valley **I demonstrated that the quantity of the ground water content changed only when the intensity was between 5-10 mm/day.** Below this value the precipitation was too few to drench the soil, while above this value the rain was too intense to be able to infiltrate into the soil on the slope and mostly run off the surface.

Table 1. Correlation coefficients between the tilt components and the measured parameters calculated by Pearson and Spearman rank correlations.

Correlation	Tilt direction	Data type	SWC	ST	AT	NWS	EWS	P	ET_0
Pearson	ET	Raw	–0.319	0.467	0.337	0.035	0.088	-	-
		Daily	–0.301	0.468	0.345	-	-	0.027(N)	0.079(N)
		Low-pass	–0.308	0.471	0.347	0.044	0.121	-	-
		High-pass	–0.093	0.005(N)	0.138	0.036	–0.023	-	-
	NT	Raw	0.718	–0.592	–0.194	0.151	–0.191	-	-
		Daily	0.712	–0.597	–0.201	-	-	0.067(N)	0.006(N)
		Low-pass	0.719	–0.590	–0.200	0.190	–0.262	-	-
		High-pass	0.099	0.010(N)	0.079	0.003(N)	–0.011(N)	-	-
Spearman	ET	Raw	–0.194	0.458	0.348	0.102	0.092	-	-
		Daily	–0.174	0.459	0.347	-	-	0.029(N)	0.034(N)
		Low-pass	–0.183	0.460	0.349	0.121	0.112	-	-
		High-pass	0.024	0.087	0.282	0.013(N)	0.008(N)	-	-
	NT	Raw	0.729	–0.616	–0.215	0.126	–0.136	-	-
		Daily	0.726	–0.618	–0.213	-	-	0.055(N)	0.066(N)
		Low-pass	0.740	–0.613	–0.209	0.169	–0.135	-	-
		High-pass	0.003(N)	–0.122	0.084	0.013(N)	–0.004(N)	-	-

Note: ET and NT are the east and north tilt components, respectively; SWC is the soil water content; ST is the soil temperature; AT is the air temperature; NWS and EWS are the north and south components of the wind speed, respectively; P is the precipitation and ET_0 is the reference evapotranspiration; N denotes not significant results.

3. **Based on the measures made in the Hidegvíz Valley I proved that the wind speed also has an effect on the tilting values via the vegetation, however it can affect only when the ground water content is high and mostly in the active (leafy) period of the vegetation, when it can sway the trees more because of their leaf canopy. I demonstrated that the change caused in the tilting values does not only depend on the speed of the wind but also on its direction and duration.** A wind with a longer duration and high speed, and a wind which is pushing the trees downslope can cause a permanent change in the line of tilting values.

4. I calculated the evapotranspiration of the three research areas with Thornthwaite and Penmann-Monteith methods**. I demonstrated that the vegetation significantly influences the water content of the ground with its living processes (absorption and evaporation), and as I have mentioned it before the soil moisture content has the greatest effect on the stability (Figure 2.). I proved that the tilting values on all of the three test areas show a similar yearly periodicity like the living processes of the vegetation** (increasing tilting values in spring, decreasing values from autumn) (Figures 2. and 3.), which means that the effect of the vegetation should be treated also as an important influential factor on the areas endangered by landslides.

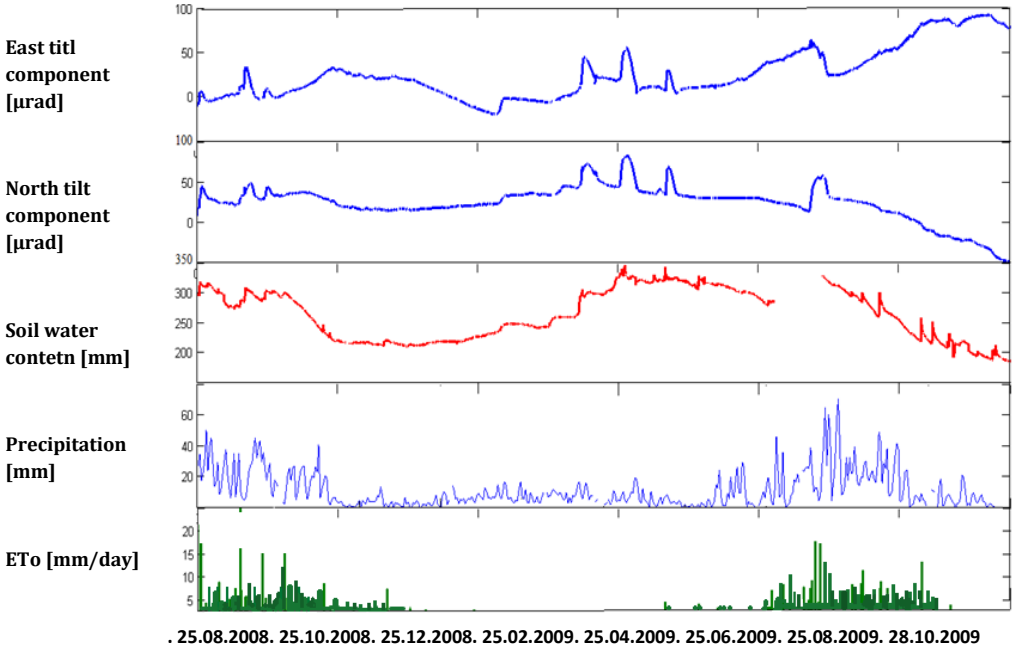

Fig. 2. *The daily evapotranspiration, the precipitation, the soil water content, and the daily east and north tilt amplitudes*

5. **I developed a method based on Fuzzy-logic to analyse the effect of the different plant species which prevents or contributes to the formation of landslides**. Based on the data of the professional literature of different plant species I studied the plant species at the Dunaszekcső and Dunaföldvár research areas. **According to my results the acacia and walnut tree can be considered as a positive species in the protection against the landsliding processes on both areas, whereas the apple tree, the pear tree and the wine has a negative effect on the slope stability. The**

effect of the other species depends on the proximity and number of individuals (table 2.). The correctness of my theoretical results has been also proved by the traces of previous landslides found at the test areas. With the further elaboration of this method it would be possible to develop an effective natural protective method in the future.

Table 2. Defuzzyficated value of different species and their effect to the stability

species	defuzzyfication value	effect to the slope stability
acacia	**0.821**	**GOOD**
apple	**0.107**	**BAD**
ailanto	0.5	NEUTRAL
box elder	0.5	NEUTRAL
cherry	0.5	NEUTRAL
peach	0.5	NEUTRAL
pear	**0.0976**	**BAD**
plum	0.5	NEUTRAL
sour cherry	0.5	NEUTRAL
walnut	**0.804**	**GOOD**
wine	**0.082**	**BAD**

IV. The usefulness of the results

The formation of landslides is caused by the joint effect of several factors. They react sensitively to the smallest change in their environment. When studying the exact relations we have to reveal the modifying effects of complex systems on one another. The results of my PhD work are the first step of this process, with the help of which there will be a possibility (while taking into consideration the environmental changes) to get closer to the solution in order to decide whether certain areas in the future can become endangered by landslides. These results can play an important role in the prediction of landslides, as in the course of further research we will be able to set up ambient threshold values based on them.

Finally, my results regarding the classification of the vegetation can form the base of a future natural method with which we can guard against landslides more successfully while keeping the landscape-fitting solutions in focus.

V. Publications related to the subjets

Reviewed papers in foreign language, pressed abroad

1. **Bódis, V.B.,** Mentes, Gy. 2012. The role of vegetation in the daily and yearly small tilt variations of the Danube's high bank, Hungary Zeitschrift für Geomorpholigie 56. 2. 133-141.
2. Mentes Gy., **Bódis, V.B.** 2012. Relationships between short periodic slope tilt variations and vital processes of the vegetation Journal of Applied Geodesy 6. 2. 83-88.
3. Mentes, Gy., Bányai, L., Újvári, G., Papp, G., Gribovszki, K., **Bódis, V.B.** 2012. Recurring mass movements on the Danube's bank at Dunaszekcső (Hungary) observed by geodetic methods Journal of Applied Geodesy 6. 3-4. 203-208.
4. Mentes, Gy., **Bódis, V.B.,** Vig, P. 2014. Small slope tilts caused by meteorological effects and vital processes of trees on a wooded slope in Hidegvíz Valley, Hungary. Geomorphology 206. 239-249.
5. Mentes,Gy., Bányai, L., Újvári, G., **Bódis, V.B**. 2014. Rutschungsprozesse des Hochufers der Donau bei Dunaszekcső. AVN, 121, 8, 1-7.

Reviewed papers in Hungarian

6. **Bódis, V.B.**, Mentes, Gy. 2010. A vegetáció és a felszíni tömegmozgások kapcsolatának vizsgálata. Geomatika Közlemények XIII./2, 149-157.
7. Újvári, G., Bányai, L., Mentes, Gy., Papp, G., Gribovszki, K., **Bódis, V.B.** 2011. Utómozgások a Dunaszekcsői magasparton. Geomatika Közlemények XIV/1
8. **Bódis, V.B.** 2011. A dunai magaspartok mozgásviszonyait befolyásoló növényi életfolyamatok és a csapadék. www.e-tudomany.hu, e-tudomány, 2011/2. I, 1-7.

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9. Mentes, Gy., Bányai, L., Újvári, G., Papp, G., Gribovszki, K., **Bódis, V.B.** 2011. Recurring Mass Movements On The Danube's Bank at Dunaszekcső (Hungary) Observed by Geodetic Methods. Proceedings of the Joint International Symposium on Deformation Monitoring. Hong Kong, China, 2-4. November 2011. Session 3E: Applications in Geosciences on Local and Regional Scale II. 3E-04. 159.pdf

10. Mentes, Gy., **Bódis, V.B.** 2011. Relationships Between Short Periodic Slope Tilt Variations and Vital Processes of the Vegetation. Proceedings on the Joint International Symposium on Deformation Monitoring. Hong Kong, China, 2-4 November 2011. Session 3I: Natural Effects (Groundwater, Erosion, etc). 3I-02. 158.pdf

Conference papers in Hungarian

11. **Bódis, V.B.** 2009. A növényzet hatása a földcsuszamlásokra. In: XXIX. OTDK Országos tudományos diákköri konferencia. Gödöllő, Magyarország 2009 Gödöllő 197.
12. **Bódis, V.B.** 2010. A növényzet hatása a földcsuszamlásokra. XII. Országos Felsőoktatási Környezettudományi Diákkonferencia OFKD 2010. 2010. április 6-7. Sopron 156.
13. **Bódis, V.B.** 2011. A növényi életfolyamatok hatása a földcsuszamlásokra. In: Doktoranduszok Tudományos Konferenciája az Erdőmérnöki Karon. Sopron, Magyarország, 2011. április 13. Sopron. 83-86. (ISBN:978-963-334-013-4)
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15. Újvári, G., Bányai, L., Mentes, Gy., Papp, G., Gribovszki, K., **Bódis, V.B.** 2011. Utólagos deformációk a dunaszekcsői magasparton geodéziai mérések alapján. In: VIII. Veszélyforrások Konferencia. Visegrád, Magyarország, 2011.06.01-2011.06.03. Visegrád. 16.
16. Mentes, Gy., **Bódis, V.B.** 2011. A növényi életfolyamatok hatása a partfalmozgásokra. In: VIII. Veszélyforrások Konferencia. Visegrád, Magyarország, 2011.06.01-2011.06.03. Visegrád. 13.

Presentations on foreign conferences

17. **Bódis, V.B.** 2011.Investigation of the factors causing small surface tilts on the high loess bluffs along the River Danube. Arbeitskreis Geodäsie-Geophysik wiss. Interessengemeinschaft ohne rechtlichen Status 2011.10.4-7. Németország-Nördlingen

18. Mentes, Gy., **Bódis, V.B.** 2011. Relationships Between Short Periodic Slope Tilt Variations and Vital Processes of the Vegetation. Joint International Symposium on Deformation Monitoring. Hong Kong, China, 2-4. November 2011. Session 3I: Natural Effects (Groundwater, Erosion, etc). 3I-02.
19. Mentes, Gy., Bányai, L., Újvári, G., Papp, G., Gribovszki, K., **Bódis, V.B.** 2011. Recurring Mass Movements On The Danube's Bank at Dunaszekcső (Hungary) Observed by Geodetic Methods. Joint International Symposium on Deformation Monitoring. Hong Kong, China, 2-4. November 2011. Session 3E: Applications in Geosciences on Local and Regional Scale II. 3E-04.
20. **Bódis, V.B.**, Bányai, L., Újvári, G., Mentes, Gy. 2012. Relationship between slope stability and vital processes of Vegetation. International Scientific Conference on Sustainable Development & Ecological Footprint March 26-27 2012. Sopron, Hungary
21. **Bódis, V. B.** 2012. Effect of vegetation and meteorological parameters on wooded slope. VII. Autumn Seminar on Geodesy for PhD Students 12 October 2012, Sopron, Hungary)
22. **Bódis, V.B.** 2012. Environmental effects on vegetated slope Herbsttagung des Arbeitskreises Geodäsie/Geophysik, Németország, Kloster Drübeck, 19.11.2012 - 22.11.2012.
23. Mentes, Gy., Bányai, L., Újvári, G., **Bódis, V.B.** 2013. Rutschungsprozesse des Hochufers der Donau bei Dunaszekcső in Ungarn Herbsttagung des Arbeitskreises Geodäsie/Geophysik, 15.10.2013-18.10.2013, Heppenheim, Németország

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30. Újvári, G., Bányai, L., Mentes, Gy., Papp, G., Gribovszki, K., **Bódis, V.B.** 2011. Utólagos deformációk a dunaszekcsői magasparton geodéziai mérések alapján. pp. 16. VIII. Veszélyforrások Konferencia. A Magyarhoni Földtani Társulat és a Magyar Bányászati és Földtani Hivatal szervezésében. 2011. június 1-3., Hotel Visegrád, Visegrád.
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35. **Bódis, V. B.** 2009. A növényzet hatása a földcsuszamlásokra. XXIX. OTDK Országos tudományos diákköri konferencia. Környezetgazdálkodás I. tagozat. 2009. április 6-8. Gödöllő