Location of Steel Reinforcement and Other Reinforcing Elements using 3D GPR

T. Kordina* & Z. Kadlecová**
Brno University of Technology, Faculty of Civil Engineering, Department of Building Testing
** Corresponding author: kordina.t@fce.vutbr.cz*
*** Corresponding author: kadlecova.z@fce.vutbr.cz*

J. Štainbruch
Inset s.r.o., Czech Republic

ABSTRACT: This paper evaluates the results of the first experimental 3D GPR measurements by the DIBEKON scanner on a physical model. The objective of the series of measurements carried out was to determine the applicability of various types of antennae (800 MHz and 1600 MHz) in the detection of steel reinforcement and the influence of the measurement density on the quality of the resulting image of the environment examined.

KEY WORDS: GPR (Ground Penetrating Radar), NDT, concrete.

1 INTRODUCTION

One of the progressively developing non-destructive diagnostic methods is the method of Ground Penetrating Radar (GPR). This method was originally developed for geological applications, but, due to the technological development and market requirements, it is beginning to be applied more and more in the building industry.

Although the professional literature gives a number of examples of GPR applications from the USA, Europe and other advanced parts of the world, in the Czech Republic this method had not been used very much so far, and the only company systematically engaged in the georadar diagnostic research is the company INSET s.r.o. Under the auspices of this company, the first partial experimental measurements were carried out on a physical model simulating by its properties a building structure. The aim of the measurement was to evaluate the possibilities of using this method for the location of steel reinforcement and other anomalies, defects and failures in building structures.

2 THEORETICAL BASIS AND PRINCIPLE OF THE GPR METHOD

The GPR method works on the principle of radiating high-frequency electromagnetic pulses into the environment examined and registering their reflections within a time window. Measurement devices used for the diagnostics of structures work in the frequency range of 108 – 109 Hz. The signal propagation in the environment depends primarily on its electromagnetic properties – permittivity and conductivity. The speed of electromagnetic pulse propagation can be determined, in a simplified way, from the following formula:

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

where
v is the speed of electromagnetic signal propagation in the environment
c is the speed of propagation in the vacuum (c = 0,3 m/ns)
εr is the relative permittivity of the environment.

The electromagnetic signal attenuation α (dB/m) and the related maximum signal penetration depth H (m) are primarily dependent on the conductivity of the environment σ (S.m). For non-magnetic materials, we can calculate the attenuation coefficient using the following equation:

$$\alpha = 1,64 \frac{\sigma}{\sqrt{\varepsilon}}. \qquad (2)$$

For high-frequency electromagnetic pulses, the conductivity and therefore also the value of attenuation coefficient are frequency-dependent. At higher frequencies, the attenuation is greater, and the measurement depth range therefore lower.

On the boundary of two environments with a step change of electromagnetic properties, part of the signal is reflected.

The ability of the georadar method to detect non-homogeneities depends on many factors. A major role is played by the size of the anomaly, particularly in relation to the depth of its position and to the frequency of the measurement device. As a general rule, the georadar can detect objects larger than one half of the wavelength. To calculate the wavelength, we can use the following relation:

$$\lambda = \frac{v}{f}, \qquad (3)$$

where
λ is the wavelength
v is the speed of electromagnetic signal propagation in the environment
f is the average frequency of the emitted signal.
Devices working with higher frequency antennae therefore have a greater resolving power, but their disadvantage is a smaller depth range. The sensitivity of the measurement is similarly dependent on the ratio between the useful signal and the noise, i.e., on the "tuning in" of the system, intensity of the surrounding interference (electromagnetic smog), etc.

3 DESCRIPTION OF THE MEASUREMENT

All experimental measurements on the physical model were carried out in the Prague premises of the INSET s.r.o. company, which provided sufficient background for executing research activities.
The measurements proceeded according to the agreed scenario to obtain the greatest possible amount of data from one measurement system for detailed processing. Two different types of GPR antennae were used for measurements - with transmission frequencies of 800 MHz and 1600 MHz.

3.1 Instrumentation

The measurement was carried out by means of the RAMAC GPR radar system manufactured by Swedish Malå GeoScience. The system used was a RAMAC X3M Corder in combination with shielded antennae with a medium transmission frequency of 800 MHz with a real depth range of 0.6 – 0.8 m and further the RAMAC CX system with a shielded 1600 MHz antenna with a depth range of approx. 0.3 m.

To achieve the required precision of the measurement grid of georadar scanning of the measured points in the entire area of the physical model, the company INSET s.r.o. developed a solid measuring frame with a controlled moving slider for the attachment of the georadar antenna with a working name of DIBEKON (Diagnostika betonových konstrukcí - Diagnostics of concrete structures, see Figure 1).

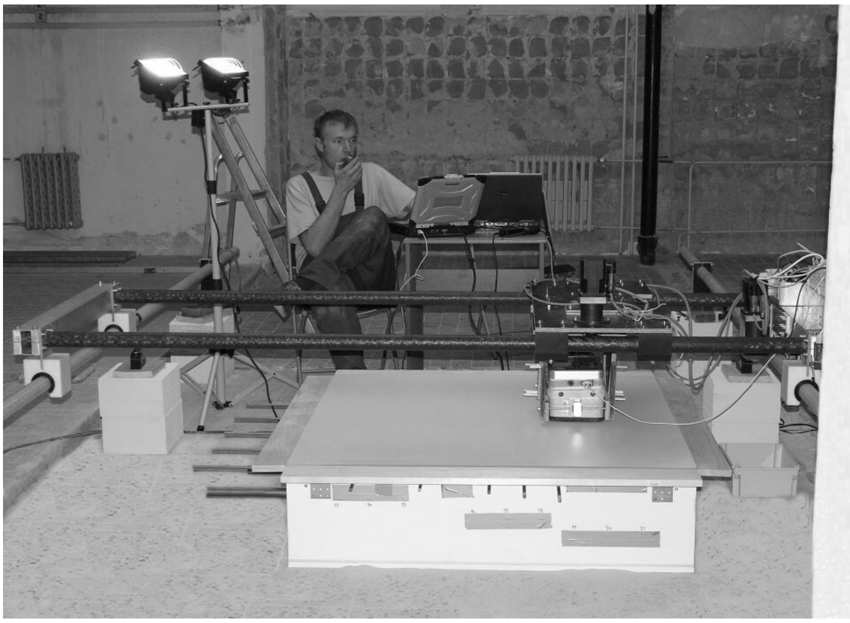

Figure1: RAMAC measuring device with a system of 800 MHz antennae attached to the DIBEKON scanning frame.

The measuring sys-tem was operated and set up and data collected by means of Ramac Ground Vision software v.1.4.5.

3.2 Physical model

To simulate a real concrete structure, a physical model was designed: the "measuring box" with external dimensions of 1200 x 1200 x 300 mm and with the familiar geometry of holes in the walls for the attachment of the diagnosed non-homogeneities. The geometry of holes was designed in order to simulate various sections of concrete reinforcement placed in the formwork (Ø 8, 10, 12 mm), ducts for the prestressing reinforcement, or other elements (Ø 30, 50, 100 mm) in the required vertical and horizontal position. In order to achieve the adequate environment equivalent to a real concrete structure, the whole space was filled with super fine silica sand after placing the concrete reinforcement. The measuring polygon prepared in this way was covered with a fibreboard, from the upper surface of which the coverage of the steel reinforcement was measured.

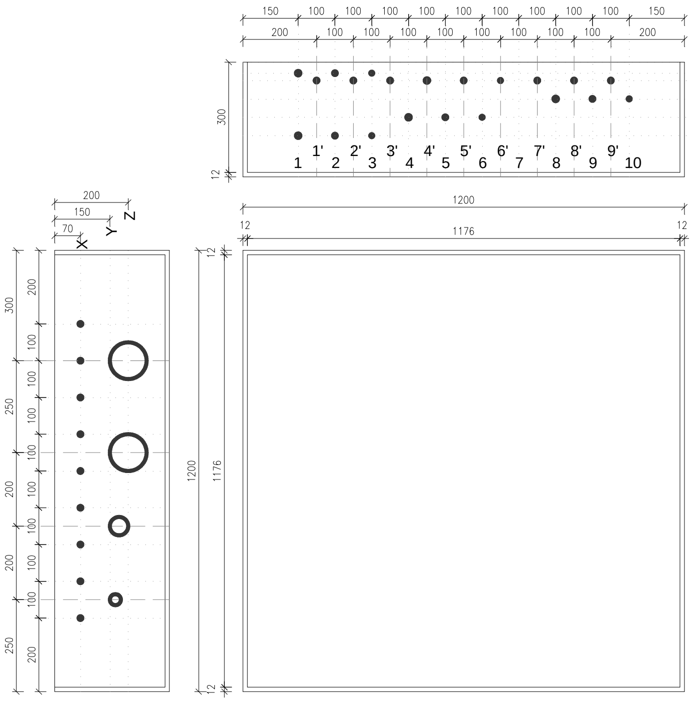

Figure 2: Diagram of the physical model.

3.3 Measurement procedure

Before the actual start of the work with GPR it was important to select the optimum arrangement of steel reinforcement in the physical model. In the first partial measurement, the concrete reinforcement bars Ø 10 mm were arranged in the X direction at distances of 200 mm with 45 mm coverage (green). Further, steel tubes Ø 30 were placed in the X direction (one free, the second one in a plastic sleeve - blue). In the Y direction, the arrangement of bars Ø 10 mm at distances of 100 mm and 200 mm was combined with 65 mm coverage (red). A control steel plate of 200 x 300 x 5 mm (grey) was placed in the formwork as the last component. For illustration see Figure 3.

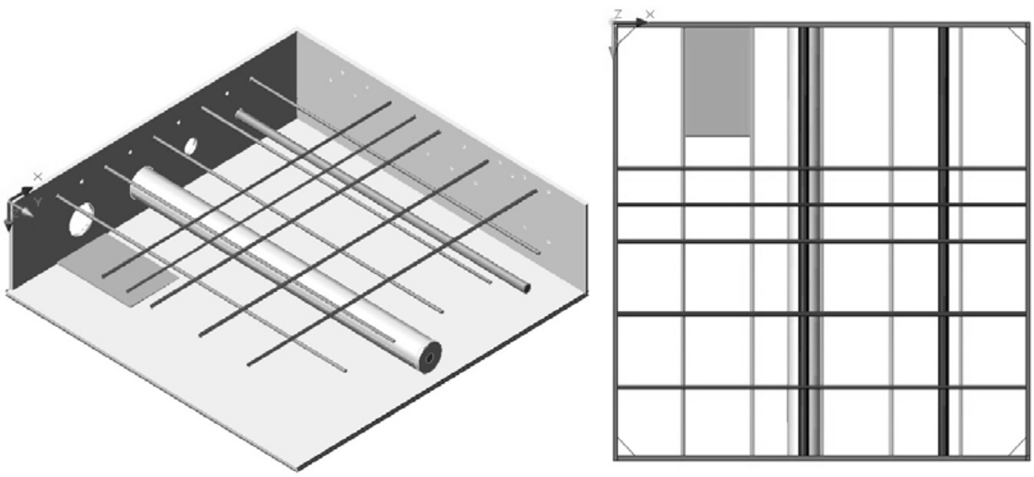

Figure 3: Arrangement of reinforcement in the physical model.

Radar measurements were carried out in the grid of measurement points given by the constant of the shift of the measuring probe along the section (in the range of 5 – 20 mm), and by the distance of the adjacent parallel sections (range 5 – 20 mm). These parameters determined the density of measurement points.

The following table shows the basic settings for individual antenna devices used.

Table 1: Basic parameters of the setting

PARAMETERS	800 MHz	1600 MHz
Antena Separation	0.140	0.060
Frequency	10129.557034	20962.778491
Frequency Steps	45	21
Stacks	8	16
Trace	26362	27900

4 DATA PROCESSING

4.1 Method of data processing

In the course of measurement, the data are recorded in the memory of the measuring computer and continuously displayed on its monitor, Figure 4 and Figure 5. This display serves chiefly as a control of system functionality. The actual evaluation of the measured data is carried out only after finishing the work on the desktop computer, by means of a special processing and graphic software (Dibekon). The measured data were processed by the ReflexW software (K.J. Sandmeier) using one- and two-dimensional filters and other mathematical operations into the shape of radar time-sections and planes.

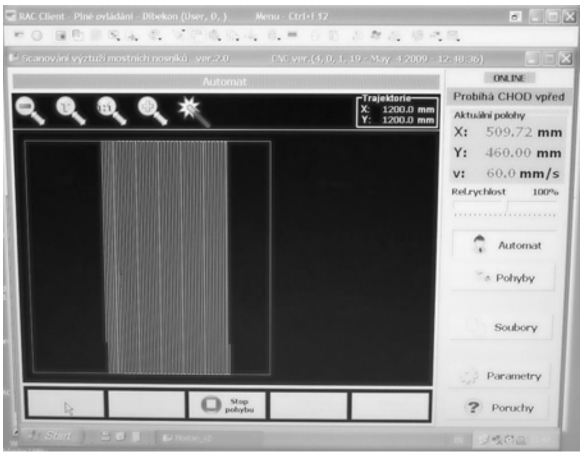

Figure4: Recording of the measurements in-situ . **Figure 5: Dibekon control unit.**

4.2 Values measured

The output of the planar measurements is a set of radar time sections for individual parallel reinforcement sections. In these sections, the individual measured traces - recordings of the amplitude changes of the reflected signal detected in time (vertical axis) - are arranged next to each other in the horizontal axis. Due to dense measurement steps, the resulting sections represent an almost continuous image of the investigated environment. At first, the sections are processed and evaluated separately by means of mathematical filtrations and operations. The processed and adjusted sections are subsequently made into a 3D file enabling a 3D processing and visualization of the results - construction of planar sections and block diagrams.

In the graphic evaluation it is necessary to distinguish the reflections of individual bars of the upper reinforcement from false anomalies at the interference of two reflections, see Figure 14.

Partial graphic outputs provide a sufficient idea about the GPR method. Figures 7-8 show the depth sections of steel bars with 53 mm coverage. Figures 9-10 show a control steel plate located at the bottom of the measuring box. These data were measured using an antenna with a transmission frequency of 1600 MHz. Figures 11-12 show the depth sections of steel bars with 53 mm coverage. Figures 13-14 show a control steel plate located at the bottom of the measuring box. These data were measured using an antenna with a transmission frequency of 800 MHz .

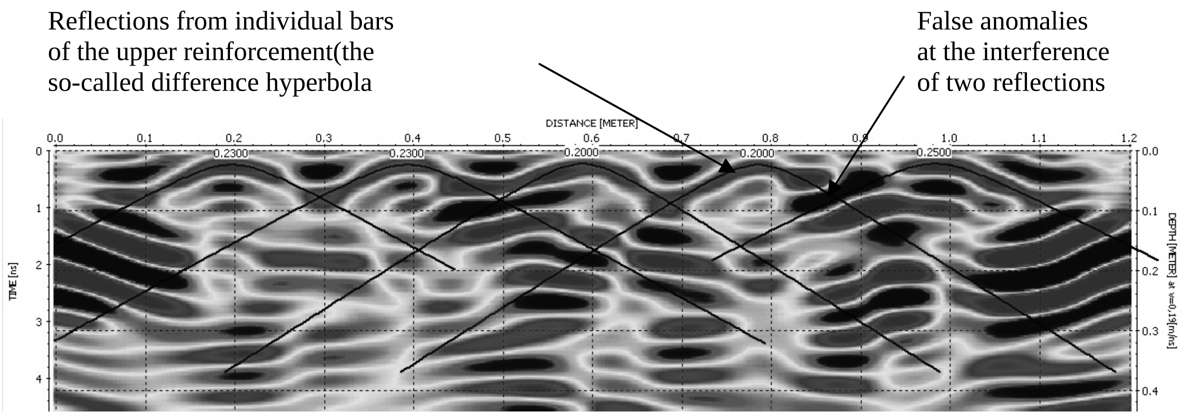

Figure 6: Longitudinal section of the radar section 1600 MHz.

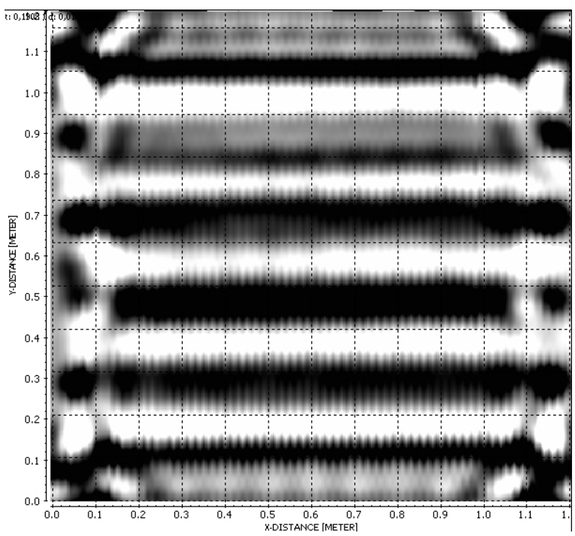

Figure 7:
Image of reinforcement in the cross direction – black and white resolution (1600 MHz).

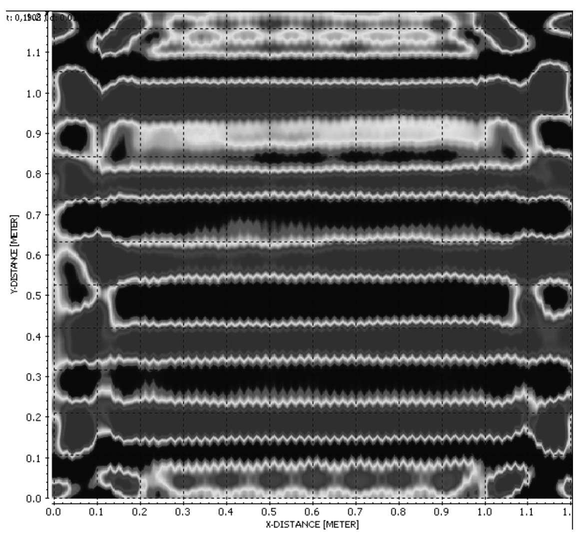

Figure 8: Image of reinforcement in the cross direction – colour resolution (1600 MHz).

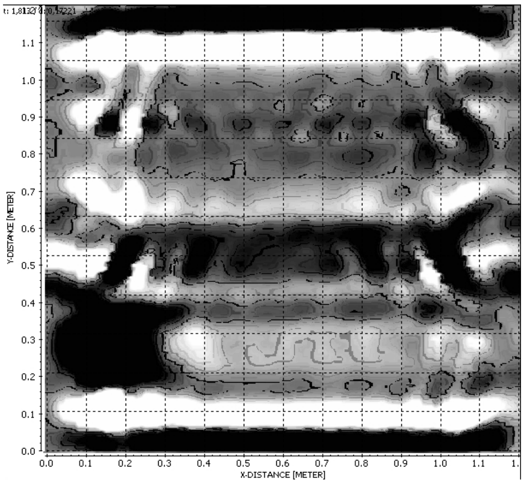

Figure 9: Image of steel plate – black and white resolution (1600 MHz).

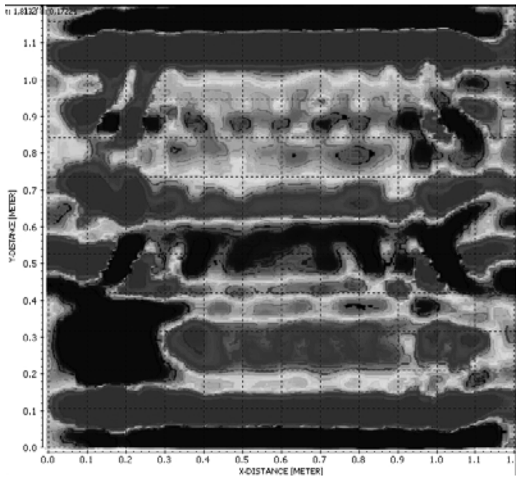

Figure 10: Image of steel plate – colour resolution (1600 MHz).

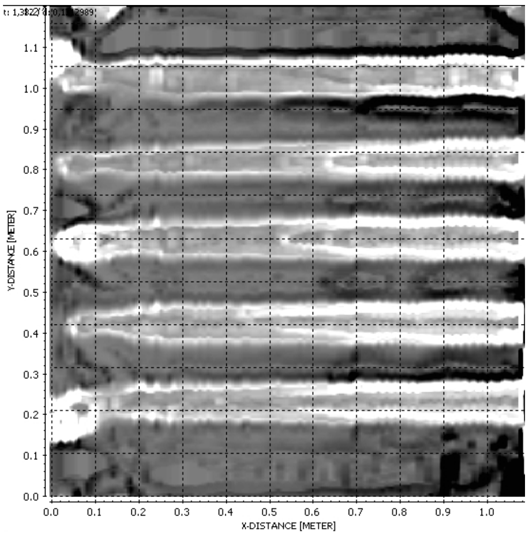

Figure 11: Image of reinforcement in the cross direction – black and white resolution (800 MHz).

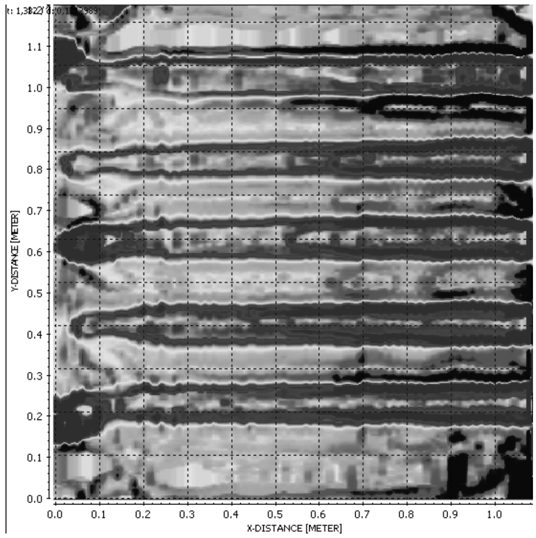

Figure 12: Image of reinforcement in the cross direction – colour resolution (800 MHz).

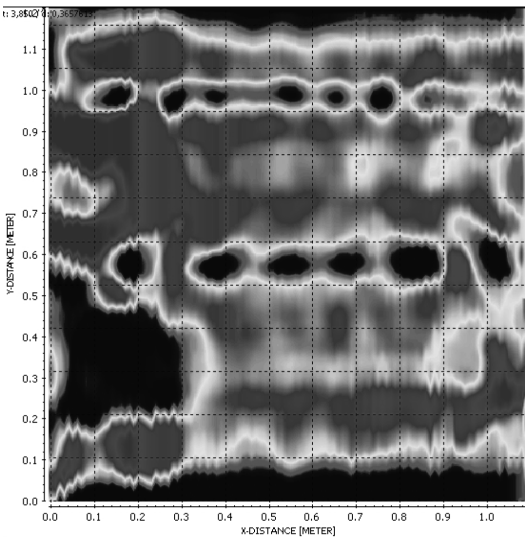

Figure 13: Image of steel plate reinforce-ment – black and white resolution(800 MHz).

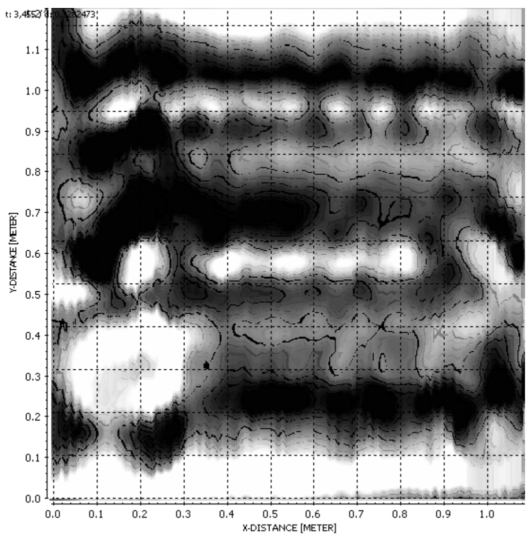

Figure 14: Image of steel plate reinfor - cement – colour resolution (800 MHz).

4.3 Evaluation of the results

On the basis of the data measured, two types of antennae were compared: 800 MHz and 1600 MHz. It was confirmed that the antenna with a transmission frequency of 1600 MHz demonstrates a considerably higher resolving power for the depth range of up to approx. 0.200 m, which is apparent from the pairs of figures: Figure 7 and Figure 11, or Figure 9 and Figure 13, and that the antenna with a transmission frequency of 800 MHz is suitable for greater depths. This measurement also confirmed that this method can be used for the detection of reinforcing elements or other anomalies in the structure.

As this was the first partial processing of a large data file, it is not possible to specify and quantify all the properties of the GPR diagnostic method. During the further processing of the data we expect specification of concrete outputs for creating a complex idea of the GPR diagnostic method.

5 CONCLUSION

The first in the series of planned experimental measurements on a physical model was focused on the comparison of applicability of two antenna systems (800 MHz and 1600 MHz) in the detection of reinforcement placed in various depths, and on monitoring the influence of the density of the measured data on the quality of the results.

The results of the measurements taken showed that the reinforcement in the given configuration was detected by both tested antenna systems, where the 1600 MHz antenna system provides, thanks to its higher sensitivity, a more detailed image of the upper parts of the examined environment, and the 800 MHz antenna system, thanks to its greater depth range, brings better results about the deeper placed non-homogeneities.

6 ACKNOWLEDGEMENTS

R&D project “Development of concrete structure diagnostics through the use of GPR scanner” has been supported and co-financed by the Czech Ministry of Industry and Trade.

REFERENCES

Chang, C. W. & Lin, C. H. & Lien, Hung S., 2009. Measurement radius of reinforcing steel bar in concrete using digital image GPR (Ground penetrating radar). Article from Construction and Building Materials.

Štainbruch, J. 2008. GPR Applicability to Thick Wall Concrete Structure Inspecion – Experiences Gained from Both Experimental Studies and Workaday Measurements. pp. 127 – 127.