GEOPHYSICAL AND GEOTECHNICAL APPROACH TO A LANDSLIDE STABILITY ASSESSMENT – A CASE STUDY

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Introduction

Landslides are complex phenomena, and the main factors that have a significant impact on their behaviour are changes in slope inclination geometry and changes in water conditions. Research works undertaken now, among others on the methods of monitoring mass movements and recognizing their causes is one of the most important issues awaiting a quick solution. Understanding the factors causing the formation of landslides, proper numerical modelling of geological structures helps to create the protective systems. The main purpose of this work was to evaluate current conditions of the landslide in Brzozówka, near Cracow, (Poland) and analysing how different levels of saturation influence the stability of the landslide. The combination of geological, geophysical and geotechnical research such as Electrical Resistivity Tomography ERT, Cone Penetration Testing CPTU, drilling and laboratory tests as well as a comprehensive analysis of their results, provided reliable information on the geological structure and geotechnical parameters of landslides that have been used in numerical simulations of the landslide stability.

Samples and methods

In this work ERT geophysical measurements were carried out using the Wenner-Schlumberger array with a spacing of electrodes equal to 5.5m. ERT measurements were made along the slope on two profiles with 258.5 and 346.5 meters length, which allowed to recognition of the subsoil to a depth of about 52 m. Three inversion methods (combined, smoothness constrained and robust inversion) have been applied. All inverse modelling was carried out by the 7-times iteration adjustment using Gauss-Newton method, wherein the Jacobian matrix was recalculated at each iteration.

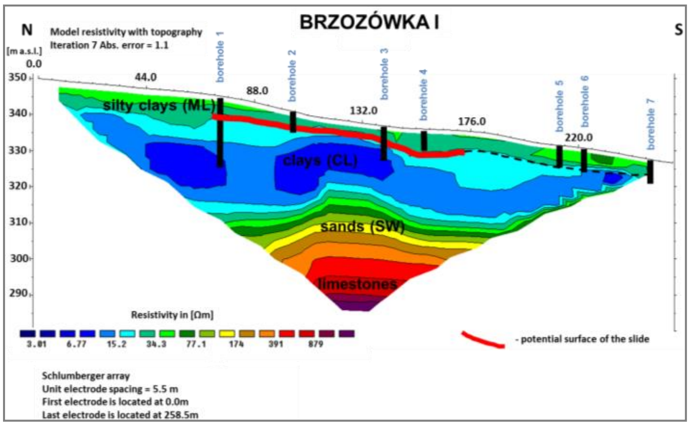
The drilling test was carried out using hand methods. The boreholes with a diameter of 0.1 m and a depth of 5 to 9 m below ground level were made at seven sites within 71m, 100m, 137m, 153m, 200m, 220m and 250m from the beginning of the profile. The basic parameters such as: cone resistance q_c, sleeve friction f_s, and pore pressure u were measured during the cone penetration test (CPTU). Macroscopic analysis of soils was performed, the groundwater level was determined and the samples were taken for laboratory tests. Laboratory tests were carried out on soil samples of silt layer above the plane of slip and clay layers below. The research of mechanical parameters was carried out using the triaxial compression test (CID method).

Information about geological structure obtained from ERT, CPTU, drilling and laboratory tests were used in numerical simulations (Finite Element Method with use of ZSoil software) of the landslide stability. The landslide stability was analyzed using the proportional reduction of soil strength parameters algorithm. The 2-phased model (soil and water) was used with effective soil strength parameters. Transient flow conditions are assumed, model with partial saturation zone is used. Stability Factor *SF* of the slope was calculated for different saturations levels of the soil, obtained from rainfall simulations.

Results

As found by the ERT calculations, the robust inversion method gives optimal results for the analyzed subsoil compared to the two other methods of inversion. ERT results correlated and confirmed by geotechnical investigations showed that the subsurface layer is made of loess and silty clays with thickness varying from 6 m in the north to about 2m. The lower layer is clays with about 15 m in thickness. The boundary between the silt and clay layers can be defined as the slip surface of the landslide. Clay is underlain with a layer of sand with a thickness of about 5 - 7 m. The position of this layer indicates the top of the substrate. The substrate is built of carbonate rocks with irregular roof sculpture, which is visible in cross-section (Fig. 1).

The observation of groundwater showed that the most intensive filtration occurs in the spring and is the result of meltwater. In the summer and autumn, groundwater filtration tends to be lower.
For initial saturation of the soil, *SF*= 3.70 was obtained from numerical simulations – which means that stability loss is practically impossible. Obtained from numerical simulations relationship between saturation in the vicinity of upper part of the sliding surface and *SF* is illustrated by the graph below (Fig. 2). The obtained sliding surface is almost flat, which was confirmed by the ERT method. The hypothesis that the landslide occurred during substantial saturation of the upper part of the slope (saturation about 0.80) was proved, obtained results are useful for engineering practice.



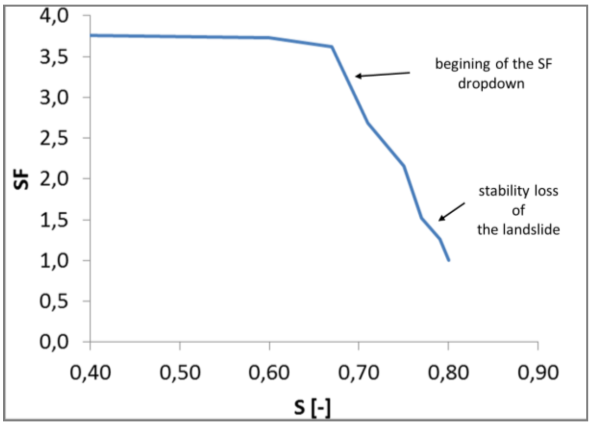


Figure 1. *ERT cross-sections with boreholes for Brzozówka 1.*

Figure 2. *Relationship between Stability Factor SF of the landslide and saturation S in the upper part of the sliding surface.*

Conclusions

This article presents the results of geophysical and geotechnical investigations and computer simulations of the landslide in Brzozówka near Cracow (Poland). Mass movements, whose effects in the form of landslide forms can be observed on the relevant slope, formed within the layers of silt (loess) soil as a result of periodic worsening of the mechanical parameters of soil material. Using geophysical (ERT method) and geotechnical (CPTU method) it was found that the slip plane is located between the silt and clay at a depth of 2 to 6m below the surface. Slip plane is almost flat. With the change of saturation the effective stresses field changes, which leads to loss of slope stability during heavy rainfall or snowmelt. The obtained results of the field observations, laboratory tests and numerical simulations show that stability loss of the landslide in Brzozówka, due to rainfall is very probably. The stability factor drops for saturation above 0.7 and stability loss occur for saturation about 0.8. Significant influence of the rainfall on the stability of the landslide is shown. Influence of the contact layer between silt and clay layers on the obtained stability loss mode (sliding surface) is obvious – majority of the sliding surface is located in the contact layer. Presented effective methodology (FEM analysis with use of 2-phase model with effective soil strength parameters, c-fi reduction method for *SF* estimation and transient flow model with partial saturation zone description) of the landslides stability analysis could be used for landslides in similar geotechnical conditions.

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