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Slope stability analysis with GEO 5 software for "Łaski" Landslide in Międzybrodzie Bialskie

Key words:
landslide,
numerical modeling
geo5 software,
factor of safety

Abstract

Abstract. Numerical modeling is an important tool to estimate slope stability. This publication shows application of a GEO 5 – slope stability software to evaluate stability of the "Łaski" Landslide in Międzybrodzie Bialskie. The slide surfaces, which were indentified in drill cores, were used to compute factors of safety (FS). The data from inclinometric measurements were used to verify the numerical model of the landslide. Calculations were carried out for three scenarios: first with normal water level, second scenario with lowered water level of 5 m and 10 m and the third scenario without water with the worst courses of sliding surfaces. As the result for each scenario the factors of safety were estimated. It was found that despite of water lowering and stabilization of existed surfaces, there is a considerable risk of a new sliding surfaces occurrence.

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Introduction

The number of landslides in the Polish Carpathians is being estimated on about 50000 (Chowaniec et al. 2013) what gives average 2.6 landslide on km2. Such landslides density causes a real danger for human activity. To protect infrastructure located on landslide, stabilization is essential. The important phase conducting to stabilization of landslide is making of numerical model and of calculations of the slope stability. This could help with determining necessary data enables for the stabilization. Recently a development of methods for the numerical modelling is significant. The problem of calculations slope stability based on the numerical modelling is a subject of numerous publications, among others: Zabuski et al. (1999); Cała et al. (2004, 2006); Cała & Olesiak (2007); Rączkowski & Zabuski (2008); Marcato et al. (2012); Cała (2013). In this work a GEO 5 program slope stability was used (ver. 5.6.6. 0) (Fine Ltd. 2012). It has a several good points: an availability, a straight service and a low price compared with other commercial software. It gives the possibility of calculating the stability in two dimensions (2D). Examples of its applications are presented by: Prasad et al. (2011), Petrýdesová et al. (2012), Sharma et al. (2012) and Trzpis (2013).

Characteristics of the landslide

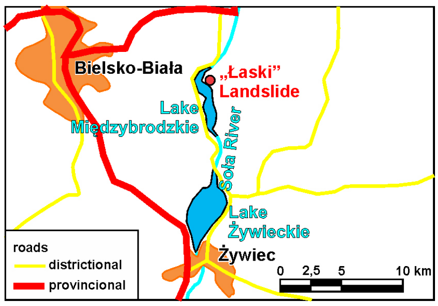

Fig 1. Location of the "Łaski" landslide

The investigated landslide is located in Łaski hamlet in Międzybrodzie Bialskie village (Czernichów district, Silesian province). It is situated on Międzybrodzkie Lake at the south-west hillside of Mt Żar (761 m) in the valley of the river Soła (fig. 1).

The landslide activity was registered in the mid-19th century (Ziętara 1968) but to May 2010 the landslide was regarded as inactive (Nescieruk & Wójcik 1996). At 19 May 2010 young landslide movements on his entire surface were occurred. At 521 m height at hillside there is a top boundary – main scarp which inclination is 35-40 deegres (Wójcik & Nescieruk 2010; Nescieruk et al. 2013a). In the centre there is a landslide ditch limited in the lower part by ridge. In the bottom part there are large numbers of landforms, the height of minor scarps is about 3 m (Nescieruk et al. 2013a). On entire area there are many landslide forms such as cracks, ridges and minor scarps (Nescieruk et al. 2013a) (fig. 2).

An upper part of the area is densely forested, whereas bottom part it is area in which the holiday building development is dominating. In centre and of the lower part all buildings were damaged (fig. 3.4), and in upper movements caused devastation of the trees stand and the development of "drunken forest".

The landslide occurred in the range of upper cretaceous, thickly bedded sandstones and shales belonged to lower Godula Beds from Silesian Unit. It is in the range of the north limb of the syncline, which axis is passing through the top of Mt Żar. Dips of stratums are estimated to about 19 degrees (Nescieruk 1996). The landslide should be classified as a complex (Varnes 1978; Bober et al. 1997). The direction of the dip of stratums with regard to main azimuth of the landslide movement is sloping. The field research shows that the tongue is descending below the water level of the Lake Międzybrodzkie, and in his range there are a few slide surfaces (fig. 5). This active landslide, causing a real danger for the infrastructure.

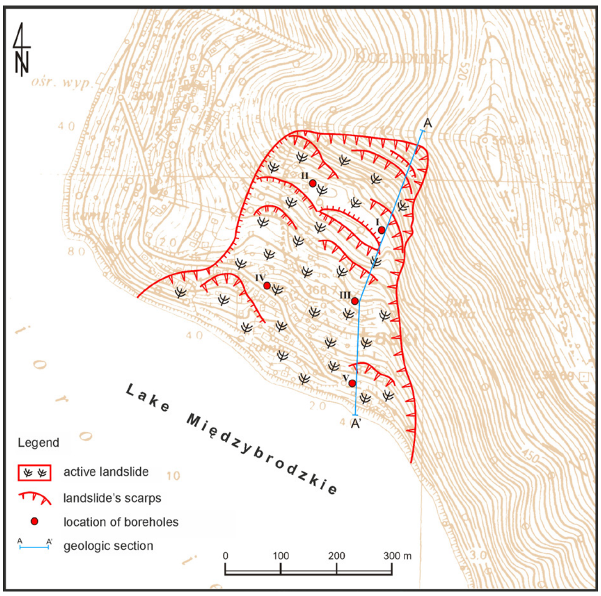

Fig 2. Map of the "Łaski" landslide (Nescieruk et al. 2012)

Input data to the numerical model

Fig 3. Damage in the houses caused by the movement of the landslide (phot. P. Nescieruk)

Layer	Bulk weight γ [kN/m³]	Angle of the internal friction Φ [º]	Cohesion of soil c [kPa]
1	22.50	25.6	9.7
2	21.73	24.7	6.3
3	21.94	25.35	7.85
flysch stratums	26.50	41	300

***Table 1.** Performed geotechnical parameters for layers*

In the framework of the Landslide Counteracting System (SOPO) performed by the Polish Geological Institute - National Research Institute (PGI-NRI) 5 full-drilled-core boreholes were carried out for depths from 25.8 to 45 m.

They were a key for obtaining information about the internal structure of the landslide. All boreholes were finished in flysch substratum. Colluviums are made from clays, silty clays and sandstone rubble with clay. Data obtained from drill cores help to recognize depth of slide surfaces. Finally 18 slide surfaces were recognized. They were described by Nescieruk et al. 2013b. In the presented work the author decided to use data from boreholes I, III and V (fig. 2). In the borehole I and III they recognised 3, and in V - 5 slide surfaces. Each surface was correlated between the boreholes and this was base to draw a geological section (fig. 5).

Using performed research in the boreholes (Wawok et al. 2011) area of cross section was divided in 3 layers. Every layer had different geotechnical parameters such as: bulk density ρ, angle of internal friction φef, cohesion of soil cef, porosity n and density of solid particles ρs. Three first parameters were obtained as a result of laboratory tests. The porosity was received concerning d20 data from grain-size distribution curve (Wawok et al. 2011). In the next step a coefficient of permeability k was estimated using the American formula (1):

(1) In the next step a coefficient of permeability k was estimated using the American formula:

$$k = 0{,}0036 \times d_{20}^{\;2,3}$$

Explanations:

k – coefficient of permeability [m/sec.];

d20 – effective diameter based from grain-size distribution curve.

(2) Next using the Bieciński's formula a total porosity n was calculated:

$$n = \mu = 0{,}117 \times k^{1}$$

Explanations:

n – total porosity;

μ - gravity drainage capacity;

k – coefficient of permeability [m/d].

(3)

$$\rho_d = \frac{100 \times \rho}{w + 100}$$

Explanations:

ρd – dry density of solid particles;

ρ – bulk density;

w – moisture content.

(4) After that using estimated total porosity n, density of solid particles was calculated:

$$\rho_s = \frac{\rho_d}{1 - n}$$

Explanations:

ρs – density of solid particles;

ρd – dry density of solid particles;

n – total porosity.

Fig 4. The movements of buildings on the landslide (phot. P. Nescieruk)

In the GEO 5 program (ver 5.6.6. 0) – slope stability (Fine Ltd., 2012) instead of the ρ bulk density ρ and density of solid particles ρs, bulk weight γ and weight of solid particles γs are being used for calculations. Therefore received values of the density were converted into weights (tab. 1).

In relation to the lack of recognition of flysch stratums below the main slide surface its parameters were assumed based on literature (Wiłun 2003; tab. 1).

A significant role had a data from inclinometric measurements of landslides carried out in boreholes as part of the monitoring led through PGI-NRI. It enabled to determine the activity of recognised slide surfaces. The measurement of displacement allows to assess the activity occurring along the surface recognised in drill cores. Data of the newest results performed research were based on oral information. Along most of slide surfaces movement are found so the landslide is still active.

Numerical modelling

Number of the slide surface (according to fig. 5, 6)	Calculated factors of safety (FS) for the groundwater level:			Calculated factors of safety (FS) for the total draining with the most disadvantageous course of slide surfaces
	orginal	lowered by 5 m	lowered by 10 m	
1	1.21	1.28	1.37	1.00
2	1.32	1.41	1.54	1.15
3	1.44	1.53	1.67	1.23
4	1.44	1.54	1.66	1.09
5	1.31	1.39	1.51	1.06
6	1.46	1.56	1.69	1.43
7	1.47	1.59	1.69	1.54
8	1.48	1.61	1.72	1.55
9	1.29	1.44	1.52	1.29
10	1.49	1.59	1.70	1.40
11	1.59	1.71	1.82	1.84

Table 2. Values factors of safety (FS) [ ] for recognised slide surfaces received from calculations made in the application of GEO 5 – slope stability (ver. 5.6.6. 0; Fine Ltd., 2012)

The numerical modelling was performed with the application of GEO 5 (ver. 5.6.6. 0) – slope stability (Fine Ltd., 2012). For the modelling of slide surfaces a Sarma's method was used (Sarma 1973) which belongs to the group of sliced methods of the limit states (LEM). The slope stability depends on the meeting the requirements of the balance of power and moments in individual blocks. Computational blocs are formed dividing ground above the potential surface of slide surface which can have a different inclination. For creating the numerical model a geological section A-A' (fig. 2) going through boreholes I, III and V was used. Scheme of the numerical model of the landslide "Łaski" with slide surfaces, for which calculations were made in the GEO 5 (ver. 5.6.6. 0) – slope stability (Fine Ltd., 2012), are presented on fig. 5, 6.

Calculations of the stability were performed based on recognised slide surfaces in drill cores. The original level of groundwater was based on data from boreholes. As the level of water in the Lake Międzybrodzkie a multi-annual mean was estimated. Additionally, a load from buildings located along geologic section was taken into consideration (fig 5).

Then calculations of slope stability for slide surfaces with original water level were performed. After the first computations the calibration of the model based on inclinometric measurements was done.

To asses slope stability a factor of safety (FS) was used. It is defined as the ratio of forces keeping their balance to forces aiming at the destruction (Cała & Flisiak 2004). As a limit of slope stability FS = 1.5 was assumed. If along of the slide surface movement were found, parameters were modified in order to FS < 1,5. If along surface there were not movement, parameters were modified to FS > 1.5. Modified parameter were slide surfaces in places in which they were not recognised. It results from the fact that their course outside boreholes is an issue of interpretation. The parameters of colluviums were not modified because these data are closely made based on laboratory tests (Wawok et al. 2011).

After verifying the model calculations were made for two hypothetical levels of the groundwater. After lowering of about 5 and 10 metres and situations without appearing groundwater at the most disadvantageous course of slide surfaces (tab. 2).

Based on calculations presented as the result of the verification of the model (according to inclinometric measurements) movements occurred along ten slide surfaces, apart from one (tab. 2). Reducing the level of the groundwater by 5 metres will cause, that factors of safety were below 1.5 along the surface number 1, 2, 5 and 9. However, reducing by groundwater level for 10 metres caused that condition of stability met the requirements for all existing slide surfaces with exception 1. Secondary landslide movement often don't appear along the same slide surfaces, but along newly-formed in the range of colluviums (Stopkowicz & Cała, 2004). Considering this relation additional calculations were performed for existing slide surfaces with the most disadvantageous course (with the smallest rate of the FS) at total draining the slope. At such conditions surfaces number 1, 2, 3, 4, 5, 6, 9 and 10 didn't meet requirements of stability (FS < 1.5) (fig.6).

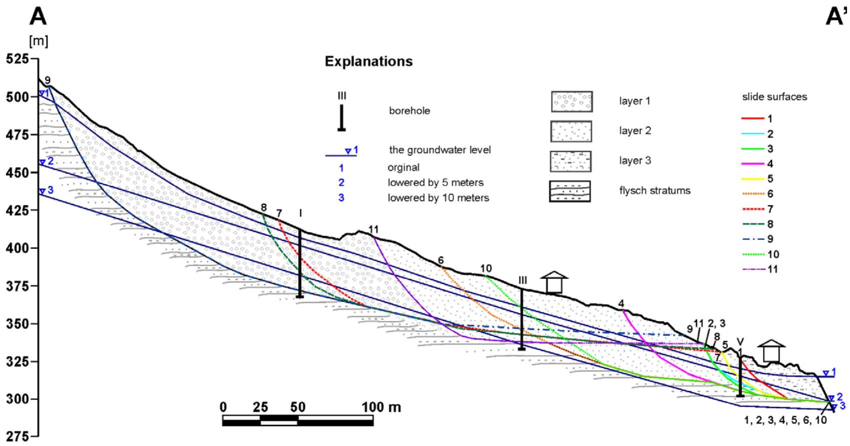

Fig 5. Scheme of the numerical model carried out in application of GEO 5 – slope stability (ver. 5.6.6. 0; Fine Ltd., 2012) "Łaski" landslide in Międzybrodzie Bialskie for recognised slide surfaces (numbering according to tab. 2)

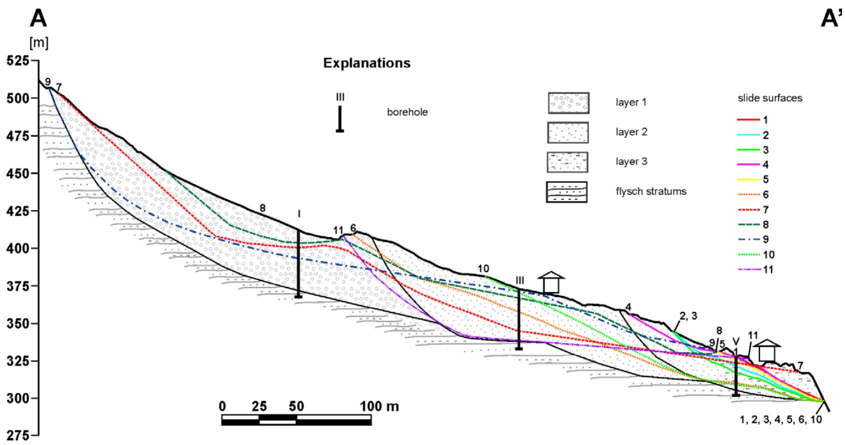

Fig 6. Scheme of the numerical model carried out in application of GEO 5 – slope stability (ver. 5.6.6. 0) (Fine Ltd., 2012) "Łaski" landslide in Międzybrodzie Bialskie for the total drainage and the most disadvantageous course of the slide surfaces (numbering according to tab. 2)

Conclusions

"Łaski" landslide in Międzybrodzie Bialskie is a danger for of "critical infrastructure". At present the landslide is active on entire surface. Reducing the groundwater level by 5 metres could help stabilizing the middle part of landslide along existing slide surfaces. However lowering by 10 metres will allow for the stabilization the upper and centre part of the landslide. In such scenario the secondary landslide movement along new slide surfaces was occur. Based on performed calculations for slide surfaces with the most disadvantageous course, even the total drainage of landslide won't prevent the landslide movement. Also a scenario of creating new slide surfaces in near ground surface seems to be very possible (fig. 6).

GEO 5 – slope stability (ver. 5.6.6. 0; Fine Ltd., 2012) is a tool which analyse conditions of slope stability. Performed analysis 2D was performed along one geologic section. In order to check the credibility of received results the 3D modelling additionally should be used. Also on the "Łaski" landslide there is a unique situation: water of the Lake Międzybrodzkie "are propping" toe of the landslide. Based on this observation it is possible to conclude that obtained results of FS are slightly underestimated. It is also possible to assume, that application of GEO 5 – slope stability is a tool for the basic evaluation of the slope stability. In order to receive the higher accuracy 3D numerical modelling should be used. This will help to get more precise results – with higher number of conditions in landslide considered.

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