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SOME EXAMPLES OF ELECTRICAL IMAGING (ERT) AND GROUND PENETRATING RADAR (GPR) IN SOLVING CIVIL ENGINEERING PROBLEMS

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A b s t r a c t: A few engineering geology and geotechnical case studies are seen in this research paper that are solved using two dimensional (2D) electrical imaging surveys (ERT) and, in four cases, ground penetrating radar (GPR). Case studies that demonstrate the versatility of the ERT method as well as other methods that complement obtained ERT data will be presented. Surveys of flotation tailings, detection of old mines, communal waste dumps, rock quality and lakebed surveys, and so on are among the case studies. Two-dimensional electrical scanning method proved its efficiency and cost effectiveness, especially when the survey needed a large surface area to be investigated.

Key words: electrical imaging (ERT); ground penetrating radar (GPR); engineering geology

INTRODUCTION

In many geological situations, 2-D electrical imaging surveys may provide valuable information that complements that obtained by other geophysical methods. Seismic methods, for example, are excellent at mapping undulating interfaces, but they fail (without using sophisticated data processing techniques) to map discrete bodies like boulders, cavities, and pollution plumes (Loke, 2012).

In certain cases, 2D electrical imaging proved to be the most effective form of investigation when addressing concerns like overflowing urban landfills and flotation tailings. This technique may also be used to investigate the consistency of rock in quarries. This work includes a number of examples that back up this claim.

In areas with conductive unconsolidated sediments, such as clayey soils, ground penetrating radar (GPR) surveys may provide more accurate images, but they have limited depth of investigation. (Loke, 2012). Electrical surveys in two dimensions should be used in combination with seismic or GPR surveys since they provide additional knowledge about the subsurface. (Loke, 2012).

1. GEOPHYSICAL SURVEY OF THE FLOTATION TAILING IN BOR

Geotechnical and geophysical surveys were performed over the ore body "H" in order to survey the flotation tailing in Bor, Serbia. The exhausted exploitation of the ore body "H" resulted in the formation of a depression, which was filled with sand dams and used as a flotation tailing. To determine the thickness of the surface (filling) layer around the depression, the depth to the bedrock and the consistency of the bedrock and filled material, geoelectrical surveys and refraction seismic surveys were performed.

The results of 1D inversion of geoelectrical sounding data acquired using the Schlumberger array (blue line) and 1D refraction seismic data analysis (red line) at the north dam of the tailings are shown in Figure 1 (top). Refraction seismic surveys are conducted with two profiles of relatively short lengths, each with three ignition points, which does not provide enough data to detect lateral changes in elastic properties and wave velocity. As a result, only two boundaries have been identified, the second of which is located at a depth of 20 meters and has a gradual dip toward the end of the second seismic profile. Throughout the length of the geoelectrical profile, this boundary is deeper than the boundary defined by geoelectrical sounding, with the exception of the end of the geoelectrical profile, where both boundaries overlap.

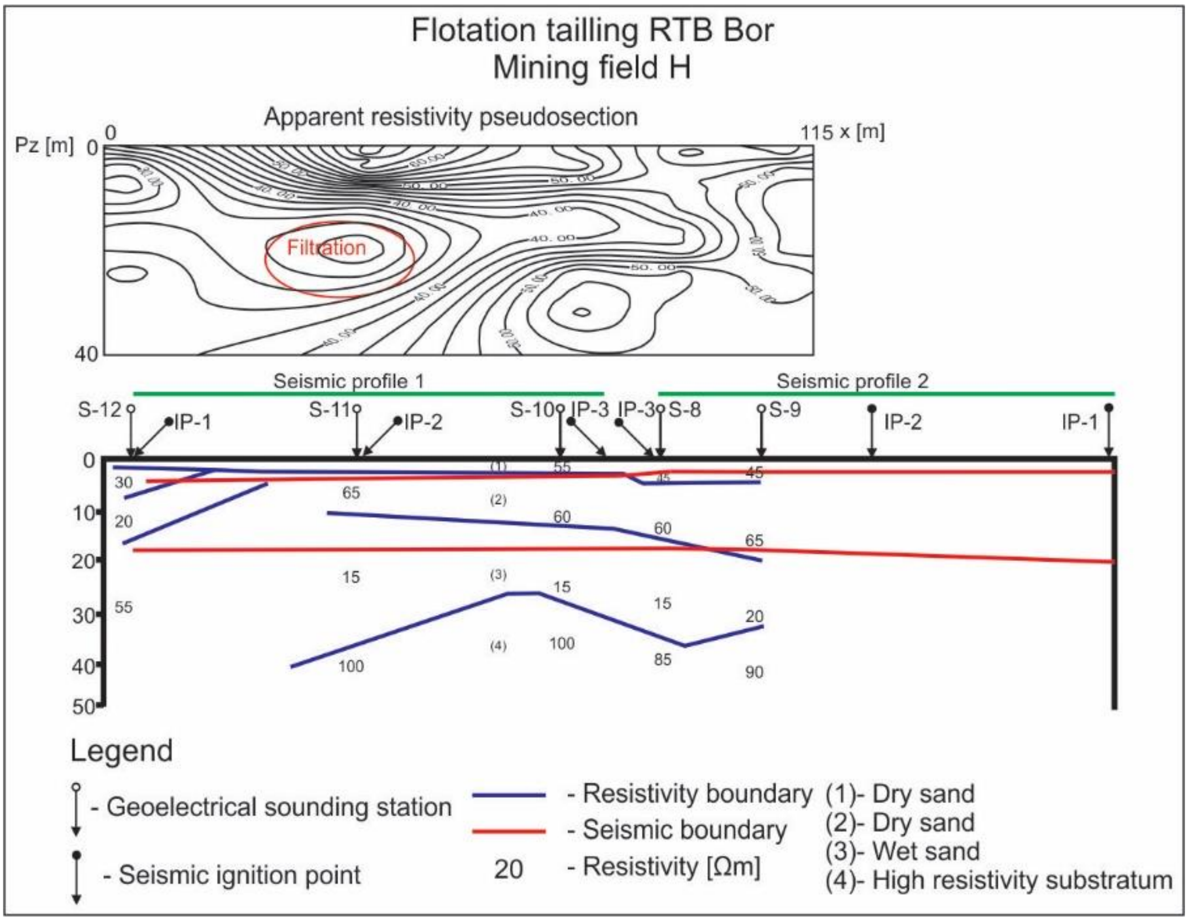


Fig. 1. Apparent resistivity section and results of 1D inversion of geoelectrical sounding diagrams and 1D refraction seismic inversion results along the sand dam axis

Since further separation of current electrodes during the Schlumberger array sounding along the north tailing dam was not feasible, the geoelectrical profile covered a smaller portion of the surveyed half space.

The apparent resistivity pseudosection (Figure 1, top) shows broad differences from a 1D surface model since apparent resistivity isolines are horizontal with small mutual gradient. Because of the divergence from a homogeneous, horizontal subsurface model between sounding stations S-11 and S-12, the results of 1D inversion of geoelectrical sounding diagrams in that region are unreliable. Since there were no lateral effects at smaller electrode spacings, 1D interpretation allowed for more accurate boundary depth determination. The subsurface model does not imply lateral changes in elastic properties at lower depths of investigation, as defined by the refraction seismic survey method.

During the survey, water began to accumulate in the depression behind the sand dam, which may be the result of water movement through the dam. The apparent resistivity section shows a region of low resistivity values, which can be attributed to the filtration of a low resistivity electrolyte from the tailings through the dam. The filtration elutriates the sand material that can lead to perforation of the dam and subsequent ecological catastrophes. When the flotation tailing dam ruptured near Majdanpek (Serbia) in 1997, large areas of arable land and one village were contaminated with flotation sludge, permanently contaminating the soil and groundwaters in the accident region.

An approximate 2D subsurface model was constructed based on a 1D geoelectrical model and the apparent resistivity section (Figure 2). The apparent resistivity section with the Schlumberger array was calculated for that subsurface model (obtained by direct modeling in RES2DMOD) (Figure 2a). Theoretically calculated section for the 2D model of the dam body generally corresponds to the section of apparent resistivity (resistivity values and overall geometry) which was constructed based upon the measured geoelectrical sounding curves (Figure 1).

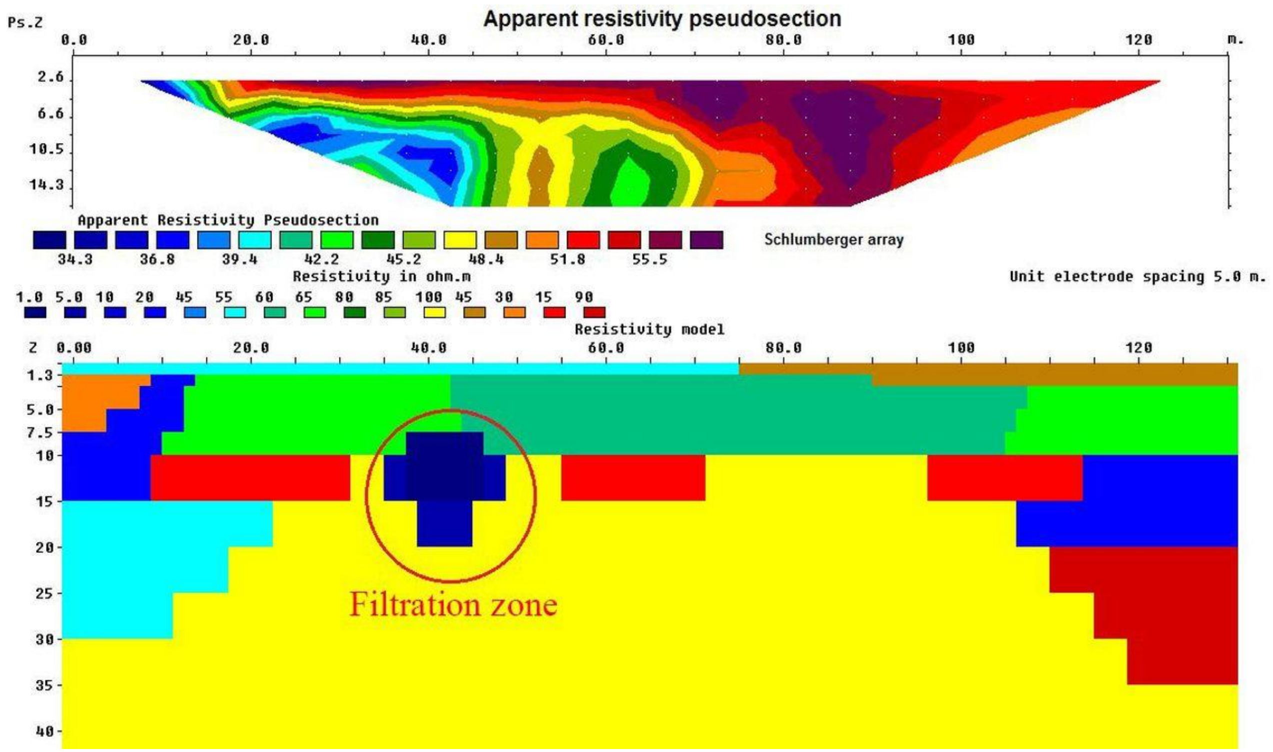


Fig. 2. 2D model constructed based upon 1D sounding curve inversion and the apparent resistivity section along the north dam axis with the Schlumberger array

A low resistivity zone (1–5 Ωm) was inserted into the 2D model to represent the electrolyte filtration zone in the flotation tailing. The RES2DINV software allowed 2D inversion of synthetic apparent resistivity sections, resulting in a 2D model (Figure 3) that better defines the subsurface architecture and true resistivity values that are closer to those described in the apparent resistivity section from Figure 2.

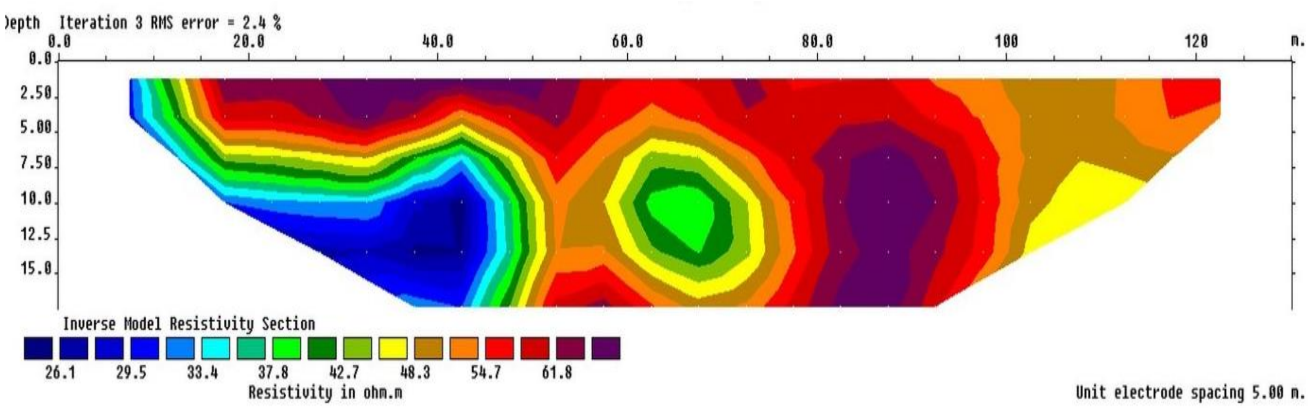


Fig. 3. 2D inversion of synthetic data for the 2D model along the north dam axis with the Schlumberger array

It is possible to create geoelectrical monitoring on all of the dams in the flotation tailing RTB Bor using the ERT method. Geoelectrical sounding surveys at the flotation tailing mining field "H" showed very low resistivity values of the tailing and electrolytes it protects (a few Ωm) allowing for detection of filtration through the dam's body. A fully automated system, described as a part of the 2D geoelectrical survey method in Loke (2012), could be used for data acquisition in order to monitor the possible contamination of groun dwater.

2. DETECTION OF OLD MINES IN KOLUBARA – FORMER MINE "JUNKOVAC"

Coal extraction in the Kolubara (Serbia) open cast mine advanced to the region of old mine underground workings, which had been abandoned since 1971 and could not be continued due to the risk of gravitational collapses and cavities. During dredging machine operations, the existence of cavities was confirmed, while the presence of collapsed zones was suggested by intermittent small depressions in the terrain over old mine workings.

The exploitation of the former mine "Junkovac" was carried out using the roof collapse process, i.e. chamber excavation method, according to the review of existing documents (Jovanović et al., 1991). The chambers were 12 × 12 × 12 meters in size, with each chamber holding 1700 m^3 of coal. Given that coal degree of utilization was about 50%, an empty chamber of 800–850 m^3 could be expected at the place where a chamber previously existed or in the space above the former chamber to the surface. Following work at the mine site, empty volumes were discovered in the region of consolidated lithological formations, which, due to their firmness, prevented the soil from collapsing and subsiding. As a result, the location of the empty volumes cannot be accurately determined based on current mine exploitation documents.

Future excavation activities were deemed extremely dangerous without additional investigations aimed at detecting and defining cavities and disturbed zones. Since drilling alone was ineffective in solving the problem, two geophysical methods were tried (GPR and 2D electrical imaging). Nine nearly parallel old mine tunnels were crossed by 2D electrical imaging profiles (and the 10th perpendicular tunnel connecting them). To confirm the results of the ERT investigations, fifteen control drill holes were planned.

Experimental investigations with the ERT method over an old mine tunnel in Junkovac proved that such empty spaces can be detected successfully (Figure 4). Since the geological setting is straightforward (gently dipping clay and sandy clay strata) (Sretenović et al., 1992), observed anomalies can be correlated to disturbed zones formed by gravitational collapses of old mine tunnels and cavities.

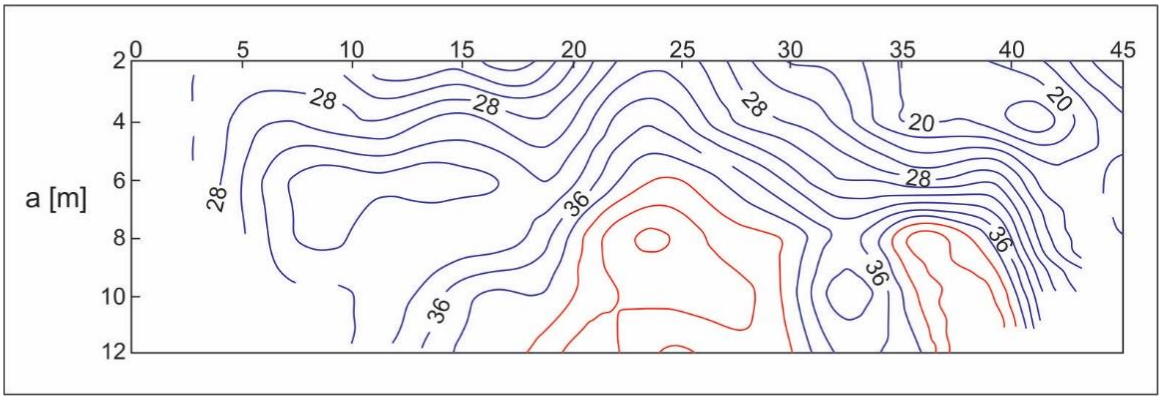


Fig. 4. Apparent resistivity section over a tunnel in Junkovac

2D electrical imaging investigations were performed along a 300-meter-long grid of parallel profiles with a 6-meter spacing between them. Twenty-five to thirty-five electrodes were used, with a minimum unit electrode spacing of ten meters, allowing for a maximum depth of investigation of 30 to 50 meters.

The apparent resistivity map (Figure 5), which was created using a grid of parallel ERT profiles with an electrode spacing of a = 40 meters (approximate depth of investigation of 20 meters), reveals the existence of two anomalous high resistivity zones (A and B). Cavities or gravitational collapses in lower resistivity clay strata may trigger these zones. Drilling data showed that zone "B" corresponds to the presence of a high-resistance sand lens embedded in a lower-resistance sandy clay. Three drill holes in zone "A" confirmed the existence of the disruption in the relatively simple regional geological setting of gently dipping clay strata overlying coal strata as follows: yellow sandy clay, grey clay, grey clay with organic lamination, and finally coal.

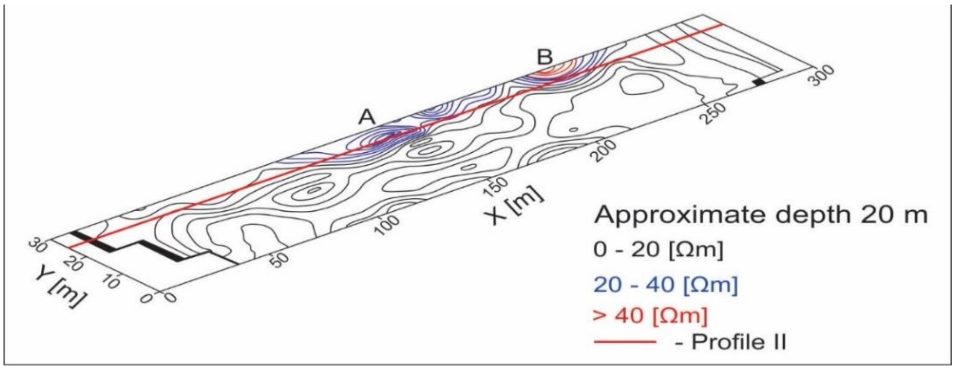


Fig. 5. Apparent resistivity map constructed for approximate depth of 20 meters (*a* = 40 m)

The apparent resistivity pseudosection along ERT profile II, as well as the 2D inversion model, were used to further investigate the anomalous zones (A and B) (Figure 6). Broad near-surface inhomogeneity spreads through the section, masking deeper structures in the apparent resistivity pseudosection. In the model, 2D inversion had to be achieved with a cell width of half unit electrode spacing (a) and 17 out of 147 data points had to be omitted (by trimming data set).

The border between grey clay and clay with organic lamination forms an anticlinal structure in the anomalous zone "A," indicating the sudden shallowing of this boundary. The depth to this boundary was determined by three control drills drilled at the 130th, 140th, and 150th meters of Profile II, respectively. Resistivity measurements on core samples indicated a strong resistivity contrast at this boundary (1:3 to 1:5), explaining the apparent resistivity anomaly.

The third hole was drilled to a depth of about 60 meters, exposing the presence of two cavities, one at 44 – 48 meters depth and the other at 54–58.5 meters depth. The second cavity in the coal strata is most likely a section of the old mine chamber that has been partly buried by collapsed strata above it. This resulted in the upper strata subsiding and the forming of the anticlinal structure that was discovered (and upper laying cavity). As a result of the high resistivity contrast between grey clay and clay with organic lamination, the collapsed zone could be detected.

The Kolubara former mine detection was also investigated in Jovanović et al., (1991).

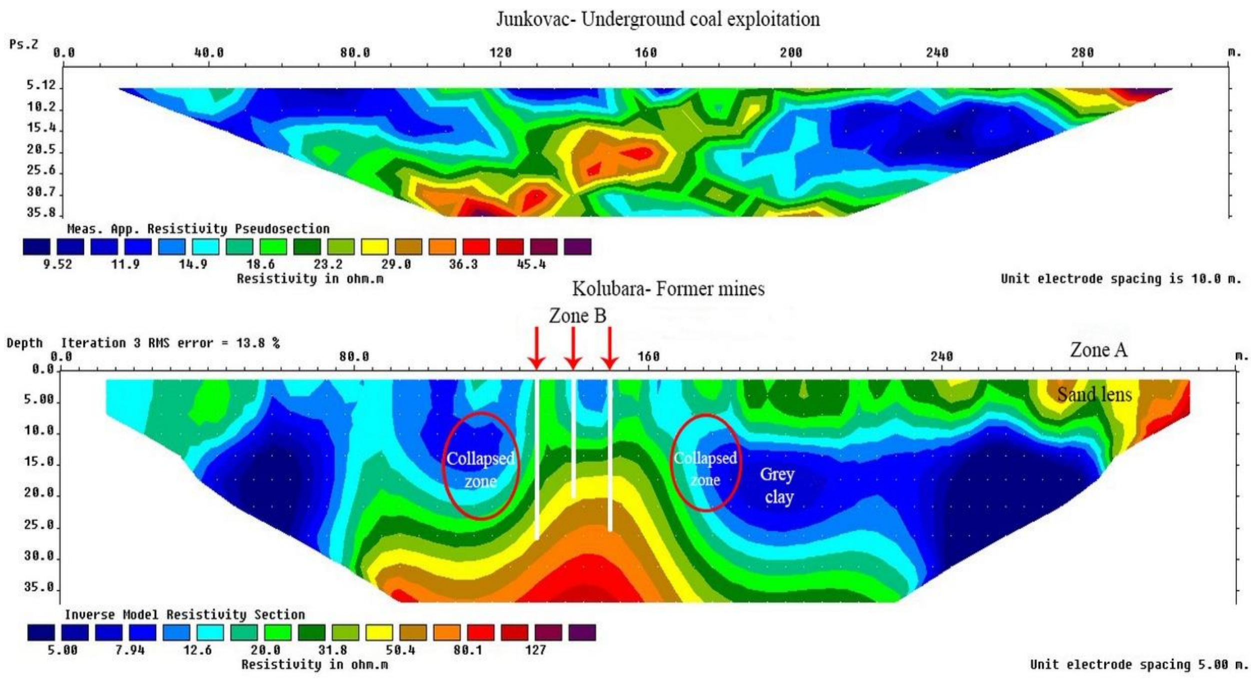


Fig. 6. Apparent resistivity pseudosection and 2D inversion model along Profile II

3. SURVEY AT THE COMMUNAL WASTE DUMP SITE "ADA HUJA"

Zones with filled artificial material or abandoned communal and industrial waste dumps can be detected using ground penetrating radar and geoelectrical surveys. In certain cases, there is inadequate knowledge of the distribution and composition of this material, which has unique geotechnical conditions. Figure 7 depicts the findings of the geoelectrical scanning survey conducted over the former communal waste dump at Ada Huja. The former communal waste dump was to be transformed into a train track and station known as "Karaburma".

A total of 17 electrodes were used in the geoelectrical surveys, with a unit electrode spacing of 5 meters. The survey was conducted on five depth levels, allowing for a total depth of investigation of 12. 5 meters. The landfill's geometry is clearly evident, with low resistivity zones containing communal waste (dark clay, vehicle tires, building and organic material, and so on), and high resistivity zones containing marl and clay. The resistivity of gray sand with organic material is relatively low. Decomposition of organic material creates low-resistivity liquids (leachates), which can reduce the resistivity of the surrounding sand. The deepest part of the profile is made up of compact dark grey marl, which resistivity-wise is nearly identical to the filed material.

In comparison to the geotechnical profile, which was constructed with three boreholes, the 2D geoelectrical model can better define the subsurface. By reducing the unit electrode spacing in a multi-electrode array, the horizontal resolution of geoelectrical surveys can be enhanced, allowing for a more accurate image of subsurface lateral resistivity changes.

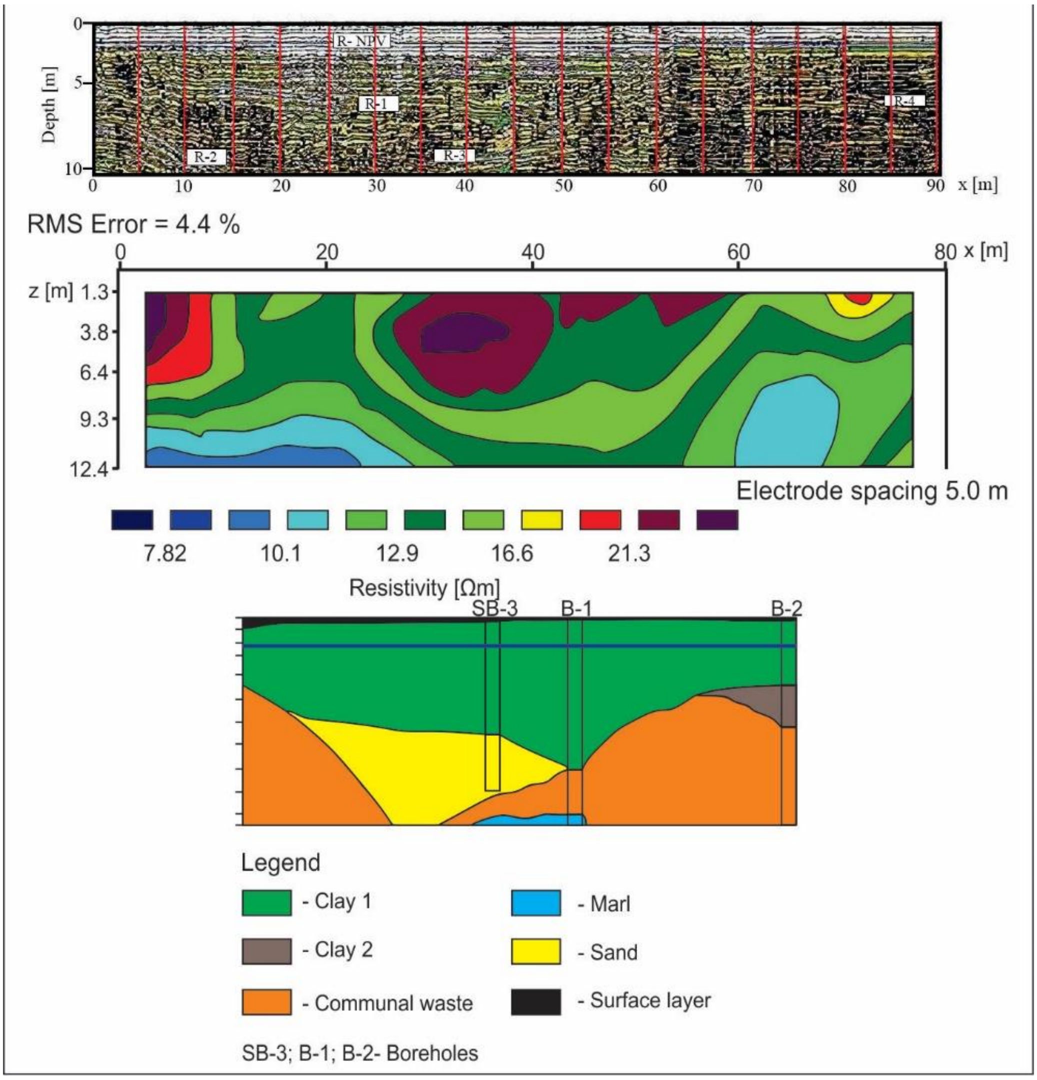


Fig. 7. GPR section (top), ERT section (middle) and the geotechnical profile (bottom)

Ground penetrating radar was used as part of a survey to determine the feasibility of constructing the railway plateau without excavating the communal waste complex. The GPR survey successfully demonstrated the ability to identify the spatial relationship of the communal waste dump, its base and surface layers, as well as the groundwater level and different composition zones within the communal waste dump. Figure 7 (top) shows the GPR survey results, which were collected using a 300 MHz antenna along the same route as the geoelectrical profile. At shallower depths, distinct amplitude reflections can be seen as a result of the surface gravel layer, which has a thickness of a few decimeters; the next reflection R-npv corresponds to the groundwater level determined by borehole results. For each GPR reflection one thinner and two thicker stripes ("triples") that correspond to one sinusoidal signal with a one-color amplitude (peak), a zero line (thinner line), and then a negative amplitude (trough) can be seen. The boundary of dark grey clays and sand corresponds to reflection R-1, the boundary of communal waste-sand to reflection R-2, the boundary of marl-communal waste to reflection R-3, and the boundary of dark grey clays – marl clays to reflection R-4.

Given the extremely low resistivity values found in the surveyed subsurface, which can attenuate the electromagnetic signal, the obtained results are excellent in terms of both depth of investigation (around 10 meters) and resolution. The series of resistivities found in the subsurface was advantageous in this survey; the surface layer has a resistivity of around 30 Ωm, which is accompanied by lower resistivities found deeper in the subsurface with a resistivity of around 10 Ωm. The detected marl cannot be distinguished from communal waste based on resistivity, but it does contain a significant amount of water, which can cause a contrast in the GPR section. In comparison to the geotechnical profile, the GPR section has more details and a higher resolution than the geoelectrical profile. Figure 7 shows the original GPR section with the attenuated zones (darker zones) as well as the 2D geoelectrical imaging model and the geotechnical model.

Geoelectrical scanning could be done with more electrodes and a smaller unit electrode spacing (less than 5 meters), which would improve horizontal resolution but not vertical resolution. Following the test survey's findings, it was determined that in future detailed surveys, GPR and geoelectrical methods would be used instead of the seismic method. Depth conversion, or the transition from time domain to depth domain, can be difficult with GPR surveys. Given that distinct lateral changes can be assumed with the communal waste dump, depth conversion would be difficult with longer profiles where borehole data would be scarce. Another issue would be a low resistivity surface layer at certain points along the profile, which would attenuate the GPR signal and thus restrict the depth of investigation. Signal attenuation and lack of reflection continuity are strong indicators of potential contamination, and they can help map contaminated areas.

An extensive investigation into the communal waste dump "Ada Huja" is given in Sretenović et al. (2019).

4. ROCK QUALITY SURVEYS WITH THE GEOELECTRICAL SCANNING METHOD

In order to investigate the rock quality at the granitoid rock quarry " Pločnik " in Brajkovac near Lazarevac, complex geophysical, geotechnical, and remote sensing surveys were conducted. In order to achieve the most reliable and cost-effective combination of geophysical methods, GPR, geoelectrical scanning, and seismic refraction with one geophone (single geophone refraction profiling – SGRP) were used. Five boreholes were available during the geophysical data acquisition, three of which revealed unusually high surface layer thicknesses (up to 15 meters). The top layer is made up of a thin layer of clay and disintegrated material. In addition, distinct lateral changes in thickness and physical properties were estimated. Due to signal attenuation of the low resistivity clay surface layer, GPR and SGRP were unable to provide useful information.

The Single Geophone Refraction Profiling (SGRP) method was used along the electrical scanning profiles to investigate the lateral variations in rock masses using another physical property, lateral velocity variations, which revealed a relatively thinner covering layer. The tests were carried out with two separate offsets and maximum penetration depths of around 5–8 meters. This relatively simple and fast geophysical qualitative approach had a strong connection with the results of the 2D analysis of electrical imaging data sets (increased arrival time denoting lower velocity and resistivity in Figure 8) and could be used as a supplement to confirm the existence of sharp lateral lithological variations.

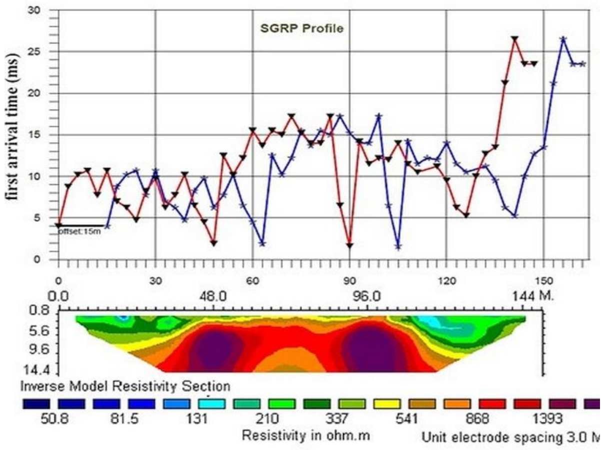
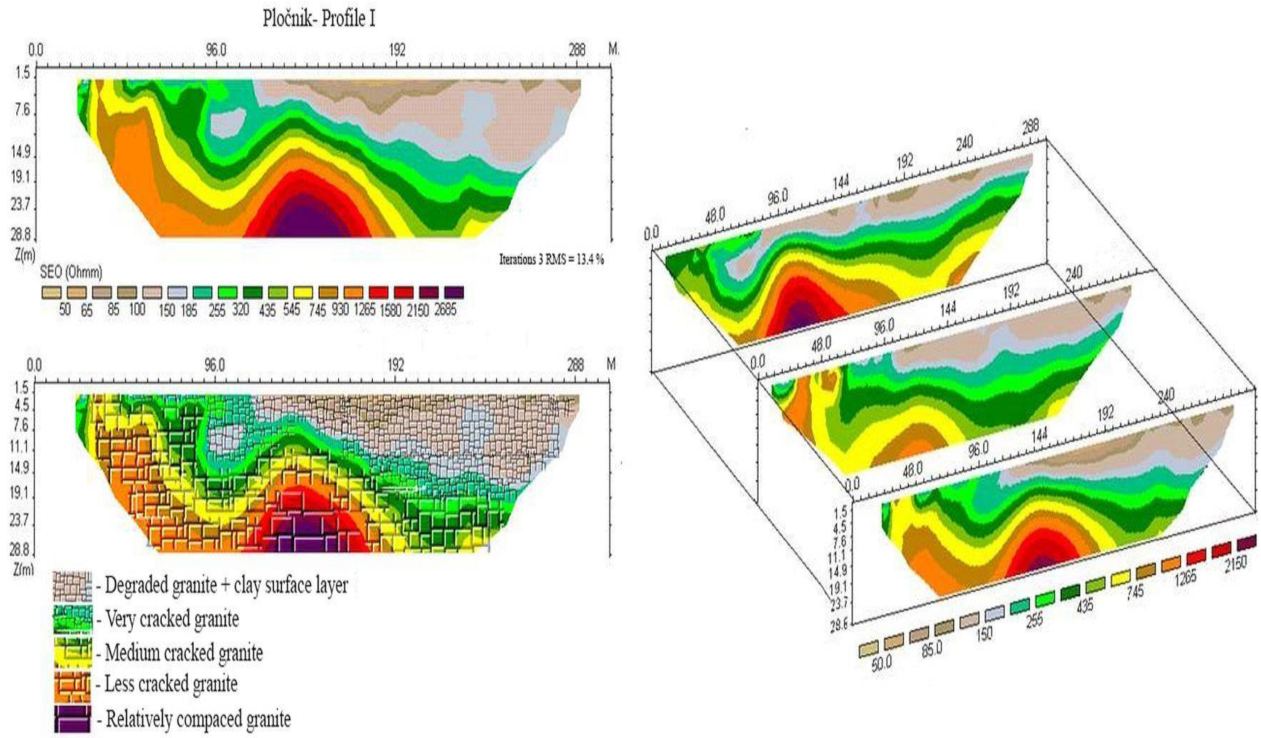


Fig. 8. Qualitative refraction survey with the SGPR method (measurements are attached to the position of the ignition point – red line, and to the position of the geophone – blue line)

Figure 9a demonstrates how geoelectrical scanning was useful to a depth of over 30 meters, enabling disintegrated material with lower resistivity values to be separated from more compact rocks with higher resistivity values. On a series of parallel profiles, the lateral changes were correlated, suggesting the 2D geometry of subsurface structures (Figure 9b). The geoelectrical survey was carried out on ten depth levels, with a varying unit electrode spacing controlled by the thickness of the surface layer, allowing for different depths of investigation and horizontal resolutions. Bigger unit electrode spacings were imposed by thicker surface layers, lowering horizontal resolution.

The Pločnik quarry has also been investigated in Sretenović et al. (1999).



a) b)

Fig. 9. (a) 2D model obtained after inversion of profile I at "Pločnik"
(b) Correlation of three parallel profiles at the rock querry "Pločnik"

5. 2D GEOELECTRICAL SURVEY FOR THE SAINT VASILIJE OSTROŠKI TEMPLE FUNDING

It is important to assess the condition of the soil and bedrock during the construction of a building in order to fund and determine the risk of subsidence. 2D geoelectrical surveys will provide detailed information on the type of bedrock and the overall subsurface where a potential structure will be constructed. Figure 10 shows a 2D electrical imaging survey along two perpendicular profiles on the site of "Saint Vasilije Ostroški" proposed temple in Banjica (Belgrade). Profile I has an east-west heading and indicates a steady rise in the thickness of high resistivity sediments (humus, marl like deluvium, clays, etc.) from the 76th to the 100th meter on the profile, with a west heading.

Local low resistivity inhomogeneities (most likely dusty clays) can also be seen in the sediment region between the 12th and 16th meters, the 20th and 24th meters, and the 52nd and 60th meters. The 3.2 percent RMS difference between observed and theoretically calculated data indicates that local inhomogeneities have no significant impact on 2D data inversion. Profile II, which has a north-south heading and a lower RMS value of 2.7 percent, can be approximated graphically as a simple 1D subsurface architecture. Profile II measurements were taken with a unit electrode spacing of 3 meters, allowing for greater horizontal resolution and a shallower depth of investigation of 9.5 meters compared to profile I (13 meters).

Due to signal attenuation and ambient noise, refraction seismic surveys that were also conducted, which identified the near surface layer with a thickness of a few meters but had limited depth of investigation. Borehole data allowed for the geological identification of geoelectrical layers, as well as the investigation of the drilling core through geomechanical laboratory experiments. Since there are no discernible lateral changes in the geoelectrical survey area, the data from the geomechanical laboratory may be extended to the entire survey area, lowering the survey cost.

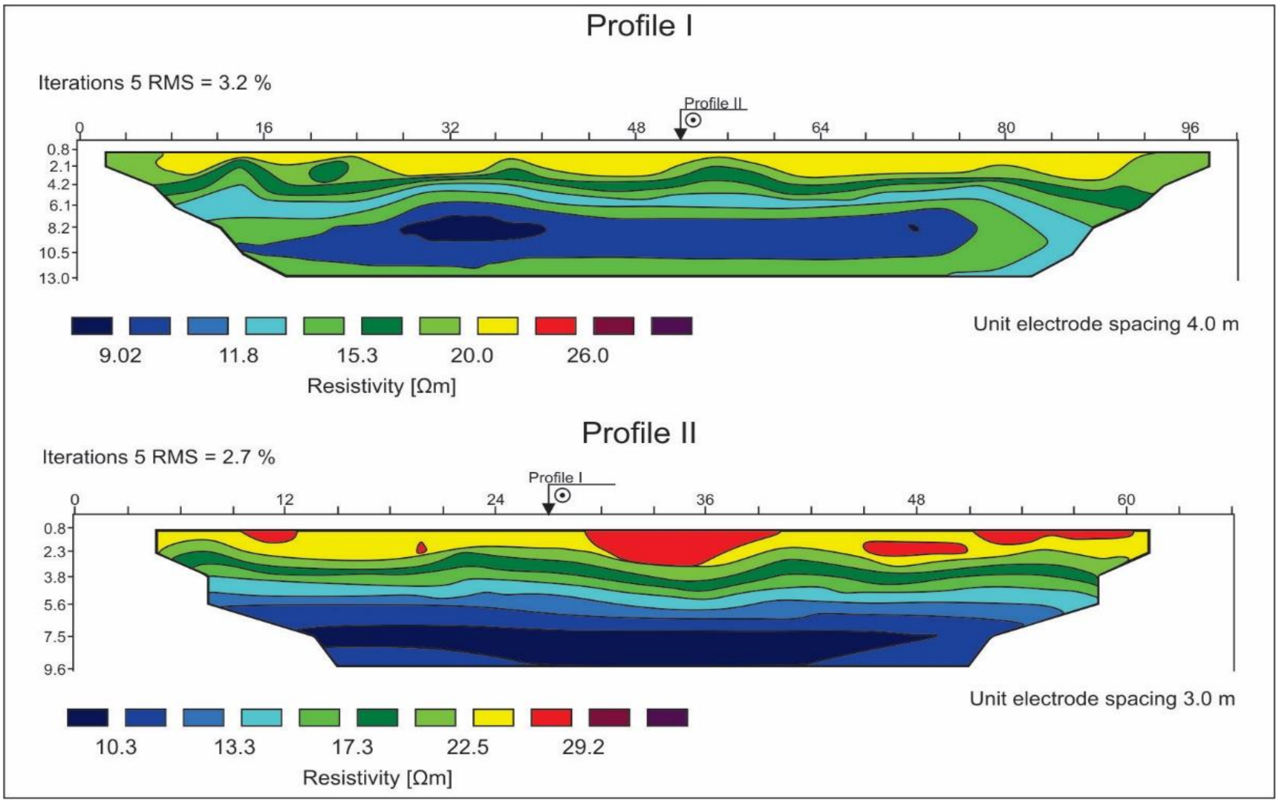


Fig. 10. 2D geoelectrical survey for the funding of the temple of Saint Vasilije Ostroški

6. "ADA CIGANLIJA" LAKEBED GPR SURVEY

The artificial lake "Ada Ciganlija" is a popular tourist, leisure, and excursion destination in Belgrade (Serbia), attracting hundreds of thousands of visitors each day during the summer season. At the same time, since this lake is close to the groundwater resource "Makiš," it should be given special attention as a form of ecological protection.

Divers and an eco-sounder were used to assess the thickness of the sedimented mud and sludge during the monitoring process. Without knowing the structure of the lakebed, those measurements could only reflect its morphology. The use of ground penetrating radar allowed data on lakebed thickness and morphology to be collected. A plastic boat was used to conduct the GPR survey (plastic material does not alter the propagation of electromagnetic waves), with an 80 MHz antenna. The maximum depth of investigation was about 8 meters, which is similar to the maximum depth of investigation that an 80 MHz antenna in water would achieve.

Figure 11 depicts the lake's morphology clearly, with just a few reflections from the mud and clay bedrock. Figure 11 shows that the mud thickness is very low, so the pond succession process is not considered dangerous. Because of the lower slope angle, the east side produces better reflections. In the presence of higher slope angles, reflective methods are known to be limited. When it comes to the slope angle, GPR surveys have a limit of 30 – 35 degrees; values above that limit represent the electromagnetic signal towards the surface, i.e. the receiving antenna. Over the winter, while the lake is frozen, the same survey may be done more effectively. Since ice is essentially an insulator, it does not interfere with electromagnetic wave propagation. Since water is homogeneous and has a constant electromagnetic wave propagation velocity of 3.3 cm/ns, GPR surveys over water bodies are among the easiest to interpret.

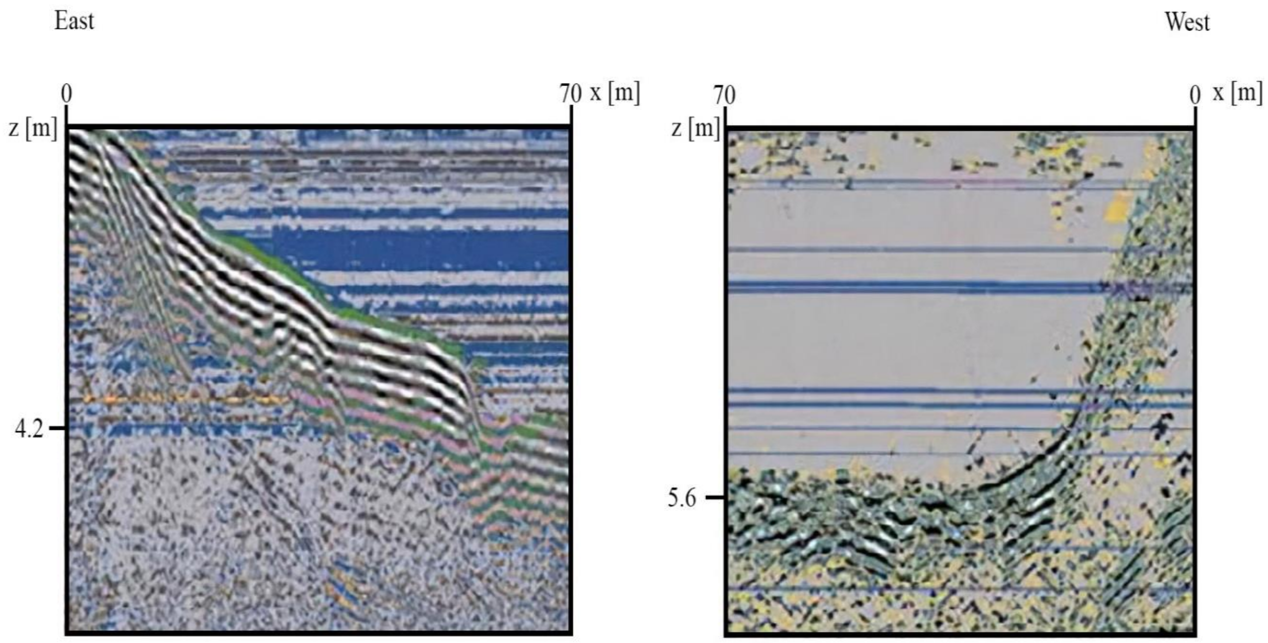


Fig. 11. GPR survey over the east and west coast of the Ada Ciganlija lake

7. BELGRADE AIRPORT RUNWAY GPR INVESTIGATION

The Belgrade Airport's runway needed immediate reconstruction in order to extend its operational lifetime, improve protection when in use, and install visual navigation instrumentation. GPR surveys were conducted during the preliminary phase of runway reconstruction to ensure that the data acquired was of high quality. The main aim of the test was to look for potential linear cavities at the intersection of the concrete slab and the gravelly buffer layer, as well as the buffer zone's boundary with the lost bedrock.

Because of the runway's layout, anomalies in the zone of metal joints between concrete slabs are probable. Since the same anomaly can be observed in cavity zones, this was just an observation. A 500 MHz antenna was used to fulfil the preliminary project goals; the antenna acted as a compromise between the depth of investigation, which was about 1.5 meters, and the resolution needed to detect the 0.5 × 0.1-meter cavities. The 40-ns length of the GPR radiogram was sufficient for obtaining a satisfactory depth of investigation; however, depending on the antenna velocity, a total of 12 – 25 impulses per second ("scans") were used. The maximum speed of the acquisition vehicle was 20 km/s, and each profile (scan) contained 512 digital samples.

Multiple high-amplitude reflections at the metal joints between concrete slabs that are uniformly spaced at 8 meters is clearly visible in the raw GPR subsurface image (Figure 12a). The reflections from the boundary concrete-gravel buffer layer, as well as the reflections from the gravel-loess bedrock boundary, are partly hidden by these high reflections. The antenna noise is visible in the raw data at 30 ns, as well as some high frequency noise. The noise effects were minimized by data processing that included horizontal and vertical data filtering with a low bandwidth filter. A minor deflection on the profile's left side that can lead to concrete slab failure. Increased water content can be indicated by an increase in dark coloured amplitude reflections at the contact of gravel and loess in the non-disturbed region, which increases the contrast between dielectric constants in two mediums.

Figure 12[b] shows the most remarkable example of GPR surveys' powerful resolution. With both reconstructed and non-reconstructed runway areas, the profile traverses above the field.

The Belgrade Airport runway survey can also be seen at Sretenović et al. (1997)

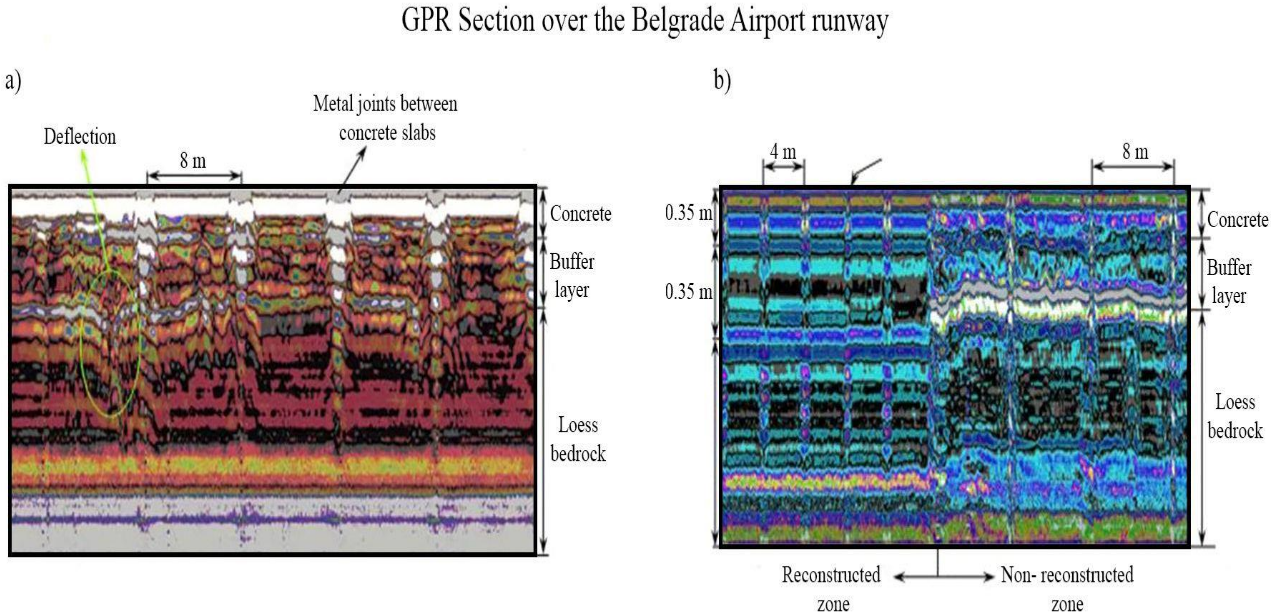


Fig. 12. (a) Raw GPR image, (b) GPR image over the reconstructed and non-reconstructed zone

8. CONCLUSION

In comparison to simpler refraction seismic surveys with inadequate number of ignition points, geoelectrical surveys that are based on the 2D imaging method provide better results. With a large enough number of ignition points, refraction seismic surveys could better assess lateral changes and the velocity of elastic wave propagation in the subsurface.

Where there is a need to cover a wider surface area, which borehole data cannot provide effectively, the geoelectrical scanning method shows its benefits. The ERT method provided useful surface knowledge about plausible cavities in the "Junkovac" example. Two anomalies were subjected to boreholes, one of which was discovered to be a sand lens and the other to be a cavity. Borehole data should resolve the uncertainty between the high resistivity material and cavities.

In the case of the "Ada Huja" communal waste dump, the low resistivity communal waste is easily detected and differentiated from the higher resistivity marl bedrock using the ERT method. The geoelectrical model, as in the previous case, revealed more information about the subsurface than the geotechnical model. Signal attenuation and a lack of reflection continuity during GPR surveys at the "Ada Huja" communal waste dump site were strong indicators of subsurface contamination.

The SGRP method, in conjunction with the ERT method, provided valuable information about subsurface lateral changes at the "Pločnik" granitoid quarry. Furthermore, the ERT method provides accurate data on the degree of rock disintegration.

When using the GPR method to survey a lakebed, a coast with a lower slope value, usually between 30 and 35 degrees, should be favoured. Since water is homogeneous and has a constant electromagnetic wave propagation velocity, GPR data interpretation over a water body is relatively simple.

At the Belgrade Airport runway, GPR surveys demonstrated its high-resolution capabilities.

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Р е з и м е

НЕКОИ ПРИМЕРИ НА ПРИМЕНАТА НА МЕТОДОТ НА ЕЛЕКТРИЧНО СКЕНИРАЊЕ (ЕРТ) И ГЕОРАДАР (ГПР) ВО РЕШАВАЊЕ ПРОБЛЕМИ ОД ГРАДЕЖНОТО ИНЖЕНЕРСТВО

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Клучни зборови: електричен метод (ЕРТ); георадар (ГПР); инженерска геологија

Во овој истражувачки труд се сретнуваат неколку инженерско-геолошки и геотехнички истражувања на случаи, кои се решени со помош на дводимензионален (2D) електричен метод (ЕРТ), а во четири случаи со георадар (ГПР). Прикажани се случаи кои ја демонстрираат разновидноста на ЕРТ-методот, како и други методи кои ги надополнуваат добиените ЕРТ-податоци. Извршени се истражувања на флотациска јаловина, детекција на стари рудници, депонии на комунален отпад, истражувања на квалитет на карпа и корито и сл. Методот на дводимензионално електрично скенирање ја докажа својата ефикасност и ефективност во поглед на трошоците, особено кога истражувањето бараше да биде истражена поголема површинска зона.