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Landslide mapping with the GIS

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Abstract

Any new technology allows an improved approach to the processing of expert data. The article describes how to make the recording of the data of engineering geological landslide mapping of the best possible quality by exploiting the possibilities offered by GIS. All input landslide data acquired during mapping, called landslide elements, were classified, as customary in GIS, into three groups: point, line and polygon elements. A list of the typical landslide elements noted in landslide survey was made for each group. Each element came with a description of its origin and appearance, the surveying method and the graphical representation in GIS. Additionally, a presentation of the landslide in three layers was introduced, historically reviewing the landslide. The first layer represented the past shapes before sliding, the second layer represented the recent signs of sliding and the third one (for old landslides) represented the shapes that arise after sliding. The graphical landslide data were connected with the attributes kept in the descriptive landslide database. The described approach involving the use of GIS considerably improves the quality of data capture in engineering geological landslide mapping. An example of a landslide map prepared according to the described system is attached to the article.

Kratka vsebina

Vsaka nova tehnologija omogoča izboljšan pristop k obdelavi strokovnih podatkov. V članku opisujem, kako čim bolj kvalitetno shraniti podatke inženirskogeološkega kartiranja plazu z izrabo možnosti, ki jih nudi GIS. Vse vhodne podatke o plazu, pridobljene pri kartiranju, ki jih imenujem elementi plazenja, sem razvrstil, kot je običajno za GIS, v tri skupine: točkovni, linijski in poligonski elementi. Za vsako grupo sem izdelal seznam tipičnih elementov plazenja, ki nastopajo pri pregledu plazu. Za vsak element podajam opis nastanka in pojavljanja, način zajemanja na terenu in grafični prikaz v GIS-u. Poleg tega uvajam prikaz plazu v treh slojih, ki plaz zgodovinsko obravnavajo. Na prvem sloju so prikazane reliktne oblike pred začetkom plazenja, na drugem sveži znaki in na tretjem (za stare plazove) dogajanja po končanju plazenja. Grafične podatke o plazu sem povezal z atributi shranjeni v opisni bazi podatkov o plazu. Opisani pristop z uporabo GIS-a zelo izboljša kvaliteto zajema podatkov pri inženirskogeološkem kartiranju plazu. K članku prilagam primer izdelane karte plazu po opisanem sistemu.

Introduction

New technology, which GIS no longer is actually, also enables feedback. Those who master it can tackle the professional tasks that have been customary to date in a different way, from another aspect. In this way, new professional possibilities appear. The aim is not only to make data capture as appropriate for the GIS technology as possible, but to also improve the professional quality through a different aspect enabled by GIS.

Many experts have dealt with the use of GIS for landslides, so that there is a vast literature on various approaches and techniques. I have myself frequently used GIS in landslide mapping and thus discovered certain views and considerations that were new to me and which I hope will be at least partly new and useful to somebody else. My goal was not to develop a new system, but to create a useful method of landslide mapping.

Landslide presentation in GIS

One of the usual techniques in GIS is that when a new spatial problem is being worked on each of the influential factors is presented in its own information layer. When mapping fossil landslides with more or less blurred shapes of sliding, one observes the geological and morphological forms that are or are not the signs of landsliding occurring in the past.

My work showed that the one of the most appropriate approach was the method in which information layers were divided into four groups:

1. original forms appearing before landsliding,
2. forms as the consequence of landsliding,
3. forms appearing after landsliding,
4. forms due to human activities.

The first group includes all morphological forms already existing before landsliding, like remnants of terraces, slope levelling, streambeds and similar features. The second group of information layers contains the forms appearing as the consequence of displacements during landsliding, which are later described in detail. The third group involves the forms that blurred or highlighted the shapes of landsliding, for instance the action of erosion on a landslide which subsequently eroded part of the landslide. Finally, the fourth group contains forms occurring during any landslide restoration or other human activities interfering with the surface of the area concerned.

All morphological forms for which it is not clear whether they arose due to landsliding are inserted in the information landslide layers. When, after the field processing and digitalisation of data, the information landslide layers are drawn separately, the previously hidden integral image of the landslide is clearly revealed. This is, naturally, only true of very large landslides which occurred in the geological history, but not of the smaller and more recent ones, most of whose characteristics can already be determined during mapping. However, I also use for these landslides the division to the forms before, during and after landsliding, because this makes their presentation much clearer. Sometimes such an approach shows that there have been several landsliding stages. In this case, the landsliding shapes are divided into information layers of individual landsliding stages. For a final determination whether a landslide is an old one, the morphological signs must be added by the geological signs of soil composition, pointing to a possible landsliding. Such signs are not treated in this paper.

The second basic characteristic of using GIS is that the graphical elements, in this case landslide elements, are presented as points, lines, polygons or bodies. The point elements may be sources, boreholes or measurements on a landslide. The line elements are all main scarps and cracks on a landslide. In time, the line elements of a recent landslide become blurred and rounded, and in old landslides they appear as ridges or steps. Then, it is frequently more appropriate to present them as plane units by polygons.

Plane units are the typical forms of different landslide areas occurring during the movement of the sliding masses down the slope. The typical plane forms are flat or undulating planes of characteristic shapes.

It depends on the rock in the base and its susceptibility to sliding how fast the initially distinct landsliding forms will disappear and become less and less recognisable. Another factor influencing the recognisability of landsliding is the size of the landslide and the dimensions of the displacements of the sliding masses. Very large landslides with extensive displacements remould the terrain to such an extent that the landslide shapes may remain visible even for several hundred years.

Only an assembly of several typical morphological forms with appropriate geological signs constitutes a reliable proof that there was a landslide in a certain place, while individual, although characteristic, forms could have occurred during other natural or anthropological events.

The point data are not important for landslide identification by itself. In the GIS presentation, they are used for marking water spring, measurement points, etc. In detailed mapping, point elements are used for the measurements of the morphological form characteristics, like the inclination of the terrain at a certain point. Below, point measurements connected with the line and polygon morphological forms are described in more detail.

Line morphological forms

For landslide identification, line data as the remnants of landslide scraps and cracks are more important. In precise measurements, certain line elements can also be presented as polygons. The most typical line forms are shown in the following pictures of the characteristic landslide profile and ground plans:
Main scarp
Minor scarp
Right and left flank
Transverse cracks
Longitudinal cracks

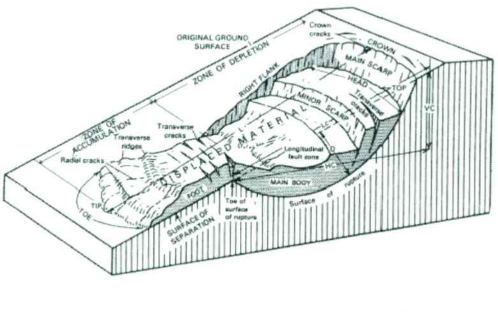


Fig. 1. Landslide terms (Cruden & Varnes, 1996)

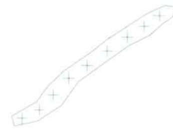
In the process of ageing, fresh cracks become increasingly blurred, the weathering rounds them, and erosion turns longitudinal cracks into ditches. Thus, with old landslides, the following forms are found instead of fresh cracks:

The main scarp is usually rounded and followed by a steep plane, ending in a more or less levelled terrain.

Appearance
in the nature (sketch): Presentation in GIS:

A longitudinal ridge (left and right) is a remnant of the lateral flank in areas where the material on the sides was piled-up over the edge of the landslide. It is more frequent in the lower part of the landslide.

Appearance
in the nature (sketch): Presentation in GIS:



A longitudinal ditch (left and right) is also a remnant of the lateral landslide flank (left or right) which, after the slide, became lower than the displaced surrounding. It is often deepened by line stream erosion.

Appearance
in the nature (sketch): Presentation in GIS:

Oblong concavity appears in the form of a ridge which usually crosses the landslide transversely. Concavities may be of different dimensions – heights and widths. Ordinarily, they are the consequence of a step in the landslide whose edge later became blurred or plastic deformation of the sliding material. Concavity may also appear in a landslide when the landslide material with plastic behaviour gets compressed, raising the terrain.

Appearance
in the nature (sketch): Presentation in GIS:

Oblong convexity usually appears when the landslide is moving, with the material opening up and deforms plastically (tensile stress). It may also be formed as the consequence of an uneven shape in the surface of rapture.

Appearance
in the nature (sketch): Presentation in GIS:

A step is a sharp transition of the terrain from a gentler slope to a steeper one. It differs from a concavity by the sudden change in the inclination. The form of a step is similar to the edge of a terrace. In the field, both inclinations are measured and the point values of the measurements are given. During landsliding, a step may also appear as a sliding surface in the very body of the landslide. One of the opportunities for it to form is also when the rock in the base on which the material is sliding locally changes its direction from a gentler inclination to a steeper one.

Appearance in the nature (sketch): Presentation in GIS:

In the mapping of line morphological forms, the line shapes that probably appeared due to sliding are added by the line shapes that had existed before sliding (displaced paths, stired terraces, boundaries of changes in the vegetation, etc.) and those that formed after sliding (erosion ditches, new waterways, etc.).

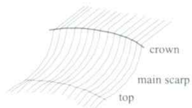
As far as the forms appearing after sliding are concerned, we are interested in the extent to which they have covered up the signs of sliding. The natural signs are primarily connected with erosion, frequently with the carrying away of the landslide material, and the anthropological signs are mostly connected with farming, afforestation, remoulding of the terrain by a bulldozer, etc.

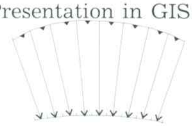
Plane morphological forms

The most reliable evidence of landsliding in the past can be obtained by analysing plane forms. When mapping or identifying old landslides, I found many other characteristic plane shapes, with some of the most frequent being presented below:

The main sliding surface appears under the crown and represents the slide of material along the main scarp. This movement is usually the largest one in the body of a landslide. With fossil landslides, the main sliding surface is one of the most distinct features showing that sliding has occurred in the past. In old landslide identification, a distinct lack of soil volume is recorded in this part.

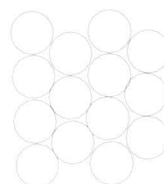
Appearance in the nature (sketch): Presentation in GIS:





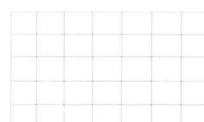
An undulating surface as a very frequent sign of old landsliding appears when the landslide material has plastic properties. When moving down the slope, the sliding material becomes compressed or expands, with various irregularities in the form of the landslide material and the wet masses in the landslide body finding their expression in plastic deformations of the material.

Appearance in the nature (sketch): Presentation in GIS:



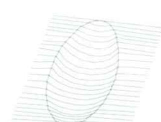
A horizontal or an inclined plane, on the other hand, normally appears in areas where the sliding is even and regular. It may be a remnant of original levelling before sliding.

Appearance in the nature (sketch): Presentation in GIS:



A concavity is a round or elliptical depression appearing in a landslide. It often contains water or becomes marshy. It is formed on the upper part of the landslide as a lack of the material that slid or due to the uneven movement of the landslide, with the sliding mass being of such a material that can get plastically deformed.

Appearance in the nature (sketch): Presentation in GIS:

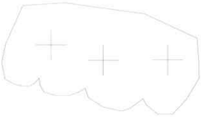


A convexity is round or elliptical and looks like a small hill on the landslide. It points to a local accumulation of masses in the landslide, primarily in its toe.

Appearance in the nature (sketch): Presentation in GIS:

The zone of accumulation appears in the area where the shear resistance of the ground increases largely, thus stopping the sliding masses, although they are still under pressure of the higher sliding masses. Due to the slowing down of the landslide, the pressures in the landslide directed towards the slope result in the accumulation of material and even in the rising of the surface in the area of zone of accumulation. The latter are typical of the toe of the landslide.

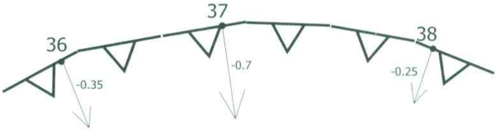
Appearance in the nature (sketch): Presentation in GIS:



Landslide measurements

When determining the characteristics of line and plane units mostly of an active landslide, it is sensible to also perform point measurements, which provide additional information on the characteristics of the forms: Main scarp, minor scarp or new scarp:

Height of vertical displacement – presentation:

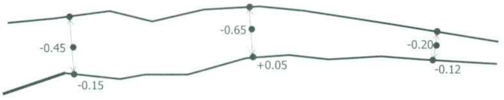


36 .... ID No. of point, → direction of movement, –0.35 vertical movement in meters

Right and left flank:
Height of vertical displacement (upwards or downwards), horizontal displacement, expansion to the sides – presentation:

Transverse cracks and longitudinal cracks:

Openness and depth of cracks – presentation:

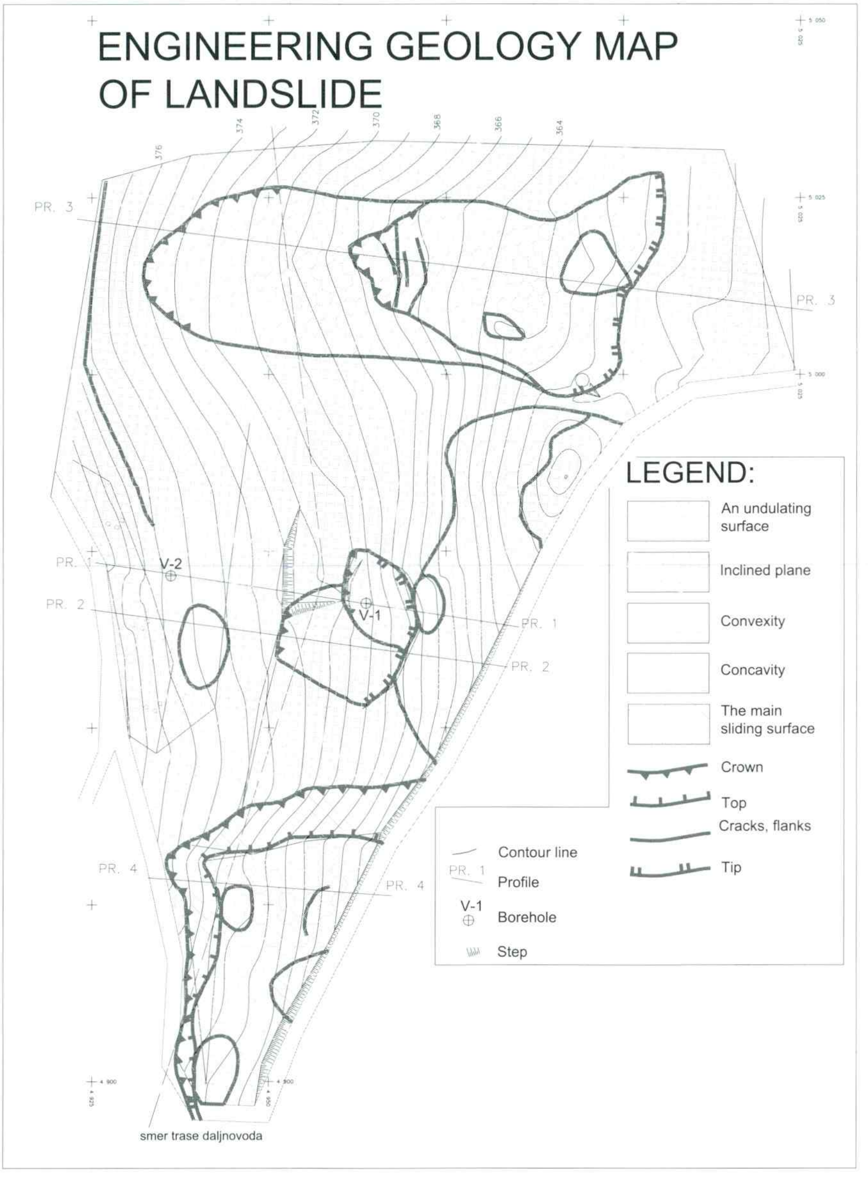


Similarly it can be presented also next landslide elements (units):

Longitudinal ridge:	height of ridge
Longitudinal ditch:	depth of ditch
Step:	inclination of terrain above and under the step
Main sliding surface:	inclination of the sliding surface
Undulating surface:	distance between two concavities or convexities
Inclined plane:	inclination of the inclined plane
Convexity:	depth of convexity
Concavity:	height of concavity
Zone of accumulation:	height and superposing of the zone of concavity

Conclusion

When mapping old landslides, one no longer encounters fresh signs of landsliding, primarily expressed as lines, but blurred consequences of sliding which mainly appear as plane morphological forms. According to the procedure described in the paper, GIS is used to present these forms in separate information layers, thus supplying new information on landsliding, which is shown in the following picture.



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