2-5 Non-Destructive Field Measurements of Unsaturated Seepage Flow by Using Ground-Penetrating Radar

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ABSTRACT

Surface ground-penetrating radar (GPR) was assessed as a non-destructive method to measure the temporal and spatial variability of unsaturated seepage flow under uniform wetting conditions on a homogeneous sandy soils. GPR profile survey with 400MHz antenna was conducted after the uniform infiltration. GPR reflected wave from advancing wetting front during uniform field infiltration experiments was used to map the front depth variability with time. The dielectric constant of soil measured by vertical soil moisture probe below the ground surface was used as standard measures of soil moisture to compare with the GPR estimated unsaturated seepage flow behavior. Traceability of the wetting front depth variability with time was found with GPR profile survey.

KEYWORDS

ground-penetrating radar, unsaturated seepage flow, sandy soils, Non-destructive measurements

INTRODUCTION

Measuring unsaturated seepage flow behavior is the most common form of vadose zone monitoring. For the rainfall-induced slope failures or the levee failures caused by seepage, it is important to monitor ground-water tables or soil water content profiles over time. This necessitates a non-destructive measurement that can be made repeatedly. Recently, there has been a considerable amount of research on the use of surface ground-penetrating radar (GPR) to detect buried objects and geological structures and to measure soil water content. GPR has been identified and tested as a non-intrusive geophysical method (Parkin et al., 2000, Huisman, 2001, Galagedara et al., 2003). GPR has a couple of advantages over the intrusive soil moisture sensors and tensiometers in unsaturated soils. GPR system offers a simple approach for in-situ determination of unsaturated seepage flow behaviors or soil water content profiles and a completely non-destructive measurement.

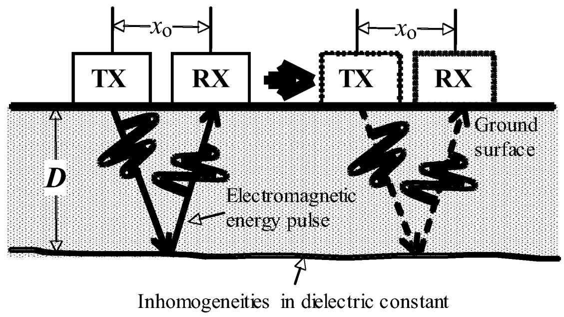

Figure 1. Schematic diagram of GPR profile survey.

In this paper, the potential of surface GPR for measuring unsaturated seepage flow in sandy soils was evaluated. It is shown from field infiltration experiments performed in homogeneous unsaturated dune sands. The temporal and spatial variation of the wetting front caused by two-dimensional unsaturated seepage flow under uniform infiltration was non-destructive measured by using GPR profile survey. GPR estimated wetting front depth variability with time are assessed by comparison to computed unsaturated seepage flow behaviors and measured soil moisture content values. Traceability of the wetting front depth variability with time was found with GPR profile survey.

MATERIALS AND METHODS

1. Ground-Penetrating Radar

The GPR technique is based on the propagation of an electromagnetic energy pulse into the subsurface from a transmitting antenna at radio frequencies between 10 and 1000 MHz. When the radiated energy encounters inhomogeneities in the dielectric properties of the subsurface, some energy is reflected back to the radar antenna and some is transmitted downward to deeper material. Inhomogeneities of the dielectric properties of the soil are present in most hydrogeologic settings and are determined primarily by water content, dissolved minerals, and expansive clay and heavy-mineral content in the subsurface material (Haeni et al 1987). Figure 1 illustrates the schematic diagram of GPR profile

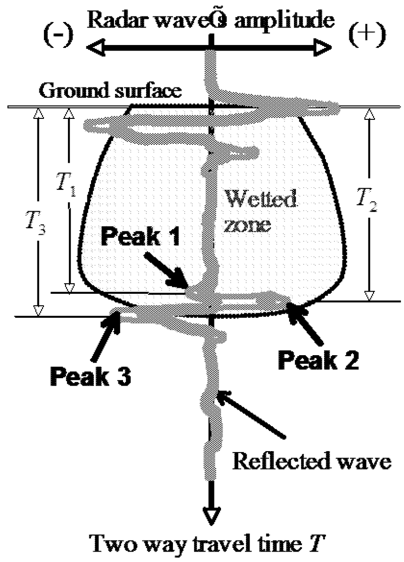

Figure 2. Illustration of relationship between radar wave's amplitude and two way travel time

survey mode with the antennas on the surface. A receiver on the surface detects reflections of the energy pulse that occur where the radiowave velocity changes. Such velocity changes occur where the dielectric properties of the soil change. The reflected signal is amplified, transformed to the audio-frequency range, recorded, processed, and displayed. The record shows the total travel time for a signal to pass through the subsurface, reflect from an inhomogeneity, and return to the surface. This two-way travel time is measured in nanoseconds (1 ns = 10^{-9} seconds). The depth D to the reflector is approximated from the two-way travel time for the electromagnetic wave to propagate vertically downward and back to the surface.

$$D = \frac{\sqrt{(TV)^2 - x_o^2}}{2} \quad (1)$$

where T = two-way travel time; V = electromagnetic wave velocity in the medium; and x_o = the antenna separation (spacing between transmitter and receiver).

GPR measurements are based on transmission or reflection of an electromagnetic wave in the studied medium. Electromagnetic wave propagation velocity depends on the dielectric constant of the medium and its spatial variations; electromagnetic wave velocity varies from 0.3m/ns in air to 0.055 to 0.17m/ns in soils (Reynolds, 1997). The relative dielectric constant ε_r is the ratio between the dielectric constant of the medium and that of the air. The electromagnetic wave velocity in the medium is expressed as

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

where c = the speed of light in the air (= 3×10^8 m/s).

Water content is the main factor of the dielectric variations observed in unsaturated soils. GPR profile surveys were used to trace the wetting front of wetted zone coursed by unsaturated seepage flow. If x_o is negligible small compared with D in Figure 1, Equation 3 is derived from Equations 1 and 2.

$$D = \frac{Tc}{2\sqrt{\varepsilon_r}} \quad (3)$$

Two-way travel times of GPR measurements were converted to depths using Equation 3.

An accurate determination for the travel time of reflected wave from GPR waveform data is very important to search the reflection fro[illegible] peak of waveform is decided. The [illegible] measured by GPR profile survey for unsaturated seepage flow is illustrated in Figure 2. The major reflection event visible in Figure 2 at three peaks (Peak 1 to Peak 3) is assumed to represent the wetting front of unsaturated seepage flow. In this study, the positive peak 2 was picked as typical reflected wave peaks for the wet-

Table 1. Properties of Tottori dune sand for infiltration experiments

Dry density (g/cm^3)	Field saturated volumetric water content	Initial volumetric water content	Field saturated hydraulic conductivity (cm/s)	Coefficient of uniformity	D_{10} (mm)
1.48	0.38	0.03 - 0.06	2.0×10^{-2}	2.05	0.2

ting front.

2. Field experiments

The Arid Rand Research Center of Tottori University, Tottori, Japan, which has a well-drained homogeneous dune sand soil profile, was selected for this filed experiment. The properties of Tottori dune sand are listed in Table 1. Schematic diagram of infiltration experiments are shown in Figure 3. The uniform infiltration experiments were performed on a flat 4m × 0.6m area. The uniform infiltration was provided by using a water spray. One uniform infiltration work was conducted for 5 minutes at 0.0159m^3/min. and subsequently infiltration was interrupted for 3 minutes. The GPR profile survey was performed while infiltration was suspended. A series of the uniform infiltration and GPR survey work was conducted continuously ten times. Transient behavior of the wetting front caused by two-dimensional vertical unsaturated seepage flow from the uniform infiltration was non-destructive measured by using GPR profile survey. A vertically installed soil moisture sensor (Delta-T devices Inc. Profile prove type PR1/4) was used to measure dielectric constant at 4 different depths from 0.1 to 0.4m below the ground surface within a vertical unsaturated seepage flow. The GPR data were acquired with a Geophysical Survey Systems Inc. SIR-3000 system using 400MHz antennas with survey wheel.

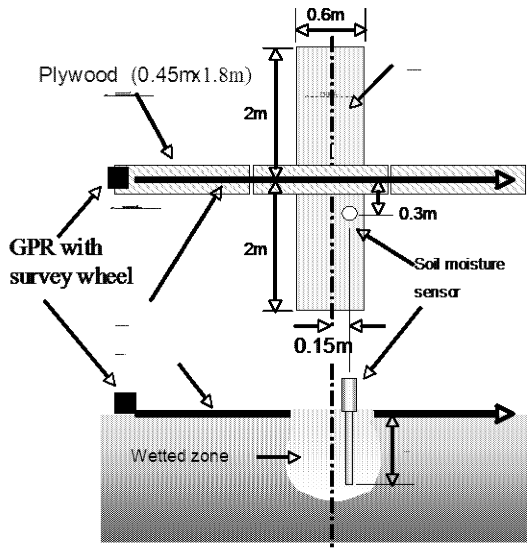

Figure 3. Field layout of infiltration experiments.

RESULTS AND DISCUSSION

The tomographic images of the transient wetted zone variation of two dimensional unsaturated seepage flow were produced by GPR profile survey. Selected GPR tomographic images before infiltration examination and 5 , 37, 53 minutes after infiltration started are shown in Figures 4. The major reflection event visible in Figure 4(b), 4(c) and 4(d) at watered plot is assumed to represent the vertical seepage flow. It is considered that the transient wetted zone variation of unsaturated seepage flow can be evaluated qualitatively by continuous GPR profile survey.

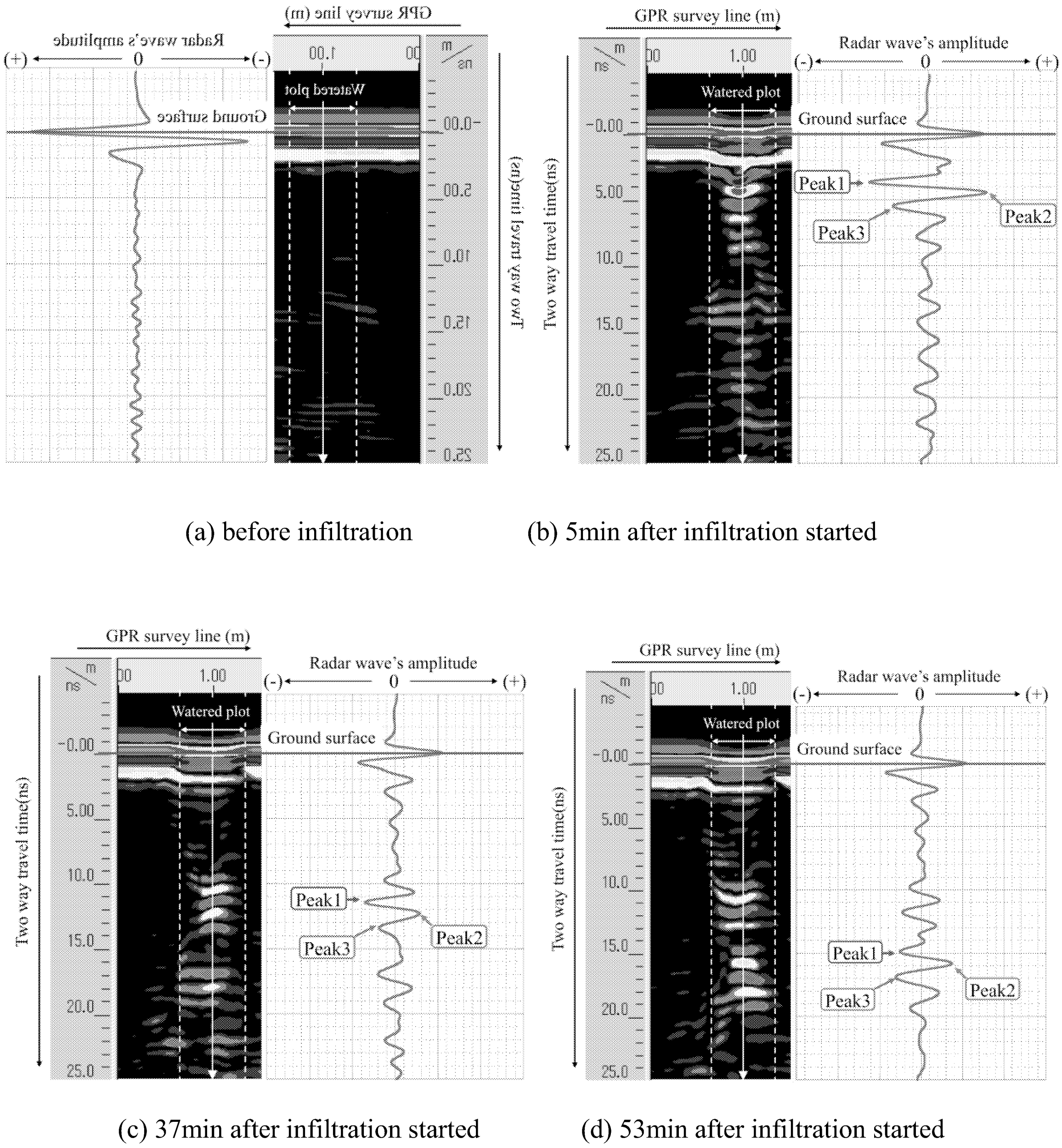

Figure 4. GPR tomographic images under GPR profile survey line and GPR reflected waveforms in the center of the watered plot.

CONCLUSIONS AND PERSPECTIVES

This study examined the potential of surface ground-penetrating radar (GPR) for measuring unsaturated seepage flow in sandy soils. It is shown from field infiltration experiments performed in homogeneous un-saturated dune sands. The following are conducted;

1) The tomographic images of the transient wetted zone variation of two dimensional unsaturated seepage flow can be produced by GPR. The transient wetted zone variation of unsaturated seepage flow can be evaluated qualitatively by continuous GPR profile survey.

2) The temporal and spatial variation of the wetting front caused by two-dimensional unsaturated seepage flow under uniform infiltration can be non-destructive measured by using GPR. Traceability of the wetting front depth variability with time was found with GPR profile survey.

3) GPR profile survey offers a fast and non-destructive way for measuring the unsaturated seepage flow and may be a useful tool for low-cost mapping the transient behavior of wetting front for in-situ permeability tests.

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