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Volumetric water content estimation of C-30 concrete using GPR

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HIGHLIGHTS

- A non-destructive method as GPR can be used for the water content of concrete.
- The dielectric permittivity of concrete mostly depends on the water content.
- The water content of concrete can be monitored by time-lapse GPR measurement.

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ABSTRACT

In this research, we consider a laboratory specimen of C-30 concrete block using a geophysical technique called GPR (Ground-Penetrating Radar). The volumetric water content of the C-30 concrete block can be estimated using a central frequency of 2 GHz shielded GPR antenna in a non-destructive way. In this purpose, time-lapse GPR measurements were applied over the C-30 concrete block that took about 150 days. We estimated relative dielectric permittivity of concrete block from the scatters on GPR profiles that caused by an iron bar in the concrete block. Data were acquired consecutively 5 times in each day to calculate the arithmetic mean of relative dielectric permittivity. To estimate the volumetric water content of a sample, we used previously suggested formula for various concrete classes. Based on information from the factory, the volumetric water content of the sample was 7.31% according to its composition. However, based on our estimation by the formula, the volumetric water content was estimated 7.19% at the 3rd day after the concrete block was prepared in the factory. This experiment suggests that the water content variation of the corresponding concrete sample can be monitored using the GPR method in a non-destructive way. The result may be extended to other classes of concrete as well. The suggested method is a fast, economic and simple way to estimate the volumetric water content of a concrete sample. Our time-lapse measurements can be a guide to estimate volumetric water content of C-30 concrete class.

1. Introduction

Some geophysical methods provide important information about the content of material in a non-destructive way. These types of non-destructive methods appear in the civil engineering. Detection of rebars in concrete is one of the most common applications of Ground-Penetrating Radar (GPR) in civil engineering. GPR method has been applied widely in civil engineering applications such as determination of the location of reinforced bars, buried pipes [1,2], concrete thickness [3], void detection in concrete [4,5], rebar size [6], safety management of ancient buildings [7,8].

The estimation of moisture is another common application of GPR studies. Several authors introduced applicability of volumetric water content in subsurface materials by GPR [9–14]. The dielectric permittivity of concrete can also be estimated using TDR (Time Domain Reflectometry) method [15,16]. However, [17] studied about the relationships between volumetric water of soil and the dielectric permittivity in some various soil types. They derived an empirical equation that can be used to estimate the volumetric water content of soil using the value of dielectric permittivity. For instance, [18] studied to estimate water content of different soil samples with varying sandy and loamy compositions from the dielectric permittivity measurements with TDR method. [19,20] used soil samples to describe water content of soils in similar studies as well. The main problem with this approach is that it requires probes/wires to be imbedded into a material makes it a destructive method which is unwanted for its application to concrete mass. To be able to assess moisture content in any location of the concrete mass, and in a totally non-destructive way, GPR was proposed [21], as it has the same kind of propagation wave and similar equations governing as TDR [22].

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The dielectric permittivity is dependent on density, texture, salt content, temperature and water content [17]. However, the dielectric permittivity of a material is strongly dependent on the water content [23]. The volumetric water content of concrete has a great importance to control concrete condition. The dielectric permittivity of concrete mostly depends on the water content as well. The same approach and procedure, which has been applied to soils, may be extended to concrete samples to estimate water content. There are several studies for estimating of water content in concrete by GPR in the literature. [24] investigated the water content in concrete samples with different saturations by controlling the water content by an oven. [6] studied on estimation of water content of concrete samples besides estimating the location of rebars. [25] introduced an approach to estimate porosity properties of concrete. [26] studied on the influence of dielectric properties of concrete in GPR testing. In this paper, we consider on C-30 concrete class. C-30 concrete class is one of the most used concrete types in the construction sector. Therefore, C30 type concrete was preferred in this study and made time-lapse measurements to estimate volumetric water content of concrete as a function of the time.

2. GPR principles and EM wave estimation

GPR method is based on electromagnetic wave theory. The EM wave is transmitted to a medium by a transmission antenna and it propagates in that corresponding medium/media and recorded by a receiver antenna by the function of time. Some of the energy of the EM wave reflects back in due to the difference electrical properties of the media [27]. There is a relationship between the EM velocity, the geometry and the dielectric permittivity of the medium, which allows obtaining the latter when the first two are known. The propagation velocity v of the electromagnetic wave in a concrete block can be characterized by the dielectric permittivity (dielectric constant) ε and magnetic permeability μ of the medium [23,28]:

$$v = \frac{1}{\sqrt{\varepsilon\mu}} = \frac{1}{\sqrt{\varepsilon_0\varepsilon_r\mu_0\mu_r}} \quad (1)$$

where $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m is the permittivity of free space, $\varepsilon_r = \varepsilon/\varepsilon_0$ is the relative permittivity of the medium, $\mu_0 = 4\pi \times 10^{-7}$H/m is the free-space magnetic permeability, and $\mu_r = \mu/\mu_0$ is the relative magnetic permeability. In most medium especially soils, concrete etc., magnetic properties are negligible, yielding $\mu = \mu_0$, and (1) becomes;

$$v = \frac{c}{\sqrt{\varepsilon_r}} \quad (2)$$

where $c = 3\text{x}10^8$ m/s is the velocity of light that is equal to EM wave velocity in the free space.

There are generally three basic modes of GPR operation to collect data in a field. (a) Reflection mode: the distance between transmitter and receiver antenna is fixed (fixed off-set), (b) Wide angle reflection and refraction (WARR) and Common mid-point (CMP) modes: the distance between transmitter and receiver antenna increases step by step (variable off-set). (c) The transmitter and receiver antennas are at the opposite sides of the material which is called as a transillumination mode [29]. In generally, this mode is preferred for a tomography study.

Practically, there are two different approaches to estimate the EM wave velocity in GPR applications. In this study, the profiles above the concrete were measured in the Reflection mode to estimate the background EM wave velocity. The estimation of EM wave velocity can be obtained by using both reflection and CMP modes. When there is an iron bar in a concrete, it is easy to estimate EM wave velocity using a hyperbola fitting since there is a hyperbola on the radargram (B-scan). An iron bar inside the concrete used to obtain a scatter to estimate EM wave velocity. Once the EM wave velocity estimated, it is possible to calculate the relative dielectric permittivity using Eq. (2), which is going to lead us to the water content. In case of there is no iron bar inside the concrete, the EM wave velocity can be estimated using WARR mode measurement or transillumination mode.

3. Experimental design and GPR measurements

In order to pour the concrete and prepare the experimental test model, a box shaped wooden cover was prepared. Inside of the wooden box was covered by tar to remove from concrete block easily. The fresh concrete was waited in the concrete box for two days to lose its viscous form. This process was done in the factory of the commercial concrete manufacturer. After the third day pouring of the concrete block, it was moved to the laboratory where the measurements performed. The first data was collected at the 3rd day pouring of the concrete block. At the beginning of the experiment, the data was acquired each day. After 20 days, we extended the period of measurements time. We observed very close numerical values between 12 and 20 days and we decided to increase measurement period. The total period of time was 150 days at the end of the research. GPR measurement over the experimental design was performed for 24 days within this period of time. The sizes of experimental design are 45 × 45 × 30 cm (Fig. 1). A 10 mm thick (diameter) iron bar was embedded at 10 cm below the surface of the experimental model (Fig. 2). The diameter of the iron bar was chosen as 10 mm to see the reflection. There is nothing

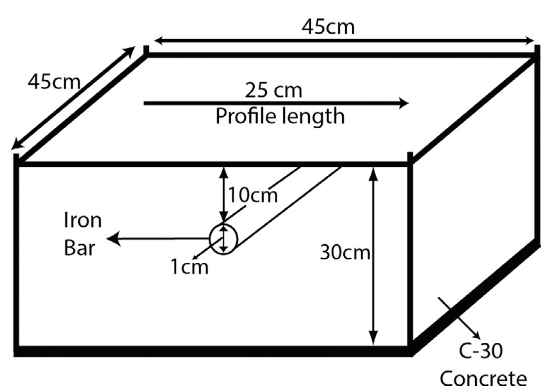

Fig. 1. The sizes of experimental model.

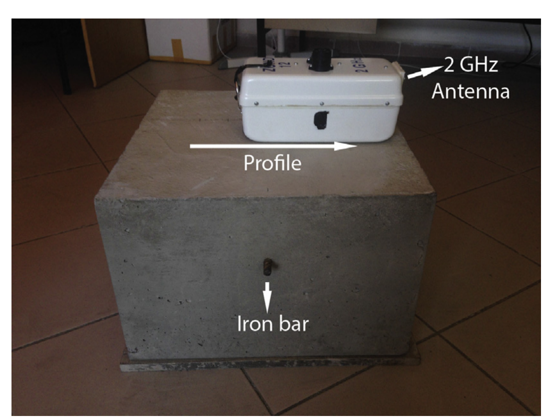

Fig. 2. C-30 concrete sample, 2 GHz GPR antenna and the profile direction.