Application of GPR in Rebar Detection of Building Structures

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Abstract. The detection of rebar in pillars, beams and floor slabs of building structures is a critical issue in urbanized areas. However, due to some natural and artificial objective factors, the quantity of various rebars is not always consistent with the design data, which directly affects the quality and safety of the building. To ensure structural integrity, quality inspectors must make full use of GPR testing technology. In this paper, we discuss, compare and evaluate the geophysical detection methods and effects of GPR technology regarding the possible hidden safety hazards of reinforced concrete structures. Real testing data shows that GPR detection can provide the precise quantity and positioning of rebars within buildings.

1. Introduction

High-frequency GPR (Ground Penetrating Radar) technology, frequently used in archaeology, is one of the best non-destructive detection methods for distinguishing shallowly buried objects. With the significant improvement of digital computing capabilities in recent decades, it has readily been applied in civil engineering since the mid-1990s [1]. GPR is a high-resolution method involving the propagation of high-frequency electromagnetic waves in the soil and detection of the signals reflected from subsurface ground layers and structures [10]. When this technique is used to detect the internal structures of buildings, its center frequency is usually in the range of 10-5,000 Mhz. The emitted high-frequency electromagnetic waves are reflected by the target and gathered by the receiving antenna [6]. Based on the two-way travel time, amplitude, phase, and other information determined by the reflected waves, scientists interpret the signal to infer the shape and properties of the underground medium, which allows them to identify targets quickly, intuitively, and non-destructively [2]. In addition, the GPR instrument is simple and quick to use in various application areas.

Based on the GPR survey from the Gantang to Wengcheng section of the Beijing-Zhuhai national highway, Xia and Li researched how GPR can be applied in karst cave exploration [11]. Zhou et al. [15] used GPR detection technology studies of shallow surface geological stratification in Nanjing to show the effectiveness and practicality of utilizing this technique in an urban shallow environment and for engineering geophysics [15]. Taking Beijing-Guangzhou high-speed railway K1609 + 730 ~ K1609 + 790 subgrade settlement section as an example, Zhang applied GPR to the area where high-speed ballastless tracks appeared to be settling to reveal the most impacted area [14]. By using GPR to detect the lateral and vertical extension of the subsurface void in a main road located in downtown Bangkok, Thitimakorn et al. were able to provide the necessary technical support for road reconstruction [8]. In addition, Shapovalov et al. utilized this technique to clarify the dimensional parameters of layers within tunnels, analyze the transportation infrastructure in detail and determine the volumetric moisture content [7]. Luo, Yao and Feng's research on rebar detection in the diversion tunnel revealed that the distribution and quantity of rebars were clear in the first layer of GPR, however, the signals from the deeper layers could not be detected [5]. With regard to the detection of reinforced concrete in a tunnel in Hunan...
Province, Yang, Hu, and Liu also illustrated the problem of the mutual interference of deep rebar signals [12]. Wu, Yang, and Luo used GprMax software to forward all GPR data to combine it with a bridge box girder detection method that was used in Nanning and propose a rebar artifact feature and identification method of superposing multiple signals [9]. Yang and Luo proved that the enhanced wavelet transform method can be used to accurately locate the rebars, and the static wavelet transform can be used to determine their diameters [12]. As discussed in this paper, we used real-world GPR data to detect rebars in pillars, beams and floor slabs to analyze its effectiveness and practicality in the construction business.

2. Method

Generally, GPR is used in the construction industry to determine the precise quantity and positioning of rebars within building structures. Therefore, the first step is to obtain clear and precise reflected wave information from rebars, which are generally distributed inside pillars, beams, and floor slabs. In real-world detection, the survey line is perpendicular to the structural trend, because this design will show the maximum change of rebar within the survey area. When electromagnetic waves come into view in the concrete layer, the rebars inside the building appear as a hyperbolic waveform on the GPR profile due to a strong reflective nature. Figure 1 shows the GPR profile obtained during rebar detection. We can precisely determine the quantity and position of rebars through such hyperbolic events.

![GPR image of rebar detection.](image)

However, the resolution of a GPR image is related to the center frequency of the antenna, which is generally determined based on the depth of the target to be detected on site. Generally, if we hypothesize that the actual detection depth is 1.5 times that of the required detection depth, the sampling frequency and number should be increased as much as possible to improve the reliability of the detection results [4]. For example, in the rebar detection site, discussed in the Real Data section, we used three different frequency antennas (900MHz, 1.6GHz, and 2.6GHz) from the SIR-4000 series of the American GSSI company that offer the most effective methods of detection. We found that pillars and beams could be most effectively detected with 2.6GHz antennas, and floor slabs could be most efficiently located with 1.6GHz antennas.

In order to precisely interpret the radar waveform GPR data, it must first be processed in order to suppress the interference wave and display the rebar reflection wave on the GPR image at the highest possible resolution. The next step is to determine various useful parameters of the reflected wave (including electromagnetic wave velocity, amplitude, phase, and frequency, etc.) to accurately identify the locations of the rebar. Commonly used GPR data processing methods include preprocessing, time zero correction, background removal, gain adjustment, digital filtering, and deconvolution [3]. The preprocessing phase includes format conversion, coordinate correction, and other preliminary work; Time zero correction is used to predict the true zero position in a pulsed GPR system; Background removal can eliminate background noise from radar images and enhance useful signals; Gain adjustment can be used to compensate for the amplitude; Digital filtering uses spectrum characteristics to suppress various interference waves, such as direct waves and multiple reflected waves; Deconvolution can suppress multiple interference waves and improve vertical resolution.
3. Real-world data

3.1. Rebar Detection in Pillars

Figures 2 and 3 show how GPR can be used to detect rebar in pillars. As seen in Figure 2, the detection was performed anticlockwise in the order of I, II, III, and IV (The north-south direction is the X-axis and the east-west direction is the Y-axis.) on a pillar arranged with four survey lines. The on-site construction is shown in Figure 2b, and the detection results are shown in Figures 3 (a-d). The positive and negative peaks of the waveform are shown in black, white and grayscale, respectively. In this way, the event can vividly represent the hyperbolic reflection of the rebar.

![Figure 2. The arrangement of the rebar survey lines in a pillar at a construction site.](image)

On building quality surveys, GPR can achieve better results than shallow seismic exploration because the buried targets are often too shallow and GPR is relatively less constrained in such a site. Moreover, it is non-destructive, which can prevent damage to the building structures. The GPR reflected wave, shown in Figure 3, was continuous, and the parts shown in red boxes were the reflections of the rebars detected in the four survey lines I, II, III, and IV, respectively. The quantities of the detected rebars were 5, 6, 5 and 6 respectively, and their depths from the pillar surface were 8 cm, 12 cm, 11 cm, 8 cm. Their horizontal positions were also deduced from the GPR profile in Figure 3. Thus, through the above analysis, we were able to detect the precise quantity and positioning of rebars in various building structures.

![Figure 3. GPR detection results of rebars in a pillar.](image)

3.2. Rebar Detection in Beams

Figure 4 shows a construction site on which a GPR detection beam was utilized. The beam was arranged based on two parallel survey lines, which were perpendicular to the trend of the rebars in the beam. Four rebars were detected by the two survey lines, which were consistent with the design plan, as shown in Figure 5 (a-b). As seen in the photos below, GPR detected obvious hyperbolic reflections in the rebars, and the characteristics of the reflected wave groups were also very obvious. The results of the two survey lines contrasted significantly, and we were able to precisely define the quantity of rebars in the beam. As shown in Figure 5, the depths of both the rebars measured 6 cm from the beam surface. The horizontal
position can also be observed from the two GPR profiles. Building structures are basically made up of only rebars and concrete, the dielectric constants of which are significantly different. Therefore, using GPR to detect rebars can not only precisely determine their quantity but also their positioning.

![Figure 4. Construction site of rebar detection in a beam.](image)

**Figure 4.** Construction site of rebar detection in a beam.

![Figure 5. GPR detection results of rebars in a beam.](image)

**Figure 5.** GPR detection results of rebars in a beam.

### 3.3. Rebar Detection in Floor Slabs

Figure 6 shows the rebar survey line arrangement in a floor slab at a construction site. Considering that the trends of the rebars in the concrete are two directions perpendicular to each other, two perpendicular survey lines (at the X-axis and Y-axis) were arranged on the floor slab to better facilitate detection. Figure 7 shows the GPR results, and the red box indicates the reflection of the rebars. The hyperbolic reflection of the two-layers, which are parallel, can be seen clearly in the GPR profiles. Thus, we inferred that the image depicts the two-layer rebars designed to strengthen the floor slab for greater safety. Figures 7 (a-b) show the rebar detection results via GPR along the X and Y axes. Figure 7 precisely shows that the quantity of rebars in the upper and lower layers along the X-axis was 12 and 10, respectively. We also used the GPR data to calculate the average buried depth of rebars in each layer, the first of which was 18 cm, and the second was 28 cm. Furthermore, we calculated the average spacing of rebars in each layer. The mean spacing of the upper layers was 150 mm, and that of the lower layers was 147 mm. Similarly, the quantity of rebars detected in the upper and lower layers along the Y-axis was 11 and 12, respectively. The average buried depth of the rebars in the first layer was 18 cm and 28 cm in the second. The mean spacing of rebars was 150 mm in both the upper and lower layers. It can be seen that no matter whether the detection was performed along the X or the Y-axis, the average buried depth and mean spacing of the rebars were very consistent, and the detection results were consistent
with the design data. Therefore, this experiment proves the value of utilizing GPR to detect the location of rebars in urban building structures.

![Figure 6](image1.png)  
**Figure 6.** Arrangement of rebar survey lines in a floor slab at the construction site.

![Figure 7](image2.png)  
**Figure 7.** GPR detection results of rebars in a floor slab.

### 3.4. Excavation verification
Figures 8 (a-c) are excavation verifications of rebars. The GPR images are shown on the left side. The hyperbolic reflection of rebars in pillars, beams, and floor slabs can be clearly seen within the GPR profiles. The excavation verification of various parts is illustrated on the right side of these figures. After on-site verification, it became obvious that the quantity and positioning of these rebars, detected by GPR exactly matched the results of the excavation. (The red arrows in these figures represent the rebars.)

### 4. Conclusions
Based on the above analysis, we found that GPR can be used to accurately detect rebars in building structures. This technique, which is ideal for shallow detection tasks, avoids the shortcomings of more traditional geophysical detection methods, that are very destructive. GPR can be used to not only detect the quantity of the rebars but also their precise locations. Therefore, we believe that the role of GPR in urban geological surveys will become increasingly significant.

However, at present, the use of GPR to directly obtain the diameters of rebars in concrete must be further researched. Although it is now possible to eliminate the diffraction waves of rebars through the migration algorithm in order to calculate the diameters, there are still some issues associated with this technique. For example, quality inspectors must not only know the spatial distribution of the rebars but also their precise diameters in order to ensure the structural stability and earthquake resistance of the building. Therefore, in future research, we will focus on high-precision migration imaging algorithms to improve the accuracy of rebar diameter detection.
Figure 8. GPR detection results and excavation verification in pillars, beams and floor slabs.

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