Application of electric resistivity tomography for investigation of geological situation closed to railways

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Abstract. The paper reviews methods of engineering geophysics which can be applied to sections of railway tracks. The method of electrical resistivity tomography is used to study the properties of the geological situation under an engineering structure. In the course of practical work, two-dimensional geoelectric sections were obtained. Interpretation of the sections allowed to understand the structure of the near-surface zone.

1 Introduction

The application of methods of engineering geophysics is perspective for solving a wide range of engineering and geological problems. The object of research, most often, is the near-surface section (NSS), characterized by considerable heterogeneity, variability in the lithological composition, structure and physical properties of the rocks. That can be applied for studying the space under the railway tracks. The efficiency of geophysical researches is achieved by using methods of various physical nature, with high accuracy of observations, obtaining integral characteristics, reflecting the features of the structure and properties of the rock massif in its natural occurrence, the possibility of repeated observations without disturbing enviroment's structure [1,2]. The leading methods are seismic: the method of refracted waves, more rarely - the method of reflected waves. The complex of electroprospecting methods used for engineering investigations includes electroprofiling by methods of apparent resistivity and natural field, georadiolocation, vertical electric sounding (VES), and electromotography.

The inability to use seismic methods is due to the proximity of the railway network, which introduces additional interference waves, which are heavily distinguishable from the useful signal when processing the set of seismic trains [3].

Georadar's methods are based on the study of the permittivity of the enviroment. The high value of the dielectric constant depends directly on the water content in the rocks [4]. Thus, the priority object of investigation of georadar locating methods can be watered areas in the near-surface zone.

The combination of methods of electroprofiling and vertical electrical sounding makes it possible to carry out measurements by the method of electrical resistivity tomography, which

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is characterized by high detail of the NSS with a wide manifestation of natural processes, human engineering activities and changing physical properties.

In this regard, in our study, an example of the use of the method of electrical resistivity tomography for solving a problem that arose in the immediate vicinity of an engineering structure related to a railway network was considered. In this connection, in our study an example of using the method of electrical resistivity tomography for solving a problem that appeared close to an engineering structure related to a railway network is considered.

2 Resistance methods

One of the most common methods of engineering geophysics nowadays are the resistance methods. The resistance methods are a group of methods based on the study of electrostatic fields created in the earth's crust by point or dipole sources. The standard electrode array for this method consists of 2 source electrodes (AB) through which a direct current is passed to the ground and 2 measuring electrodes between which the potential difference is measured.

The group of resistance methods includes vertical electrical sounding (VES), electrical profiling and the charged body method (CBM). When working with the VES method, the dependence of the apparent resistivity on the distance between the field sources and the points of its measurement is studied. With the increase of this distance, the depth of investigation grows. So, values of apparent resistivity are affected by deeper parts of the geological section. Application of VES method is preferable in horizontally layered media.

In case of electrical profiling the size of the electrode arrow and, consequently, the depth of investigation remain the same, and the arrow itself after each measurement moves along the profile. This method allows to study the geological structure along the profile or the network of profiles and is informative in case of presence of steeply falling layers in the section [9].

The method of a charged body (CBM) is used to study the shape, size and position of geological formations which resistivity is significantly less than the resistivity of the host rocks. In the apparatus for this method one of the electrodes of the source line is located directly in the studied geological body (at the point opened by drilling), and the second is placed at the distance, so that its electrical field can be neglected. The electric or magnetic field of a charged body is studied on the ground surface using measuring electrodes or an induction frame. The behavior and character of the equipotential lines over the charged body allows to determine the shape and position of the charged ore body in the earth's crust [10].

Electric resistivity tomography is a modern modification of the resistance method. The main features of this technique are multichannel measurements provided by a system of electrodes arranged along the same profile at equal distances from each other. At each moment of time a measurement is carried out with apparatus which has a predetermined arrangement of the source and measuring electrodes, the electrode spacing and the position of the measure point. This approach leads to a substantial increase in the measurement density. Systems of this type provided the ability to carry out fully automatic measurements and quality control, which brings the electrical exploration by the resistance method to a qualitatively new level.

3 Practical research

Electromotography is a whole complex, which includes both the field observation technique and the technology for processing and interpreting field data. The specificity of the method is that the positions of the electrodes fixed on the observation profile are used repeatedly as feeding and measuring devices [8]. This approach allows, on the one hand, to work with modern high-performance equipment, and on the other hand, to apply effective modeling and inversion algorithms. Interpretation of the data of electromotography is carried out within the framework of two-dimensional (2D) and three-dimensional models (3D). This essentially broadens the range of problems solved by electrical prospecting, by examining media that are significantly different from the "classical" horizontal-layered ones. First of all, 2D electrical survey has a high density of observations, achieved by the application of appropriate surveillance schemes. [5]. Another component of two-dimensional electrical prospecting is an automatic two-dimensional inversion of data, primarily within the framework of "smooth" models [6].

In recent decades, the technique has become widespread in the West. In Russia, because of the practical lack of multi-electrode equipment, the introduction of this approach is just beginning.

Figure 1 shows a comparison of multichannel and multi-electrode instruments. Multi-channel multi-electrode equipment is actively used: 10-channel Syscal-Pro (Iris Instruments), 4-channel SAS4000 (ABEM) and others [7]. Such meters allow one to obtain values of the potential difference for several receiving dipoles in one measurement cycle (Fig. 1B). Due to this, it was possible to increase the speed of field observations several times, which was always a fundamental limitation of direct current geophysics. In multi-electrode sensing, hundreds of thousands of measurements are carried out at one installation position, so the speed of observations plays a very important role. In addition, rapid measurements open up new opportunities for using electrical reconnaissance in monitoring various engineering processes.

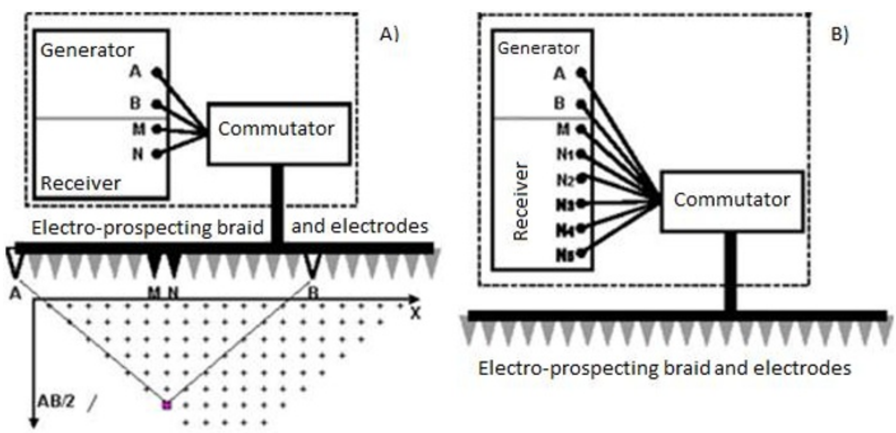

Fig. 1. Schemes of multi-electrode (A) and multi-channel (B) equipment [8].

All of the above advantages allowed the company "Geophyspoisk.", engaged in the solution of complex engineering problems, to conduct the work by the method of electrical resistivity tomography, in the difficult conditions characteristic for the railway. On the railroad, where the Russian-Finnish Allegro train passes, an emergency situation occurred. On both sides of the road, excavations were dug for directional drilling. During the work, there was an involuntary pushing of the drilling device on the surface. This is due to the fact that the drilling rig was designed for sandy soil, but at a certain place, presumably, there were rock outcrops of a more dense composition. The work was stopped, the installation was removed from the ground, as a result of which, the ground at the work site sank. To clarify the reasons, it became necessary to study the nature of the bedding. The goal was to obtain information about the geological structure of the site, the underlying strata, differing in the value of the electrical resistivity

During electrical exploration, the measurements were carried out using a multichannel electrical prospecting equipment "SYSCAL Pro", with a combined receiver, generator and commutator together. The apparent resistivity values are recorded every 2 seconds and transmitted to the control computer. Specialized software enables view the graphical representation of results, including sections of apparent resistivity, in real time.

Sealed 24-electrode electro-probes were used with a distance of 1.5 meters between the electrodes. After connecting the electrodes (pins made of titanium alloy 40 cm long and 10 mm in diameter) to the spit, one electrode was set to "infinity" in a perpendicular direction with respect to the position of the braid. The distance from the center of the braid to the "infinite" electrode was about 250 m. The second current (supply) electrode was the electrode on the spit. When the current was passed, measurements were made on all remaining electrodes of the braid, where the distance between the electrodes MN of the receiving pair along the observation line varied from 1.5 to 4.5 m, depending on the removal of the supply electrode. After the measurement cycle was completed, the current electrode became the next-in-order electrode on the spit, and the potential difference was measured on the remaining pairs of spit electrodes in the same manner as described above. As a result of using such a technique, the values of the apparent resistivity along the profile section of interest were obtained.

To process and analyze the quality of measurements, the program "COM-Zond", specially adapted for working with the used set of equipment, was used.

At the first stage, estimates of the measurement variances were calculated, and measurements that were clearly overestimated or underestimated compared to the remaining values were rejected. The quality of the measurements was also monitored and directly during the measurements - according to the standard deviation values. In addition, to assess the quality of field materials, a special algorithm based on the properties of the potential and the principle of reciprocity was used.

Also, the data were analyzed for individual rebounds of the measured parameter associated with methodological measurement errors. The data was then devided into separate elements and analyzed together. As the elements, measurements were used for the same spacing and positions of the current electrodes. If the data for one of the elements was very different from the neighboring ones, then such an element was excluded from the processing. The total percentage of rejects amounted to no more than 1.5% of the total number of measurements at the research site.

For further processing, the data was "stitched together" into a single array and used in the "ZondRes2D" program, which allows solving the direct and inverse problem of electrical resistivity tomography.

As a result of the final processing of electro-prospecting materials, a geoelectric profile profile was obtained (Fig. 2). The values of electrical resistivity in the area of work vary from the first dozen ohm meters to tens of thousands of ohmmeters. The sections are mainly represented by a three-layered environment. The upper part of the section is most likely composed of high-resistivity, slightly water-saturated sandy-pebble soil. The watercourses of the rocks gradually increase with depth, which is clearly seen from the lower values of the resistivity in the depth interval 3-6 meters.

On the profile of PR_OCH, traversed directly under the railroad track, a high-resistivity region (resistivity up to 4000 Ohm) is presumed in the lower part of the section, presumably corresponding to a dense rocky ground. The roof of the proposed rock formation lies beneath the rail embankment at depths of 2.7 meters to 4 meters. The reliability of the received materials is confirmed by the data of the verification (PR_2 and PR_3) profiles. Some misalignment of the cuts at the points of intersection can be explained by the effect of the lateral (three-dimensional) influence of the environment.

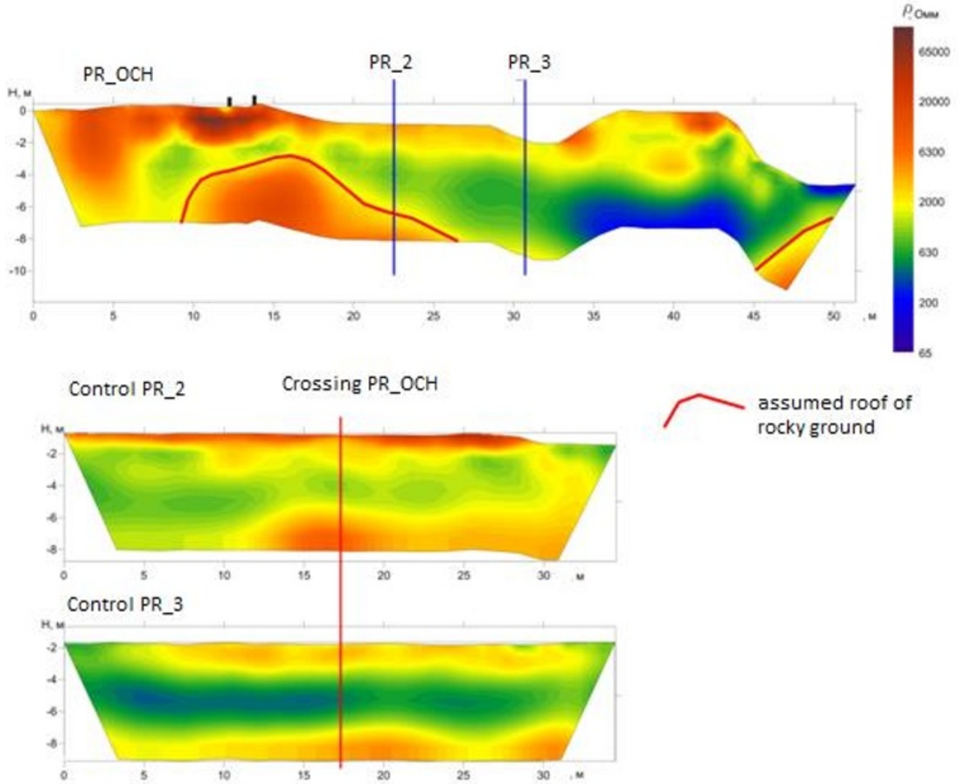

Fig. 2. Geoelectric sections obtained by the results of electrical resistivity tomography, PR_OCH - the profile of the area of work that crosses the railway tracks, The PR_2 is the verification profile orthogonal to PR_OCH at point 2, The PR_3 is the verification profile orthogonal to PR_OCH at point 3.

4 Conclusion

Proceeding from the received data, the conclusion is made that the method of electrical prospecting used under these conditions is fully operational for solving the tasks set. Difficulty in interpreting the data causes a lack of drilling data. Nevertheless, the received materials are trustworthy, as evidenced by the satisfactory results of comparison of geoelectric sections at the intersection points.

Such work is best done in conjunction with other geophysical methods (in order to improve the reliability of the results) and prior to the construction of the transitions, since the presence of a construction and drilling tool on the research site is a serious problem for most geophysical methods. The prospect of using electrical survey methods to check railway tracks for wear during operational operation is obvious. Low cost of work, as well as the express method allows timely allocation of hazardous areas and apply preventive measures.

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