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EXAMINATION OF LEVEE CONDITION BY MEANS OF GPR

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Abstract: Levees are very important elements of hydro-protection of regions placed in the neighbourhood of rivers or water reservoirs. They are subject to influence of many destructive factors. Therefore, it is necessary to examine the condition of levees periodically. Every weakening of their structure should be debugged in order to avoid breaking of the levee and consequent risk of flood.

The paper presents results of examination of levees by means of an electromagnetic geophysical method: Ground Penetrating Radar (GPR). This method enables the structure of the levee to be investigated in a fast and noninvasive way. The results of GPR measurements were compared with those obtained by means of geological sounding. All the measurements were carried out on some section of the levee of the Odra River in Wrocław, Poland.

1. INTRODUCTION

In order to minimize flood hazard it is necessary to evaluate the condition of levees periodically. The evaluation is obligatory for a local authority because levees are usually under their management [1], [2]. According to the Polish Civil Engineering Law [3], levees should be checked up once a year. However, once in five years they should be investigated to evaluate their condition. It is carried out by means of classical methods of evaluation. The standard method consists in visual evaluation of a long section of the levee and drilling bore-holes in order to get samples. Samples are investigated in a laboratory. Results of the sample analysis are used for approximation of the structure of the levee. The method does not ensure detection of the levee local weakening due to a small number of bore-holes. In the case of high level of water in a river or some reservoirs the levee could be broken mainly in the place where the weakening is located.

The paper presents results of the preliminary examination of some sections of levee by means of GPR. The electromagnetic geophysical method considered allows measuring levees in a linear and noninvasive way. The results obtained help to indicate places where the structure of the levee has changed [4]–[6]. In this place, more detailed examinations should be carried out, for example, by geological sounding.

The paper also presents basics of GPR: the principle of operation and method of interpreting the measurement result. The results of GPR measurements were compared with those of geological sounding getting a good agreement between the two methods.

2. GROUND PENETRATING RADAR (GPR)

In the GPR method, electromagnetic waves cover short and ultrashort electromagnetic wavebands. A transmitting antenna radiates a pulse wave into the ground. The wave is reflected from the boundary of ground layers differing in electrical properties. It can be reflected from the materials occurring in the ground, as well. The magnitude of the reflected wave is a function of the reflection coefficient. The magnitude of the reflected wave increases when the difference between the equivalent conductivity of layers (contrast between layers) increases [7]. Table 1 contains values of the equivalent conductivity and attenuation coefficients of some geological materials.

Table 1

Values of equivalent conductivity and attenuation coefficients of some geological materials

Medium	σ (mS/m)	α (dB/m)
air	0.0	0.0
fresh water	0.5	0.1
salt water	3000	1000
dry sand	0.01	0.01
humid sand	0.1÷1.0	0.03÷0.3
siltstone	0.5÷2.0	0.4÷1.0
clay	2.0÷1000	300
silt	1.0÷100	1.0÷100
granite	0.01÷1.0	0.01÷1.0

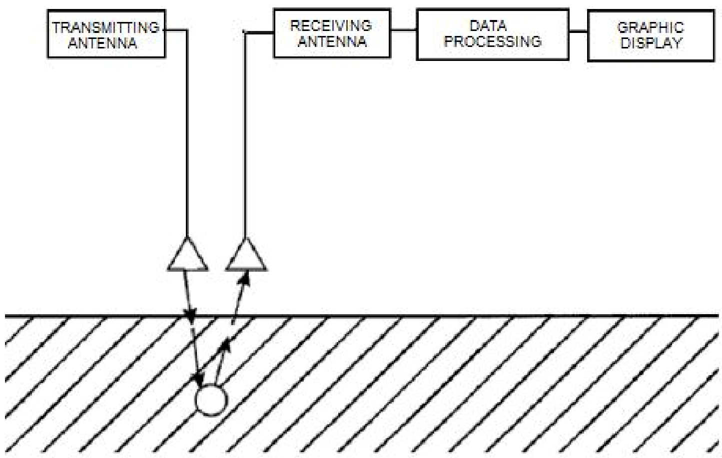

Fig. 1. Diagram of GPR measuring principle

The reflected wave (received by the receiving antenna) is registered in time and presented in the form of the GPR profile image. In practice, the measurements with the GPR method rely on the transmitting and receiving antenna displacement at a fixed speed along the established profile. The system is placed on the surface of the ground. The obtained image reflects the geological structure of the ground. Additionally, it helps to indicate anthropogenic materials in the ground. The GPR measuring system is shown in figure 1.

A very high vertical and horizontal measuring resolution is an advantage of the GPR. The measurement of some profile allows the structure of the ground to be determined. It is helpful to indicate horizontal (distance from measuring start point) and vertical (depth) coordinates of all inhomogeneities. A disadvantage of the method is a strong dependence of penetration depth on the ground geological conditions. It follows that attenuation of electromagnetic waves increases with: humidity of medium, content of well conducting minerals and porosity of medium. That is why the measuring system requires appropriate setting of its parameters before beginning the measurements.

2.1. SETTING GPR PARAMETERS

GPR operates in a pulse electromagnetic wave regime. The block diagram of an electronic part of GPR is shown in figure 2 [8]. As mentioned above, GPR can be divided into two main parts: transmitter (signal power oscillator working at frequency f_0 and transmitting antenna) and receiver (receiving antenna, signal processing circuits and display). The system additionally contains a part that is responsible for measurement control (switching an antenna between transmitting and receiving circuits).

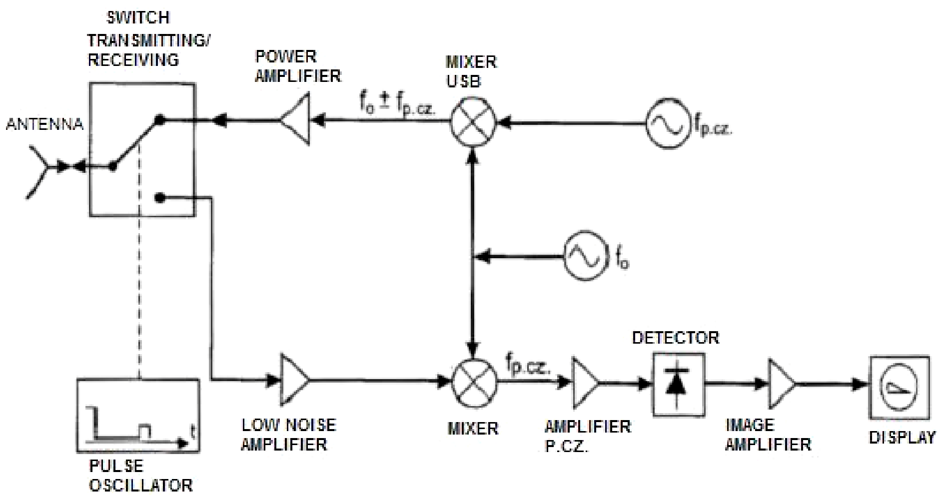

Fig. 2. Block diagram of pulse GPR [8]

The parameters of GPR that should be set before carrying out measurements include:

f_S – inverse of time interval at which incoming signal is sampled (sampling frequency),

T_i – measuring step (trace interval),

v – velocity of wave propagation in the medium under investigation.

By changing the sampling frequency f_S one can change energy of measured electromagnetic pulses. Decreasing time interval of the sampling (increasing frequency) causes a decrease of the energy of reflected pulses. Then pulses reflected from deep layers are not sampled and consequently, the depth of penetration of GPR decreases. Thus, the choice of f_S influences the range of vertical penetration.

The choice of the trace interval T_i influences the accuracy of the measurement horizontal resolution.

The wave propagation velocity v in the medium investigated depends on electrical permittivity ε_r of the medium:

$$\upsilon = \frac{c}{\sqrt{\varepsilon_r}} \tag{1}$$

where c – electromagnetic wave velocity in the free space equal to 3×10^8 m/s.

Electrical permittivity is part of the above mentioned equivalent conductivity. For the frequency range used by GPR ε_r plays a main role in values of equivalent conductivity. Electrical permittivity strongly depends on the properties of the medium: humidity, content of well conducting minerals, and porosity. The choice of the wave velocity influences the accuracy of vertical resolution of measurements.

3. RESULTS OF LEVEE EXAMINATION

The paper presents results of the measurements of some section of the Odra River levee in Wrocław, Poland. The levee under examination belongs to the first class of a hydro-engineering structure. This means that this levee protects a large area against flood (protected area > 300 km^2). The geological profiling of the levee was carried out in this section and the cohesion degree was measured by means of a dynamic penetrometer. Examinations were performed at the 118th meter of the levee section investigated. The same section of the levee was measured by means of GPR. The GPR measurement contains a place where geological profiling and cohesion degree measurements were carried out in order to compare the results obtained by all the measuring methods used.

3.1. EXAMINATION BY MEANS OF DYNAMIC PENETROMETER

Figure 3 shows results of geological investigations (dynamic penetrometer sounding and cohesion profiling) at the 118th meter. The most important parameter of sounding is the number of strokes required to drive the probe at a depth of 0.1 m. This kind of investigation allows evaluation of cohesion degree (I_D) [10] of the near-surface ground. For the first and second-class levees this coefficient should be higher than 0.6 ($I_D \geq 0.6$).

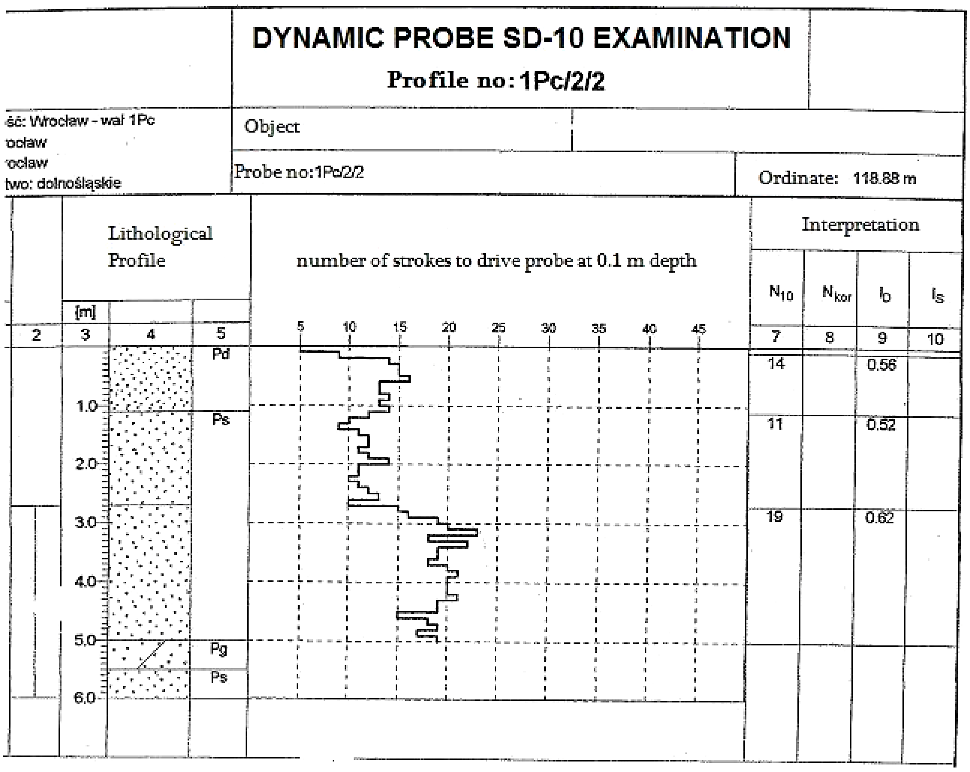

Fig. 3. Results of geological measurement carried out by means of dynamic penetrometer

The result of the measurement shows that 11–14 strokes are required to drive the probe at a depth of 0.1 m to the depth of 2–2.5 m. It corresponds to an I_D coefficient equal to 0.52–0.56. The values of I_D characterize grounds of a middle class of cohesion.

The ground placed deeper than 3 m is characterized by higher cohesion (19 strokes every 0.1 m), which corresponds to $I_D = 0.62$. The value of I_D still rates the ground in the middle class of cohesion.

The section of levee investigated was in bad condition: its top and sod formations were rough, and a fill slope was deformed. The results of examinations showed that this section of the levee does not meet specifications ($I_D < 0.6$) for the first class levee. Therefore, it was destined for repair.

3.2. EXAMINATION BY MEANS OF GPR

Figure 4 shows results of GPR profiling of 200 m section of levee. The profiling was carried out by means of GPR made by a Swedish company Mala Geoscience. GPR had a shielded antenna working at a frequency of 250 MHz [9]. Measurements were performed for the following GPR parameters: f = 4.289 GHz; T_i = 0.3 m; v = 100 m/μs. In order to compare the results of GPR measurements with results of dynamic penetrometer measurements, a more detailed analysis of the 118th m of levee was performed.

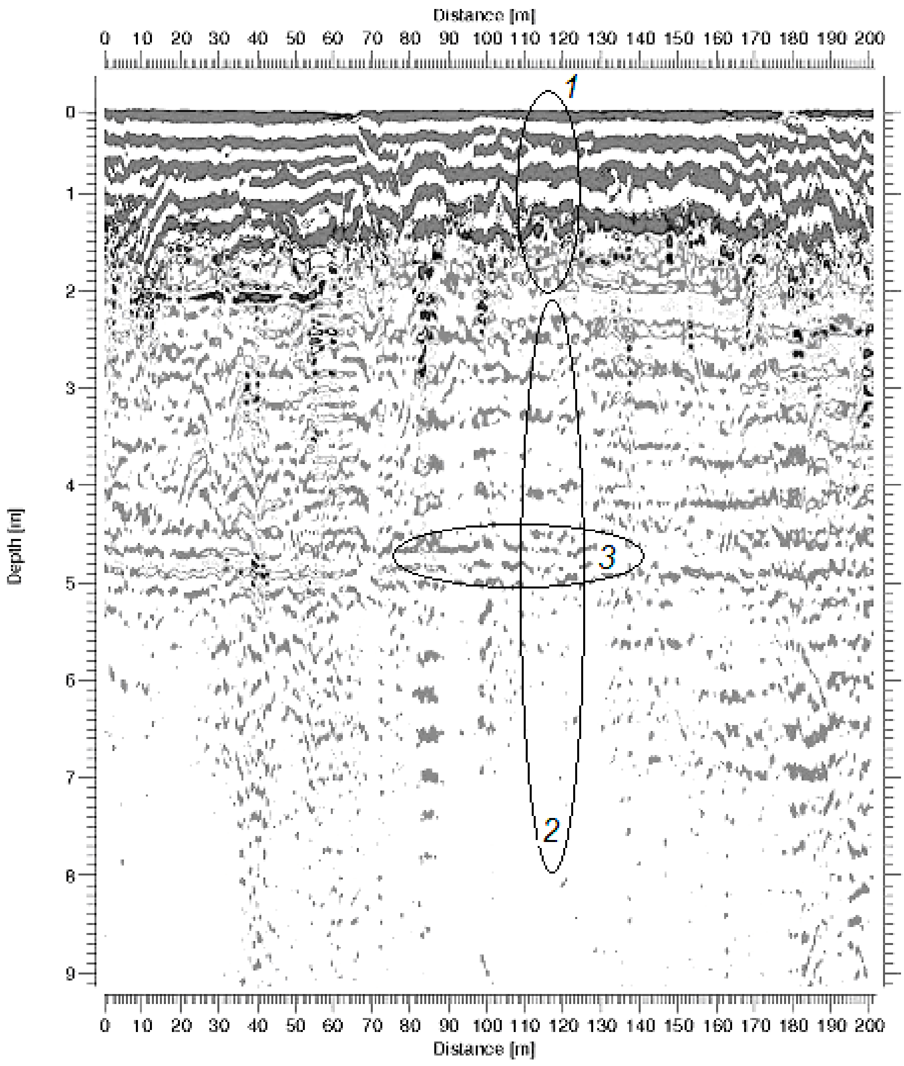

Fig. 4. Results of GPR profiling of levee section (GPR image)

It is clear that at the 118th m (marked with 1) of the levee section the top layers of the levee have different structure than layers placed at a depth below the 2nd m. In comparison with geological profiling (figure 3) the thickness of these layers is equal to 2.8 m. Bad setting of a GPR parameter ν causes a difference between those thicknesses. Velocity of the wave propagation depends on the ground humidity degree. It can have a different value for every ground stratum. Therefore, for GPR measurements one can assume some average value of ν. This assumption could cause some error in evaluation of the depth of ground layers.

The dynamic penetrometer measurement result shows that layers located below the 3rd m of the levee have a higher degree of cohesion. Those layers are clearly visible in the GPR measurement result (marked with 2). One can see that those layers have different properties than the strata placed at 0–3 m in depth. The depth of those layers reaches the 7th m, which is equal to the maximum depth of GPR penetration (for set measurement parameters).

Other interesting results of GPR measurements are obtained at the depth of the 5th m (marked with 3). The GPR measurements detect the different structure of the levee. Results of geological sounding showed that the clay was placed at this depth.

Appropriate interpretation of the GPR measurement results allows us to determine the structure of the levee. By means of analysis of individual layers of GPR profiling one can attempt to determine the degree of ground cohesion. This requires a lot of measurements by both methods and determination of some coefficients to match GPR measurement results with ground parameters.

4. CONCLUSION

The evaluation of condition of levees by means of geological methods is a time-consuming process. Such investigations give very accurate information about the levee structure. But visible choice of places where a bore-hole is being made could be unreliable because it is very easy to omit places where weakening of the levee occurs.

It can be very useful to carry out preliminary examination of levee by means of a geophysical method. The method should give as accurate results as possible. The duration of measurements by means of this method should be short. This paper showed that GPR can be used for preliminary levee examination because it is a very fast and noninvasive method common in near-surface geophysics.

A disadvantage of GPR is the difference between the depth shown on a GPR image and the real depth. But this error does not have any influence on detection of inhomogeneities in the levee investigated.

The levee profiling by means of GPR gives information about the structure of it in a short time. On the basis of GPR image one can indicate places where more accurate, geological examination should be done.

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