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LANDSLIDES SURVEY IN THE NORTHEASTERN POLAND

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Abstract. Investigation of landslide processes in the northeastern Poland represents a part of geological work: *Identifying and cataloguing natural geological hazards (especially landslides and other geodynamic phenomena) over Poland’s territory* commissioned by the Ministry of the Environment and financed by the National Fund for Environmental Protection and Water Management. As it was assumed, all aspects of geological hazards should be a subject of inventory. As the range of the observed phenomena was much bigger then expected, the investigations were concentrated on selected zones, strongly influenced by geological hazards. Except for landslides and other mass movements recorded in inventory cards, numerous objects of smaller hazards dimensions or scale were observed and listed for further documentation.

Detailed geodetic survey and resistivity geotomography, and shallow geological drillings were made in some landslides creating a significant hazard to prepare the entrance data for digital models of landslides construction and its preparatory recognition, preceding possible systematic monitoring of landslide processes. Zones of relatively intense landslide processes were distinguished taking into account similar genesis and similar geomorphological and geological conditions of landslides groups, i.e. Baltic coast with active landslides connected with marine abrasion, and the Lake District of the northern Poland with numerous moraine hills.

Key words: landslides**,** mass movements, inventory, geodetic survey, resistivity geotomography, northeastern Poland.

Abstrakt. Badania procesów osuwiskowych na obszarze północno-wschodniej Polski wykonano w ramach tematu: *Rejestracja i inwentaryzacja naturalnych zagrożeń geologicznych (ze szczególnym uwzględnieniem osuwisk oraz innych zjawisk geodynamicznych) na terenie całego kraju*, zamówionego przez Ministerstwo Środowiska i finansowanego przez Narodowy Fundusz Ochrony Środowiska i Gospodarki Wodnej. Skala obserwowanych zjawisk, znacznie większa od przewidywanej, spowodowała konieczność koncentracji badań na wybranych obszarach i w strefach szczególnie zagrożonych. Obok osuwisk i innych skutków powierzchniowych ruchów masowych, zinwentaryzowanych w postaci kart dokumentacyjnych, zaobserwowano i odnotowano do udokumentowania liczne obiekty o mniejszych rozmiarach lub o mniejszej skali zagrożenia.

Dla wybranych osuwisk, stwarzających istotne zagrożenie dla otoczenia, wykonano dokładne pomiary geodezyjne, badania geoelektryczne metodą tomografii opornościowej i płytkie wiercenia geologiczne. Celem tych prac było przygotowanie wstępnych danych do opracowania cyfrowych modeli osuwisk i ich wstępne rozpoznanie, poprzedzające ewentualne rutynowe monitorowanie procesów osuwiskowych.

Biorąc pod uwagę zespoły osuwisk o podobnej genezie i podobnych uwarunkowaniach geomorfologicznych i geologicznych wyodrębniono następujące strefy objęte względnie intensywnymi procesami osuwiskowymi, tj. wybrzeże Bałtyku z aktywnymi procesami osuwiskowymi wywołanymi abrazją morską i obszar pojezierzy północnej Polski z licznymi wzgórzami morenowymi.

Słowa kluczowe: osuwiska, ruchy masowe, inwentaryzacja, pomiary geodezyjne, tomografia opornościowa, północno-wschodnia Polska.

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INTRODUCTION

Investigations of landslide processes in the northeastern Poland area were conducted as a part of the geological work entitled *Identifying and cataloguing natural geological hazards (especially landslides and other geodynamic phenomena) over Poland's territory*, commissioned by the Ministry of the Environment and financed by the National Fund for Environmental Protection and Water Management (Lemberger ed., 2005). As it was assumed, all aspects of geological hazard should be a subject of inventory. Due to higher then expected range of observed phenomena, the investigations had to be concentrated on selected zones, significantly influenced by geological hazards (Ilcewicz-Stefaniuk *et al*., 2004 a, b). Except for the landslides and other mass movements effects recorded in *Inventory cards*, numerous objects of smaller dimensions or hazard scale were observed and listed for further documentation.

An estimation of recent activity and development rate of particular landslides is more or less subjective. Valuation criterions of activity of soil masses movements, variable in time and scarcely predictable, are of course not much precise. "Freshness" of landslide presence or lack of vegetation, its age and type and deformations were taken into account as evidences of landslide movements.

The following types of research were applied in some landslides creating a significant hazard: detailed geodetic survey, resistivity geotomography, and shallow geological drillings. The aim of investigations was to prepare the input data for digital models of the landslide construction and its preparatory recognition preceding a possible systematic monitoring of landslide processes (Koryczan, Mżyk, 2004). The zones of relatively intense landslide processes were distinguished based on groups of objects of similar genesis and similar geomorphologic and geological conditions. The most important factors that decided on surface mass movements development, as for instance presence of uplands escarpments and ice-marginal valleys, influence of marine abrasion and river erosion, etc., were taken into account. The selected zones were:

— Baltic Sea shore with active landslide processes along the cliff sections, connected with marine abrasion (Subotowicz, 1982, 1988; Horska, 2002; Uścinowicz *et al*., 2004).

— Lake District of the northern Poland with numerous moraine hills and small landslides (Kondracki, 1972; Musiał, 1992).

AN OUTLINE OF GEOLOGY

Forms and sediments of the northern Poland glaciation origin, play a crucial role in the development of mass movements. The landscape of the area is mainly a result of the final phases of the Baltic glaciation, of the erosional and accumulating marine activity in the seashore zones as well as of the rivers activity in the Holocene. The presence of young postglacial landscapes, i.e. basal and terminal moraines with numerous isolated depressions and lakes, generated by the inland ice decay, is an attribute of the Lake District. Glacifluvial forms represented by sanders, kame hills and esker banks play an important role in the landscape forming, as well (Musiał, 1992).

The Quaternary sediments crop out at the surface. A relatively thick (up to 250 m) complex of moraine tills and glacifluvial gravels, sands, silts and clays completely covers the area (Kondracki, Pietkiewicz, 1967). The sub-Quaternary surface built of Miocene and Upper Cretaceous sediments has been significantly changed due to the glacial erosion, exaration and glacitectonic activity (Nowak, 1977; Lisicki, 1996). The glacitectonic processes were important in creating the complex geological structure of the area. They contributed to some surface forms inside moraine upland, as well. Possibly, they are the push moraines, appearing inside sediments of the older Quaternary periods as well as in sediments of the Pomeranian phase of Baltic glaciation (Dobrowolski *et al*., 2004).

INVENTORY AND CHARACTERISTICS OF LANDSLIDE PROCESSES

BALTIC SEA SHORE

Postglacial forms and sediments dominate in the geological structure of the seashore. High cliffs occur in zones of mechanically resistant complexes of tills and outcrops of the Neogene sediments (Olszak *et al*., 2002; Rudowski, 1965). The majority of the enlisted landslides are located in the cliff zone of the open marine shore and the Gdańsk Bay. Some of them are in the area of the city of Gdańsk, at the erosional edge of the upland. Cliff shores concentrate both along the western coast of the Gdańsk Bay and between Cetniewo and Jastrzębia Góra in the zone of the open marine coast (Subotowicz, 1982). The development of different types of mass movements is dependent on the geological structure of the cliff escarpment. Slides and rock falls dominate in the tills, while debris falls, debris flows and creeps are predominant in

Fig. 1. Landslide Chłapowo (cliff sea-shore of Baltic)

the glacifluvial sediments. In some regions, the presence of the ice-marginal lakes clays resulted in sandy-clayey debris flows during periods of the intensive precipitation. The mass movement processes frequently have a complex character.

Zones and objects especially endangered were distinguished by the inventory works. They correspond to a coast section close to Jastrzębia Góra and complex landslides — close to Chłapowo village (Fig. 1), and the cliff zone of the western coast of the Gdańsk and the Puck Bays. In the first mentioned area, complex landslide processes directly endanger buildings located nearby so the diversified protection works have been undertaken there aiming at the cliff stabilisation. High level of the coastal line hazards is characteristic for the studied areas. In the area of the city of Gdańsk, even the minimum displacement of the earlier stabilised landslides causes a significant danger and wastes. The zone of the upland edge loaded by new buildings and undercut by earthworks in the lower part of the slope, is a problem in the Treble City area. All objects are practically active, most often showing a bi-annual course activity or, less frequently, the multi-annual one. The landslide activity is frequently connected with small soil displacements during an intensive precipitation.

THE AREA OF THE NORTHERN POLAND MORAINE HILLS

Numerous small landslides appear in that area because of the surface morphology and of the differentiation of the basement lithology. Most of them are located on the slopes of river and stream valleys, mainly in the runway escarpments. The landslides are mainly the earth slides in the Quaternary sediments developed as horizontal complexes of sands tills and gravels. Mainly, the Geophysical Exploration Company conducted studies in the Lake District area (Koryczan, Mżyk, 2003).

The areas of the enlisted landslides equal up to 6.5 hectares, their width does not exceed 1300 m, and length remains below 200 m while their height can reach 35 m. They are mainly slides and combined forms, accompanied by the occurrence of ground or surface waters. Forests or bushes cover over 70% of the slopes containing the landslides.

The naturally invented landslides were generated as a result of lateral rivers and streams erosion (Figs. 2, 3). The landslides process was amplified by an infiltration of rainwater and outflows or exudations of the water in the slopes.

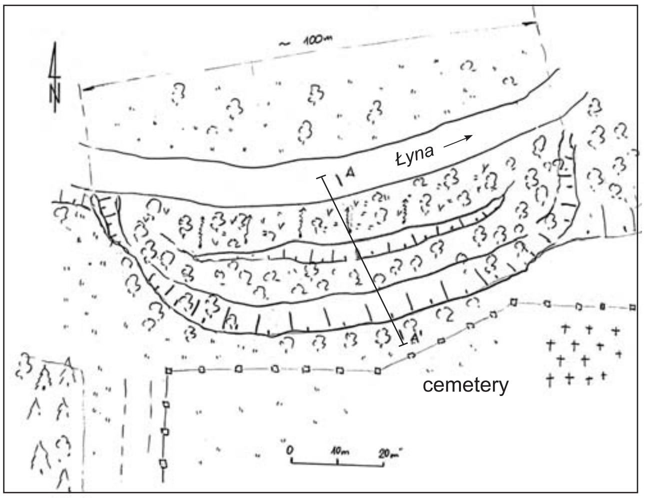

Fig. 2. Plan of the Bartoszyce landslide

Fig. 3. Landslide Bartoszyce (moraine escarpment of the Łyna river valley)

GEODETIC MEASUREMENTS AND RESISTIVITY IMAGING IN LANDSLIDE RECOGNITION

A geodetic survey was carried out on four selected landslides. The objective of the measurements was to construct topographic maps at the scale of 1:500, and to obtain data to develop the spatial numerical model of the landslides. Horizontal co-ordinates were given in "1942" coordinate system while the altitude was calculated in the "Kronsztadt 60" system. One landslide occurred at the seashore while the other three were developed in the river valleys. A vast active landslide in the Chłapowo village area was a part of the cliff, the length of which exceeded 400 m (Fig. 4). That landslide was inaccessible as it was cut with canyons and covered with forests and bushes with abundant piles of soil and wind fallen trees.

The landslide in the Bartoszyce region is situated at the northern bank of the Łyna River, northeast of the town (Fig. 5). It is also covered with the forest and bushes, swampy and inaccessible to measurements. The next landslide occurs at the eastern bank of the Nogat River, in the northern end of the town of Malbork, on a steep slope. Due to the abundant bushes and waste dump location, the access to the area wss difficult. The fourth landslide is small, exposed and easily accessible, and it occurs at the northern bank of the Vistula River, in the town of Chełmno (Fig. 6).

The measurements covered landslides and 10 m of their surrounding, and were referred to the state horizontal and verti-

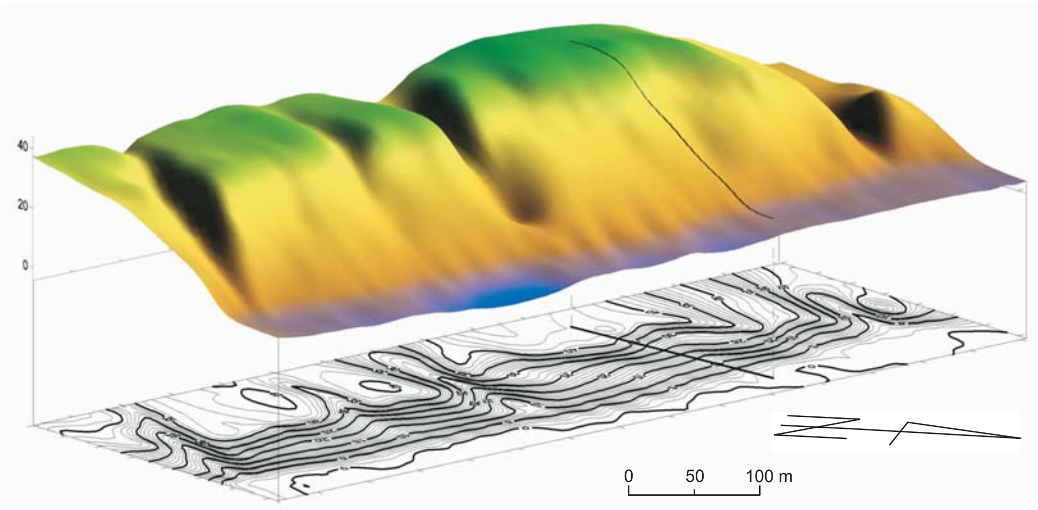

Fig. 4. Digital model and contour map of landslide surface according to detailed geodetic measurements (Chłapowo area)

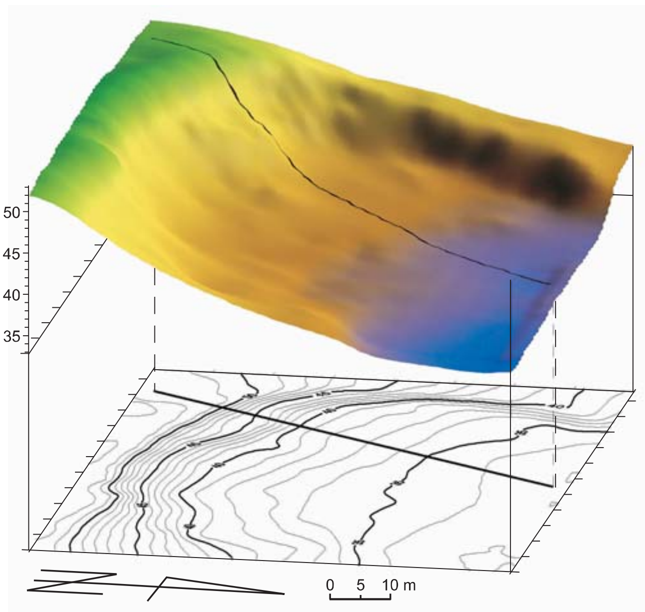

Fig. 5. Digital model and contour map of landslide surface according to detailed geodetic measurements (Bartoszyce area)

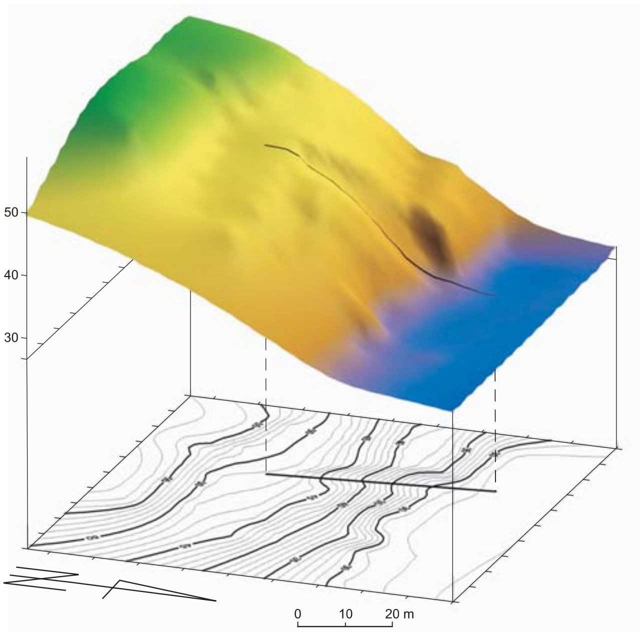

Fig. 6. Digital model and contour map of landslide surface according to detailed geodetic measurements (Chełmno area)

cal geodetic nets. The GPS Rapid Static method was used to determine sites of the measurement net, whereas the "Stop and Go" technique was applied to detailed measurements of the topographic sites in the open areas. Two two-frequency GPS receivers of the Leica 300 system, with sensor SR 9500 and Leica SKI software were used for GPS data processing. In areas covered with bushes and trees, the measurements were made with the use of automatic electronic tachymeter Leica TCA 1100 that was compatible with the GPS Leica 300/SR9500 system. The applied measurement technique enabled co-ordinates of the measurement sites, x, y, z, to be determined with 5 cm accuracy in relation to the nearest sites of horizontal and vertical geodetic nets. Measurement results were processed to obtain x, y, z co-ordinates in "1942" system, and altitudes in Kr-60 system. Topographic maps of the landslides were prepared in 1:500 and 1:1,000 scales.

Geophysical investigations by means of Electrical Resistivity Tomography (or Resistivity Imaging) method were carried out on the three landslides: in Chłapowo, Bartoszyce and Malbork areas (Fig. 7–9). The objective was to recognise the character and deep structure of the landslides. A geophysical profile at each landslide ran along the geological boreholes line drilled in landslide axes. The measurements were taken with the use of ARS-200 measuring system (produced by GF Instruments) with multi-electrode automatic recording system, and two-meter-long electrode spacing. A symmetric Schlumberger array with current electrode spacing, AB, ranging from 6 to 62 m was applied. The recording technique enabled a continuous observation of the apparent resistivity distribution along the measured profiles to the depth range of 1 to 15 m.

Measurement data were processed with the use of the RES2DINV Geotomo Software. The geoelectric cross-sections were prepared for each measurement profile down to the depth of 15 m. As a result, the apparent resistivity cross--sections (resistivity measured measurement system) were obtained for soil, and the resistivity cross-sections were interpreted from 2D modelling using the inversion method.

The resistivity distribution along the -mentioned above profiles is variable and typical of a multi-layer medium. The apparent resistivity ranges from several to several dozen Ωm (sporadically exceeding 200 Ωm). The similar resistivity distribution has been obtained from the interpretation of the values of resistivity range of 30 to 4500 Ωm.

The results of geophysical investigations were compared with the drilling data. A great similarity in resistivity distribution can be observed for geological formations. The geological identification of the landslide structure was carried out based both on the boundaries of geoelectric complexes with contrasting resistivity, and obtained by the drilling data. The boundaries of the geoelectric complexes were identified due to the computer modelling of SGE curves for selected sites, where the layers lie flat. This enabled the recognition of a probable boundary between the intact and slid-down soil, and the determination of a surface separating the old and young colluvia.

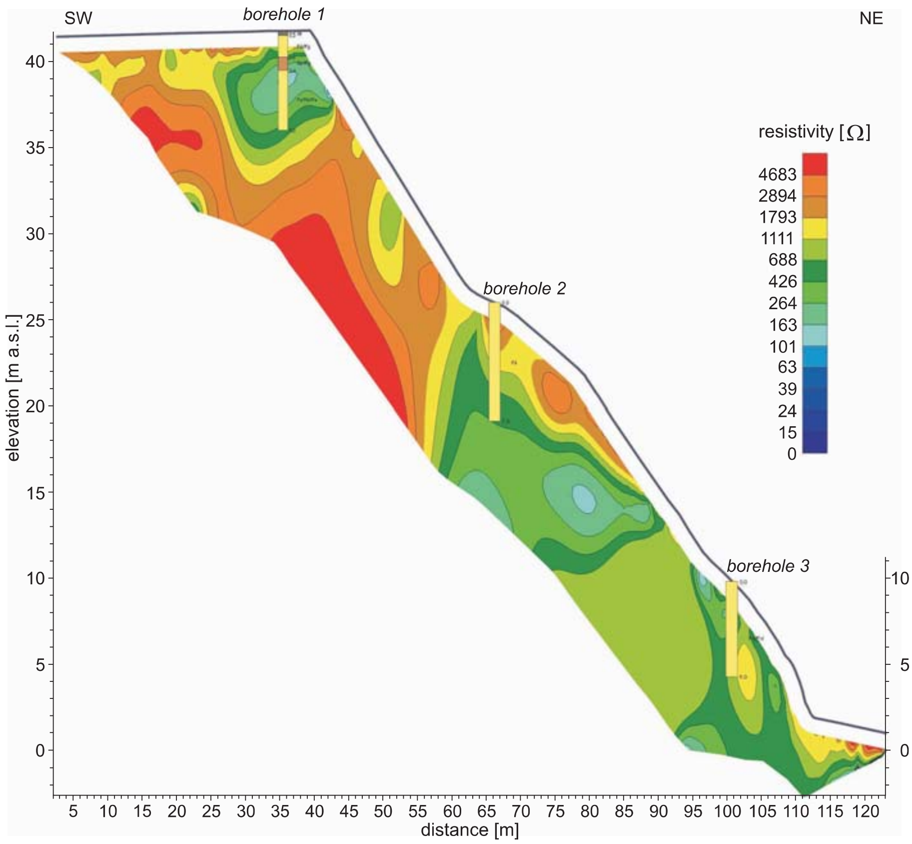

Fig. 7. Resistivity cross-section on the basis of Electric Resistivity Tomography profile, landslide Chłapowo

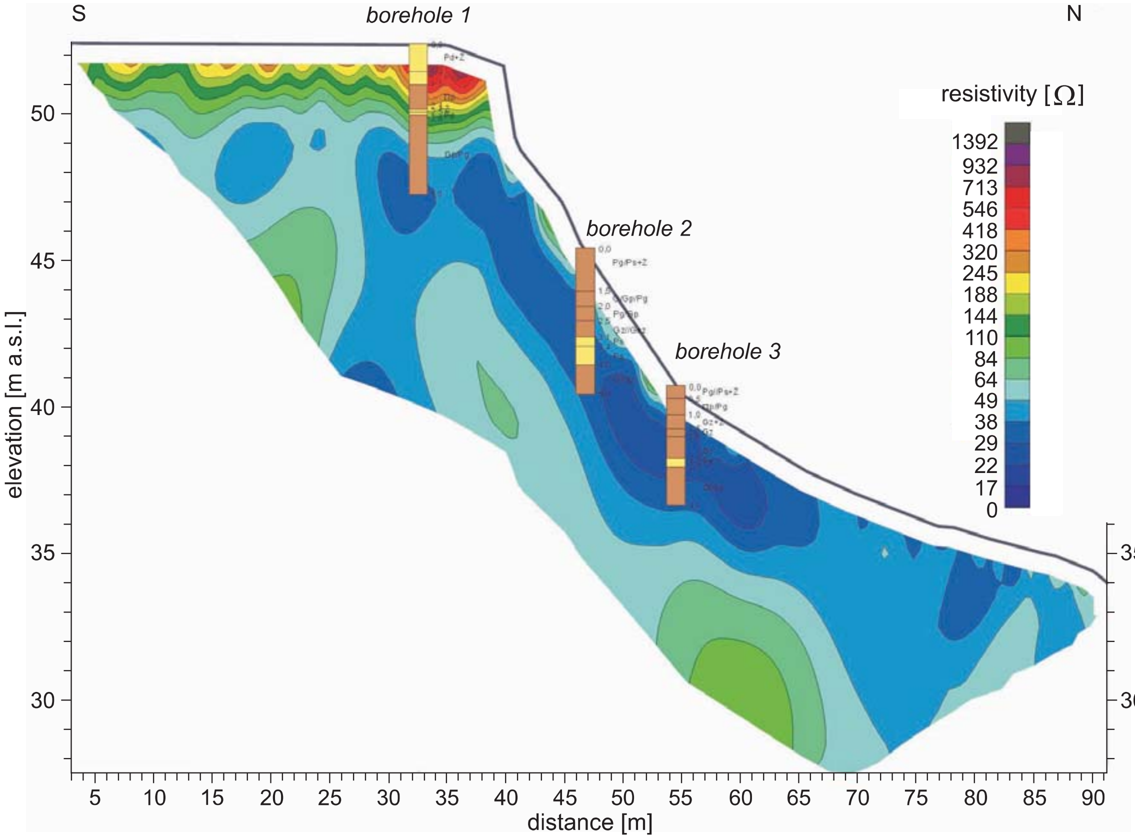

Fig. 8. Resistivity cross-section on the basis of Electric Resistivity Tomography profile, landslide Bartoszyce

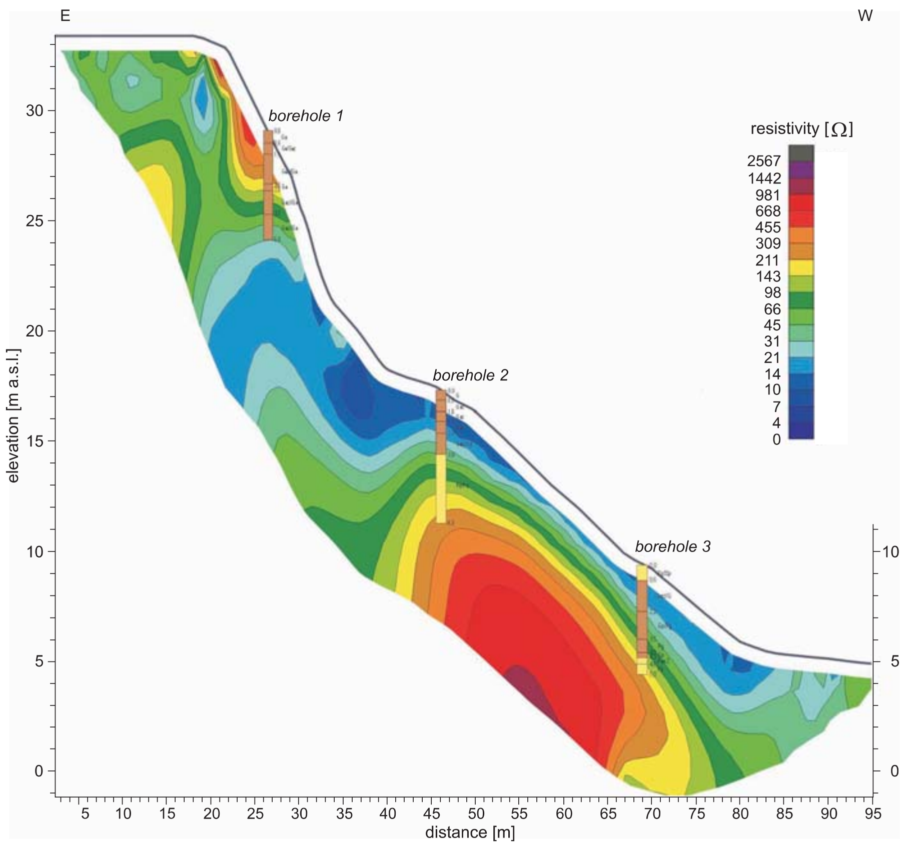

Fig. 9. Resistivity cross-section on the basis of Electric Resistivity Tomography profile, landslide Malbork

The results of investigations proved that geoelectrical methods could be successfully applied to identify the deep landslides structure. The geoelectric measurements enabled to determined slide surfaces down to the depth of the colluvium. The slide surfaces were obtained based on the changes of a resistivity distribution and the geometry of the landslides. The effect of the landslides steep slopes on the quality of measurements cannot be excluded. In particular, rapid changes of the landslide surfaces configuration could affect the electric current flowing between the electrodes, which in turn, could change the resistivity values.

CONCLUSIONS

The moraine deposits are relatively stable and do not easily undergo the landslide processes. Some manifestations of these processes were recorded on steep slopes i.e. on high cliffs, scarps or river valleys banks and ice-marginal valleys. Therefore, the marine abrasion and the fluvial erosion could be considered as the main reasons of landslide development in the moraine regions. The geological structure and hydrogeological conditions are of minor importance, and they determine the slopes steepness and the character of the surface mass movements. The landslides, which do not result from the marine abrasion and fluvial erosion, are scarce.

The described above cataloguing has included only a part of the landslides and should be continued. Due to the fast development of landslide processes, the systematic observations of recognised landslides should be carried out, particularly in the areas with an increased landslide activity. In zones where buildings, roads and other infrastructure objects are endangered, a routine monitoring of landslide processes should be conducted. The monitoring techniques should be adequate to the scale and to the intensity of processes as well as to the hazard degree. The geophysical investigations, which yield data to construct digital models of the objects, are of great significance for the most hazardous areas.

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