

The role of recent tectonics and hydrological processes in the evolution of recurring landslides on the Danube's high bank in Dunaföldvár, Hungary

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ABSTRACT

There are high loess banks prone to landslide along the River Danube in Hungary. One of these is the high loess bank in Dunaföldvár, where several landslides occurred in the last decades. Quantitative relationships between the movements of the high loess bank and the variation of the water level of the River Danube, the ground water table, precipitation and temperature are investigated by two borehole tiltmeters and a vertical borehole extensometer. The twelve-year long observation from 2002 to 2014 made it possible to distinguish between the high bank movements due to slow recent tectonic and geomorphologic processes and the short-period (from hours to months) movements caused by hydrometeorological effects. The results revealed that besides geomorphologic processes recent tectonics can play an important role in the recurrence of landslides in the area. In the investigated period the total tilt of the high bank was $162 \mu\text{rad}$ in the SSE direction according to the geomorphologic and recent tectonic processes in the surroundings of Dunaföldvár. Investigations of the relationships between the high bank movements and the water level of the River Danube, ground water table changes and the precipitation revealed that the tilt magnitudes caused by the ground water table variations are two orders of magnitude greater than the tilts caused by the water level regime of the river and the direct effect of the precipitation on the high bank tilts can be disregarded.

1. Introduction

The 30–80 m high loess banks along the west side of the River Danube in Hungary are greatly prone to landslides (Kleb and Schweitzer, 2001). The abrupt mass movements cause a lot of damage in settlements, industrial structures built on the high banks. Several landslides (e.g. in years 1960, 1970, 1973, 1994, 2004 and 2005) caused damage in the small town Dunaföldvár which is partly built on the high loess bank. This was the reason for the detailed hydrological, geological, and geomechanical investigations carried out earlier in the area (e.g. Horváth and Scheuer, 1976; Karácsonyi and Scheuer, 1972; Kleb and Schweitzer, 2001; Pécsi, 1971; Pécsi et al., 1979; Scheuer, 1979; Szabó, 2001) but relationships between movements of the high bank and geophysical, hydrometeorological, etc. processes were not studied at that time. In 2001 a test site has been established by the former Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences (now Geodetic and Geophysical Institute, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences (GGI RCAES of HAS)) to study the relationships between high bank movements and different natural factors. First a geodetic monitoring network was established, based on yearly repeated geodetic

measurements (GPS, EDM, precise levelling) and continuous borehole tilt measurements (Mentes and Eperné, 2004). In 2005, a vertical borehole extensometer also was installed on the test site to monitor the vertical deformation of the high bank. Besides the deformation measurements, temperature, ground water table variations were monitored and water level fluctuations of the River Danube and precipitation data were involved into the investigations.

In contrast with the geodetic measurements the highly sensitive ($0.1 \mu\text{rad}$ corresponding to 0.0001 mm m^{-1}) continuously recording borehole tiltmeters are well suited for observation of short periodic and small ground tilts due to ground water level and pore pressure variations, as it was proved by pump tests (Fabian and Kümpel, 2003; Kümpel et al., 1996, 2001). Such kind of tiltmeters were used for landslide monitoring by e.g. García et al. (2010). Highly sensitive, continuously recording borehole tiltmeters and extensometers provide more information about the landslide movements than the intermittent measurement techniques (Uhlemann et al., 2016; Brückl et al., 2013; García et al., 2010; Corsini et al., 2005). They make possible to seek for quantitative connections between river bank movements and hydrological, meteorological processes (water level of the river, ground water table variations and precipitation events), which are in connection with

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the slow seepage material transport from the basal sediment to the river and the river erosion of the basal material. Many authors (e.g. Casagli et al., 1999; Chu-Agor et al., 2008; Fox et al., 2007; Guzzetti et al., 2008; Rahimi et al., 2010; Rinaldi et al., 2004) studied the effect of the precipitation, ground water and stream level variations onto river bank stability in connection with seepage caused slope failures and erosion. Wilson et al. (2007) carried out laboratory experiments on the basis of field measurements to study the impact of soil properties on seepage erosion and the resulting stream bank failure. Schnellmann et al. (2010) investigated experimentally the effect of rising water table in an unsaturated slope model. Angely et al. (1998) developed a combined hydrology/stability model by means of which the cumulative landslide displacements could be estimated as a function of precipitation. The direct connection between hydrological processes and landslide movements have also been investigated by several authors (e.g. Bogaard and Greco, 2016; Lehmann et al., 2013; Springman et al., 2013).

Similarly to other effects, active tectonics can also play an important role in development of landslide processes as they are able to modify the slope geometry, causing structural discontinuities, and changing the gravity field (Alexander and Formichi, 1993; Rapolla et al., 2010). To detect the slow tectonic movements and their effects long-period and high accuracy deformation monitoring is necessary. This is why the relationship between landslides and tectonic movements has been mostly investigated using geomorphologic approaches (e.g. Agliardi et al., 2001; Dramis and Sorriso-Valvo, 1994). Only some authors, e.g. Brückl et al. (2013) have carried out seismic measurements and continuous deformation measurements by geodetic methods and continuously recording extensometers.

In this paper the quantitative relationships between the movements of the high loess bank and the water regime of the River Danube, the ground water table, precipitation and temperature are investigated by two borehole tiltmeters and a vertical borehole extensometer. The possible effect of recent tectonics on the high bank movements is also studied on the basis of twelve-year long continuous data series recorded from 2002 to 2014.

2. Study area

Dunaföldvár is situated in the middle of Hungary on the right side of the River Danube, on the margin of the Mezőföld, which is characterized by NW-SE oriented valleys (Fig. 1). The bottom right corner of the

Figure shows the locations and dates of the largest landslides in Dunaföldvár and the study area which is situated on the 120–130 m high a.s.l. (a.s.l. = above Baltic Sea level) Felső Öreghegy (Upper Old Hill). Fig. 2 shows the investigated section of the high bank and the traces of the landslide occurred in February 2005. In Fig. 3 the contour map of the study area is depicted. The loess plateau of the Felső Öreghegy has a 20–30 m steep, nearly vertical hillside to the flood plain of the River Danube. The Felső Öreghegy is separated from the Alsó Öreghegy (Lower Old Hill) by a 150–200 m wide, N-S oriented, valley. Fig. 4 shows the simplified geological cross section of the area based on the results of geotechnical surveys carried out by Pyrus Ltd (1994). A detailed description of the geological setting of the high bank is given by Horváth and Scheuer (1976), Karácsonyi and Scheuer (1972) and Schweitzer et al. (1978).

The hydro-geological properties of the area are strongly influenced by the subsurface water flow from the elevated loess hinterland which is a water catchment area. The water supply is derived from the sand layers intercalated in the loess sequence, where the ground water is accumulated, and from the confined water stored in the first sandy Upper-Pannonian deposit (Fig. 4). The average depth of the ground water table, depending on the characteristics of the terrain, is about 25–40 m in the loess-mantled area west of the margin of the high bank (Karácsonyi and Scheuer, 1972). The ground water flow direction is mainly eastward, but this is influenced by the valleys which reach the ground water table. In Fig. 3 the broken arrows show the direction of the ground water flow to the investigated high bank from the NW and SW (Horváth and Scheuer, 1976). At the margin of the high bank the ground water table falls steeply and the water is transferred to the sediments of the River Danube or breaks to the surface in form of springs or seepages 0.5–1 m above the mean water level of the river (Scheuer, 1979). The height of the ground water table is about 104–106 m a.s.l. in the sandy layer (Pleistocene loess complex) of the high bank and in the Holocene sandy gravel layer on the bank. Since the ground water has a hydrological connection with the River Danube, its level is largely influenced by the water level of the river (Horváth and Scheuer, 1976).

The study area is bordered on the NNW-SSE orientated Bölskei valley from the west (Fig. 3). The 1–1.5 km wide Bölskei valley is filled with silts of high organic content and it is a soggy area, 98–102 m a.s.l. The Pannonian basement rises gradually towards the west. On the east side of the town Dunaföldvár, the strip of the high bank is 64–87 m high

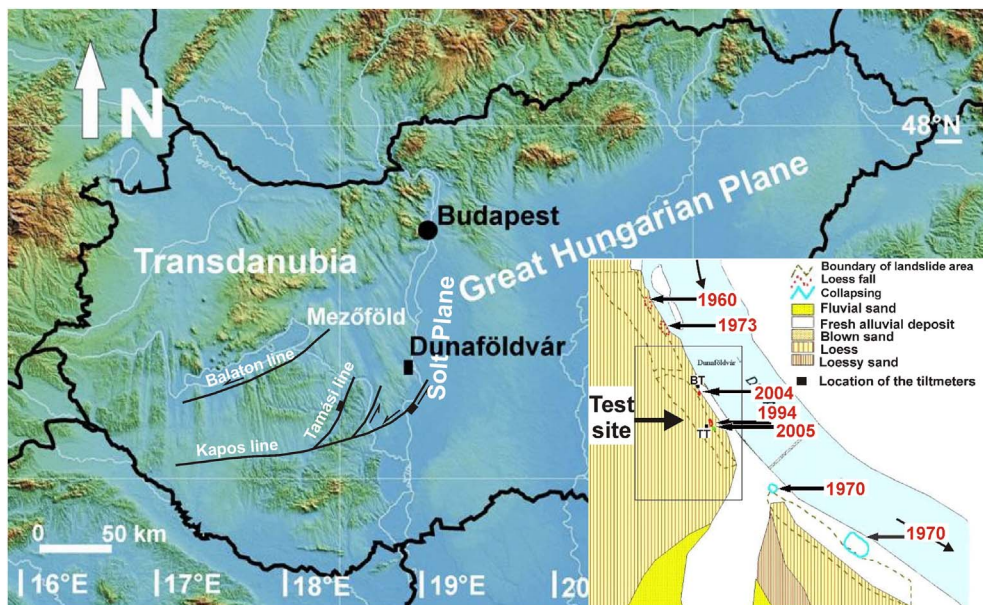


Fig. 1. Height map of Hungary showing the location of Dunaföldvár and the main geomorphologic units and fault lines (after Fodor et al., 2005; Horváth et al., 2006; Bada et al., 2010) in the vicinity of the study area. In the bottom right corner the locations and years of the largest landslides on the test site and some geological features of the area are shown.

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