APPLICATION OF GPR METHOD IN DIAGNOSTICS OF REINFORCED CONCRETE STRUCTURES

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Summary

This paper presents an application of the ground penetration method (GPR) for diagnostics of reinforced concrete structures. In situ measurements were conducted for three civil engineering structures: the ground floor structure, the abutment of the railway viaduct and the concrete well. The dual polarized ground penetrating radar with the antenna operating at a center frequency of 2 GHz was used for GPR surveys. Three different methodologies of measurements were analyzed. The results showed that the GPR method enables quick and efficient diagnostics of concrete structures. Based on GPR results it is possible to identify the distribution and amount of reinforcement, as well as the thickness of the concrete layer.

Keywords: non-destructive diagnostics, electromagnetic waves, ground penetrating radar method, experimental investigations, reinforced concrete structures

ZASTOSOWANIE METODY GEORADAROWEJ W DIAGNOSTYCE KONSTRUKCJI ŻELBETOWYCH

Streszczenie

W artykule przedstawiono zastosowanie metody georadarowej do diagnostyki konstrukcji żelbetowych. Pomiary polowe przeprowadzono na trzech obiektach inżynierskich: konstrukcji podłogi posadowionej na gruncie, przyczółku wiaduktu kolejowego oraz rurze betonowej. Badania doświadczalne wykonano za pomocą georadaru z anteną bipolarna o częstotliwości 2 GHz. W pracy przedstawiono trzy typy metodologii pomiarów georadarowych. Przeprowadzone testy wykazały, że metoda georadarowa umożliwia szybką i wydajną diagnostykę konstrukcji żelbetowych. Na podstawie uzyskanych wyników badań była możliwa identyfikacja rozkładu i ilości zbrojenia, a także grubości warstw betonu.

Słowa kluczowe: diagnostyka nieniszcząca, fale elektromagnetyczne, metoda georadarowa, badania doświadczalne, konstrukcje żelbetowe

1. INTRODUCTION

Reinforced concrete is one of the commonly used materials for the construction of engineering structures like bridges, dams, towers or components of building structures (e.g. floors, slabs, beams, frames, columns, walls, etc.). Concrete and steel in reinforced structures are continuously subjected to degradation due to static and dynamic loading, changes in temperature and humidity or other corrosive factors. The assessment of existing structures is of great importance to improve their reliability and safety. The actual state of a structure can be evaluated in the process of diagnostics, preferably diagnostics of non-destructive type.

In recent years, various non-destructive diagnostic techniques for concrete structures have been investigated, for example ultrasonic testing [1–3], acoustic emission [4], acoustic and vibroacoustic methods [5, 6]. Of particular interest for diagnostics of reinforced concrete is the ground penetration radar (GPR) method utilizing propagation of electromagnetic waves. This method is widely used for non-invasive assessment of concrete structures, especially for damage assessment or assessment of the current technical state of engineering structures [7–10].

The purpose of this paper is the examination of the ground penetration method for non-destructive diagnostics of reinforced concrete structures. In situ measurements were conducted for three civil engineering structures: the ground floor structure, the abutment of the railway viaduct and the concrete well. Three different methodologies of GPR measurements were analyzed and compared.

2. DESCRIPTION OF GPR METHOD

2.1. Theoretical background

The GPR method uses the phenomenon of propagation of electromagnetic waves. The radar antenna emits a signal that passes through a test medium, reflecting from borders between materials characterized with different electrical properties, i.e. electrical conductivity and permittivity. Foregoing properties of electromagnetic wave propagation can be utilized in non-destructive diagnostics. In testing of engineering structures, a part of the wave penetrates into a structure, while the rest is reflected or scattered from any heterogeneities contained within the tested structure. A transmitting antenna is moved along the test surface and in any position, a receiving antenna captures the reflected signals as GPR traces (Fig. 1a). Assembling of individual waveforms results in creation of a time-position plan also known as a B-scan or a radargram. Reflection from any point inclusion (e.g. crack, reinforcing bar) is represented in the radargram as a parabola (Fig. 1b).

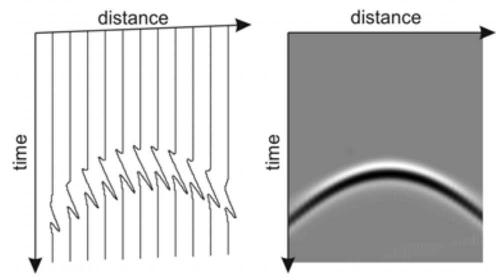

Fig. 1. Signals acquired during GPR measurements: a) GPR traces, b) radargram

In order to identify the depth on which the inclusion occurs, it is necessary to determine the speed of propagation of electromagnetic waves within the considered material. In the case of homogeneous, isotropic material, the speed of wave propagation can be established using the following formula [11]:

$$v = \frac{c}{\sqrt{\varepsilon_r}}, \qquad (1)$$

where c = 30 cm/ns is the speed of electromagnetic waves in the vacuum and ε_r denotes the permittivity of the medium. Knowing the value of wave speed propagation and multiplying it by the time axis, the depth axis can be obtained.

2.2. Instrumentation

Experimental investigations presented in this paper were performed using GPR Aladdin structures kit. The system consists of the antenna, the control unit, the portable computer and the battery. The antenna operating at a center frequency of 2 GHz is bipolar, which means it has two pairs of transmitter-receiver and allows to acquire GPR data in two perpendicular directions. The control unit with a pulse repetition frequency of 400 kHz is responsible for the control of the antenna and the digitization of data. Additional equipment is the mat PSG (Pad Survey Guide) having a series of parallel grooves spaced at a distance of 0.78 cm which permits dense scanning with the highest resolution. For data acquisition K2 FAST WAVE software is used while the interpretation and visualization of measurement data is performed using the software GRED HD [12].

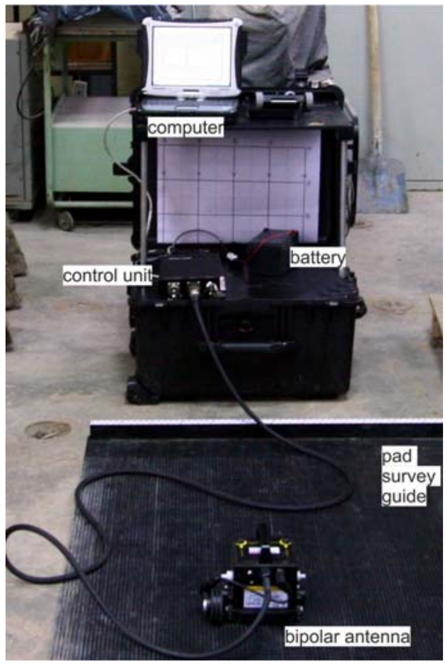

Fig. 2. GPR apparatus

2.3. Methodology of GPR surveys

Depending of the applied methodology of GPR surveys, various visualizations of reinforcing bars can be obtained. The simplest approach in measurements of reinforced concrete structures is to perform a single scan along a selected profile (Fig. 3a). As result of such measurement methodology, detection of those bars, which are perpendicular to the scanning direction, is solely possible. The GPR map provides information about the depth on which bars are situated and the distance between them.

Another possibility is acquisition of data along both longitudinal and transverse profiles. In this way, a three-dimensional image of the reinforcement in a structure can be obtained (Fig. 3b). It is also possible to estimate the diameter of reinforcing bars based on position of the parabolas on the radargram.

The third approach is the use of bipolar antenna for scanning along closely spaced longitudinal profiles parallel to each other. Application of such methodology makes possible generation of transverse scans based on measured solely longitudinal ones. As a result, a tomography showing the reinforcing mesh at a given depth can be obtained (Fig. 3c). Due to the large number of required scanned profiles, this methodology is the most labor-intensive and time-consuming.

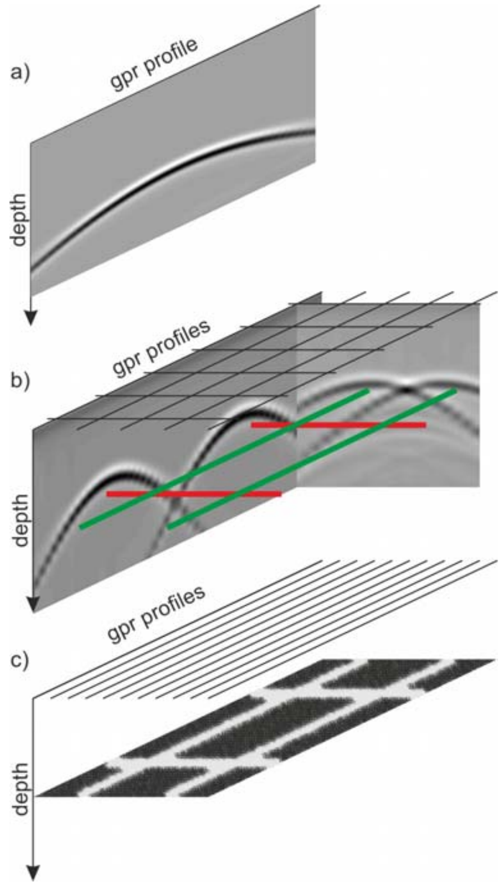

Fig. 3. Measurement methodology: a) data acquired along selected profile provide radargram, b) data acquired along longitudinal and transverse profiles provide 3D rebar visualization, c) data acquired along closely spaced longitudinal profiles provide tomography showing the reinforcing mesh on the selected depth

3. EXPERIMENTAL INVESTIGATIONS

3.1. Ground floor structure

Investigations were carried out on the ground floor structure in the laboratory room (Department of Building and Material Engineering, Gdansk University of Technology). The first test was performed before planned renovation of the room to change its use (Fig. 4). Since there was no documentation for the floor structure, the assessment of the existing state was performed in the process of diagnostics by the GPR method in order to determine the amount and distribution of the reinforcement and the presence of potential damage of concrete [10]. The GPR measurements were repeated after renovation to compare the influence of new surface layer on obtained results. Two types of measurements were performed on the selected area of the floor: in the first radargrams were acquired along transverse and longitudinal profiles spaced at intervals of 6 cm while in the second radargrams were acquired along longitudinal profiles spaced at intervals of 0.78 cm.

Fig. 4. Ground floor structure during GPR surveys

Figure 5 shows selected radargrams obtained before and after renovation for the selected longitudinal profile. Two rows of bars were identified at a depth of 4 cm and 37 cm. The maps revealed the average spacing of bars equal to 20 cm. The offset between the upper and the lower row of

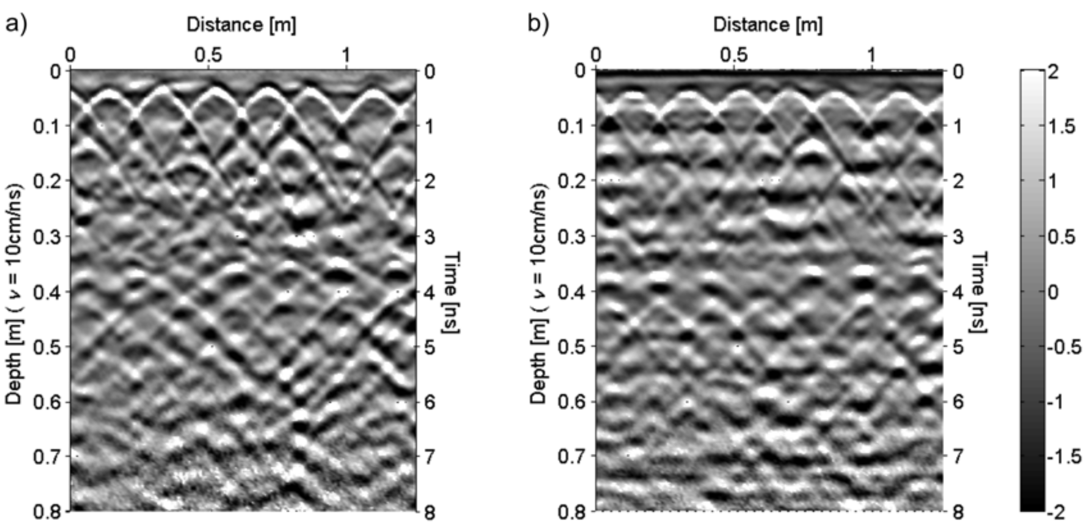

Fig. 5. Example of radargram for ground floor structure: a) before renovation, b) after renovation

bars was about 10 cm. In the area under investigations no anomalies were detected which could indicate the presence of damage in concrete. However, in the radargram obtained after renovation, a new surface layer is visible and its thickness can be identified as 2 cm.

In Fig. 6 three-dimensional visualization of reinforcement in the measured area of the ground floor structure is shown. The individual bars were inserted in the vertex of parabolas based on radargrams acquired along longitudinal and transverse profiles. The diameter of bars was estimated as 20 mm.

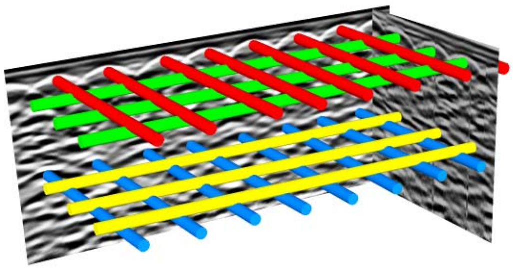

Fig. 6. Three-dimensional visualization of reinforcement in ground floor structure

The analysis of experimental data registered along closely spaced longitudinal profiles and the recovery of transverse data using the bipolar antenna allowed to obtain tomographic imaging of examined area of the floor. Figure 7 gives the GPR tomography at the upper reinforcement mesh. This picture provides precise information about the arrangement of the reinforcement.

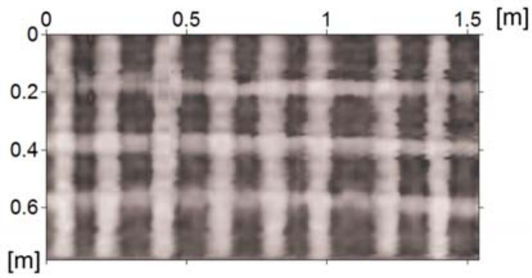

Fig. 7. GPR tomography of examined area of floor

3.2. Abutment of the railway viaduct

A concrete railway viaduct is located within the Pomeranian Metropolitan Railway. GPR surveys were performed on the bridge abutment (Fig. 8). A segment with an area of 250 cm × 240 cm was examined with transverse and longitudinal scans spaced at intervals of 10 cm.

Figures 9 and 10 show the radargrams for selected transverse (T) and longitudinal (L) profiles marked in Fig. 8. The inclusions in the form of rebars resulted in two rows of parabolas. In the transverse GPR map (Fig. 9) the first row can be observed at a depth of about 4 cm and the second at a depth of about 36 cm. The map obtained for the longitudinal profile (Fig. 10) clearly shows the first row of rebars at a depth of approximately 6 cm. Dense spacing between bars and very high value of steel conductivity caused that reflections from the lower level of reinforcement bars are less visible. Nevertheless, at a depth of 34 cm repetitive pattern of parabolas can be observed. Based on the radargrams shown in Fig. 9 and 10 we can also determine that the horizontal bars are spaced with a distance of 20 cm while the vertical with a distance of 10 cm. Additionally, on the map for the transverse profile (Fig. 9) reflection at a depth of 40 cm provided information about the boundary between concrete and ground. This value was confirmed based on the technical documentation for the object. Below a depth of 0.5 m any reflection or interference can be seen. Because strong noise appearing below 70 cm, it can be concluded that the effective depth of penetration of the electromagnetic wave in this case was about 70 cm.

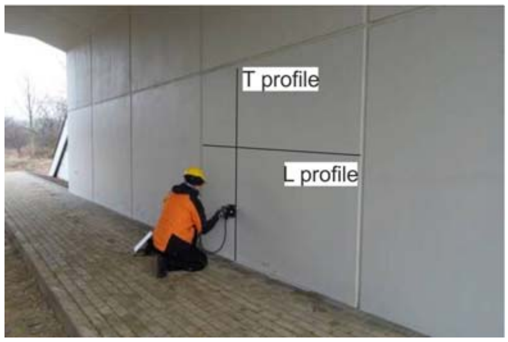

Fig. 8. Abutment of railway viaduct

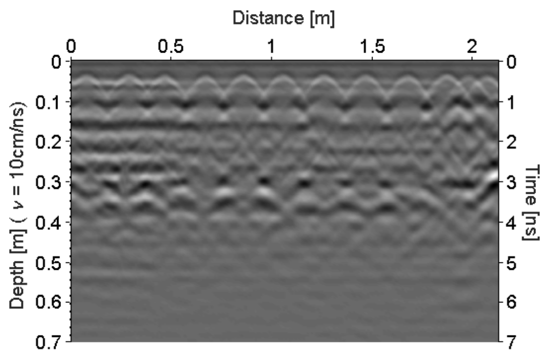

Fig. 9. Radargram obtained for transverse profile

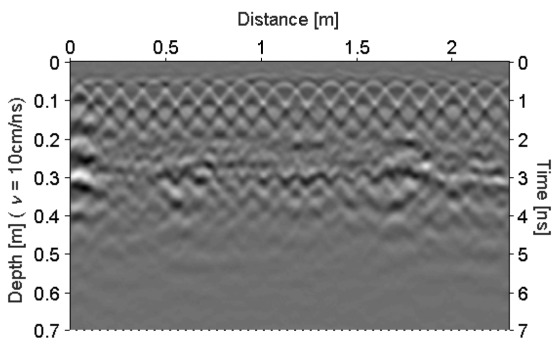

Fig. 10. Radargram obtained for longitudinal profile

3.3. Concrete well

The last examination of the GPR method was carried out on a concrete well with a radius of 170 cm and a wall thickness of 25 cm. In this case one scan along circumference profile was performed, as indicated in Fig. 11.

Figure 12 shows the GPR map collected along the circumference of the well. A set of distinct parabolas can be easily identified at a depth of approximately 3.5 cm and 21.5 cm. It indicates regularly spaced (at a distance of about 20 cm) steel reinforcing meshes. Strong reflection form the underside of the well is visible at a depth of about 25 cm.

Fig. 11. Concrete well

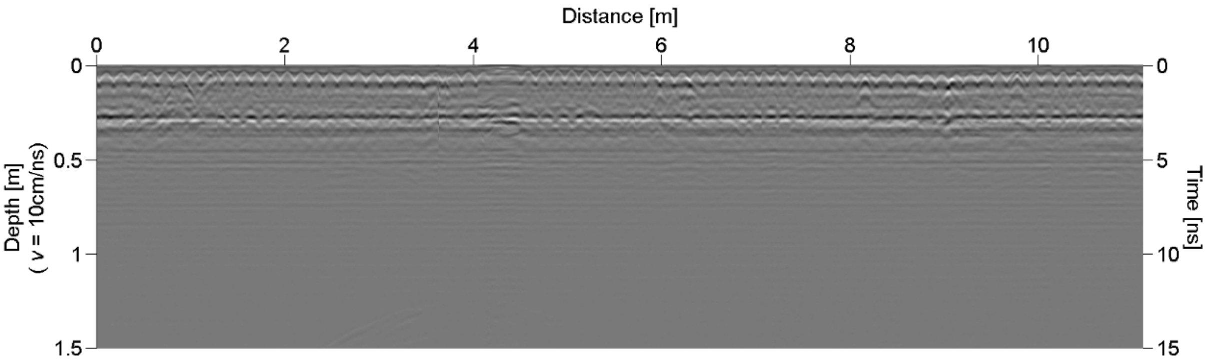

Fig. 12. Radargram of concrete well obtained along circumference profile

The GPR map shown in Fig. 12 do not present the curved nature of the examined object. To properly reproduce the actual shape of the structure, the radargram should be wrapped. This operation was performed using the MATLAB® environment and the Image Processing Toolbox. The result of the wrap transformation is shown in Fig. 13.

Fig. 13. Curved GPR map of concrete well

4. CONCLUSIONS

This paper presents an application of the GPR method for diagnostics of reinforced concrete structures. The dual polarized ground penetrating radar with the antenna operating at a center frequency of 2 GHz was used for in-situ surveys. Three different methodologies of measurements were analyzed: (i) a single scan along a selected profile to obtain a radargram, (ii) a set of scans along both longitudinal and transverse profiles to obtain a three-dimensional image of the reinforcement, (iii) a set of closely spaced scans parallel to each other to obtain a tomography image.

In the study three civil engineering structures were analyzed: the ground floor structure, abutment of the railway viaduct and the concrete well. On the floor two types of tests were performed, the first with dense profiles with one direction and the second with sparse longitudinal and transverse profiles. In this way it was possible to generate tomography of the examined area and to provide the three-dimensional visualization indicating the distribution and the position of reinforcing meshes. In the case of the abutment and the well single scans along selected profiles were performed. Based on radargrams it was possible to identify the distribution and amount of reinforcement, as well as the thickness of the concrete layer. The results of the study showed that the GPR method enables quick and efficient diagnostics of concrete structures.

BIBLIOGRAPHY

[1] Manaj W., Sikorski K., Kurzydłowski K. *Application of ultrasonic techniques for the evaluation of the properties of prestressed concrete structures*. Diagnostyka, vol. 44, pp. 49–51, 2007.
[2] Rucka M., Wilde K. *Non-destructive diagnostics of concrete cantilever beam and slab by impact echo method*. Diagnostyka, vol. 55, pp. 63–68, 2010.
[3] Rucka M., Wilde K. *Experimental study on ultrasonic monitoring of splitting failure in reinforced concrete*. Journal of Nondestructive Evaluation, vol. 32, pp. 372–383, 2013.
[4] Gołaski L., Goszczyńska B., Świt G., Trąmpczyński W. *System for the global monitoring and evaluation of damage processes developing within concrete structure under service load*. The Baltic Journal of Road and Bridge Engineering, vol. 7, pp. 237–245, 2012.
[5] Radkowski S., Gałęzia A., Mączak J., Szczurowski K. *Structural condition evaluation of prestressed concrete structures based on vibroacoustic monitoring*. Diagnostyka, vol. 44, pp. 105–112, 2007.
[6] J. Hoła, Ł. Sadowski, K. Schabowicz, *Nondestructive identification of delaminations in concrete floor toppings with acoustic methods*. Automation in Construction, vol. 20, pp. 799–807, 2011.
[7] Barrile V., Pucinotti R. *Application of radar technology to reinforced concrete structures: a case study*. NDT&E International, vol. 38, pp. 596–604, 2005.
[8] Bęben D., Mordak A., Anigacz W. *Ground penetrating radar application to testing of reinforced concrete beams*. Procedia Engineering, vol. 65, pp. 242–247, 2013.
[9] Courard L., Gillard A., Darimont A., Bleus J.M., Paquet P. *Pathologies of concrete in Saint-Vincent Neo-Byzantine Church and Pauchot reinforced artificial stone*. Construction and Building Materials, vol. 34, pp. 201–210, 2012.
[10] Rucka M., Lachowicz J. *Zastosowanie metody georadarowej w badaniach konstrukcji podłogi posadowionej na gruncie*. Inżynieria Morska i Geotechnika, vol 5, pp. 452–458, 2014.
[11] Drobiec Ł., Jasiński R., Piekarczyk A.. *Diagnostyka konstrukcji żelbetowych. Tom 1*. Wydawnictwo Naukowe PWN, Warszawa, 2010.
[12] GRED HD Software. *GPR High Definition Data Post Processing. User Manual.* Pisa, 2013.

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