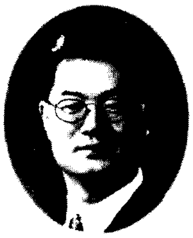
Imaging of Steel Bars Embedded inside Mortar Specimens for Nondestructive Testing



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ABSTRACT

Ground Penetrating Radar (GPR) with 1 GHz antenna has been used to locate a steel bar embedded inside laboratory-prepared mortar specimens. Four mortar specimens are made with the dimensions of 100 cm (length) × 100 cm (width) × 14 cm (depth). One specimen had no bars and the other three specimens had a D19 steel bar at 4, 6, and 8 cm depth.

As a part of the experimental work, the dielectric constants of mortar specimens are measured during curing. As the curing time increased, the dielectric constant decreased with decreasing moisture content inside the specimen.

The steel bar embedded inside mortar specimens has been successfully identified in all three cases. The results using signal processing scheme developed in this study significantly improved the output of a commercially available radar system .

Keywords : Ground Penetrating Radar, mortar, steel bar, signal processing, dielectric constant, Nondestructive Testing (NDT)

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1. Introduction

The radar method is frequently used recently for the probing of concrete structures for nondestructive testing (NDT) purposes. A systematic approach is needed to enhance the radar method as an efficient and reliable NDT technique. The study should include i) the measurement and establishment of electromagnetic properties of concrete as a function of frequency and other factors,(1,2) ii) the modeling of electromagnetic wave propagation and scattering using computer,(3) iii) the experimental measurements of concrete specimens to develop various measurement cases,(4,5) and finally iv) the development of proper signal processing techniques.(6)

One of the fundamental and important application of the radar method to concrete structures is to locate and identify steel reinforcing bars embedded inside concrete. Detecting steel bars in real structures can be difficult because of placement of a multiple number of bars which causes interference and ringing of the radar signals. In simple cases of the condition assessment of concrete structures, locating the bars in the top layer is still useful in confirming the proper placing. In more complicated cases, locating multiple bars and delaminations can be performed.

In this paper, a series of radar measurements has been made to determine the existence of a steel bar at 1 GHz center frequency using different mortar cover depths. Mortar specimens are used for the measurements prior to application to the concrete specimens because of their homogeneous characteristics. The results show that the displayed output of the radar measurements improved significantly after applying the developed signal processing technique. Thus, the results provided a basis for further development of the radar method for NDT.

2. Measurement Parameters and Mortar Specimens

In detecting a steel bar inside concrete, the factors relating to incident wave, measurement setup, and target are to be considered. The incident wave has a center frequency and frequency bandwidth which determine resolution and penetration capability. In this experiment, the center frequency of the radar wave is 1 GHz and the frequency bandwidth is also 1 GHz. For the measurement setup, the radar is placed on the top of mortar specimen. A schematic diagram of the measurement setup is shown in Fig. 1.

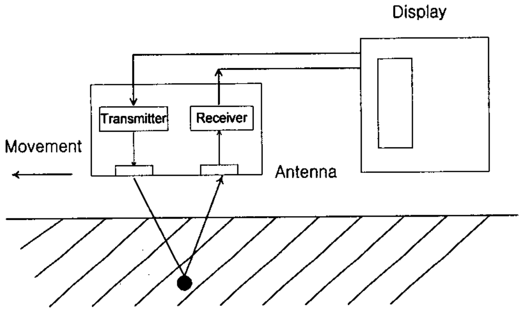

Fig. 1 Principle of ground penetrating radar

Mortar specimens are cast with mix ratio of water : cement : sand = 1 : 2.22 : 5.61 by weight. The dimensions of the specimens are 100 cm (length) x 100 cm (width) x 14 cm (depth). A D19 bar was placed inside mortar

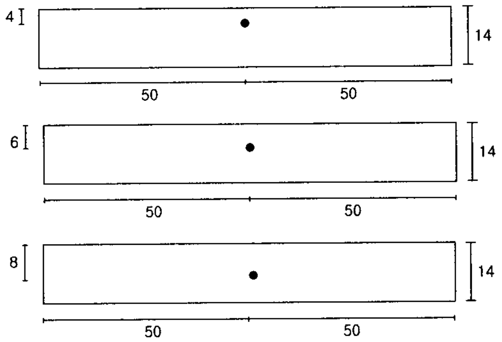

Fig. 2 Cross-sections of mortar specimens with a steel bar (unit: cm)

specimens at 4, 6, or 8 cm depth. Cross-sections of the mortar specimens are shown in Fig. 2.

3. Experimental Setup

The 1 GHz antenna traveled along the top surface of a specimen while transmitting and receiving signals over the measured distance as shown in Fig. 3 which illustrates the experimental setup.

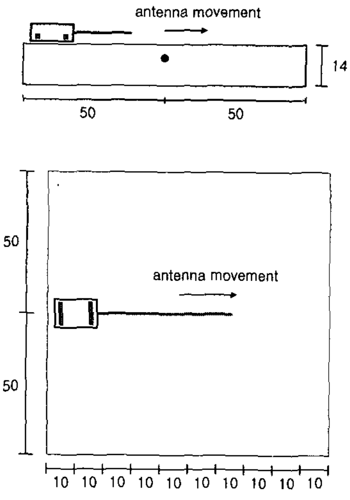

Fig. 3 Measurement setup (unit: cm)

4. Results and Discussion

Dielectric constants of the specimens are measured before the radar measurements. The electromagnetic properties affect the radar measurement and data interpretation by determining the wave velocity inside concrete. As a part of the dielectric constant measurement, the properties are recorded over the curing period of 8 weeks. The variation of the dielectric constants are plotted in Fig. 4. As moisture content decreases over the curing period, dielectric constant also decreases. The dielectric constant makes the wave slow down inside concrete as shown by Equation 1:

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

where v is the velocity of the wave inside specimen, c is the speed of light (3×10^8 m/sec), and ε_r is the dielectric constant.

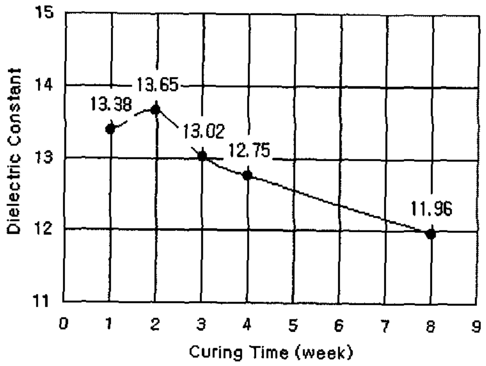

Fig. 4 Dielectric constant vs. curing time

The results of the radar measurements are presented in Figs. 5~10. As shown in Figs. 5, 7, 9, typical output generated by commercially available radar system, it is difficult to identify the exact location of the bar. The data interpretation is usually based on the judgement of an experienced operator rather than a systematic process.

In Figs. 6, 8, and 10, the data are processed using the reflection coefficient and impedance mismatch. When a wave is confronted with a material mismatch, there is a reflection.

Different materials have their own mismatching coefficients which are called the impedance mismatch. Equation 2 shows the relationship.(7)

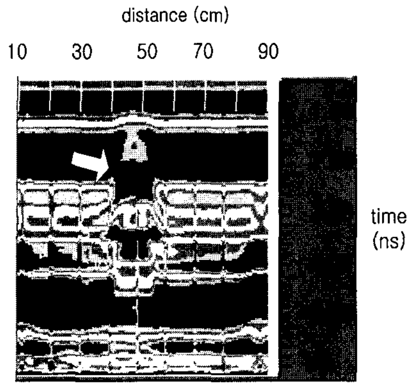

Fig. 5 Raw data at 4 cm depth

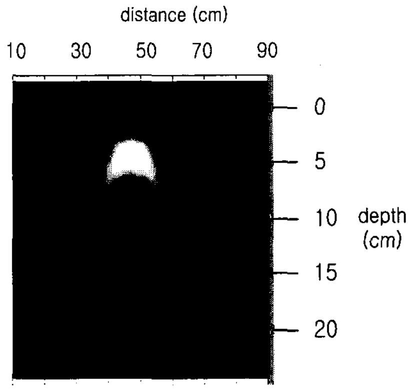

Fig. 6 Signal processed data at 4 cm depth

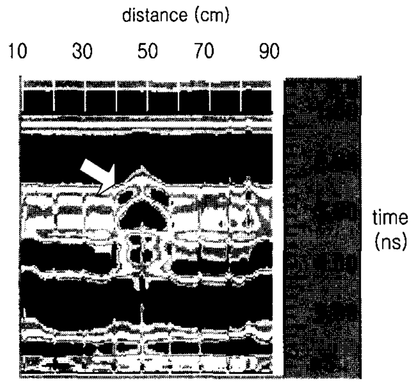

Fig. 7 Raw data at 6 cm depth

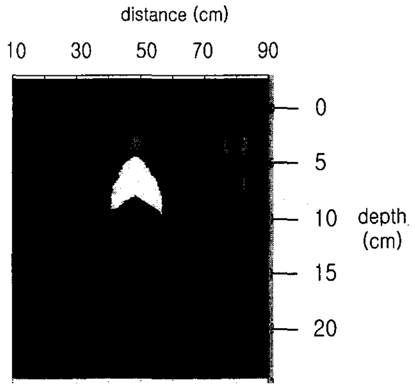

Fig. 8 Signal processed data at 6 cm depth

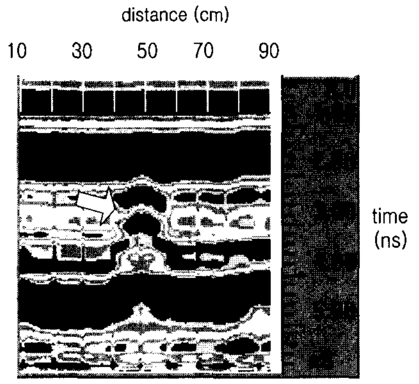

Fig. 9 Raw data at 8 cm depth

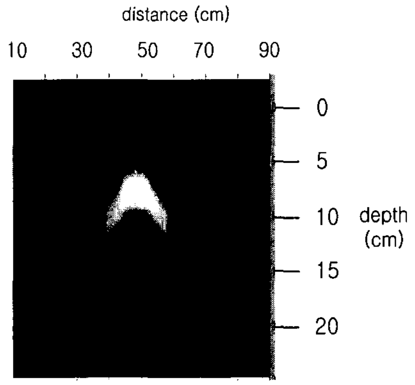

Fig. 10 Signal processed data at 8 cm depth

$$\Gamma = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} = \frac{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}} \quad (2)$$

where η_1 and η_2 are characteristic impedances for materials 1 and 2, and ε_r' s are dielectric constants.

As the radar wave hits the steel bar, which is a perfect conductor, the strongest reflection and impedance mismatch occur. Improved imagery of the specimen can be obtained, if that mismatch is captured. The results of newly processed data are given in Figs. 6, 8, and 10.

In Figs. 6, 8, and 10, the existence and location of the bars are clearly seen. It is even possible for an inexperienced operator to identify the bar. As the impedance mismatch is increased at the bar, the intensity of the mismatch is presented as the whiter mark in the output display. This developed technique significantly improves the rebar detection capability of a radar system compared to the existing commercially available systems.

The actual and measured rebar locations are tabulated in Table 3. It is shown that the error is less than 10 % and is acceptable. The error increases as the bar is located deeper from the surface.

Table 3 Result of measurement (unit: cm)

Actual Location	4.30	6.10	8.10
Measured Location	4.30	6.03	7.82
Error (%)	0	1.15	3.46

It should be pointed out that the more accurate interpretation is possible by incorporating exact dielectric constant of the specimen into the calculation. Sometimes, radar operators in the field do not use an exact dielectric constant. Assumed or approximate value of the dielectric constants are frequently used in the field. This is an inappropriate way of using the radar. Thus, it is important to use the correct dielectric values, which typically vary over frequency and other factors as moisture content.

The other thing is that if the bar is located close to the surface, radar cannot detect it. The coupling between the radar and the specimen at close range interferes correct measurement. This phenomenon is also observed and confirmed with commercial radar operators.

5. Conclusions

An improved radar method has been studied experimentally which enhances the output of measurements by utilizing a dielectric constant and an impedance mismatch of concrete and steel bar. It has been shown that the developed technique significantly enhances the accuracy of the output compared to the raw data. Further study will include the investigation of concrete specimens with multiple steel reinforcing bars.

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