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Application of electrical resistivity tomography to detection of geological setting

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Results of the geological structure recognition of chosen grounds tested by the method of electrical resistivity tomography are presented. In Warsaw (Poland), four areas of a different geological structure and of different origin were selected. They are two areas in the Vistula river valley and two areas on a glacial plateau. The geological structure of the areas was confirmed by the documentary evidence of drillings and geological cross-sections. Investigations were executed by the electrical resistivity tomography method, which allowed in a 2D scheme to present the distribution of real resistivity in the soil. The obtained distribution of electric resistivity was correlated with the lithology of soils indicated by geological drillings. The results of investigations executed by the method of electrical resistivity tomography prove a relationship between the distribution of electric resistivity and the geological structure. This relationship is well visible in simple geological structures, particularly where soils have contrasting values of electric resistivity, e. g., sands and clays or dry and saturated sands. In the case of complex geological conditions with a wide range of variations, the measured picture of electric resistivity distribution did not agree with the geological cross-section.

Key words: electrical resistivity tomography, geological structure, Warsaw, Poland

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INTRODUCTION

Electrical resistivity tomography is one of a few methods that allow to concetrate the punctual recognition of a geological setting defined by drillings or penetration tests. Like other methods, tomography has its advantages and drawbacks. The unquestionable small invasiveness is the greatest advantage of this method (the investigation itself moves to inserting 15 cm long electrodes into the ground), along with the speed of measurement.

One of the drawbacks of this method is the difficulty and inequivalence of interpretation caused by the non-homogeneity of ground structure not only as a whole, but also by the lithological inhomogeneity of individual layers.

The interpretation of geological setting employing electrical resistivity tomography depends on the degree of the complexity of the geological structure and the accuracy of its recognition. To show the influence of the geological setting complexity on the possibility of interpretation, four different grounds were chosen for the analysis. Two of them, representing a simple geological structure, are situated in the river valley in Warsaw (Tarchomin and Stegny) and the other two near the interfluve edge (Kiedacza and St.Catherine) (Fig. 1).

THE METHOD OF ELECTRICAL RESISTIVITY TOMOGRAPHY

Electrical resistivity tomography is the most up-to-date geophysical ones method of geoeloctrical investigations. Geoelectical methods were described in different papers (Keller, Frischknecht, 1966; Szymanko, 1993). The method of geoelectrical imaging was described, for example, in (Griffiths, Barker, 1993; Mościcki, Antoniuk, 1998; Rudzki, 2002). Only a brief review of the method is presented in this paper. This method is known under different names, such as resistivity imaging, continuous vertical electrical sounding, electrical resistivity tomography. In Poland, the electrical resistivity tomography method has been used since 2000. In this method, automatic recording with digital data accusition and numerical interpretation is used.

The electrical resistivity tomography method is a combination of a few methods, such as geoelectrical sounding, spontaneous potential and geoelectrical cross-section. The direct current is used for measurements.

To start the whole process, it is enough to set the electrodes in a line. The distance between the electrodes is constant. Every electrode is connected by a multiline cable with the main controller. The main controller consists of a multiplexer and an

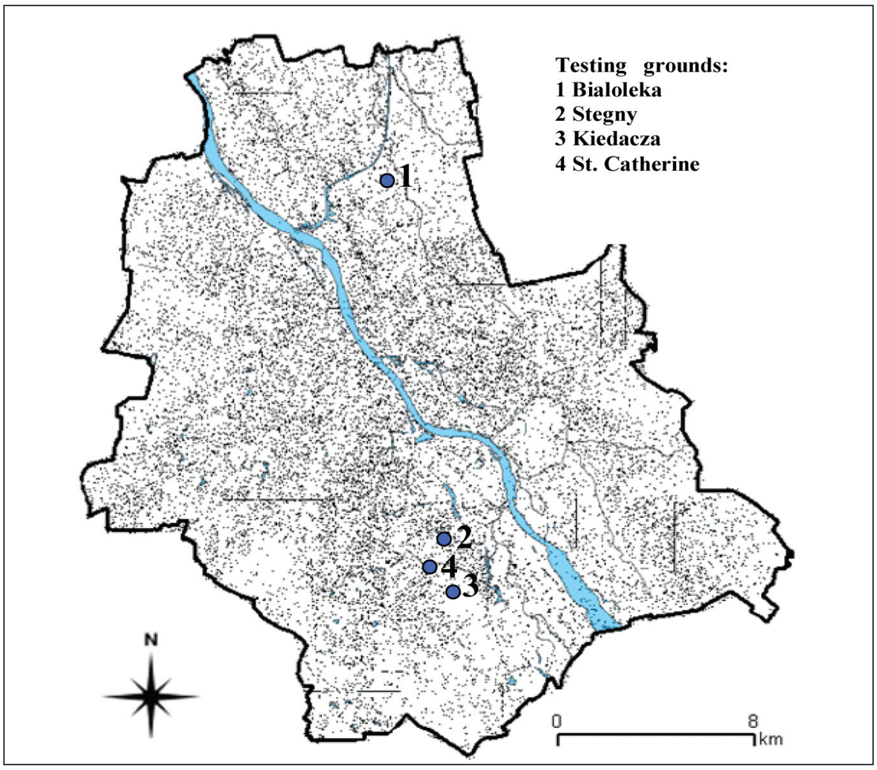

Fig. 1. Localization of testing grounds in Warsaw

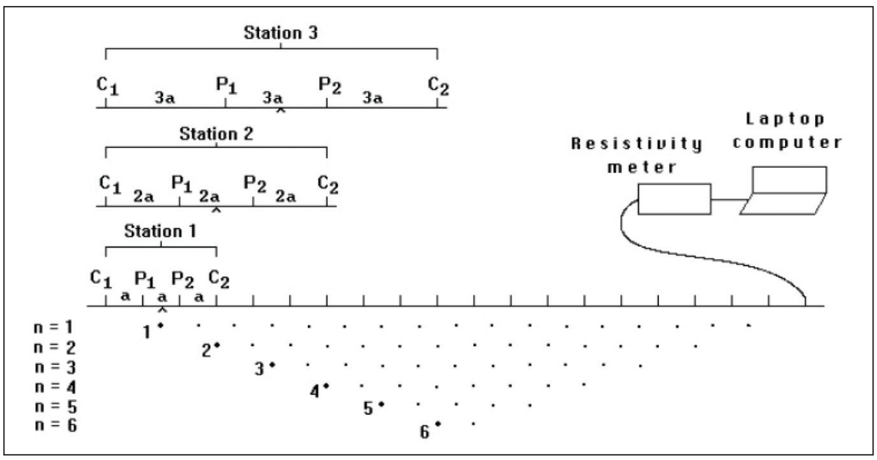

Fig. 2. Sequence of measurements to build up a pseudo-section using a computer-controlled multi-electrode survey setup (Res2DINV Manual, GEOTOMO Sofware)

electric resistivity meter with the possibility of data accquisition. Measurements of apparent resistivity are done for a chosen combination of electrodes (Fig. 2).

After measurement, the combination of electrodes (C_1C_2–P_1P_2) (Fig. 2) is changed automaticly according to a previously set scheme. The final effect of a measurement series is a 2D distribution of apparent resistivity in soils. We can visualize the obtained results, to process and interpret them. The processing is conducted of the automatic 2D inversion. The inversion is based on the smoothness-constrained least-squares method. The least-squares method was described in deGroot-Hedlin, Constble, 1990; Loke, Barker, 1996; Loke and Dahlin, 2002; and Sasaki, 1992. The final result of using the inversion method is a model of the real resistivity of soils with a real depth. Based on at least one geological borehole close to electric measurements, one may eliminate complexes of soils with differing real resistivity. The method of electrical resistivity tomography is applied in the soils in which there are differences in electrical resistivity, for example, for the recognition of the geological structure and hydrogelogical conditions and also for the protection of the environment.

Electric field investigations were carried out by using the SYSCAL Pro Switch apparatus (Fig. 3). For processing the resistivity data, Res2DINV software was used.

GEOLOGICAL SETTINGS

The geological structure of four testing grounds is described below.

Tarchomin testing ground

This is an area characterized by a simple geological structure (Fig. 4). The study site was situated in the Vistula River valley on the river terrace. Geological layers are characterized by the horizontal position. The near-surface layers are built by alluvial soils (clayey sands). Their thickness is less than 1 m. Below

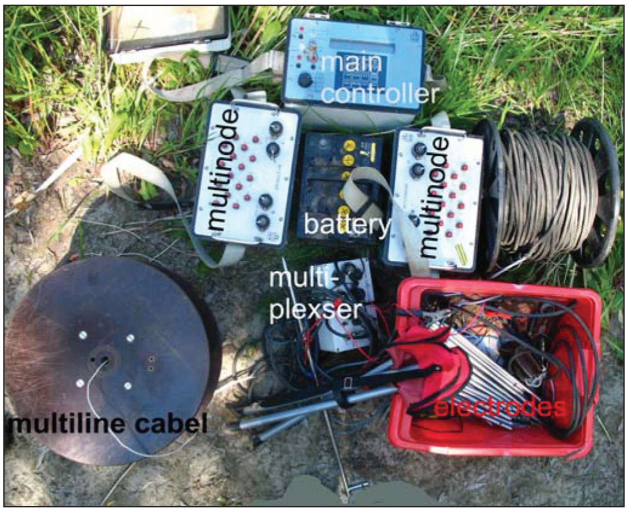

Fig. 3. SYSCAL Pro Switch apparatus

there are medium and coarse sands whose thickness is more than 8 m. The first groundwater level is at a depth of 2.3 m below ground surface.

Stegny testing ground

This testing ground is situated on the boundary of the Vistula valley. It was chosen because of shallow covering Tertiary clays. These soils are characterized by a low electric resistivity – about 15 Ωm. Tertiary clays are found in this place at a depth of approximately 4 m below ground surface. The first groundwater level is at a depth of 3 m below ground surface. The geological cross-section of the Stegny testing ground is shown in Fig. 5. The geological structure is simple, with horizontal positions of geological layers.

Kiedacza testing ground

The testing ground is situated on a glacial plateau near the edge of the Vistula valley slope (Fig. 6).

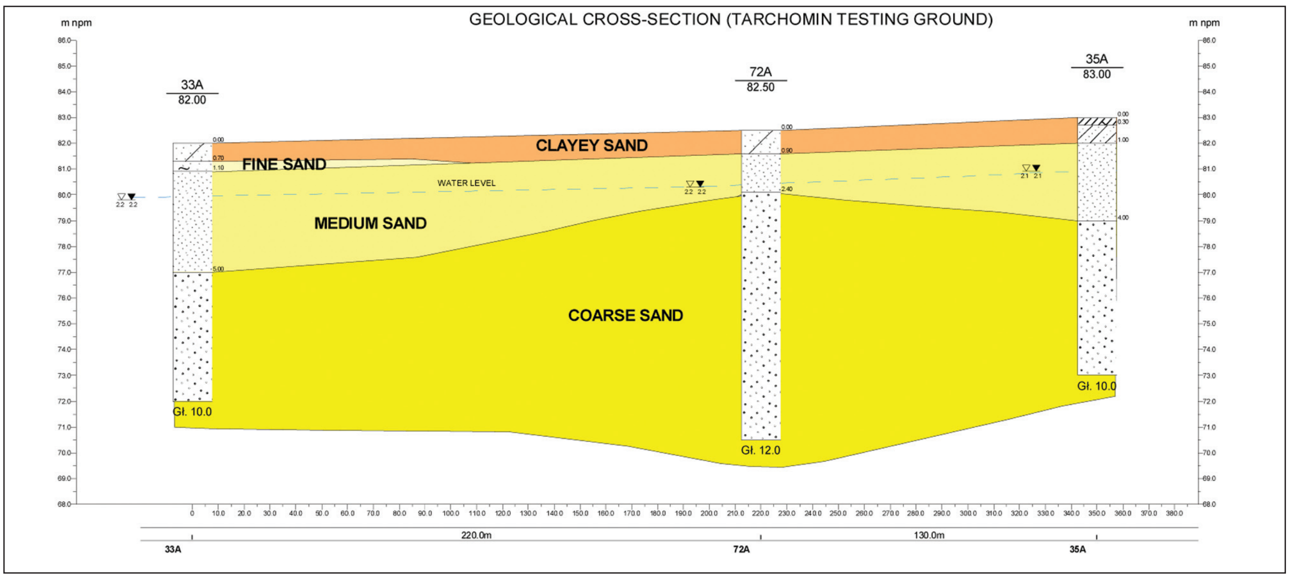

Fig. 4. Geological cross-section of the Tarchomin testing ground

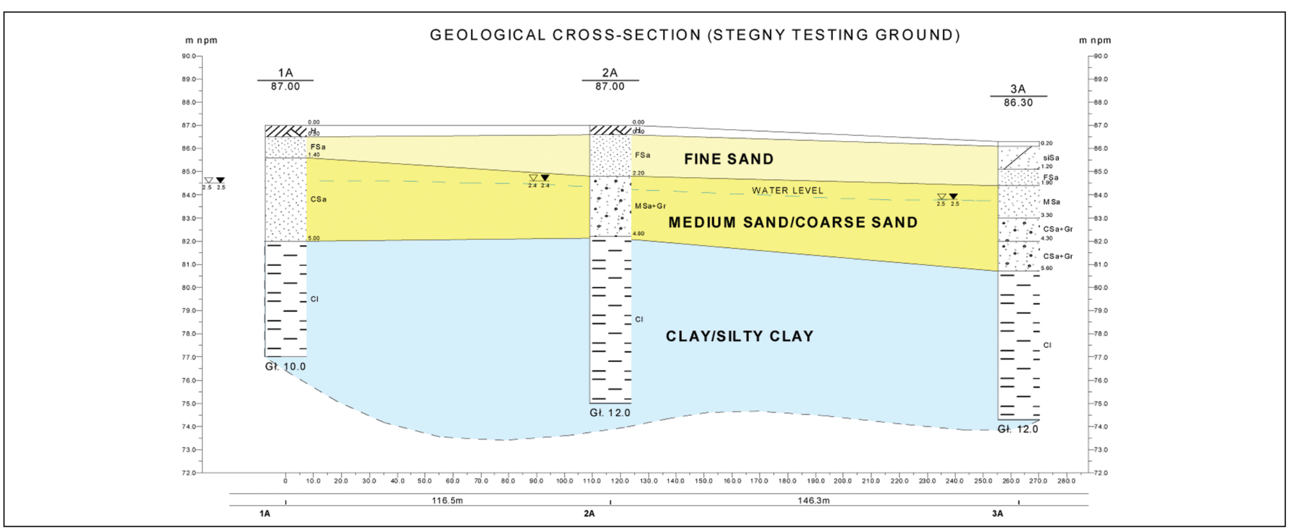

Fig. 5. Geological cross-section of the Stegny testing ground

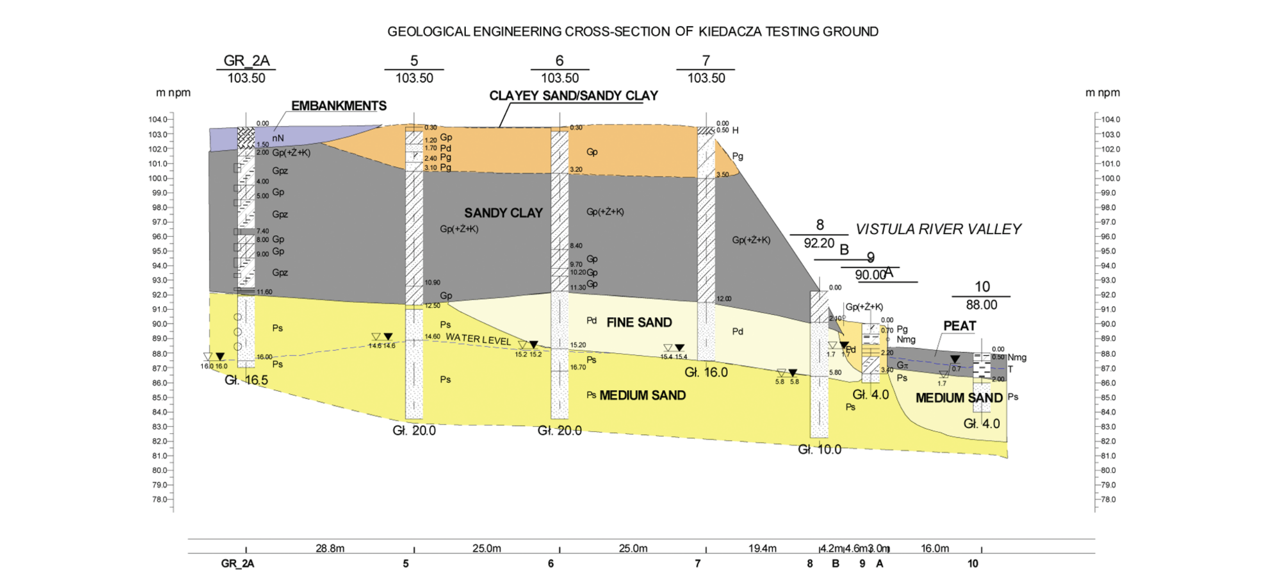

Fig. 6. Geological cross-section of the Kiedacza testing ground

Directly by the foot of the slope there is the old river bed filled up with organic sediments. The slope is built with glacial sandy clays about 9 m thick. Because of a deep water-gathering ground (approx. 11 m p.p.t) these soils are very overdried at the top.

St. Catherine testing ground

The area of the St. Catherine testing ground is built with glacial soils (sandy clays and fluvioglacial sands). The geological conditions are complex. The near-surface layers are built with embankments less than 1 m thick. Below, there lie fluvioglacial higher sands (sands and gravels) with the thickness from tens of centimetres to 3 m. Below them, there is a continuous level of glacial clays 2.6 m to almost 10 m thick. Under the glacial clays there lie fluvioglacial lower sands. Below, there are unpenetrated glacial sediments (clayey sands and sandy clays). The geological cross-section of St. Catherine testing ground is presented in Fig. 7.

RESULTS OF ELECTRICAL RESISTIVITY TOMOGRAPHY

Measurements using the electrical resistivity tomography method were executed along the above described geological cross-sections. The results of measurements, together with their interpretation, will be presented below.

The Vistula River valley – Tarchomin district

The profile was situated along the line of the geological section presented in Fig. 4. The distance between the electrodes was 5 m; 32 electrodes were applied. The proposed scheme of the electrodes allowed the recognition of the real distribution of electric resistivity to a depth of approx. 25 m below ground surface. Based on the geological cross-section presented in Fig. 4, in the electric section (Fig. 8) we may distinguish two layers with various electric resistivity.

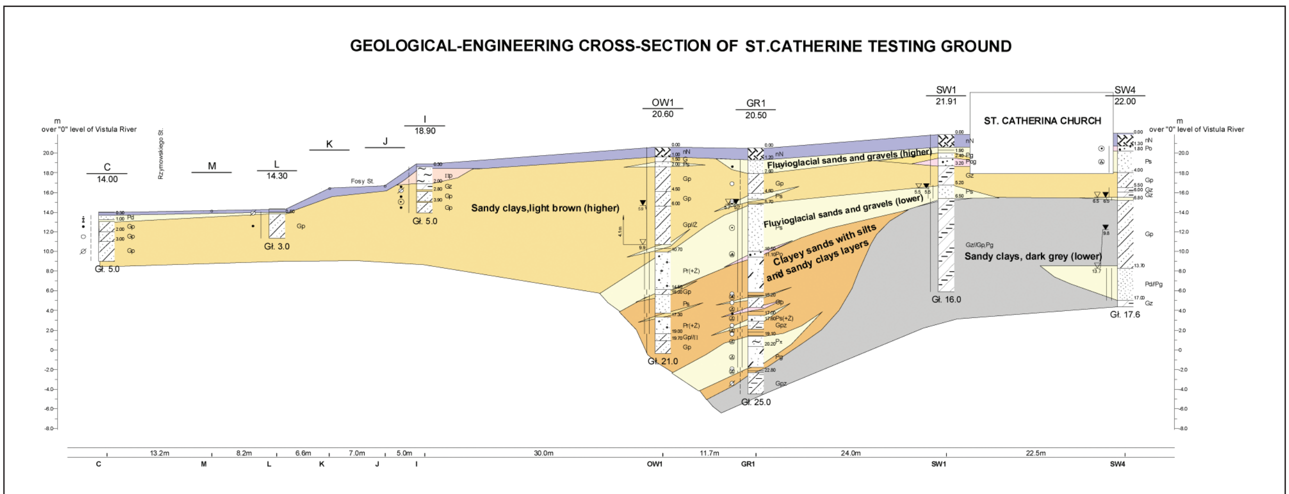

Fig. 7. Geological cross-section (St. Catherine testing ground)

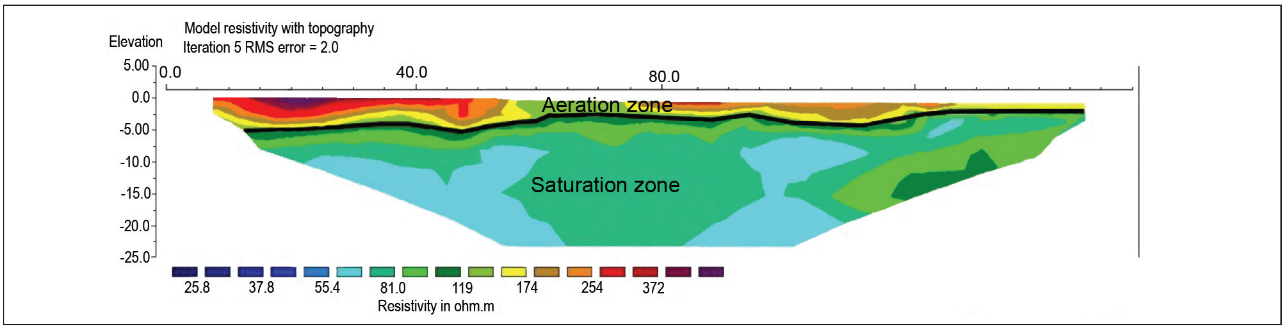

Fig. 8. The distribution of real resistivity *s* in the Vistula river valley, Tarchomin district

The first layer, near the surface, is dry sand. Its electric resistivity is approx. 250 Ωm. The second layer is saturated sand. Its electric resistivity is approx. 90 Ωm. The first layer is the zone of aeration, the second one being the zone of saturation. The border between these zones is the free level of groundwater in a wide compartment of the depth approx. 2–5 m below ground surface. Such result is not accurate, if we compare the level of groundwater obtained in the geological boreholes (Fig. 4). The depth of groundwater shown by the geological boreholes (Fig. 4) is approx 2.1–2.2 m below ground surface. The local changes of grain-size distribution in river sands and their moisture give an inaccurate groundwater position.

The Vistula river valley – Stegny district

The measured profile was situated along the line of the geological section introduced in Fig. 5. The distance between the electrodes was 2 m. In the profile, 32 electrodes were applied. Proposed scheme of the electrodes, let the recognition of the real distribution of electric resistivity to the depth approximately 10 m below to the ground surface. Basing on the geological cross-section introduced in Fig. 5, and on the electrical section (Fig. 9) we can distinguish three layers with different electrical resistivity.

The first layer is dry sand. Its electrical resistivity is approx. 400 Ωm. The second layer is saturated sand, electrical resistivity approx. 150 Ωm. The third layer is clay, electrical resistivity approx. 10 Ωm. The geological border of clays is marked with a black line (Fig. 9). The depth of groundwater shown by the geological boreholes (Fig. 5) is approx. 3 m below ground surface.

This level is seen also, but faintly, on the electrical profile (Fig. 9). The faint contour indicates the level of groundwater and is caused by rains which increased soil moisture. It also caused the back of clear contrasts in electrical resistivity. In the electrical resistivity section (Fig. 9) we can notice a vertical area with a diminishing electric resistivity near the 33rd metre of the profile in the layer of sands.

This field with a lowered electrical resistivity is created by the presence of lost pipes in soil, left after geological drilling near the measured profile.

A glacial plateau – Kiedacza st.

The profile is situated along the line of the geological cross-section shown in Fig. 6. The distance between the electrodes was 1 m. In the profile, there were applied 92 electrodes. The scheme of the electrodes allowed the recognition of the real distribution of electrical resistivity to a depth of approx. 15 m below ground surface. We can distinguish three layers of different electrical resistivity in the geological cross-section presented in Fig. 6, in the electrical section (Fig. 10).

The first layer is an embankment. Its electric resistivity is approx. 100 Ωm. The second layer is sandy clay with the electrical resistivity of approx. 30 Ωm. The third layer is sand, its electrical resistivity is approx. 90 Ωm. Its geological borders are marked with black lines (Fig. 10).

If we compare the course of geological borders in the geological cross-section (Fig. 6) with the electrical section (Fig. 10), we can notice differences in the interpretation of the third layer. Soils of this layer were distinguished in the geological cross-section (Fig. 10) as medium sands. However, in Fig. 6 the third layer

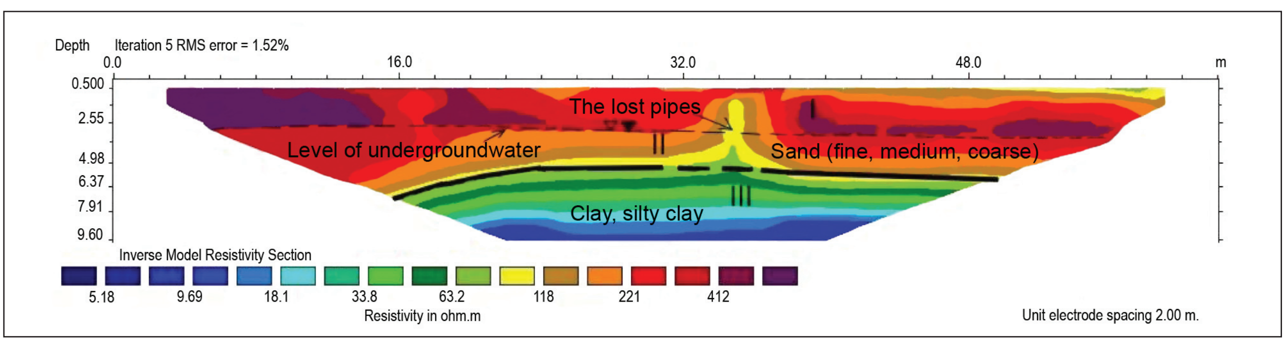

Fig. 9. The distribution of real resistivity in Vistula river valley, Stegny district

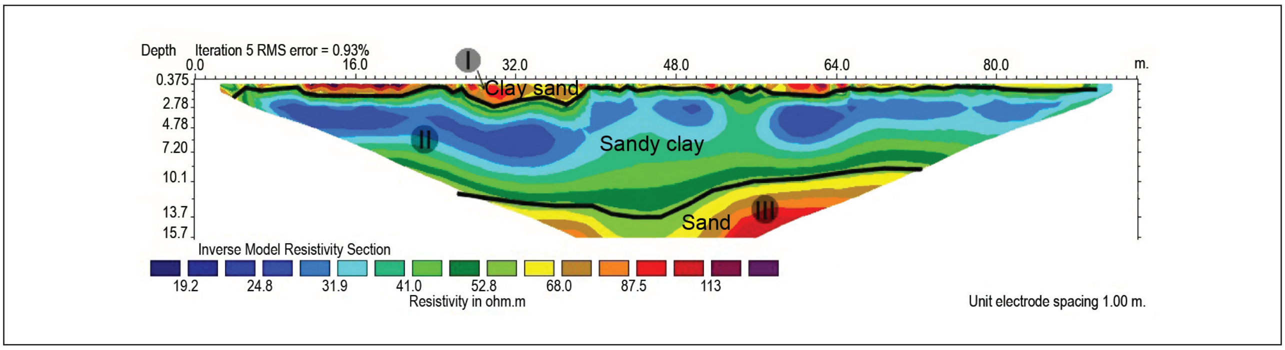

Fig. 10. The distribution of real resistivity in a glacial plateau, Kiedacza st.

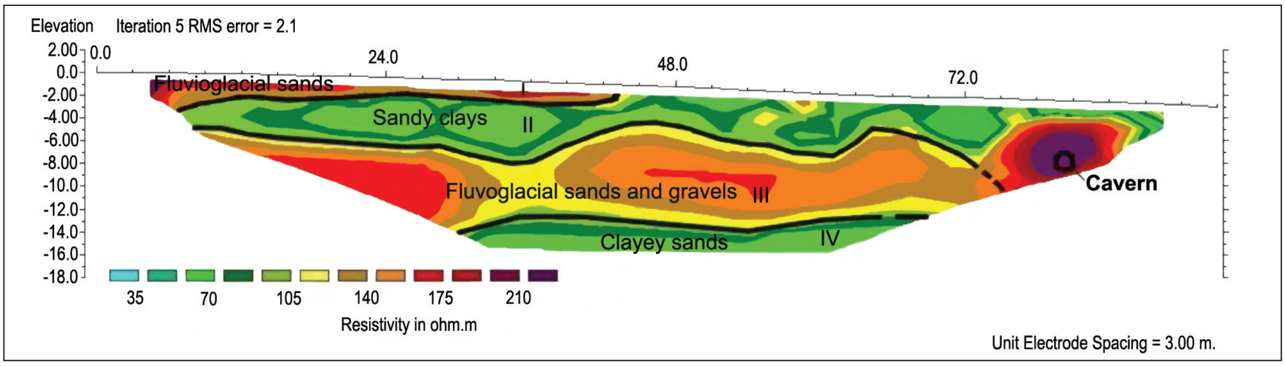

Fig. 11. The distribution of real resistivity s. Glacial plateau – St. Catherine's church

soils were classified as fine and medium sands. This difference is caused by the low contrasts of electrical resistivity in sands.

A glacial plateau – St. Catherine's church

The profile was situated along the line of the geological cross-section presented in Fig. 7. The distance between the electrodes was 3 m. There were applied 32 electrodes. The proposed scheme of electrodes allowed the recognition of the real distribution of electrical resistivity to a depth of approx. 15 m below ground surface. We can distinguish four layers about the various electric resistivity in the geological cross-section introduced in Fig. 7, on the electric section (Fig. 11).

The first and the third layers are fluvioglacial sands and gravels. Their electrical resistivity is approx. 150 Ωm. The second and the fourth layers are sandy clays, their electrical resistivity being approx. 70 Ωm. The geological borders are marked with black lines (Fig. 11).

The geological structure presented in Fig. 7 is very complicated. We can distinguish here a dozen geological layers of various thickness. The distribution of electrical resistivity presented in Fig. 7 imitates only an approximate scheme of the geological structure showing only the thickest layers. The accuracy electrical resistivity tomography decreases with the depth. In the right corner on the profile of resistivity distribution (Fig. 11) we can notice a considerable increment of the electric resistivity of the soil, shown in the figure by the purple colour. This is probably a cavern. The historical dates of the neighbourhoods of the St. Catherine's church prove, that this can be the ground corridor connected with the existing Masonic box.

CONCLUDING REMARKS

The results of investigations executed by the electrical resistivity tomography method prove the existence of a relationship between the distribution of electric resistivity and the geological structure.

This relationship is well visible in a geological structure with simple conditions, especially where soils have contrasting values of electric resistivity, e. g., sands and clays or dry and saturated sands.

We can see this situation on profiles situated in the valley of the Vistula river, e. g. Tarchomin (Fig. 8), Stegny (Fig. 9) and on a glacial plateau near the Kiedacza st. (Fig. 10).

In the complex geological conditions, where a high geological changeability is expected, the measured picture of the electrical resistivity distribution does not agree with the geological cross-section. We can see such an example on the edge of a glacial plateau near St. Catherine's church (Fig. 11).

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ELEKTRINĖS TOMOGRAFIJOS METODO TINKAMUMAS TIRIANT GEOLOGINĘ SANDARĄ

Santrauka
Straipsnyje pateikiami geologinės sandaros tyrimų, atliktų elektrinės tomografijos metodu, rezultatai. Bandymai atlikti keturiose Varšuvos eksperimentinėse aikštelėse, kurios skiriasi nuogulų geneze ir sandara. Dvi aikštelės yra Vyslos slėnyje, o dar dvi – moreninėje lygumoje. Aikštelėse pragręžti gręžiniai ir pagal juos sudaryti geologiniai pjūviai. Elektrine tomografija atlikti tyrimai leido 2D sistemoje pateikti varžų sklaidą tiriamuose gruntuose. Realios elektros varžų vertės buvo koreliuojamos su litologija. Tyrimų duomenimis, tarp litologijos ir elektrinės tomografijos rezultatų yra stiprios sąsajos, ypač kai gruntams būdingos kontroversiškos varžų vertės (pvz., smėlis, priemolis arba molis). Esant dideliam gruntų kintamumui, išmatuota elektros varžos sklaida ne visai atitinka geologinę sandarą pagal gręžinių duomenis.

Kamil Kiełbasiński, Radosław Mieszkowski

ZASTOSOWANIE METODY TOMOGRAFII ELEKTROOPOROWEJ DO ROZPOZNANIA BUDOWY GEOLOGICZNEJ

Streszczenie
W niniejszym artykule przedstawiono wyniki rozpoznania budowy geologicznej wybranych poligonów badawczych za pomocą metody tomografii elektrooporowej. Wybrano cztery poligony badawcze w obrębie Warszawy o różnej budowie geologicznej i różnej genezie osadów. Są to dwa poligony w obrębie doliny rzeki Wisły oraz dwa poligony w obrębie wysoczyzny polodowcowej. Budowa geologiczna poligonów jest udokumentowana przez wiercenia i przekroje geologiczne. Badania wykonane metodą tomografii elektrooporowej pozwoliły na przedstawieniu w układzie 2D rozkładu oporów rzeczywistych występujących w gruncie. Otrzymany rozkład oporów rzeczywistych został skorelowany z litologią osadów rozpoznanych wierceniami geologicznymi na wybranych poligonach badawczych. Rezultaty wykonanych badań dowodzą, iż istnieje związek między rozkładem oporu elektrycznego a litologią. Związek ten jest dobrze widoczny w przypadku prostych warunków budowy geologicznej, szczególnie tam, gdzie występują osady o kontrastowych wartościach oporu elektrycznego, np., piaski i gliny. W przypadku złożonych warunków geologicznych, tzn. takich, gdzie występuje duża zmienność w wykształceniu litologicznym i genetycznym osadów, zmierzony obraz rozkładu oporów elektrycznych nie w pełni pokrywa się z przekrojem geologicznym.

Камиль Келбасиньски, Радослав Миешковски

ПРИМЕНЕНИЕ МЕТОДА ЭЛЕКТРИЧЕСКОЙ ТОМОГРАФИИ ПРИ ИССЛЕДОВАНИЯХ ГЕОЛОГИЧЕСКОГО СТРОЕНИЯ

Резюме
Исследования геологического строения осуществлены в Варшаве на четырех экспериментальных площадках методом электрической томографии. Площадки различаются генезисом образований и их строением. Две площадки находятся в долине Вислы, а две другие – на моренной равнине. На площадках пробурены скважины, и по их данным составлены геологические разрезы. Выполненные методом электрической томографии исследования позволили в системе 2D представить изменчивость электрического сопротивления в грунтах. Значения сопротивления коррелировали с данными по литологии. Полученные результаты показывают, что между литологией и результатами электрической томографии имеется тесная связь, особенно, когда грунты имеют противоположеные значения сопротивления (например, песок–суглинок или глина). При значительной изменчивости грунтов замеренные значения электрического сопротивления не всегда соответствуют геологическому строению, установленному по данным скважин.