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Calculation of the moving landslide masses volume from air images

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Abstract

The landslide Slano blato is of great dimensions, longer than 1 km and wider than 300 m. The movements of 10 m per day mostly happen in heavy rainy seasons and afterwards calm down, while the landslide progresses for a few 100 meters at the time. Because of the size and the inaccessibility of the landslide, common surveying was not possible. So the observation of the sliding masses movements was only possible by successive photography from a plane. For this purpose we carried out two special photo shoots with a special plane equipped for remote sensing. The existent snap shots from regular cyclic remote sensing prior to landsliding were also applied. On the basis of the snaps, TIN meshwork was created for each photo shoot separately. Geodetic maps in 1:2000 scale with contour lines 1 m apart were also produced for this purpose.

It is important to know the volume of the moving masses so we can determine which measures are significant for stopping the landsliding (mudflow) that threatens the village of Lokavec. As we had available data of the area size before landsliding, we could easily calculate the mass volume sliding by cross-sectioning the area of the two conditions at different times of aerial photo shoots. The problem in the calculation was the landsliding masses that joined the mudflow from the ground. These were the masses from the previous older slidings, known to had happened at least twice – 100 and 200 years ago. The volume of the old landslide was estimated with the help of geological evaluation which we used to access the depth of the slope base. Geological evaluation was partially based on field drilling and partially on presumption of the depth of weathering cover. The landslide depth data were interpreted with the help of two longitudinal sections and transverse sections each 25 m apart. We put the surface lines from each remote sensing on each cross-section and calculated the volumes of the landslide between two cross-sections. By means of this procedure we assessed that the volume of all the sliding masses was 684.000 m^3 (April, 2001). With regard to this and other parallel results we determined that we should stop the sliding before it gets to the village by draining and pushing the masses aside. Part of the masses was impossible to withhold on the slope (between 300.000 m^3 and 400.000 m^3), so it was removed by means of vehicles to the deposit.

It was confirmed that the calculation of the volumes with the help of remote sensing is a very suitable method for large landslides, but will only give the right results by detailed geological interpretation of landsliding.

Kratka vsebina

Plaz Slano blato je izrednih dimenzij, daljši od 1 km in širine do 300 m. Premiki na njem velikosti do nekaj deset metrov na dan se dogajajo po deževnih razdobjih in se zopet umirijo, ko plaz napreduje več sto metrov. Ker s klasičnimi geodetskimi meritvami zaradi velikosti plazu in nedostopnosti ni bilo mogoče spremljati premikov plazečih se mas, so bila dogajanja na plazu spremljana s pomočjo zaporednih slikanj iz letala. V ta namen sta bili izvedeni dve posebni snemanji s posebnim letalom za daljinsko opazovanje, uporabljeni pa so bili tudi obstoječi posnetki rednega cikličnega snemanja še predno se je plaz sprožil. Na osnovi posnetkov so bili izdelani TIN in GRID površine za vsako snemanje posebej in geodetske karte površine v merilu 1:2.000 z izohipsami na 1 m.

Za odločitev, kateri so nujni ukrepi za preprečevanje premikanja plazu, ki ogroža zaselek Lokavec, ki je neposredno pod plazom, je pomemben podatek, kolikšen je volumen premikajočih se mas. Ker je bila na razpolago prvotna površina terena pred plazenjem, se je izračun volumnov mas, ki so se "razlile" kot blatni tok preko prvotne površine, določil enostavno s presekom površin dveh stanj površine v različnih časih letalskega slikanja. Problem so predstavljale tiste plazeče se mase, ki so se vključile v blatni tok iz podlage. To so bile mase od starih plazenj, saj je poznano, da je bil plaz aktiven najmanj že dvakrat - pred dvesto in sto leti. Volumen stare plazine smo ocenili s pomočjo geološke ocene, s katero smo določili globino do hribinske podlage.Geološka ocena je temeljila deloma na terenskih vrtanjih, deloma pa na predpostavkah o debelini preperinskega sloja. Podatki o debelini plazu so bili interpretirani s pomočjo dveh vzdolžnih profilov in prečnih prerezov na razdaljah po 25 m. V vsak prerez so bile prenešene linije površin posameznih snemanj, dobljene s presekom med ploskvami površin in vertikalno ravnino prereza ter interpretirana linija podlage.. Volumni plazeče se mase med dvema profiloma so bili določeni s produktom polovice vsote ploščin preseka plazu med zaporednima presekoma in razdalje med presekoma. Po tem postopku je bil določen celotni volumen gibajočih se mas, ki je znašal 684.000 m3 (maja 2001). Ob upoštevanju teh in drugi vzporednih rezultatov se je pokazalo, da je za preprečitev prodora plazečih se mas do vasi Lokavec treba čim več mas zadržati z osuševanjem in odrivanjem na boke na plazu, tiste mase po oceni v količini med 300.000 do 400.000 m3 , ki ni mogoče zadržati na pobočju, pa odvoziti na deponijo.

Pokazalo se je, da je izračun volumnov s pomočjo letalskega slikanja za velike plazove zelo primerna metoda, ki pa da rezultate šele ob podrobni geološki interpretaciji dogajanj na plazu.

Introduction

It is very probably in connection with the global climatic changes which, apart from dry periods, also brought extremely rainy seasons in recent years that four very large landslides have occurred in Slovenia after 2000, such as had not been observed for decades before that. Due to several reasons, we decided to obtain geodetic bases by aerial photography. These reasons were:

- inaccessibility of landslide bodies,
- large dimensions of landslides,
- requirements for quick acquisition of geodetic bases (implementation of urgent restoration measures),
- large displacements of soil masses in short time periods,
- comparison of the state before and after the triggering of landsliding,
- calculation of the volumes of the moving landslide masses.

We made air images of all four landslides on the same flight. One of these landslides was Slano blato, treated in this paper.

For landslides of extraordinary dimensions, like Slano blato, the calculation of volumes (volumes of moving masses, volumes to the base and potential volumes of new sliding) is important because it provides a basis on which answers of better quality can be given to the following questions:

- Is a final landslide restoration possible and sensible at all?
- Is it possible to restore it by regrouping the sliding masses?
- Is it sensible to remove a part of the landslide material?
- What masses may endanger the settled area under the landslide?
- What volumes of masses may move at the same time?
- What is the most probable sliding prognosis?

Only the calculation of the volume of potential and moving masses of the landslide material provides the basic answers specifying to which extent the works on a landslide would contribute to its stabilisation. The calculation also shows approximately what funds will be needed for landslide restoration.

Some basic data on the landslide:

• Location:	Above Lokavec at Ajdovščina in Primorska
• Date of triggering:	18 November 2000
• Surface of the landslide:	~ 20 ha, length: ~ 1270 m
• Largest width:	~ 250 m, between 360 and 660 above sea level
• Largest progress:	~ 90 m/day

- Rock in the base: flysch (marl and sandstone)
- Composition of the sliding mass: weathered flysch – clayey gravely soil
- Age of the landslide: first reference dating 200 years ago
- Landslide restoration: first performed in 1903, lasting for 17 years.

In order to calculate the volumes of moving masses, aerial photographs were used as follows:

1. The original surface was taken from aerial photographs taken in 1998, before sliding,
2. The second shoot was carried out at the end of November 2000,
3. The third shoot was carried out in mid April 2001.

Preparation of geodetic bases and calculation of volumes between different states of surfaces

The preparation of the geodetic bases for the calculation of the volumes was carried out by the Geodetic Institute of Slovenia, which has an aeroplane for aerial photography and all the software needed for data processing.

The hardware used was:

- aerial photography equipment on the aeroplane with a RC30 aerial metric camera,
- analytical photogrammetric instrument Adam Promap,
- GPS receivers,
- PCs,
- electronic theodolite LEICA TCR 307.

The data gathered were processed by means of the following software:

- Adam System Software,
- AutoCAD,
- QuickSurf,
- Archos,
- KarTop,
- Polar.

The tests at comparative points showed that the error in the determination of the heights does not exceed two metres, which provided a satisfactory precision for the calculation of the volumes, in particular since it is known that landslide displacements of several metres in a short period are no exception.

The results of the geodetic processing which, in addition to aerial photography, also included the determination of new photogrammetric reference points by GPS measurements on the field as well as classical geodetic survey photography and the inventory of all buildings by entering house numbers, were the following products:

- a topographic map of the original state before landsliding of 1998 in the scale of 1:2000,
- a topographic map of the landslide state in November 2000 in the scale of 1:2000,
- a topographic map of the landslide state in May 2001 in the scale of 1:2000,
- TIN1998,
- TIN2000,
- TIN2001.

As examples of geodetic processing, the picture below presents TIN98 states before landsliding (yellow colour) and TIN2001 meshwork of movements in the upper part of the landslide (blue colour):

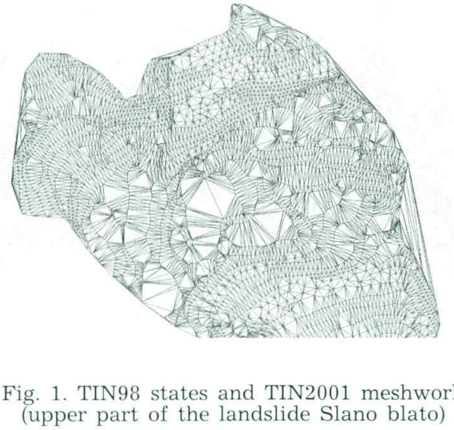


Fig. 1. TIN98 states and TIN2001 meshwork (upper part of the landslide Slano blato)

In the first step, we tried to calculate the changes in the volume over time due to the expansion of the landslide by simply determining the volume between two TIN meshworks. The checking of the data obtained showed unsatisfactory results, because the volume of the change in surfaces between two states did not provide a satisfactory answer about the sliding masses actually involved in landsliding. Consequently, we decided to calculate the volumes of the sliding masses in a more time-consuming way according to the profile method explained below.

Calculation of the volumes of sliding masses

The calculation of volumes is a long and complex procedure which can practically not be performed by hand. The calculations were made by means of a computer with the software applications AutoCAD 2000, QuickSurf and Microsoft Excel. In order to transfer the data between AutoCAD and Excel, short programs were written in Visual Basic.

First, QuickSurf was used for constructing the planes of surfaces for each aerial shoot. These planes were cross-sectioned transversely against the slope at distances of approximately 25 m (right picture – presentation of the upper part of the landslide).

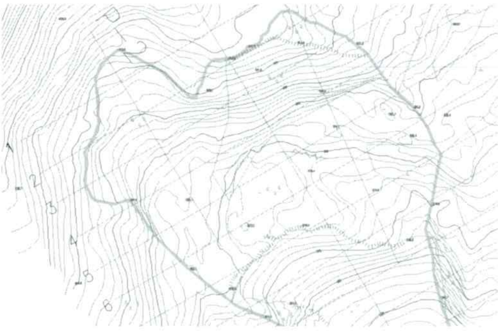


Fig.2. Presentation of the upper part of the landslide

We obtained three lines of states for each shoot. The fourth line, representing the depth of landsliding, was constructed for each case by means of the data gathered by probe wells and the interpretation of the geological structure, digitalised and transferred to the other three lines. The result was 51 transverse sections, with three of them being shown below as examples:

The procedure of calculating the volumes was the following:

• For each cross-section, the surface from the reference height was first determined for each of the three landslide states at different times and for the base by means of the Boundary and Area commands in AutoCAD.

• The data for the surfaces calculated in this way were transferred to Excel, where the calculation was continued.

• The surfaces were mutually subtracted for each case. The surfaces November 2000 and April 2001 were subtracted from the original surface (1998). We also searched for the difference between the state in April 2001 and the interpreted base. A negative difference between surfaces means that masses were carried away from the cross-section area, while a positive difference means that they were brought from elsewhere.

• The volume between two cross-sections was calculated by halving the sum of both surfaces and multiplying it with the distance between the two cross-sections:

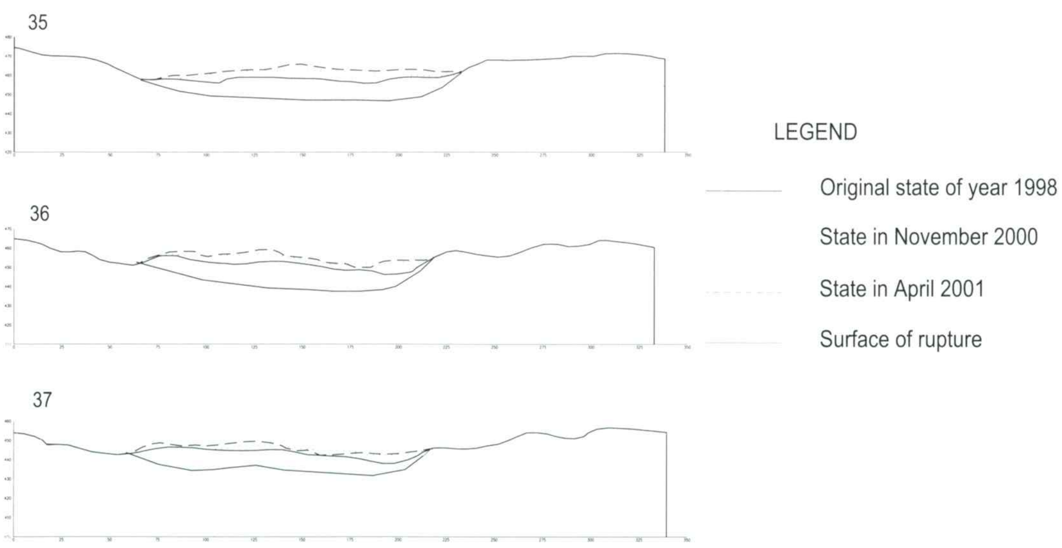
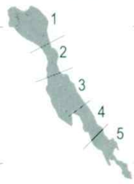


Fig.3. Transverse cross-sections

Tab.1. The results of the volume calculation

Volumes (m^3)	00–98	01–98	01–00	01–Pod
1. upper part of the landslide and Slano blato	–35,876	–61,190	–25,313	144,800
2. upper channel	–12,714	–25,716	–13,002	42,742
3. "Blatno jezero"	53,431	63,229	9,798	292,092
4. lower channel	459	99,404	98,944	174,403
5. area above the waterfall	0	10,274	10,274	24,344
TOTAL	5,300	86,001	80,702	678,381



• The results obtained were further used for drawing charts and for various summary tables and calculations.

$$Vk = \frac{p_k + p_{k+1}}{2} * d_k^{k+1}$$

p_k k- cross-section
p_{k+1} k+1- cross-section
d_k^{k+1} distance between k- and k+1- cross-sections
Vk volume of k- area between two cross-sections

For easier understanding, the whole landslide was divided into five typical sections. The first "upper part of the landslide and Slano blato (1)" is the area of landsliding, from where all the sliding masses originate. In the area of "upper channel (2)", these masses moving downhill become wet and turn into a mud mass, which continues its way as a mudflow. After long periods of heavy raining, the mudflow moves several hundred metres downwards, until it loses its energy within some days and stops for a few months. In the area of "Blatno jezero (3)" ("Mud Lake"), it spreads, thus producing a secondary accumulation of stagnating mud. When "Blatno jezero (3)" is full, the mud runs out along the "lower channel (4)" and starts to accumulate in the "area above the waterfall (5)".

The calculations showed that 680.000 m^3 of material was involved in sliding until April 2001. Each movement of the sliding masses includes new amounts of landslide material, partly also from the base, like the remnants of old landsliding.

The basic question is what are the total masses that may get involved in landsliding over the long run. This is shown in the chart below, which presents the changes in the volume along the landslide. The chart and

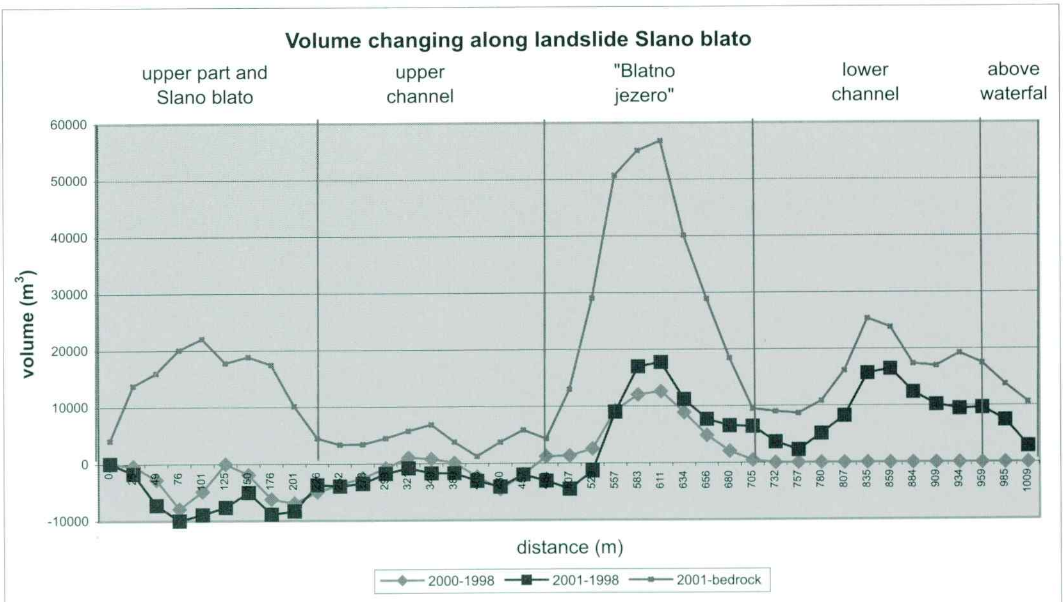


Fig.4. Volume changing along landslide Slano blato

the table above show that there are still potential large sliding masses in the base in the areas of the upper part of the landslide and of "Blatno jezero". The "upper part" and "Blatno jezero" still contain around 150.000 m^3 and 290.000 m^3, respectively, and along the whole landslide there is around 680.000 m^3 of landslide material.

Landslide restoration

The results of volume calculations of landslide masses indicate that successful landslide restoration is possible. Nevertheless, restoration will be time-consuming and financially demanding, taking several years.

The above volume analysis show that restoration measures should include:

- prevention of the sliding mass from becoming wet (draining),
- regrouping of the soil masses from the central landslide area to its sides with the aim of decreasing the sliding amount,
- carrying away of the sliding material in the amount of 300.000 m^3 to 400.000 m^3 to a deposit area.

The volume analysis also indicated that over time increasing amounts of mud masses get involved in landsliding. Consequently, any delay in restoration measures results in a more difficult and expensive restoration. The calculation of the movement until November 2000 thus showed that landsliding included ~50.000 m^3, while in April 2001 ~170.000 m^3 of material was already sliding. Approximately ~150.000 m^3 of unstable masses thus still remained in the upper part of the landslide. One-third to half of this material is already sliding. There are some additional sliding masses in unstable sides and the right part of the landslide.

Taking into account these and other parallel results, it turned out that in order to prevent the sliding masses from reaching the village of Lokavec as much as possible of the sliding masses should be retained in the upper and central parts of the landslide by draining and pushing the masses to the sides of the landslide, while the masses that cannot be retained on the slope – assessed to between 300.000 m^3 and 400.000 m^3 – should be carried away to a deposit area.

Conclusion

It was shown that the calculation of volumes by means of aerial photography was a very appropriate method for large landslides which, however, only produces results after a detailed geological interpretation of the events in the landslide.

If a long-term extensive landslide restoration is not carried out, in a few years, the whole of this mass will also activate and begin to move downhill. In this case, the mudflow would reach the village of Lokavec.

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