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Measurement of iron mass in concrete wall using ultra-wide band radar

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Abstract: Here, it is aimed to measure and detect the iron mass of a concrete solid wall, column, floor by using of ultra-wide band radar. Electromagnetic waves boundary conditions, reflection, and refraction of waves that radiate in solid material are analysed. GPR imaging methodology and scanning types such as A, B, and C are analysed. Ultra-wide band radar imaging is used for detecting measuring the diameter of the iron material.

1 Introduction

Today too many researches are made about scanning of short range depth of concrete wall. These researches are made mainly for the purpose of detecting, recognising, and classifying the materials in the concrete. In construction technology, it is possible to measure the amount of iron in the concrete floors, walls, and columns. The measuring of iron mass that used in the producing of concrete floor, walls, and columns ensures us the information about the strength of the building against the earthquakes etc.

It was a hard way to get the strength information of the building after the construction phase. Strength measurement of the constructed building should be done without damage to the building. For this purpose, researchers work on non-destructive measurement methods. Ultrawide band radar technology should be used in this area as a non-destructive measurement device.

Ultra-wide Band is a technology for the radiation of signals spread over a very large frequency band. Ultra-wide band consumes a very low power level for short-range and high-bandwidth communications over a wide radio spectrum [1]. Ultra-wide Band use very low power spectral density. The spectral density reduces interference and high bandwidth can provide very high sensitivity for position and imaging devices [2]. Ultra-wideband radar systems transmit signals at a very wide frequency than narrowband radar systems, and it is often very difficult to detect these signals in comparison to narrowband systems. The transmitted signal has a very low power spectrum and it is lower than the permissible radiation emissions level [3].

In this research, we mainly focus on, detecting, measuring of the iron mass in concrete buildings using ultra-wide band radar technology. Electromagnetic waves that radiate in solid materials can be reflected or refracted according to the boundary conditions. For this reason, Snell laws and Fresnel laws are analysed.

2 Electromagnetic wave parameters of scanning

Reflection and refraction parameters have to be well analysed in scan. It is normal that the medium changes of the electromagnetic waves radiates. The analysis of the medium-changing plane waves is done according to the boundary conditions. For this reason, Snell and Fresnel laws must be analysed.

2.1 Snell's laws

Electromagnetic waves generally travel in different mediums in nature. During an incident, electromagnetic wave passes through an interface of different medium. This medium change of incident wave usually generates a reflected wave in the first medium and a transmitted wave in the second medium. Transmitted wave is known as refracted wave. Reflection and refraction directions of the plane wave are expressed by the Snell's law. Amplitude phase of reflected and refracted wave is expressed by the Fresnel's law [4].

In GPR, medium 1 can be thought as the air environment and medium 2 thought as the ground or the material to be radiated. Electromagnetic wave velocity is always faster than other materials (Fig. 1).

The angle of reflected wave and incident wave is equal.

$$\mathrm{k_i} \times \sin\theta_i = k_t \times \sin\theta_t \tag{1}$$

$$k = \frac{\omega}{v} \tag{2}$$

Sine of the refracted and incident wave are proportional to the phase velocity of the plane.

$$\frac{\sin\theta_i}{v_i} = \frac{\sin\theta_t}{v_t} \tag{3}$$

2.2 Fresnel's laws

Fresnel's laws expresses how the amplitudes of the electromagnetic fields vary across an interface between two mediums. A plane EM wave passes through a boundary; it is partially transmitted and partially reflected as shown below. The amplitude of the incident wave is denoted as I, and the reflected wave is denoted as RI; and transmitted wave is denoted as TI [5] (Fig. 2).

These two wave fields are shown in Fig. 3. These waves are named as transverse electric (TE) field and (transverse magnetic (TM) field waves. As shown in the figure, the TE wave's electric field is direct into page and parallel to the interface's plane and the TM wave's magnetic field is direct to out of the page and in the interface's plane.

TE and TM wave's reflection and transmission (refracted) coefficients have different mathematical forms by the reason of different field behaviours.

$$I_{\mathrm{TE}} + R_{\mathrm{TE}} \times I_{\mathrm{TE}} = T_{\mathrm{TE}} \times I_{\mathrm{TE}} \tag{4}$$

$$\mathrm{I_{TM}} + R_{\mathrm{TM}} \times I_{\mathrm{TM}} = T_{\mathrm{TM}} \times I_{\mathrm{TM}} \tag{5}$$

I_{TE}: Electric field strength for the TE wave,

I_{TM}: Magnetic field strength for the TM wave.

The mathematical expressions of R and I are obtained by aid of two fundamental laws. First, Snell's law must be satisfied. Second,

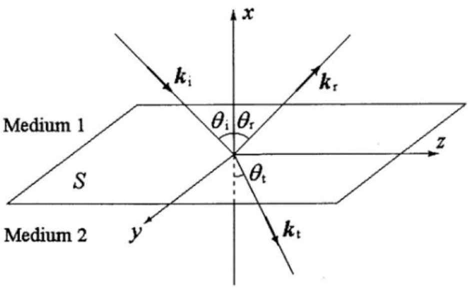

Fig. 1 *Incident, reflected and transmitted wave*

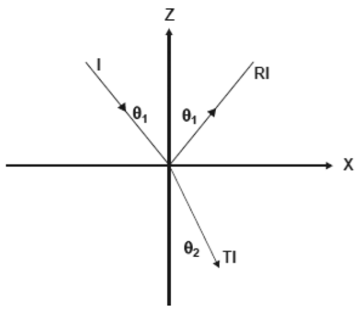

Fig. 2 *Fresnel's reflection laws*

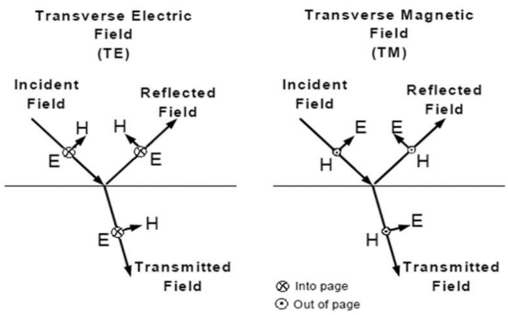

Fig. 3 *TE and TM*

electric and magnetic fields must be same on each side of the interface (boundary), and electric current and magnetic flux density must be same on each side of the interface boundary. With the aid of two fundamental laws, the reflection and transmission coefficients can be obtained by the fallowing equations [5]:

$$R_{TE} = \frac{Y_1 \cos\theta_1 - Y_2 \cos\theta_2}{Y_1 \cos\theta_1 + Y_2 \cos\theta_2} \quad (6)$$

$$R_{TM} = \frac{Z_1 \cos\theta_1 - Z_2 \cos\theta_2}{Z_1 \cos\theta_1 + Z_2 \cos\theta_2} \quad (7)$$

$$T_{TE} = 1 + R_{TE} = \frac{2 \times Y_1 \times \cos\theta_1}{Y_1 \cos\theta_1 + Y_2 \cos\theta_2} \quad (8)$$

$$T_{TM} = 1 + R_{TM} = \frac{2 \times Z_1 \times \cos\theta_1}{Z_1 \cos\theta_1 + Z_2 \cos\theta_2} \quad (9)$$

The reflection and transmission wave field's parameters are expressed by the fallowing equations:

$$R_{TE}^{H} = -R_{TE}^{E} \quad (10)$$

$$R_{TM}^{E} = -R_{TM}^{H} \quad (11)$$

$$T_{TE}^{H} = \frac{Y_2}{Y_1} \times T_{TE}^{E} \quad (12)$$

$$T_{TM}^{E} = \frac{Z_2}{Z_1} \times T_{TM}^{H} \quad (13)$$

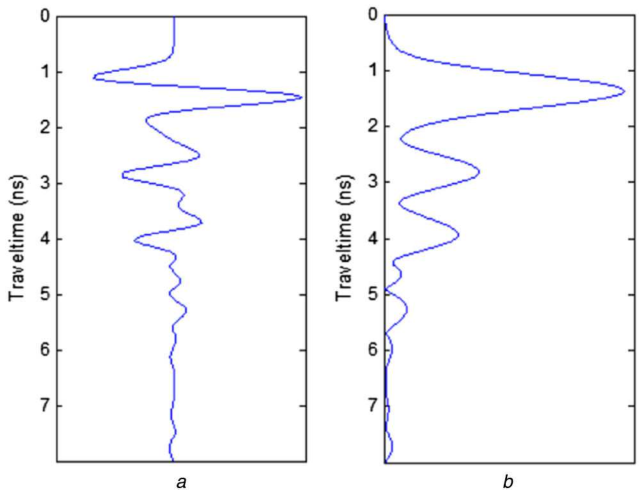

Fig. 4 *A type scan [8]*

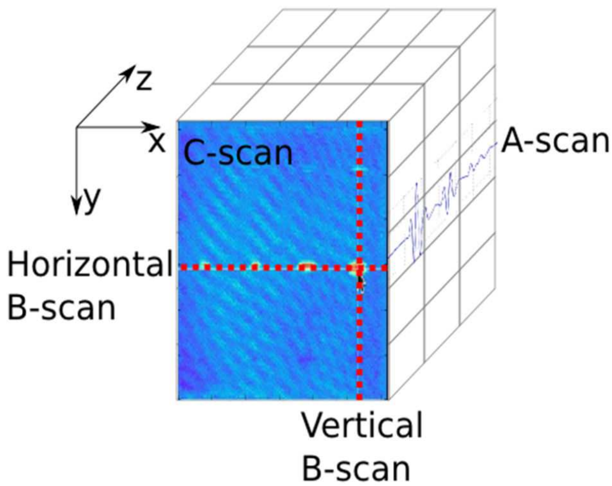

Fig. 5 *C type scan [10]*

3 Ground penetrating radar imaging

Ground penetrating radar emits electromagnetic waves in the ground and collects the backscattered signals. A backscattering occurs when the emitted signal encounters a surface between two electrically different materials. The intensity and direction of the backscattering depend on two parameters, the roughness of the surface and the electric property of the medium material.

A rough surface backscatters signal in a diffused manner, while a smooth surface tends to reflect at the same angle with respect to the surface normal. The electric property of the medium determines the refraction and absorption levels of the EM waves and affects the direction and intensity of the reflection [6].

The data collected by a GPR are generally represented and classified as a one-, two-, or three-dimensional dataset, named by A–B and C-scans. This terminology comes from acoustic. A-scan data are collected signal by a stationary measurement. The collected signal is presented as signal strength versus time delay. A-scan is a one-dimensional graph [7] (Fig. 4).

B-scan data are collected as a multiple of A-scans, measured by a line scan. The collected signal is presented as intensity on the plane of scanned width versus time delay. B-scan can be presented as a two-dimensional image.

Finally, when collecting multiple parallel B-scans, in other words, a three-dimensional data set is called as C-scan. Usually a C-scan is represented as a two-dimensional image by plotting the amplitudes of the collected signals at a given time [9] (Fig. 5).

The collected signal is presented as intensity in a box of scanned region versus time delay. A C-scan is a three-dimensional data structure. It is difficult to visualise a three-dimensional structure. C-scan is usually represented as a horizontal slice for a specific data point, which indicates the depth level [7].

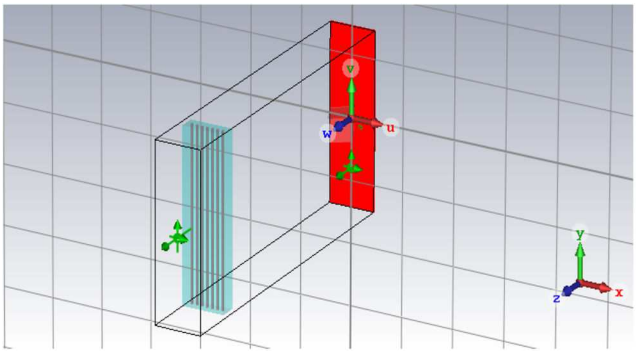

Fig. 6 *Simulation of test system*

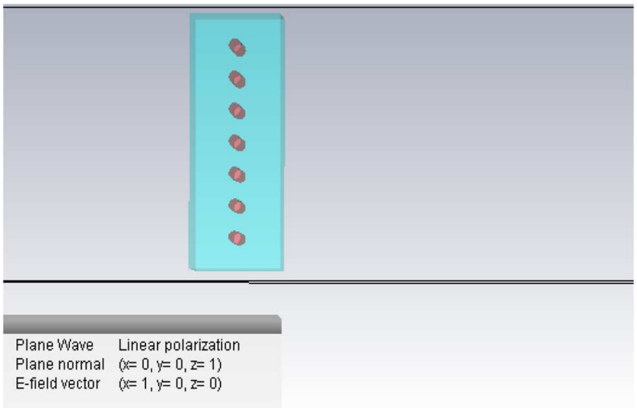

Fig. 7 *Top view of the concrete column*

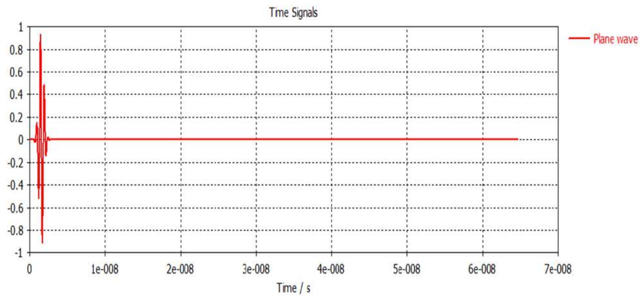

Fig. 8 *Transmitted radar wave*

4 Methodology

In our approach on detecting and measuring the iron mass in a concrete, using ultra-wide band ground is penetrating radar imaging technology. Simulation of test system is figured below in Fig. 6. A 1–3 GHz plane pulse wave, which is propagated in z direction, is used in the test simulation. A concrete column which has seven iron rod is simulated below in Fig. 7.

Methodology is based on to measure diameter of the iron material. Detection of the diameter is based on electromagnetic

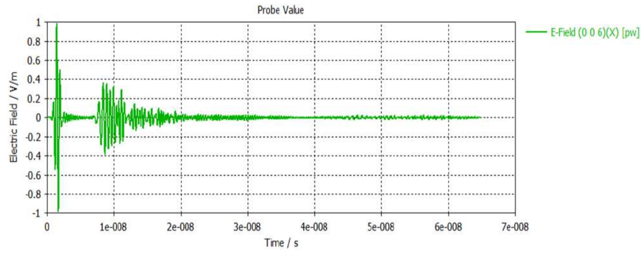

Fig. 9 *Reflected radar wave from front side of Wall*

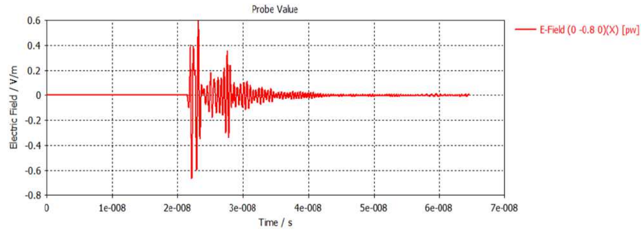

Fig. 10 *Transmitted radar wave from wall*

waves reflections. The algorithm is designed for the detection of the peak value of the reflections from the boundary of the iron material. Simulation results, transmitted radar wave, and reflected radar wave are presented in Figs. 8–10 below.

5 Conclusions

In this research, we are working on increasing the efficiency of the ultra-wide band ground penetrating radar for detecting and measuring of the iron mass in a concrete solid material. The research of the measuring iron mass is advancing on the smart analysing algorithms of the radar data on radar signal processing, antenna design, and signal enhancement.

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