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Preliminary use of ultrasonic tomography measurement to map tree roots growing in earth dikes

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Abstract

The aim is of this study to find a relevant criterion to detect and map tree roots in the surrounding soil. In each following experiments, we studied properties of propagation, especially velocity and attenuation of amplitude, as parameters to discriminate the root from the soil. Our work has been initiated on laboratory experiment with an ultrasonic transmission device to highlight relative differences between samples of soil and roots. Measurements were repeated on different root samples (species, dimension, decomposition time) to cover the diversity encountered on dikes. Then an intermediate state device reproducing in-situ conditions in laboratory was performed at the soil surface in two plastic tank containers: one control of bare soil and another containing a root sample buried in homogeneous soil. We shown with laboratory experiments that information provided by the velocity term seems relevant to localize roots in the soil for healthy root samples. Same conclusion was derived from tanks study where significant variations of velocity were observed due to root presence.

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Keywords: Embankment hydraulic structure; Ultrasonic tomography; Root detection; Wood properties

1. Introduction

This paper describes measurements conducted in laboratory, as a faisability study for the purpose of elaborating non-destructive methods able to localize and map tree roots system. Defining the position and direction of primary roots may be useful since roots may induce erosion on earth dikes (Mériaux et al., 2006). Up to now, low frequency ultrasonic prospecting method has been used widely as a non destructive technique to assess wood properties, such as anisotropic variations according to propagation direction (Brancheriau et al., 2006), or to detect decays (Pellerin et al., 1986), particularly on tree stem (Lasaygues, 2006). In each following experiment, our objective was to determinate relevant propagation parameters to discriminate propagation through a root compare to soil. Conclusions drawn from laboratory experiments will enable to design a strategy to detect root system on field on the basis of RINNTECH® methodology (Rinner, 2005).

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Fig. 1. Root sample transmission measurement along longitudinal direction of a poplar root sample

2. Material and method

Experimental measurements were carried out following 2 stages: first we worked with an ultrasonic transmission device and studied the intrinsic response of a root sample (2.1). Then we designed an experimental device including a buried root sample (2.2) and estimated the effect of root on ultrasonic propagation.

During the experiments, we choose to work with a sandy and clayey silt type of soil. Low frequency boviar ultrasound instrument (TDAS 16) was used, endowed of a computer which enable to record the data, a directional source sensor and receivers sensors (all 54 KHz center frequency). Data was acquired considering Shannon's theorem i.e with a sufficient sampling frequency ($\geq 500\text{kHz}$) in order to process signal without distortion. Signals were stacked automatically approximatively 200 times to obtained a better signal to noise ratio. From recorderd data we computed two parameters explicited in 2.3: the velocity and the RMS amplitude (Root mean square) .

2.1. Ultrasonic transmission measurement

For the ultrasonic transmission measurements we used different roots sample previously collected from excavated trees. Before each measurement, the dimension (diameter, lenght) and the weight of samples were measured. All sample were analyzed with sensors (source and receiver) disposed on both sides of the root, in longitudinal direction (Fig.1.) to prevent any anisotropy effects. In order to facilitate the coupling we applied a gel between the sensors and the surface of the root.

2.2. Ultrasonic tomography measurement

An intermediate state device reproducing in-situ conditions in laboratory was designed with two plastics tanks containers. The control container (length 50 cm, height 50 cm) was only filled with 35 cm of soil while in a similar container, root sample (diameter 6 cm length 20 cm) was buried at 10 cm in depth (Fig. 2). A poplar (*Populus alba*) root sample, previously analized on transmission, was used for this experiment.

We first saturated the soil until a thin layer of water was visible at the surface. This step allowed working on the same initial conditions of compaction and water content in both containers. The measurements were carried one week after. Hydric state of the soil was estimated using TDR measurement (Time Domain Reflectometry, with a WET-2-Sensor DeltaT Devices) at approximaty 15 % of volumetric water content.

Tomographic measurement were performed at the soil surface in plastic containers using 4 receivers and one source aligned, first the parallel and then perpendicular to the root. For each acquisition, source sensor was located at the beginning of the profile and 4 receivers were spaced from 5,10,15 and 20 cm respectively from the source (source-receiver offset value D_{SR_i}). The source position moved, in steps of 5 cm, toward the center of the tank. Burried root act as a potential reflector during the propagation of the transmitted waves. Results are expressed with X,Y,Z common depth point (CDP) coordinates, with XY the horizontal plan defined by the surface of the soil and Z the depth. Empirically for an homogeneous soil, CDP coordinates are defined as follow: $X_{CDP_i} = (X_S + X_{R_i})/2$, $Y_{CDP_i} = (Y_S + Y_{R_i})/2$ and $Z_{CDP_i} = \|D_{SR_i}\|/2$. Thus reflexion points Z_{CDP} in sub-surface are estimated at 2.5,5,7.5 and 10 cm depth.

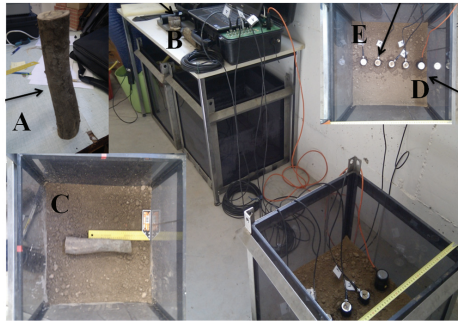


Fig. 2. Experimental device composed with A - One root sample previously analyzed (Sample Nb 5, 2.1); B - Acquisition central ; C - Centering position on the tank of the buried root sample (at $Z= 6\text{cm}$ depth); - Position of the source (D) and receivers (E)

2.3. Estimation of velocity and RMS Amplitude

Time arrivals were estimated from manual picking of the first negative perturbation. Velocity was compute knowing the length of root sample (for transmissiion measurement) and D_{SR_i} (for tomography measurement) divided by the time arrivals. Velocity analysis had to take into account uncertainties on the appreciation of time arrival, fixed empirically at $\Delta T = 1.10^{-6}\text{s}$, and inaccuracy of $\Delta D_{SR_i} = 5.10^{-3}\text{m}$. Error bars represent variations $\pm \Delta V$ on the computed velocity (V).

The second parameter computed was the RMS amplitude or level, A_{RMS} . It represents the average "power" of a signal. For a digitised signal, it may be calculate by squaring each value, finding the arithmetic mean of those squared values, and taking the square root of the result.

3. Results and interpretation

3.1. Roots properties

Considering all samples, velocity ranges from 700 m/s to 3500 m/s , while velocity in soil sample is approximatly of 700 m/s (Fig.3). Soil velocity was also estimate during tomography measurement on tank contening only soil at approximatly 400 m/s (Fig. 4). Amplitude (A_{RMS}), as well displays a variability between samples and shows non-linear positive relationship with velocity.

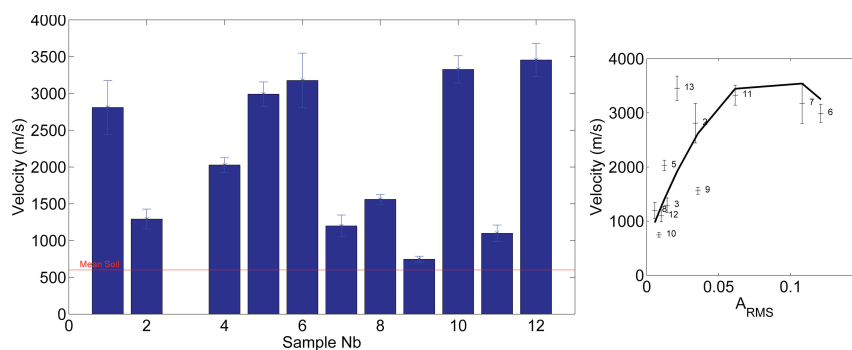


Fig. 3. Results from ultrasonic transmission measurement (source= 54kHz) through root samples along longitudinal direction; On left : Distribution of ultrasonic propagation velocity through different root samples (species, size, decay time) compare to velocity obtained on soil sample (red line) ; On right : Distribution of A_{RMS} versus velocity of root samples

It is commonly known that velocity and attenuation of amplitude are highly correlated to decay state of root sample which implies variations of density. We observed that the variability of velocity mainly comes from decay state rather

than others parameters (water content, species) but with an insufficient number of samples to conclude statistically. Nevertheless, velocity and amplitude appeared to be relevant parameters to discriminate root from the soil.

3.2. Effects of burried roots

A_{RMS} shows a regular decrease with the distance D_{SR_i} (except for D_{SR_3}), but no significant differences between tanks even for different acquisition direction.

Velocities are compute assuming that tanks were filled with an homogeneous soil. In the tank with only soil, velocity is almost the same, in mean 700 m/s, whatever D_{SR_i} . In contrast, in the tank including root, the more D_{SR_i} is high, the more the velocity increase. The most important velocity variations, was found for $D_{SR_i} = 20$ cm (i.e $Z_{CDP} = 10$ cm), for which velocity is approximatly twice as big than in tank with only soil. In that case, soil tomography velocity tends to transmission velocity obtained on root sample (Nb 5, $V = 2800$ m/s) but remained lower because the propagation integrate soil. This observation is relevant with the depth ($Z = 6$ cm) of the burried root. The increase of velocity is more visible on parallel profil where all the CDP's are located in the root zone.

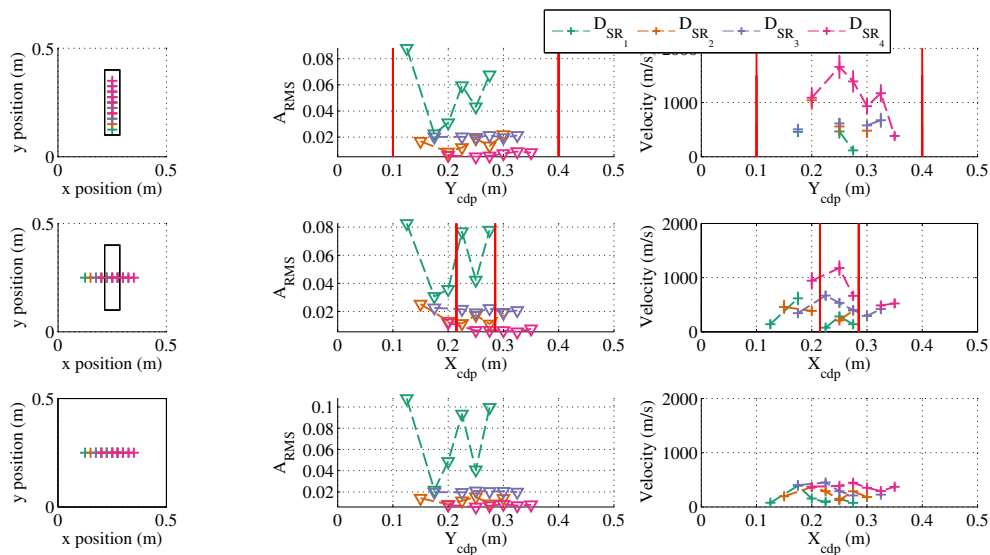


Fig. 4. Comparrison of A_{RMS} (column 2) and velocities V (column 3) of propagation obtained in the tank including a burried root, parallel (line 1), then perpendicular (line 2) to the direction of acquisition and in the tank with only soil (line 3) versus x,y,z coordinates of reflexion points (CDP). Roots position is represented as a rectangular plain black line into the tank and x,y limits as red lines.

4. Conclusion and prospects

We clearly demonstrated that the variability of roots sample implies a big range of velocity and amplitude. Laboratory experiment show good contrast of velocity for a favorable situation i.e the root is located on the shallow sub-surface of an homogeneous soil. Moreover, in contrast with soil which is fairly transparent to low ultrasound frequency, wood seems to conduct ultrasound more efficiently.

Nevertheless, additional parameters are required to reduce ambiguity on interpretation only with velocity and amplitude terms. We propose in a next study to compute spectral properties using Morlet wavelet transform which may allow us to study spectral variations along the time. Also we not solely studied the first perturbation, but also tried to extract multiple reflexions produced at soil-root interface. Finally, this approach will be tested during field experiment in order to confirm results from laboratory and then identify the strenght and limits of RINNTECH® methology (Fig.5).



Fig. 5. Example of in-situ experiment using RINNTECH® methodology on Rhône river embankment

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