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GPR Method as a Non-Invasive Method for Investigating Organic Soils Deposited under Designed Road Construction

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Abstract. GPR method is a non-invasive technique for ground exploration which detects subsurface objects and assesses their presence, as well as provides information about the geological structure of investigation site. Ground penetrating radar method belongs to the group of geophysical methods as it uses electromagnetic waves. GPR technique takes advantage of the differences between the dielectric constants, specific for the material under analysis. One of the factors that are essential to record reliable data is a clear contrast between the dielectric constant of investigated object and its surroundings. One of the major advantages of GPR is that it does not damage ground surface as well as it is completely non-invasive and safe for the environment. Moreover, the method is particularly useful in the design and realisation process of linear objects, for among the multiple aspects of its utilization there is recognition of low-bearing organic soils. The discontinuous nature of traditional methods makes it difficult to precisely specify ground layering as well as accurately locate potential anomalies. The analysis carried out in this study shows that GPR technique can detect the boundaries of soil layers, which considerably simplifies ground assessment.

Keywords: ground penetrating radar method (GPR), non-invasive ground investigation, organic soils.

Conference topic: Roads and railways.

Introduction

The presence of organic soils in the substrate, with simultaneously occurring high groundwater level requires the application of appropriate improvements to the ground. Proper selection of strengthening, however, demands a very precise diagnosis of conditions in the substrate. In the case of linear objects, such as transport routes, the standard field tests, however, may not provide the right amount of information, especially among research points.

GPR method is one of the geophysical methods, which in a non-destructive manner provides data about the structure of the substrate and subsurface location of objects. The core of this study is electromagnetic technique, based on the emission of artificially induced electromagnetic impulses at high frequencies and the registration of the waves reflected from the boundaries of media with different properties (Rucka, Lachowicz 2014a). The signal, while passing through the layers with different properties changes. The waves may be subject to such phenomena as reflection, refraction, interference, diffraction, resonance or attenuation, and the analysis of these changes enables identification of the substrate (Rucka, Lachowicz 2014b). Moreover, the more pronounced is the difference of relative parameters between the two materials, the more easily observable is the change in the process of propagation of the electromagnetic wave at the boundary.

GPR method principles

The properties of the substrate which have the greatest influence on the propagation of electromagnetic waves are magnetic permeability, dielectric permittivity, and conductivity of the medium. These parameters can significantly vary from each other depending on the structure of the lithological substrate and its chemical composition, porosity, water accumulation, the degree of loosening or salinity (Łyskowski, Mazurek 2013). Nevertheless, the main factor characterizing the electromagnetic field is the absolute permittivity, i.e. dielectric permittivity. In practice, a more frequently used parameter is the relative parameter, also known as dielectric constant (Drożdżak, Twardowski 2010), which is the ratio of dielectric permittivity of the material to electric constant, i.e. vacuum permittivity (1):

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}, \tag{1}$$

where: ε_r – dielectric constant; ε – dielectric permittivity of the material, ε_0 – electric constant (vacuum permittivity).

Consideration of the impact of various factors on the electrical characteristics of the studied media is difficult. Experimental studies have allowed, however, an approximate determination of the size of the dielectric constant of various materials, which may vary from 1 to 88, for example, clay soil 4–15, sandy-clay soil 4–20, sandy soil 4–30, water 78–88, the ice 3–8 (Sudyka, Kraszewski 2009).

GPR design used in the study of the subsoil is made up of elements such as transmitting and receiving antenna, transmitter and receiver, and the recording unit of the central unit with the computer. Electromagnetic pulse induced by the transmitter and emitted deep into the ground using a transmitting antenna propagates in the medium, and the receiving antenna registered the reflected pulse and digitized in the receiver (Karczewski 2007). The central unit is to enable monitoring of the entire system, coordination of gauges of transmitter and receiver, recording of the amplitudes of the received electromagnetic wave and presenting the results in the form of echograms (Łyskowski, Mazurek 2013). The antenna can be regarded as an essential element of GPR ensuring sufficient accuracy. Apart from the mono and bistatic antennas, there are also linear, aperture, shielded and unshielded antennas. Currently, the most commonly used antennas are shielded, whose main advantage is directing the generated electromagnetic pulse. Antennas operating in GPR can also be distinguished by the bandwidth of the emitted signals.

GPR measurements should be carried out in such a way as to obtain the most accurate information about the tested medium and, at the same time eliminate potential errors (Pasternak 2015). The basic techniques of performing measurements using GPR is reflection profiling, profiling of speed, screening and hole profiling (Sudyka, Kraszewski 2009). The use of reflection profiling, profiling of speed, screening or hole profiling does not fundamentally change the way of actual measuring process itself. In any case, the antennas are moved mainly along the adopted profile line, yet the results differ sharply (Ortyl 2006). During the simultaneous movement of transmitting and receiving antennas along the test profile, time sections are derived, which after appropriate treatment illustrate the geological structure of the substrate (Karczewski 2007). To correlate the information obtained with the depth at which there is an obstacle, the method of profiling of speed should be used, as it is necessary to determine the rate of the electromagnetic wave. Both techniques are thus related to each other to some extent (Olszak, Karczewski 2008). The main difference, however, lies in the setting of the transmitting and receiving antennas. In the case of reflection profiling, typically a parallel arrangement of bistatic antennas is applied, which are situated to each other in proximity, and then simultaneously moved along the planned route (Pasternak 2015). While in reflection profiling it is possible to use monostatic antennas, in profiling of speed it is convenient to use unshielded antennas. The essence of the method is, in fact, reflective observation of lines recorded during the subsequent changes in the spacing of the antennas.

The maximum depth range and resolution of GPR method to a large degree depend on anticipated ground conditions and the choice of testing antenna, whose mission is to induce an electromagnetic wave with a specific frequency. The maximum range of GPR is usually subject to predicted depth to which it is necessary to examine the subgrade (Nawrocki, Piasek 2006). The signal emitted into the medium is characterized by a certain frequency. The use of higher frequency results in decreased range of electromagnetic wave propagation in the ground and, at the same time increasing the measurement accuracy (Daniels 2004). Analogically, at lower frequencies, the pulse penetrates deeper, but only larger objects and clearer boundaries of deposits are visible. This relationship can be explained by the phenomenon of attenuation, which rises along with increasing frequency of the wave. The depth to which is reached by induced energy is also dependent on the length and speed of an electromagnetic wave, or indirectly, on the electromagnetic properties of investigated media, which means that many factors influence the extent of the loss of the signal propagating into the tested substrate. Depth range of GPR method is strongly associated with its resolution. Discrimination of objects that lie along a vertical plane and perpendicular to the test direction is called vertical resolution, whereas if the objects are located in the horizontal plane, and parallel to the test direction, it is horizontal resolution (Sudyka, Kraszewski 2009).

Research site

As part of the examination of subgrade by GPR method, geophysical profiling was conducted on a local road, scheduled for reconstruction. The studied areas are located near Ruda, in Krypno Commune, Monki District, in Podlaskie Province. The exact locations of profiles were identified in Figures 1 and 2. The analyzed road runs through the lowland rural areas, i.e. arable land and meadows with low-density housing. It is now, in part, an asphalt surface road (near the profile # 1), and partly hard, unmade road (in the vicinity of the profiles 2 and 3).

The studied areas lie in the eastern part of Krypno Commune, hence, regarding the physical and geographical importance, they belong to mesoregion of the Bialystok Upland and macro-region of the North Podlasie Lowland. According to the Central Geological Database, the stratigraphic structure of the area was influenced by the Riss Glaciation which gave rise to the development of glacial landscape, i.e. sand and outwash gravel. In addition, the analyzed areas belong to the catchment area of the river Narew, with its unique, anastomosing characteristics. Profile 1 is located near the watercourse Kulikówka, while profiles 2 and 3 – near the watercourse Jaskranka. Repositioning of riverbeds and development of oxbow formations (information confirmed through environmental intelligence) caused in the Holocene evolvement of such soils like sand, gravel, alluvial soils and organic soils (peat and silt) in their vicinity. Organic soils, because of their origin are the deformable type of soils, and therefore cannot provide a stable base for the planned road. Leaving a layer of peat in the substrate may result in the future in the uneven settling of the ground and accelerated aggregation. It is crutial, therefore, not only to recognize this type of soils but also to estimate the extent of their occurrence in a given area, i.e. their outlining.

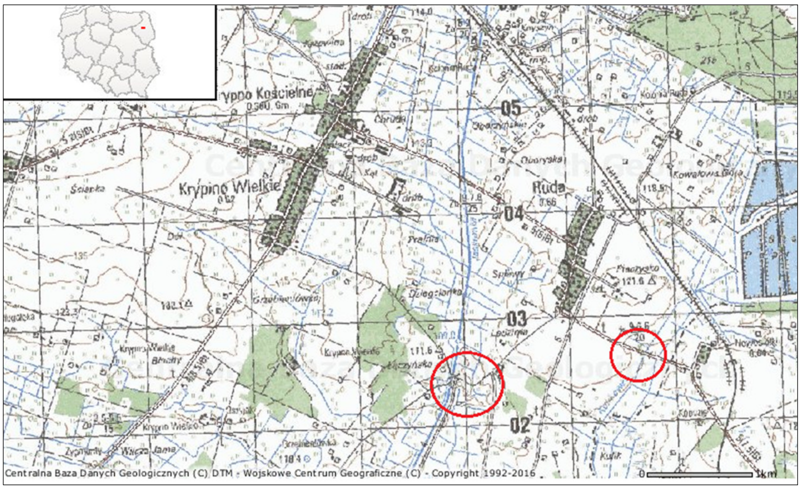

Fig. 1. Topographic map with the location of the area covered by the interpretation (Source: www.geoportal.gov.pl)

Fig. 2. Location of test points of profiles Nos. 1-3 (Source: www.geoportal.gov.pl)

Measurement instruments

Appropriate equipment and measurement parameters should be selected depending on the expected test conditions and anticipated results. In the case of substrate examination presented in the article a Latvian GPR, called Zond-12e was used, owned by the University of Technology in Bialystok. The complete set consists of a central unit connected to the computer, antennas with different frequencies, essential cables and wires, and measuring tape or measuring wheel (Fig. 3).

Before the measurements, appropriate test points must be selected in the ground and, as far as possible, the substrate should be cleared of elements which may disturb the image, e.g. stones, and then measuring tape shall be unrolled to specify the route for the passage of GPR profile. Two people best perform the measurement. The operator's task is to walk with the GPR along a given profile while maintaining a constant speed and ensuring correct placement of the equipment on the substrate. These are necessary elements in the reflection profiling technique, used in research (Karczewski 2007). As the antenna is moved to the profile, sections of time are obtained, which then enable visualization of geological boundaries. At the same time, an operator controlling the measurement should choose the appropriate measurement parameters and pre-interpret the data obtained during the test, which are displayed on the computer display during the measurement. The results are stored on computer hard drive, which allows further processing and filtering of data. An indispensable element of the radar equipment is software, compatible with the GPR. In this work Prism2 was used, a program dedicated to georadar Zond-12e. During the calibration of the equipment, the program sends signals of any errors and provides possible solutions to the problem, which greatly facilitates the work.

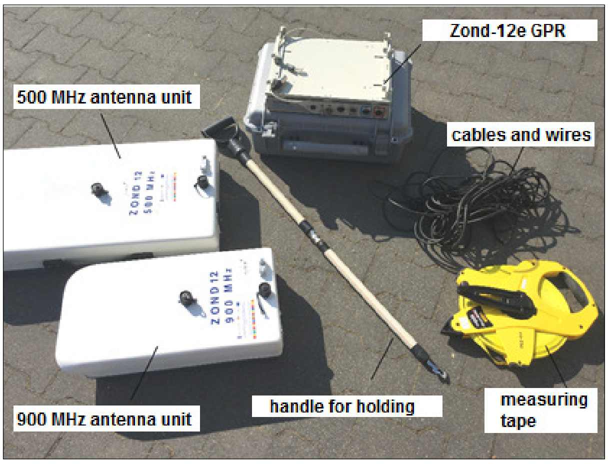

Fig. 3. Zond-12e GPR (Source: own elaboration)

To combine the data obtained from studies using GPR conventional geotechnical studies have been conducted. Investigation of the ground substrate was made by using a window impact sampling set, RKS with the diameter Ø70 mm and 50 mm, allowing the precise determination of the profile of the hole.

Test results

Performing tests of the ground substrate in the design of the road require the identification of the degree of complexity of the geotechnical conditions, which means recognizing individual layers of the substrate and determination of the water conditions. Usually, it is sufficient to drill boreholes and conduct a basic geotechnical investigation, reaching to a depth of approximately 2–3 m, at a spacing of 20 to 200 m. Long distances between holes, unfortunately, do not allow for proper execution of geotechnical sections, often required at the design stage. Even if they can be achieved, they have little in common with reality, especially in regions of the variable geological structure. On the long stretch, the alignment of the layer can dramatically change, and soils which have not been discovered before in test points may occur in the area between boreholes. Application of GPR method may achieve a more detailed description of the tests.

To identify the substrate within the planned road, 5 test holes were drilled in the ground, between which 3 GPR profiles were made. Subsequent GPR runs were conducted at different output level. When selecting measurement parameters at the stage of the performance of studies using GPR, particular attention should be given to the number of samples per scan, the time window and strengthening. Other characteristics are usually generated automatically, but there is also a possibility of manual input. The type of antenna, which, as previously stated affects the resolution of the method, and its depth range is also of high importance. The influence of the frequency of electromagnetic waves propagated in the substrate was checked on the example of 500 and 900 MHz antennas. It has been noted that the 900 MHz antenna can be successfully used in tests on the shallow substrate, but it does not prove useful in layers lying deeper.

The broad database, obtained as a result of research allowed the selection of echograms with the highest visibility and, at the same time, accurate identification of various lithological layers. Detailed analysis was performed on following echograms, conducted by using an antenna with a frequency of 500 MHz:

– run 8 in profile 1,
– run 1 in profile 2,
– run 3 in profile 3.

Images obtained from the investigation conducted by GPR method were digitized in a computer program, followed by changes to individual measurement parameters and application of filters.

As a result of both, the conventional drilling and geophysical tests organic soils have been discovered in the area, mainly peat and other soils of fluvial origin that were formed in the Holocene. Due to the low strength parameters, these soils should be subject to particular attention in the design. Therefore, echograms obtained by GPR tests were interpreted mainly regarding determining the depth of the organic soil. While it was possible to determine pass of horizons of organic soils deposits, precise description of thill of these formations was unsuccessful. To determine the depth of occurrence of the lower layer of peat an antenna with a different frequency should be used. However, the results shown in Figs 4–6, clearly demonstrate the limit of occurrence of peat in the substrate. Additionally, these drawings show the differences between the data acquired by GPR method and as a result of drilling research, which did not allow an accurate assessment of the peat horizon.

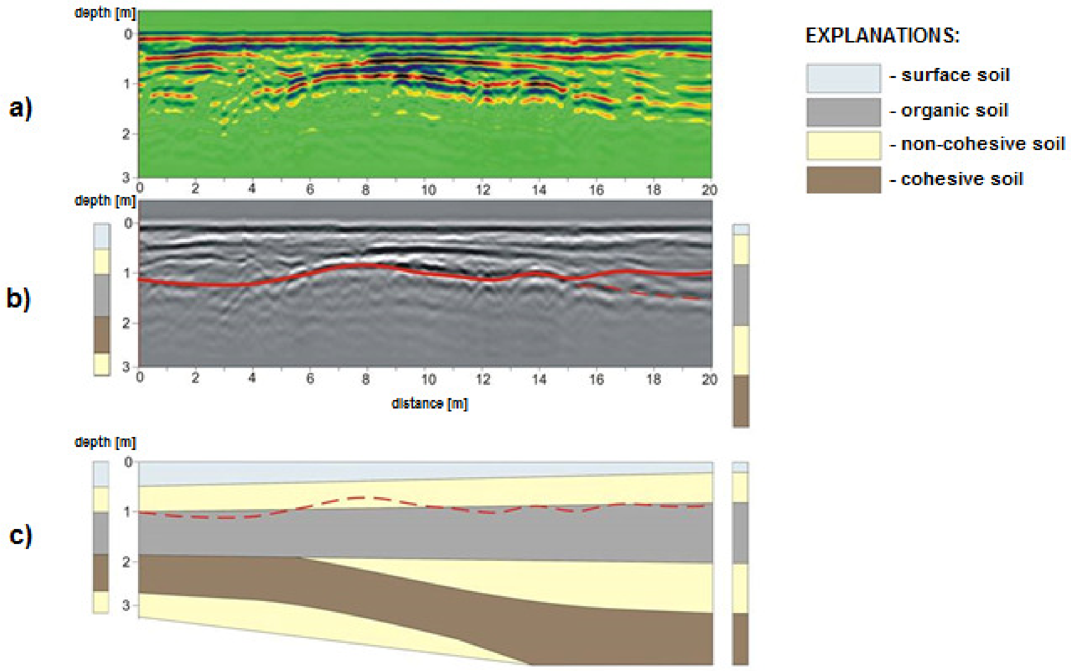

Fig. 4. Location of horizon of organic soils in profile No. 1: a) echogram obtained by GPR technique, b) the interpretation of the echogram obtained using GPR, indicating horizon of peat layer, c) cross-section of the substrate made by drilling (Source: own elaboration)

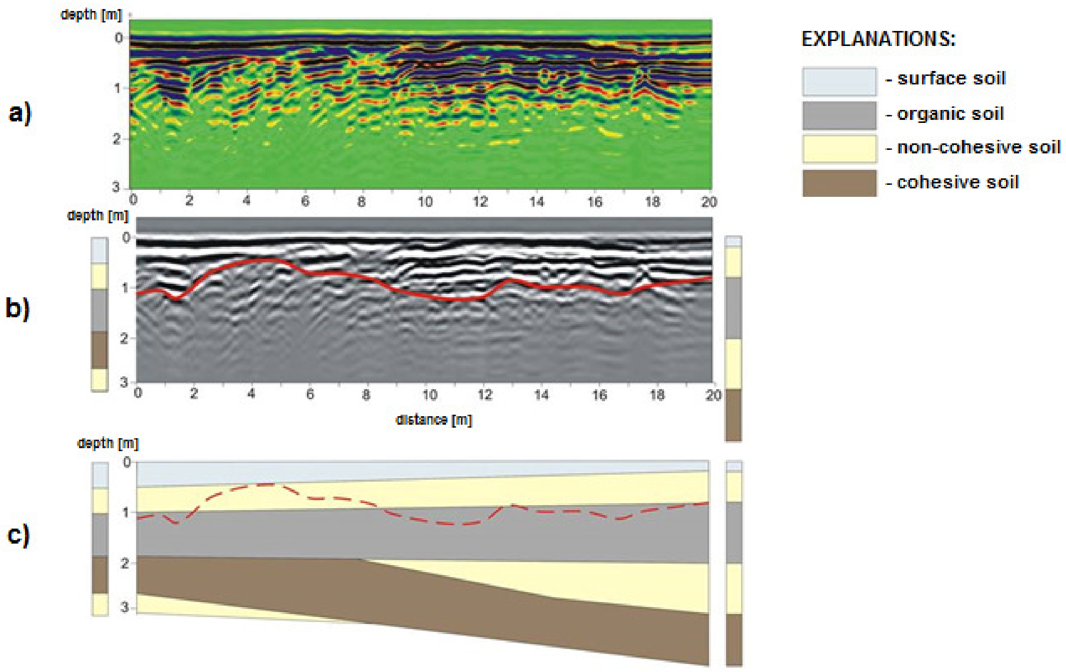

Fig. 5. Location of horizon of organic soils in profile No. 2: a) echogram obtained by GPR technique, b) the interpretation of the echogram obtained using GPR, indicating horizon of peat layer, c) cross-section of the substrate made by drilling (Source: own elaboration)

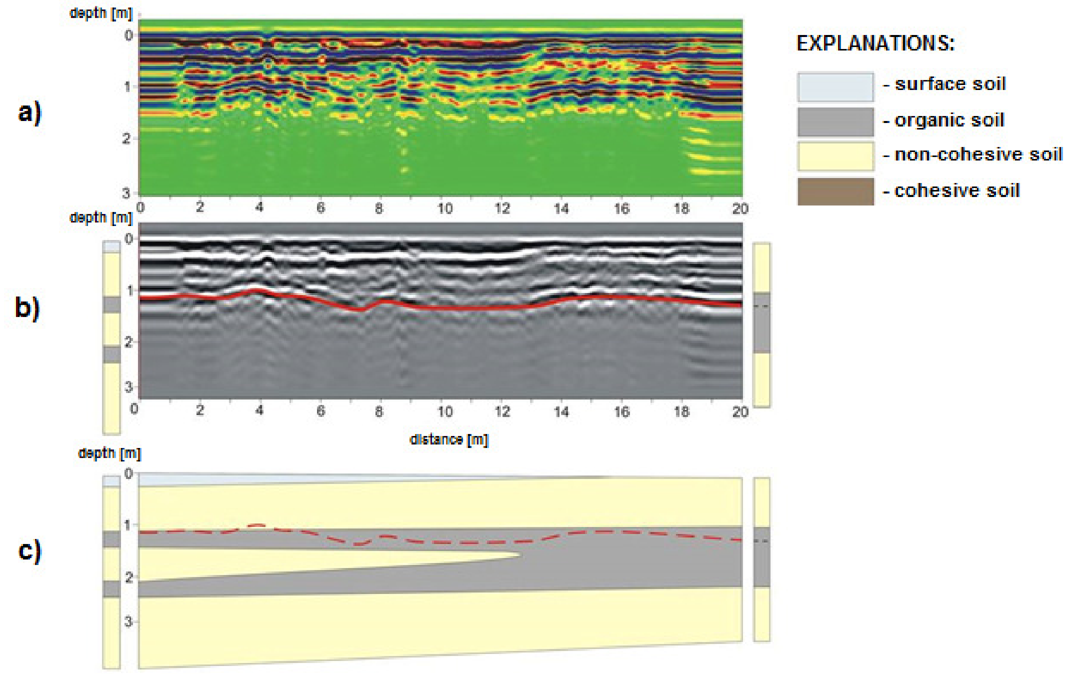

Fig. 6. Location of horizon of organic soils in profile No. 3: a) echogram obtained by GPR technique, b) the interpretation of the echogram obtained using GPR, indicating horizon of peat layer, c) cross-section of the substrate made by drilling (Source: own elaboration)

Conclusions

By the test results, the following conclusions can be drawn:

- it has been confirmed that with the increase of depth range resolution of the method decreases, hence antennas operating at higher frequencies provide superior image of the structure of shallow layers of the substrate; however, the usefulness of the method in the assessment of the ground is obtained by the correct calibration of the output parameters of the equipment;
- GPR method has a greater ease of performing the studies, yet the difficulties usually occur in the interpretation of measurements – hence, knowledge and practice of the personnel conducting the analysis is vital;
- GPR is useful especially when a specific type of soil residual in the ground is sought, characterized by properties significantly contrasting it from the surrounding environment;
- GPR method cannot replace traditional methods of research of the ground, however, it may be complementary; knowledge obtained from GPR measurements should be supported by the results obtained from other studies simultaneously carried out in the same area;
- GPR technique is especially useful in linear objects and those of a large surface, as it helps in the performance of geotechnical sections i.e. interpretation of alignment of layers between the boreholes;
- the non-destructive character of this method is its undoubted advantage; this is a feature especially valuable for studies of the ground where the breach of soil structure is undesirable.

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Disclosure statement

Authors declare not to have any competing financial, professional, or personal interests from other parties.

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