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GROUND PENETRATING RADAR (GPR) DIRECT WAVE STUDY

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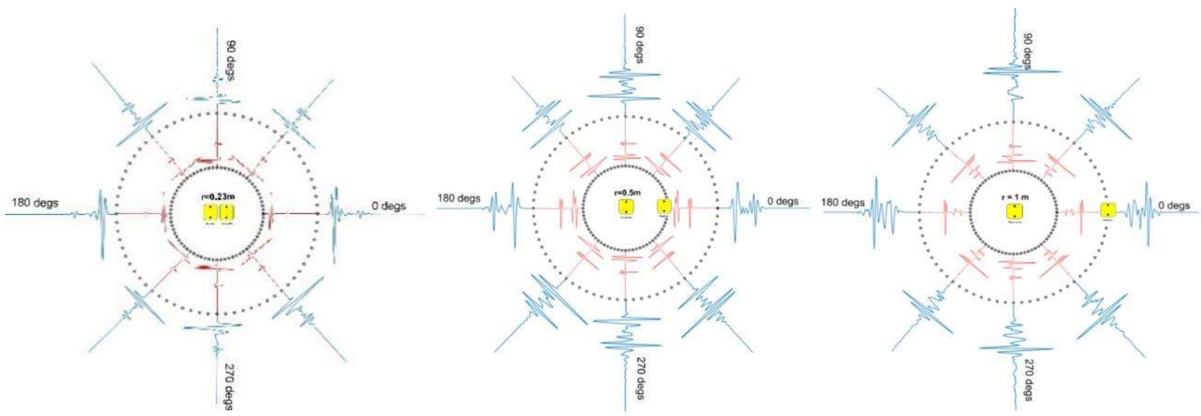

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GROUND PENETRATING RADAR (GPR) DIRECT WAVE STUDY
ΜΕΛΕΤΗ ΤΩΝ ΑΠΕΥΘΕΙΑΣ ΚΥΜΑΤΩΝ ΣΤΗ ΜΕΘΟΔΟ ΤΟΥ ΡΑΝΤΑΡ ΥΠΕΔΑΦΟΥΣ

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Cover Figure:…………………………………

Contents

Abstract

Ground Penetrating Radar (GPR) is a geophysical method based on the emission and reception of electromagnetic (EM) waves. A transmitting antenna (Tx) is emitting EM signals and a receiving antenna (Rx) is recording these signals' reflections caused by changes in the electrical properties of the subsurface. When the Tx-Rx antenna pair is at near proximity, as it is usually the case during GPR surveys, and the subsurface targets are located at shallow depths, the strong in amplitude direct EM signal recorded by the GPR receiver (i.e., the direct wave – DW) may mask the reflections (reflected wave – RW) coming from the in ground targets.

In this study, the major aim is to examine the spatial distribution of the EM signals around the GPR Tx antenna. Since the recorded signals are mostly dictated by the strong direct wave signal, we have focused on the study of this response, attempting to locate areas around the Tx where the direct wave becomes minimum, while the signal strength of the reflected wave remains ideally unchanged. The location of those local minima in the direct signal may give rise to advantageous Tx-Rx configurations, where a clear reflection can be obtained with the least possible involvement of the direct wave.

To perform such a study, field testing was performed at a site where a mostly horizontal subsurface reflector was located. This was confirmed by carrying out GPR grid measurements and validated using the electrical resistivity tomography (ERT) method. Wide Angle Reflection and Refraction (WARR) measurements were also performed to estimate the average EM wave velocity in the uppermost layer and define more precisely the depth of the subsurface features in the survey area. Having found an almost horizontal layer in the field, both the direct and reflected waves were studied by collecting static GPR data around a circle. This way both the direct and reflected waves were studied in terms of (a) changing the Tx-to-Rx antenna orientation (i.e., broadside and endfire), (b) changing the Tx-to-Rx antenna separation (with varying the circle's radius) and (c) changing the Tx-to-Rx antenna angular position (one antenna was placed at a fixed location in the circle's center while the other was moved radially in fixed angle steps around the first one).

In addition to field testing, numerical modelling was performed to study these three (3) aforementioned factors that are known to impact the EM signal distribution around the GPR transducers. For the numerical modelling work, the GPR antennas were represented either by ideal Hertzian dipoles (point dipoles) or by resistively loaded bare dipoles.

1.Introduction

Ground Penetrating Radar (GPR) is an active, non-invasive geophysical method well known for its high resolution and mostly applied to detect both natural and man-made buried targets at shallow depths. The method is relying on the emission of electromagnetic (EM) pulses into the subsurface. The emitted signal interacts with the in-ground materials, reflected and recorded. From an engineering/hardware point of view, GPR is a system which in its standard form consist of two transducers which convert propagating EM waves to electrical signals, and vice versa. The GPR transducers are the transmitter (Tx) and the receiver (Rx), which transmit and receive the GPR pulses, respectively.

The transmitter, through a transmitting antenna radiates radio waves (in the 10-1500MHz frequency range) which propagate through the earth's subsurface. This propagation is mostly governed by the EM properties of the media that the signal is passing through. The most important physical properties for GPR are the dielectric permittivity, electrical conductivity, and magnetic permeability. These properties are responsible for almost every distortion of the transmitted signals in the way that these undergo transmission, reflection or/and refraction phenomena (these will be described on a following chapter).

The history of the GPR method starts when the German physicist Heinrich Hertz built the first antennas to validate James Clerk Maxwell's electromagnetic theory (Skolnic, 1980). In 1910, Gotthelf Leimbach and Heinrich Löwy submitted the first patent for a system to emit continuous radio waves in order to map the subsurface. The idea of using radio pulses rather than continuous signals was born in 1926 by Dr. Hülsenbeck and a glacier's depth was successfully first measured in 1929 by W.Stern with the use of a GPR system. From 1955 to 1960 researchers focused on applying radio waves to study ice, motivated by altimeter errors that the United States Air Force reported, when inaccurately tried to land an aircraft on Greenland's ice sheet (Waite and Schmidt, 1962). GPR applications were limited to applying radio echo sounding in prospecting ice until 1973, when Cook introduced the use of the method in coal mines. Additionally, Holser et al. (1972), Unterberger (1978), and Thierbach (1973) used GPR to detect and derive the depth of salt deposits. In general, the technology of GPR was rapidly developed during and after the World War II for military purposes. It is also worth mentioning the Apollo 17 lunar exploration program which included GPR technology to map the Moon's subsurface as it exhibits a similar electrical behavior to ice (Annan, 1973). Much further development of the GPR method occurred between 1995 and 2000 with the evolution of computers. Since then, GPR hardware components, software for acquisition and processing of data, numerical models and commercial interest are all constantly rising (Grasmueck 1996, Annan et al. 1997, Annan 2002).

From its infancy until now, GPR's applications are numerous. Some of them serve archeological and environmental studies (e.g., Nuzzo et al., 2002; Brewster and Annan, 1994). Others include the qualitatively characterization of man-made structures such as detection of fractures in a pavement or voids in concrete (e.g., Diamanti et al., 2010). The method is furthermore applicable in hydrological studies, geological stratigraphy mapping, mining, subsurface structure visualizing etc. (e.g., Annan 2005, Batayneh et al., 2014, Francke and Yelf, 2003; Kadioğlu and Daniels, 2008).

One of the most challenging issues with GPR is data interpretation. This thesis focuses on studying the various GPR signals reaching the GPR receiver and mainly, the first arrival on a GPR recording, the direct wave (DW). The direct wave, although it is very helpful to record as it is helping define the time-zero or else, the true ground surface for a GPR survey, being the strongest response in a GPR record it may mask or interfere in some cases with the reflected signals (i.e., reflected wave – RW) which are indicators for in-ground targets. To help with GPR data interpretation, this thesis focuses in the study of mainly the DW as well as the RW, in an attempt to suggest an advantageous transmitter-receiver arrangement where the DW becomes minimum while the RW remains almost unchanged.

To make the scope and results of this work comprehensible, a fundamental comprehension of the GPR background theory is required. The propagation of EM waves in a medium is quantitatively descripted by Maxwell's equations and the interaction of an EM wave with the subsurface is ruled by the EM physical properties of the materials. Beyond these, the emission and the reception of EM waves also depend on the nature of the GPR antennas. All of these topics will be discussed in more detail on a later chapter. For more information about the structure of this thesis a general overview follows.