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The Effectiveness of Recognizing of Failure Surface of the Carpathian Flysch Landslide Using Wave Methods

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SUMMARY

The paper presents results of recognizing the failure surface of a landslide from the Carpathian flysch by means of the GPR and seismic surveys. GPR antennas with different frequencies: 400, 200 and 50 MHz were tested. The seismic survey (refraction profiling combined with 1D MASW technique) was employed to evaluate the resolution of P-wave and S-wave in that conditions. The measurements were designed basing on earlier geological engineering recognition and numerical stability analysis of the landslide. As a result, optimal parameters for GPR and seismic surveys in the Carpathian flysch conditions were chosen.

Introduction

Landslide terrains in the Polish flysch Carpathians are unfavorable as far as construction investments are concerned and quantity of existing hazardous landslides can be about a few thousands. The evaluation of landslide hazard under different flysch conditions by means of wave methods was discussed in a number of papers (Bestynski and Trojan 1975, Slusarczyk 2001, Dziewanski and Pilecki 2002, Karczewski and Zietek 2002, Marcak and Pilecki 2003, Dec et al. 2004).

Concerning this study, the main objective was an evaluation of the recognition effectiveness of the failure surface of a typical landslide from the Carpathian flysch by means of wave methods: GPR and seismics. The effect of recognition of landslide process was analyzed for different resolutions of electromagnetic and seismic waves.

Location of study area and geological conditions

The surveys were carried out at landslide no 17 developed along road no 28 in the village of Mucharz near Wadowice at the area of the flysch Carpathians. In general, the Carpathian flysch is characterized with strong inhomogeneity and anisotropy resulting from alternating layers of weak shales and strong sandstones of different thickness. Usually, the layers have steep dips and are strongly deformed by tectonic processes and changed by weathering.

The study area was chosen due to satisfactory geological and engineering information about the landslide (unpubl. results). The landslide has been classified as consequently structural type and has a complicated character because of the developed failure surfaces. Colluvia are built of the Quaternary cover formed of residual clays and weathered and fragmented rocks and tectonic breccia (Fig.1). The basement is built of Inoceramian layers in which shales prevail over sandstones beds.

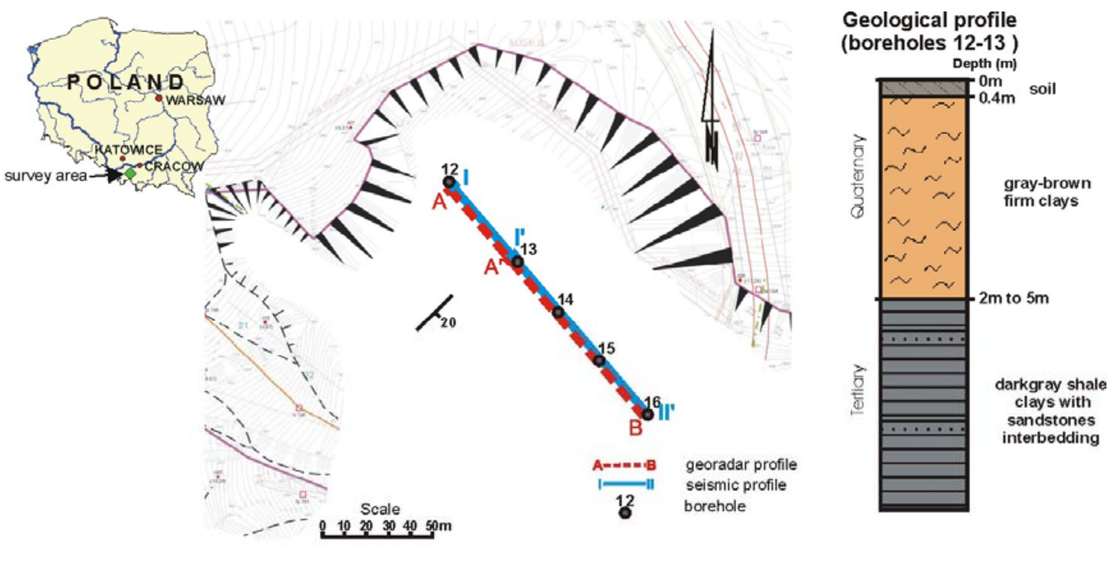

Fig.1. A scheme of the study area with a typical geological profile

Selected problems of investigation methodology

The geophysical measurements were designed based on information on geological engineering cross-sections from five testing boreholes reaching a depth range of 15,0 to 30,0

m. At the initial stage of the study, the failure surface was determined based on the numerical stability analysis (Fig.2). The calculations showed that the complex landslide process could develop in the upper part of the landslide. Probably, there are two failure surfaces: one at the contact of the Quaternary cover with strongly weathered rock mass of the Tertiary basement, the other in the basement at the contact of weathered and brecciated layer with the undisturbed by landslide process rock mass.

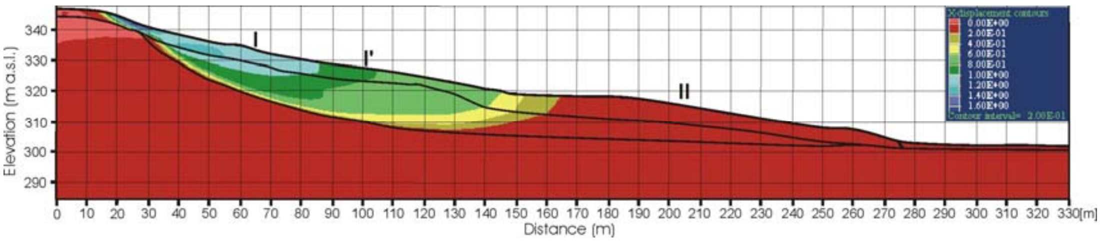

Fig.2. Results of the numerical stability analysis of landslide along profile I-II (contours of horizontal displacement)

The seismic and GPR measurement profiles were designed in such a way that the potentially deepest failure surface could be identified. The measurements were made in the wet medium. Under such conditions one should take into account the increase of electromagnetic wave attenuation and disturbances of the seismic wave pattern, especially for S-wave records. From other point of view, the development of the landslide process was more pronounced under wet conditions.

The GPR measurements were made with the use of the RAMAC system employing the unshielded 50, 200, and 400 MHz antennas. The value of the electromagnetic wave velocity (v = 8.6 m/ns), which was necessary to time-depth conversion, was determined based on WARR profiling. Measurement parameters were chosen in such a way that a possible biggest depth penetration could be obtained for each antenna (this is valid especially for antennas of 200 and 400 MHz frequency). The measurement data were processed in a standard way.

The seismic refraction profiling was made with the use of the Geode-24 apparatus and three-component 4,5 Hz geophones. The seismic wave was induced by a 4 kg hammer impact. The eight-fold signal stacking was applied. The recording time was 2 s, while the signal was sampled with a timestep of 0.125 ms. The seismic survey was designed in such a way that the records of P-waves from the contact of the cover and the basement could be readable. To do this, various tests of recording quality depending on wave source distance and record gain and signal stacking were made. At the processing and interpretation stage, the records were filtered up to 150 Hz. Calculation of a velocity model and depth model of the medium were made using the reciprocal traveltime method. The correction of the model was made by means of the inverse analysis. Seismic records were also used to Multichannel Analysis of Surface Waves (MASW).

Analysis of results

The presentation of measurement results is limited to 35 m long part I-I' (A-A') of the profile in the upper part of the landslide. The stability analysis showed the landslide process was clearly developed in that part.

GPR measurement results

The most promising results were obtained using the 200 MHz antennas. A boundary at a depth of 3.5 – 4 m can be visible in the echogram in Fig. 3a,b,c. That boundary is almost parallel to the terrain surface. A strong double reflection at a distance of 85 cm can be also visible in the echogram. That boundary can be observed at a depth of 4 m in the echogram for the 50 MHz antenna. That boundary corresponds possibly to a contact between the Quaternary cover and the weathered Tertiary basement. That boundary is almost invisible in the echogram recorded for a 400 MHz antenna. The failure surfaces can be observed in images recorded with 50 MHz and 200 MHz antennas. The failure surfaces are imaged as breaks in reflection horizon continuity that run disconformably to the horizons.

Seismic survey results

A three-dimensional model of a medium was assumed for the interpretation of P-wave refraction profiling based on earlier experience (Fig. 3d). P-wave velocity in the near-surface layer ranges from 230 to 280 m/s. That velocity is characteristic for loose sediments of a colluvium type, which contain soils with rock fragments and prevailing clays and shales. The second layer with P-wave velocity of 1700 m/s is characteristic for strongly weathered rock mass with clay filled. In the deepest layer, the refraction velocity of 2400 m/s is characteristic for a less fractured rock mass that was probably not disturbed by landslide processes. Probably, the upper refraction boundary at a depth of 4 m was a major failure surface.

Based on 1D MASW it was shown that the greater resolution of S-wave enabled the weakness zones at a depth of 3-4 m to be clearly determined (Fig. 3e,f). Normalized records of amplitude spectra show that there was fairly good wave propagation in a range of 30 to 50 Hz for refraction technique offsets. When the shot points are at greater distance from the profile of above 50 m the recognition quality is poor due to rather high attenuation.

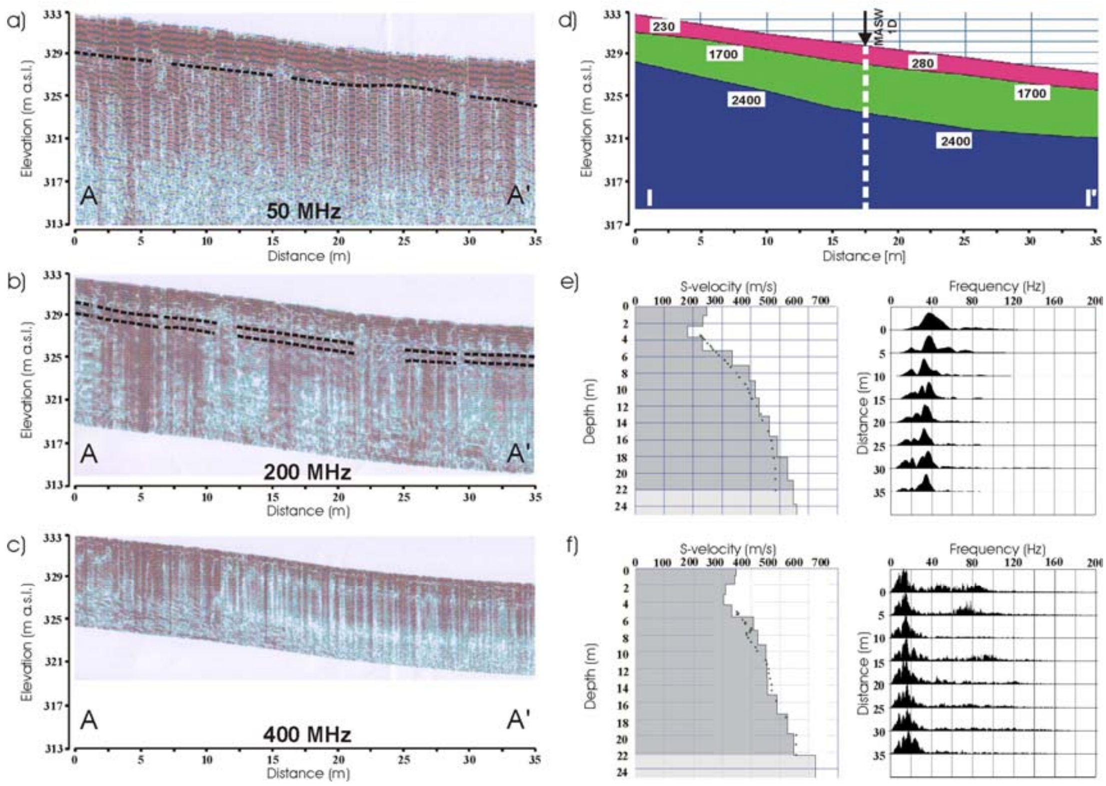

Fig. 3. Results of GPR measurements made with three antennas of frequency (a) 50 MHz, (b) 200 MHz, and (c) 400 MHz; results of refraction profiling at profile I-I' (d) results of MASW analysis for 5m offset, (e) and 70 m offset (f) at profile I-I' at the landslide in the Carpathian flysch conditions

Conclusions

The electromagnetic waves, despite their high resolution, have limited penetration in the Carpathian flysch conditions. Generally, the best results of failure surface recognition were obtained for the 200 (100) MHz antenna. However, some results obtained for the 50 MHz antenna are also interesting.

Seismic wave resolution is lower but the quality of results can be satisfactory if measurement parameters and source energy are properly chosen. Refraction profiling combined with 1D MASW seems to be an effective solution in the Carpathian flysch conditions. To obtain optimal results, the distance between geophones should be 2 to 3 m and shot points should be located in accordance with refraction scheme. Increasing of the offset in the “hammer” technique strongly decreases the quality of results.

Knowledge of the geological engineering conditions as well as factors that potentially disturb the equilibrium of the geological medium is of crucial importance to designing the survey and choosing measurement techniques. Numerical analyses of the stability of the geological medium can be helpful there.

The presented results need further analysis, and tests should also be carried out in different geological engineering conditions.

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