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Fracture System Mapping Using Pressure Probe Method

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SUMMARY

Mechanically weak zones may arise e.g. due to rock realignment in the subsurface having an effect to the near surface-, or even to the surface sediments. If they are not directly seen from the surface a new method, the so-called pressure probe (Pre-P) method may be used to detect and characterise them. This method is presented on the example of the investigation of the fracture system of a landslide. Repeatability of the Pre-P measurements, adequate sampling distance, resolution of the method and the possible data processing steps are also investigated. We know from these investigations that: 1. there are consolidated zones on the slope side of the fractures whose broadness correlates with the broadness of the given fracture; 2. both the large and the small fractures follow each other periodically; 3. even the structure inside the blocks which belong to the large fractures can be well seen which refers to the very good resolution of the method. The here presented Pre-P method seems to be the most favourable tool to map the fracture system of such kind of landslides according to its resolution capacity, speed, simplicity of its application, the interpretation of the data and its costs.

Introduction

It is principal to map the landslide endangered areas, to diagnose their dangerousness, to monitor their changes and understand their behaviors. For this aim geophysical techniques - which are summarized e.g. by Jongmans and Garambois (2007) – may be very useful. The goal of the applied geophysical techniques used to be the horizontal and/or vertical delineation of the sliding volume or - more rarely - the study of the inner structure of the landslide or the characterization of the eventually existing sliding surface.

Geotechnical methods, remote sensing techniques and geodetical methods are also distributed in landslide investigations as it is shown on the example of the in this paper presented area by Újvári *et al*, 2009, Bányai *et al*. 2012 and Bányai *et al*. 2013.

All of these techniques were however mostly used in the investigation of landslides where the sliding material differed from the massive one. In our case, however, the slide occurred in a homogeneous region where the landslide dangerous area could not be delineated by geophysical tools because of the missing contrast in the physical quantities of different rock domains. In this case the description of the fracture system may be very useful. Detecting fractures GPR investigations were carried out by Barnhardt and Kayen (2000) and Jeannin *et al*. (2006) but the results were not satisfying and the geotechnical tools which are theoretically useful in mapping fractures give, however, only punctual results. A classical paper for fracture measurements by geoelectric method is that one by Taylor and Fleming (1988).

Due to the aforementioned reasons we decided to use a tool which is able to avoid the aforementioned problem and give a detailed description about the fracture system of an area. The Pressure-probe (Pre-P) method whose application is moreover fast, cheap and effective is not else than a simplified version of the Cone Penetration Testing (CPT) technique.

Geological and geomorphological settings

The study area belongs to the Baranya Hills, in Hungary. The basement formations at Dunaszekcső are Triassic–Jurassic limestones located at 200–250 m below the surface (Hegedűs *et al*., 2008). These basement rocks are covered by clayey and sandy sediments formed in the Pannonian s.l. epoch that can be found below about 70m depth according to borehole data (Pécsi *et al*.,1979). The uppermost 70m of the sediment sequence are sandy and clayey loess layers with brown to red fossil soils accumulated during the Pleistocene (Fig 1). The flood plain of the Danube is very narrow or missing. The bluff consists of a 20–30 m high vertical loess wall above the 10–20 m high slopes that consist of reworked loess from past landslides and fluvial mud, sand and gravel deposits of the Danube. The slopes were intensively undercut by the river during each flood event (Kraft, 2005). Field observations show the development of tension cracks in the loess complex parallel as well as perpendicular to the channel of the Danube, indicating reduced rock strength.

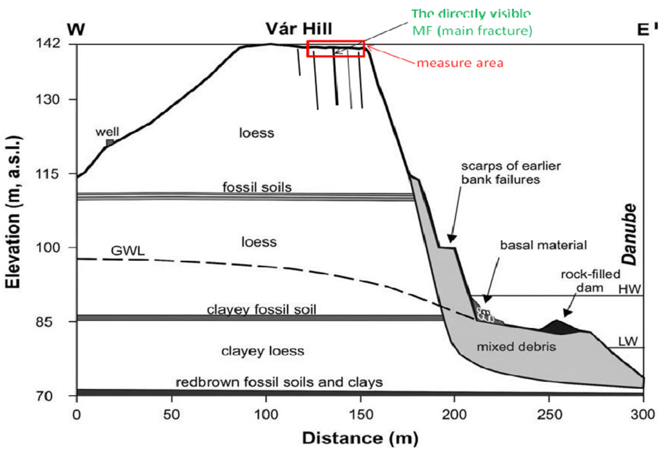

Figure 1 *Geological cross-section of the high bank at Dunaszekcső (modified after Pécsi et al., 1979 and Kraft, 2005). Elevation and distance were derived from the digital terrain model which was provided by geodetic measurements of 433 points. Vertical exaggeration: ×3. GWL=ground water level (measured in a well in July 2008); HW=highest water; LW=lowest water. The measure area is shown by the rectangle.*

The Pressure-probe (Pre-P) method

The simplified penetrometer we applied can be seen in Fig 2a, while the schema of the measurement in Fig 2b. The fractures are often covered by plants and/or soil (Fig 2c). The Pre-P method which bases on the deeper penetration of the dropped instrument in and around cracks seems to be a valuable tool to detect them.

The base of our tool is a metal rod on which a metal disc is fixed to increase its weight. One let the tool fall down as perpendicular as possible from a given height (Fig. 2c). The instrument sinked deeper only if there was a remarkable fracture. To get the fracture system map measurements on parallel profiles were carried out. The profiles were in 2m distance from each other. The sampling distance was 10 cm. The directions of the profiles were quasi perpendicular to the supposed direction of the most interesting fractures, that is those ones which are nearly parallel to the sliding front. The penetration depth of the probe was recorded. At locations where fractures supposed to be the plants were removed by a metal road. If a fracture was found there we followed it for a distance by removing the plants along the fracture (Fig 2d). It could easily be done by taking the root of the grass and uprooting it (Fig. 2d). Several fractures were found like this (Fig. 2e) and many of them were even longer excavated (Fig. 2f). Repeatability of the measurements was verified, as well (Fig 3.)

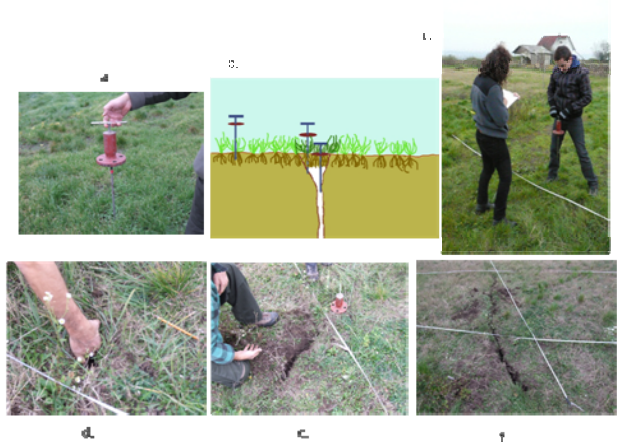

***Figure 2** The process of the measurement; a. The instrument; b. Scheme of the Pre-P method; c. Measurement and data registration, d. Removal of vegetation from the crack detected by the Pre-P method; e. A part of the crack with the unexplored parts of it. It is seen that there are not any indication in the surface to the crack; f. However, it continues.*

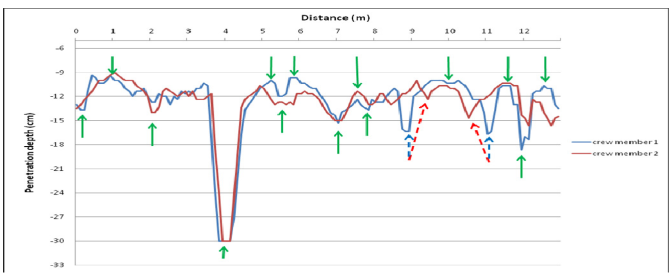

***Figure 3** Repeatability of the Pre-P measurements. They were carried out by two crew members on profiles very close (in 10 cm distance) to each other*

Results and interpretation

The significant fractures were appointed where the obtained value was much larger than the values around it. The background values (that is where no fractures are) were characteristically under 13 cm, mostly between 11-, and 13 cm. Higher values used to refer to the existence of fractures. The small variation of the background values verify both the homogeneity of the loess and the robustousness of the method. In Fig. 4 which presents a profile, like an example, three main zones can be seen. The first two of them can be further divided into sub-zones. The fractures follow each other with a certain periodicity especially in zone 2. This Figure illustrates that by appropriate sampling distance the Pr-P method is able to detect and position cracks, as well to estimate their significance.

On the Pr-P map (Fig. 5.) interpreted fractures are marked by yellow or purple dotted lines according to whether their direction is parallel or quasi perpendicular to the slide front. The thickness of the lines correlates with the expected thickness of the cracks. In the sliding area 10 parallel (I-IX) and two nearly orthogonal (XI -XII) fractures are identified. It seems that along cracks VII and VIII mass movement may happen at any time, even before the sliding along the main fracture. The nearly parallel fissures are in a distance of about 1-1.5m from each other (0-12m on the profile) near the sliding, and about 3-4m intervals further from the sliding front (12-21m on the profile) with the exception of the stable zones, especially area 3c.

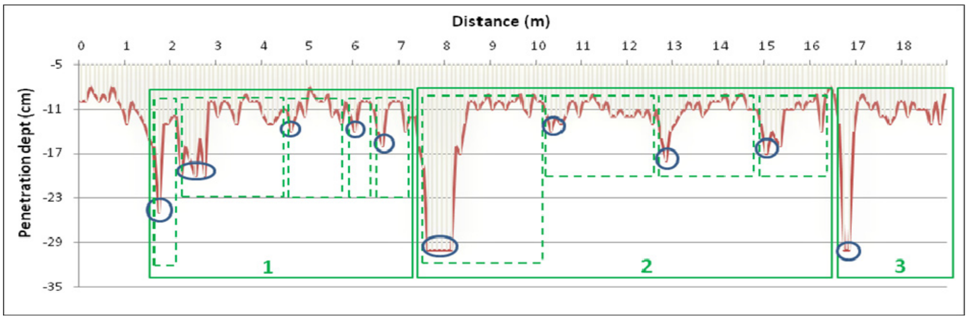

Figure 4 *One of the measured profiles and its interpretation. Zones assigned to given fractures were delineated by continuous line rectangles and numbered. These main fracture zones were further divided into smaller zones which belong to moderately significant fractures. These sub-zones were delineated by dotted-line rectangles. Ellipses show the anomalies in the measured values which refer to the supposed cracks.*

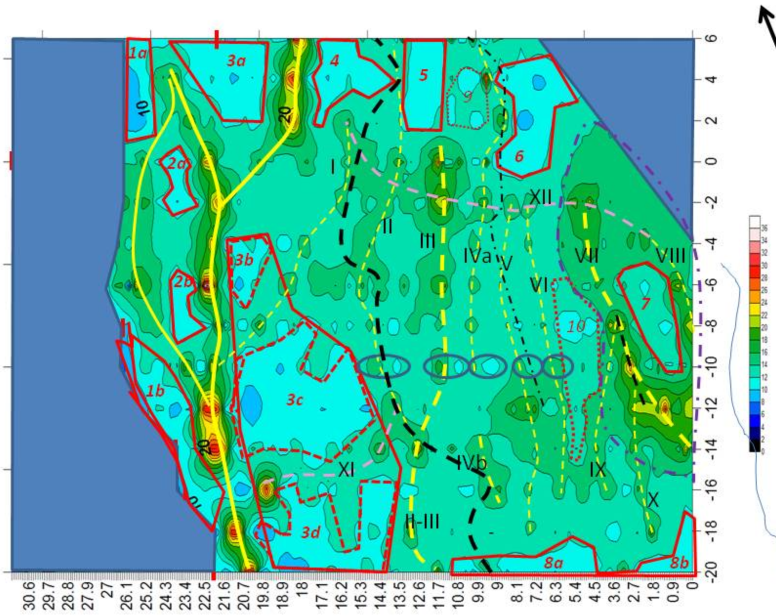

Figure 5 *The Pre-P map. Yellow solid line: the crack which can be seen directly on the surface. Yellow dashed line: on the basis of the map suggested, to the wall almost parallel cracks. Purple dashed lines: transverse cracks on the basis of the interpretation of the Pre-P map. Black dashed lines: the explored crack. Black dot-dash: partially revealed cracks. Arabic numbers indicate mechanically stable areas, while the Roman numbers the suspected cracks.*

The Pre-P method proved to be moreover suitable for mapping the fissure system of a not-yet-endangered area, too. It was shown that this area is also fractured. The cracks in this zone are in addition occurred with greater amplitude and width than in the other side of the main fracture which is directly seen on the surface.

Conclusions

A new, extremely easy to use method, the pressure probe method was introduced which measures a parameter proportional to the soil mechanical resistance. This method allows us to map the fissure systems and to delineate loose zones in areas threatened by landslides. The method thus allows to better understand the process of landslides and – among appropriate circumstances - the delineation of them in right time when other methods might have not been able to do that.

The major advantages of the Pre-P method are its: 1. cheapness; 2. relatively high speed; 3. almost arbitrarily high resolution power; 4. easy use; and that 5. its results are easily interpretable; 6. it works among almost any field conditions, including any topographic conditions, by vehicles due to vegetation or landslide's risk no or hardly accessible areas. The main limit of the method is that in areas exposed to artificial changes in soil mechanics, such as agricultural areas, or areas visited by vehicles, cannot be applied. The method would be applicable, however, in such cases, too, but the depth of penetration should to be than increased. Since it requires great mechanical strength that is the use of vehicles it would lose most of benefits listed above.

If the Pre-P method is completed with micromorphological observations and observations of vegetation and immediately in the field, at the crack-suspected positions excavations are carried out even 2-3cm wide cracks can be explored and tracked. Similar resolution image cannot get by any known method about the fracture system except for geotechnical ones, which are however, much more expensive than the Pre-P method.

The fracture system of the research area could have therefore been mapped with high resolution and it was found that the fractures: 1. have a well consolidated zone in their sliding side; 2. both the larger and the smaller ones follow each other almost periodically; 3. used to interrupt, or branch out; 4. even the smaller ones, are detectable (ie. the measurement has a very fine resolution). The results in the not-yet sliding side showed that: 1. cracks are present also there; 2. the cracks therein are at least as wide as the cracks in the sliding side; 3. that is the future slip surfaces already exist; 4. this area is divided into blocks of about twice as wide as those in the sliding area.

The Pre-P method make therefore possible the localization of the future sliding surfaces that is also the delineation of the endangered areas. The Pre-P method is particularly useful for the examination of landslides consisting from homogeneous rocks, that is exactly for landslides whose investigation is fairly limited by other methods. It may however be applicable for the examination of landslides with more heterogeneous composition, even though cannot be expected as significant results.

In this article it was demonstrated that this cheap and productive method is very well applicable in delineation of landslide dangerous areas and in mapping their fracture system if it is not too heavily influenced by human activity.

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